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Norwegian CCS Demonstration Project
Norcem FEED

Redacted version of FEED Study (DG3) Report

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Revisions to this document

Rev. no.	Revisions in chapter	Description
01	First issue Redacted version of FEED study (DG3) report	This report is a redacted version of the Norwegian CCS Demonstration Project Norcem CCS FEED study (DG3) report (Document no.: NC03-NOCE-A-RA-0001, rev. 02), issued to Gassnova for open publication.

1 EXECUTIVE SUMMARY

Through the Norwegian CCS Demonstration Project, the Norwegian Government wants to contribute to the development of cost-effective technology for capture, transportation and storage of CO_2. The ambition is to realise a cost-effective solution for full-scale CO_2 handling in Norway, given that this provides technology development in an international perspective.

The overall CCS project shall through demonstration of full scale CO_2 capture and storage contribute to the necessary development of CCS, so that the long-term climate goals in Norway and the EU can be achieved at the lowest possible cost. The purpose of the CCS project is thus to:

1) Establish a first CO_2 handling chain, including capture, transport and storage of CO_2, in Norway;
2) Facilitate technology development and learning effects as well as sharing experience and knowledge nationally and internationally; and
3) Contribute to cost reduction and maturation of a market for CO_2 management nationally and internationally

Realising a CCS demonstration project in Brevik, will constitute the first cement plant in the world with full-scale CO_2 capture. This project is a unique opportunity to demonstrate a full carbon capture and storage value chain in connection with modern and efficient cement clinker production. Of the few large-scale carbon capture plants currently in operation worldwide, only two of them (Boundary Dam and Petra Nova) capture CO_2 from flue gases (post combustion capture) and none from cement plants.

The cement industry accounts for an increasing share of the world's man-made carbon emissions, currently 5-7% [1]. The flue gas from cement production has a much higher CO_2 concentration than ordinary combustion flue gases, due to decomposition of the main raw material; limestone ($CaCO_3$), which cannot be avoided This makes the cement industry ideal for cost effective carbon capture.

The steady increase in global cement consumption, and thereby CO_2 emissions, is driven by increased urbanisation, population and welfare. Concrete will continue to be the dominant building material worldwide, and a successful carbon capture demonstration at Norcem will represent a major technology step change that will significantly impact on global CO_2 mitigating efforts.

A realisation in Brevik will provide important knowledge and experience, which HeidelbergCement, the cement industry as a whole and other CO_2 intensive industries need to understand and appreciate, as a valuable basis for future projects.

Norcem Brevik is an experienced process industry operator, located adjacent to deep water port facilities and therefore well positioned for cost effective carbon capture, conditioning and ship transportation. The Grenland area is a highly developed industry area with established logistics and easy access to the relevant competence and services around the clock.

Norcem has a great opportunity through the HeidelbergCement Group, with its 140 cement plants, and through the European Cement Research Academy (ECRA) and Cembureau (European cement producers association), to share relevant knowledge and experience in the cement industry globally. Norcem has had several meetings with these throughout the FEED phase, to present the project and discuss future opportunities.

HeidelbergCement, as a dominant global player within the cement industry, intends to continue their engagement in CCS and has signed a Memorandum of Understanding with Equinor to further explore future opportunities for CO_2 capture and storage.

The project has high focus on continuous improvement and possible simplifications. Numerous improvements, simplification and cost reduction activities have been identified and implemented throughout the Concept and FEED phases, resulting in improved solutions, reduced risk and cost reductions which will benefit this and upcoming projects.

Through realisation of the CO_2 capture project in Brevik, Norcem will detail the design, build and commission a first-of-its-kind highly sophisticated carbon capture and conditioning plant. This will represent the Best Available Technology (BAT) within carbon capture. The captured CO_2 will be conditioned for ship transportation and permanent storage below the sea bed on the Norwegian continental shelf. The carbon capture and conditioning plant will be built and commissioned according to a high HSEQ standard, whilst being cost efficient.

The CO_2 capture facility has a target CO_2 capture rate of 400 000 tons CO_2 / year. The yearly CO_2 capture capacity has been optimized (cost/ benefit) and utilizes waste heat from existing cement plant and the new CO_2 conditioning for thermal energy production. Consequently, only electricity and no additional heat or fuels are required for CO_2 capture at Norcem.

The Norcem CO_2 capture project has developed since 2005, when a desktop study on full-scale carbon capture was initiated. In 2011-2012, Norcem received support from the ECRA (European Cement Research Academy) for further studies. From 2013 to 2017 Norcem received funding from CLIMIT to test four alternative CO_2 capture technologies on actual flue gas.

In 2016, the Norwegian CCS Demonstration Project (NCD) was initiated, and Norcem received funding from the State to perform Concept and FEED studies on CO_2 capture from the cement plant in Brevik under a study agreement with the State (Gassnova).

Norcem has completed a solid FEED phase in good cooperation with the current project partners (Aker Solutions, Norsk Energi, Norconsult, FLSmidth, Periti and ÅF Advansia) and Gassnova. Excellent cooperation between the project partners throughout the FEED phase have resulted in thoroughly discussed, matured, well defined and optimised technical solutions.

Key elements of the proposed solution are:

- Norwegian novel technologies are developed specifically for the Norcem CO_2 capture project. Aker Solutions' advanced carbon capture technology (ACC™), Aker Solutions' CO_2 compressor with integrated heat recovery and Norsk Energi's waste heat recovery units have all been qualified by DNV GL for full scale carbon capture at Norcem in Brevik, securing the required performance of these technologies in operation of the CO_2 capture plant.
- Aker Solutions' CO_2 capture technology has developed over several years, through pilot testing in Brevik on real flue gas with 7400 operating hours over a period of 18 months in 2013 – 2015 and further optimisation throughout the project concept and FEED phases.
- The project comprises all necessary modifications of existing installations at Norcem. The new plant will be installed in parallel to the existing flue gas system with focus on safe, easy and smooth changeover between cement production with and without carbon capture and heat recovery thus securing both the integrity of the cement production and the expected CO_2 volumes, within the strict requirements imposed by Norwegian authorities, stakeholders and own expectations.

A 3D view of the complete new plant is shown in Figure 1 below. The coloured elements are new, while the grey elements are part of the existing cement plant.

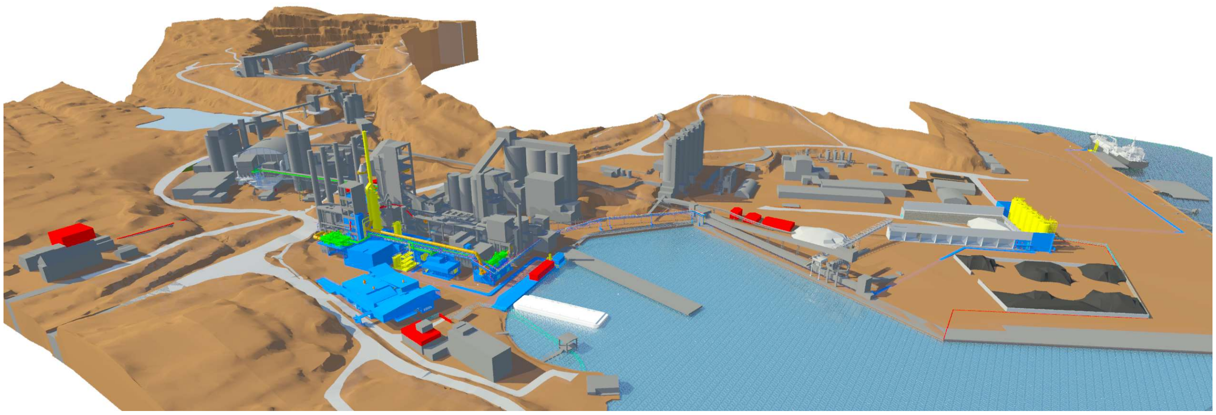


Figure 1 - 3D view of the complete new plant

Project execution timeline

The project execution timeline is shown in Figure 2 below.

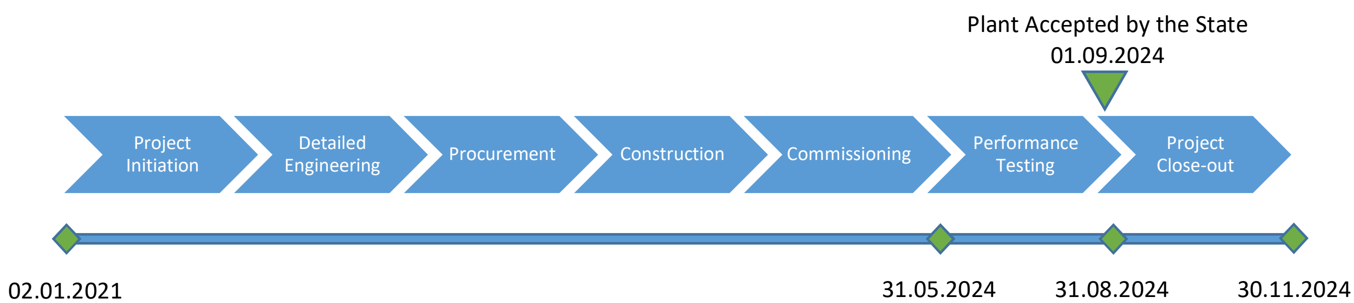


Figure 2 - Project execution timeline

The project start date is based on the assumption that the Norwegian authorities make a positive decision to realise the project by the end of 2020. Given project start-up in January 2021, the new plant will be in operation after the plant is accepted by the state in September 2024.

Cost estimates and maturity

The total estimated CAPEX including contingency is [redacted] MNOK.
The total estimated OPEX including contingency is [redacted] MNOK / year.

The cost estimates have developed throughout the Concept and FEED phases and are reduced from DG2 to DG3 with an increased confidence (estimate uncertainty reduced from ±30 % at DG2 to ±20% at DG3). The maturity of the cost estimates are concluded at DG3 to be in accordance with AACE RP18R-97 Class 2 requirements, with exceptions related to final bids and contracts.

Project execution is thoroughly planned with a lean, yet experienced and highly competent project organisation, led by HeidelbergCement and supported by advanced technology providers and well reputed civil engineering contractors.

2 NORSK SAMMENDRAG

Gjennom det norske CCS demonstrasjonsprosjektet (NCD), ønsker den norske staten å bidra til utviklingen av kostnadseffektiv teknologi for CO_2 fangst, transport og lagring. Ambisjonen er å realisere en kostnadseffektiv løsning for fullskala CO2 håndtering i Norge, gitt at dette bidrar til teknologiutvikling i et internasjonalt perspektiv.

CCS-prosjektet skal gjennom demonstrasjon av fullskala CO_2-håndteringbidra til nødvendig utvikling av CO_2-håndtering, slik at de langsiktige klimamålene i Norge og EU kan nås til lavest mulig kostnad. Formålet med CCS-prosjektet er således å:

1) Etablere en første håndteringskjede for CO_2, herunder fangst, transport og lagring av CO2, i Norge;
2) Legge til rette for teknologiutvikling og læringseffekter samt erfarings- og kunnskapsdeling nasjonalt og internasjonalt; og
3) Bidra til kostnadsreduksjon og modning av et marked for CO_2-håndtering nasjonalt og internasjonalt.

Et karbonfangstanlegg i Brevik vil være det første sementfabrikken i verden med fullskala CO_2-fangst. Dette prosjektet er en unik mulighet til å demonstrere en hel verdikjede for karbonfangst- og lagring i forbindelse med moderne sementklinkerproduksjon. Av de få storskala karbonfangst-anleggene som for tiden er i drift over hele verden, er det bare to av dem (Boundary Dam og Petra Nova) som fanger CO_2 fra røykgasser (etter forbrenning) og ingen fra sementproduksjon.

Sementindustrien står for en økende andel av verdens menneskeskapte CO_2 utslipp, for tiden 5-7%. Røykgass fra sementproduksjon har mye høyere CO_2 konsentrasjon enn røykgass fra konvensjonelle forbrenningsprosesser, på grunn av dekomponering av råmaterialet; kalkstein ($CaCO_3$), som ikke kan unngås. Dette gjør at sementindustrien er ideell for kostnadseffektiv karbonfangst.

Den stadige økningen i det globale sementforbruket, og dermed økt CO_2-utslipp fra sementproduksjon, er drevet av urbanisering, befolkningsvekst og økt velferd. Betong vil fortsette å være det dominerende byggematerialet i verden, og en vellykket demonstrasjon av karbonfangst hos Norcem vil representere et betydelig trinnskifte i teknologiutvikling som vil gi et verdifullt bidrag til den globale innsatsen for redusert CO_2 utslipp.

En realisering i Brevik vil gi viktig kunnskap og erfaring, som HeidelbergCement, sementindustrien for øvrig og andre CO_2-intensive næringer trenger å forstå og verdsette, som et verdifullt grunnlag for fremtidige prosjekter.

Norcem Brevik er en erfaren operatør innenfor prosessindustrien med en ideell beliggenhet ved etablerte dypvanns havneanlegg, og er derfor godt posisjonert for kostnadseffektiv karbonfangst, kondisjonering og skipstransport. Grenland-området er et velutviklet industriområde med etablert logistikk og enkel tilgang til relevant kompetanse og tjenester.

Norcem har en unik mulighet gjennom Heidelberg Cement Group, med sine 140 sementfabrikker, og gjennom European Cement Research Academy (ECRA) og Cembureau (europeiske sementprodusenters forening), til å dele relevant kunnskap og erfaring i sementindustrien globalt. Norcem har hatt flere møter med disse gjennom forprosjektet for å presentere prosjektet og diskutere fremtidige muligheter.

HeidelbergCement, som en dominerende global aktør innen sementindustrien, har til hensikt å fortsette sitt engasjement for CCS og har inngått en intensjonsavtale med Equinor for å utforske fremtidige muligheter for CO_2-fangst og lagring.

Prosjektet har sterkt fokus på kontinuerlig forbedring og mulige forenklinger. Mange forbedringer, forenklinger og kostnadsreduserende tiltak er identifisert og implementert både i konseptstudiet og forprosjektet, noe som har resultert i forbedrede løsninger, redusert risiko og kostnadsreduksjoner som vil være til nytte både for dette og kommende prosjekter.

Gjennom realisering av CO_2-fangstprosjektet i Brevik, vil Norcem detalj-prosjektere, bygge og ta i bruk et meget sofistikert karbonfangst- og kondisjoneringsanlegg. Dette vil utgjøre beste tilgjengelige teknologi (BAT) innenfor CO_2-fangst. Fanget CO_2 vil kondisjoneres for skipstransport og permanent lagring under havbunnen på norsk kontinentalsokkel. Karbonfangstanlegget vil bli bygget og ferdigstilt etter høye HMS og kvalitetsstandarder, og samtidig være kostnadseffektiv.

CO_2-fangstanlegget har en målsetning om å fange 400 000 tonn CO_2/år. Den årlige CO_2-fangstkapasiteten er optimalisert (kostnad / nytte) og utnytter spill-varme fra sementfabrikken og CO_2-kondisjoneringen for termisk energiproduksjon. Følgelig er det bare elektrisitet og ingen ekstra varme eller brensel som kreves for fangst av CO_2.

Norcems CO_2 fangst prosjekt har vært i utvikling siden 2005, da et skrivebords-studie på fullskala karbonfangst ble initiert. I 2011-2012 mottok Norcem økonomisk støtte fra den ECRA (European Cement Research Academy) for videre studier. Fra 2013 til 2017 mottok Norcem finansiering fra CLIMIT for å teste fire alternative CO_2 fangstteknologier på reell røykgass.

Det norske CCS demonstrasjonsprosjektet (NCD) ble initiert i 2016. Norcem mottok da finansiering fra den norske staten for å gjennomføre konsept- og forprosjektstudier på CO_2 fangst fra sementfabrikken I Brevik under en studieavtale med staten (Gassnova).

Norcem har gjennomført et solid forprosjekt i samarbeid med prosjektpartnerne (Aker Solutions, Norsk Energi, Norconsult, FLSmidth, Periti and ÅF Advansia) og Gassnova.
Utmerket samarbeid mellom prosjektpartnerne i forprosjektet har resultert i gjennomarbeidede, modne, veldefinerte og optimaliserte tekniske løsninger.

Nøkkelelementer ved den foreslåtte løsningen er:

- Ny norsk teknologi er utviklet spesielt for CO_2-fangstprosjektet hos Norcem Brevik. Aker Solutions' avanserte karbonfangstteknologi (ACC™), Aker Solutions' CO_2-kompressor med integrert varmegjenvinning og Norsk Energi's dampkjeler for varmegjenvinning er alle kvalifisert av DNV GL for fullskala karbonfangst hos Norcem i Brevik, og sikrer den nødvendige ytelsen til disse teknologiene under drift av CO_2-fangstanlegget.
- Aker Solutions' CO_2-fangstteknologi har utviklet seg over flere år, gjennom pilottesting i Brevik på reell røykgass med 7400 driftstimer over en periode på 18 måneder i 2013 - 2015 og ytterligere optimalisering gjennom konseptstudiet og forprosjektet.
- Prosjektet omfatter alle nødvendige modifikasjoner av eksisterende installasjoner på Norcem. Det nye anlegget vil bli installert i parallell med det eksisterende røykgass systemet med fokus på sikker, enkel og jevn veksling mellom sementproduksjon med og uten karbonfangst og varmegjenvinning og dermed sikre både sementproduksjonens integritet og forventet CO_2 volum, innenfor myndighetenes strenge krav og egne og interessentenes forventninger.

Et 3D-bilde av det komplette nye anlegget er vist i Figure 3. De fargede elementene er nye, mens de grå elementene er en del av den eksisterende sementfabrikken.

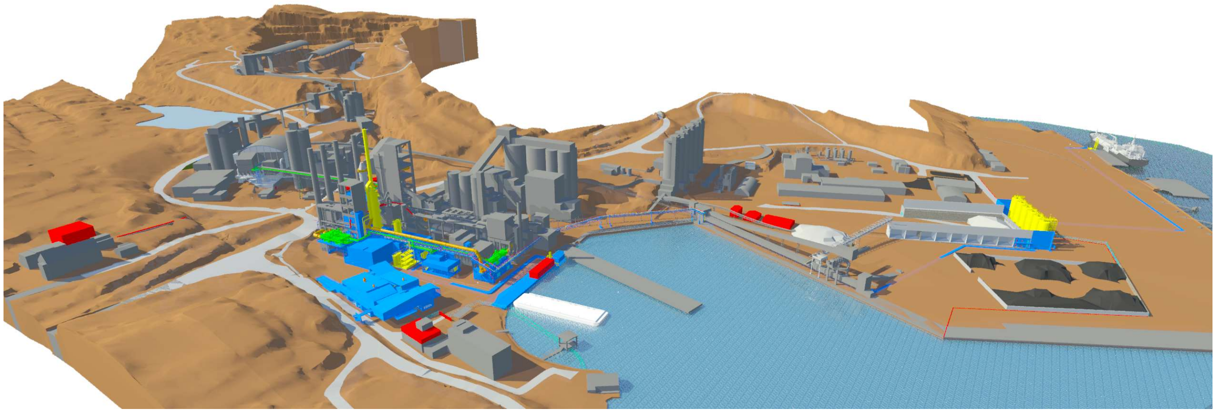


Figure 3 - 3D bilde av det nye anlegget

Tidslinje for gjennomføring
Prosjektets tidslinje for gjennomføring er vist i Figure 4.

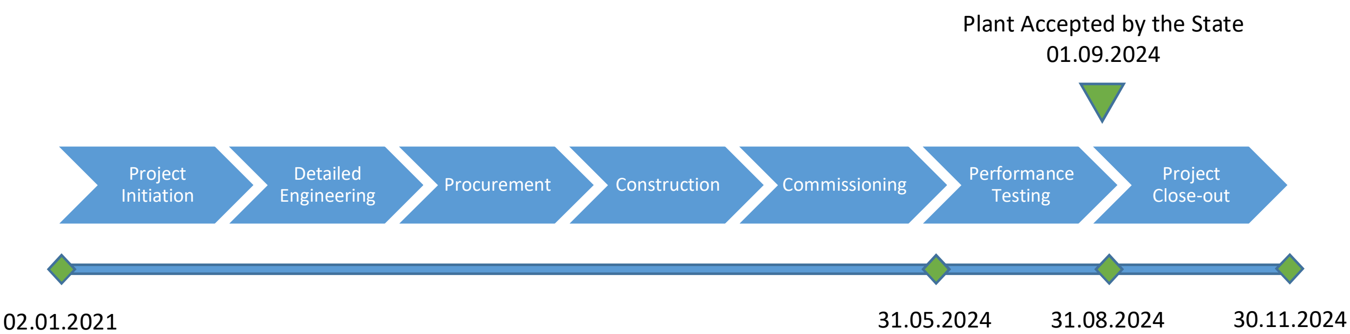


Figure 4 – Tidslinje for gjennomføring

Prosjektets startdato forutsetter at staten tar en positiv beslutning innen utgangen av 2020 om å gjennomføre prosjektet. Gitt prosjektoppstart i januar 2021, vil det nye anlegget være i drift etter det er akseptert av staten i september 2024.

<u>Kostnadsestimater og modenhet</u>
Den totale estimerte investeringskostnaden (CAPEX) for prosjektet er [redacted] MNOK.
De estimerte driftskostnadene (OPEX) for prosjektet er [redacted] MNOK / år.

Kostnadsestimatene har utviklet seg gjennom konseptfasen og forprosjektet og er redusert fra DG2 to DG3 med økt sikkerhet (estimat usikkerheten er redusert fra ±30 % ved DG2 til ±20% ved DG3). Modenheten av kostnadsestimatene er konkludert å tilfredsstille kravene til AACE RP 18R-97 Class 2, med unntak knyttet til endelige tilbud og kontrakter.

Prosjektgjennomføringen er grundig planlagt med en erfaren og meget kompetent prosjektorganisasjon, ledet av HeidelbergCement og støttet av førsteklasses teknologileverandører og velrenommerte byggentreprenører.

3 INTRODUCTION

3.1 THE PURPOSE OF THE PROJECT

3.1.1 Background and Purpose

The background for the Norwegian CCS Demonstration (NCD) project is the need to limit global warming through reduction of Green House Gas emissions, including CO_2. The NCD project shall through demonstration of full-scale CO_2 handling contribute to the necessary development of CO_2 handling, in order to reach the long-term climate targets in Norway and EU at the lowest possible cost. Demonstration of CO_2 handling shall by 2030 increase the efficiency of CO_2 capture, transportation and storage.

The purpose of the NCD project is thereby to:

- Establish a first complete CO_2 handling chain, including CO_2 capture, transportation and storage, in Norway.
- Facilitate technology development and learning effects, as well as experience and knowledge exchange nationally and internationally, and
- Contribute to cost reduction and increased maturity of the market for CO_2 handling nationally and internationally.

The State contributes to the realisation of the NCD project by giving the recipient(s) grants for the establishment and operation of the capture plant and storage facilities in accordance with regulations for public contributions to environmental measures.

Norcem shall, in accordance with the agreement with the Norwegian State, establish and operate a full-scale CO_2 capture and conditioning plant integrated with the existing cement plant in Brevik, targeting the capture of 400 000 tons of CO_2 per year with the required quality for ship transportation and permanent storage below the sea bed on the Norwegian continental shelf.

3.1.2 Project Goals and Objectives

The overall goal of the NCD project is that the demonstration of CO_2 capture and storage will contribute to the necessary development of CCS, so that the long-term climate goals in Norway and the EU can be achieved at the lowest possible cost. As part of this goal, the CCS Project must:

- provide knowledge that demonstrates that it is possible and safe to carry out full-scale CO_2 capture and storage;
- provide productivity gains for upcoming projects through learning and scaling effects;
- provide learning related to regulations and incentives for CCS; and
- establish market players, further develop suppliers and provide business development.

The Norcem part of the project shall contribute to the realisation of these goals, including implementation of the capture project at the lowest possible cost for the entire CCS chain.

3.1.3 Business Goals and Objectives

Concrete is one of the most used building materials worldwide, and the cement industry is accountable for 5 – 7 % of the world's manmade CO_2 emissions [1]. It is therefore invaluable to be able to show that CO_2 can be captured from cement production in a safe manner.

Heidelberg Cement Northern Europe (HCNE)'s sustainability strategy includes a zero-vision stating that the carbon emissions from our products, seen in a life cycle perspective, should be zero by 2030. The important last step to realising the zero vision is carbon capture and storage (CCS).

Norcem is part of the EU – ETS (Emissions Trading Scheme) and the number of allowances will be reduced for the next allocation period (2021-2030), with the result that no cement factories, including Norcem Brevik, will receive allowances that fully cover the need. The current Cross-Sectoral Reduction Factor (CSRF) of 1.74% should be increased to 2.2% in the early 2020s, which in a few years will cause the allocated quotas to be below the CO_2 emissions resulting from the calcination of limestone (540 kg CO_2 / t clinker). This will contribute to the cement industry generally being forced to make further optimisations of the production process. The emissions trading scheme will force closure of cement factories that cannot meet future performance requirements. Norcem, together with the parent company Heidelberg Cement, wants to lead the development of carbon capture within the cement industry.

Realisation of CO_2 capture from Norcem's cement plant in Brevik is expected to give Norcem increased market shares and an improved reputation, by being a frontrunner in capturing CO_2 from cement production and delivering carbon neutral concrete products to the market.

Business goals:

- Complete a successful project execution phase (time, cost, quality)
- Make the project known to the public nationally and internationally and share knowledge and experience with
  - potential future projects
  - educational and research institutions
  - relevant authorities (wrt. regulations and future financing schemes)
- Ensure stable operations of the capture plant within one year after start-up
- Develop business case(s)
- Further optimise the operation of the capture plant wrt. CO_2 capture rate, CO_2 delivery obligations, etc.

3.2 STRUCTURE OF THIS REPORT

The report is built up in accordance with the requirements as defined in the agreement between Gassnova and Norcem and with cross reference to deliveries stated in the table of content template for DG3 report document issued by Gassnova. The table of contents for this report (NC03-NOCE-A-LA-0002 - Table of Contents - DG3 Rapport) was submitted to Gassnova in association with milestone M07 – 3rd September 2018. This report is supported by extensive documentation defined in the appendix list.

3.3 ABBREVATIONS AND DEFINITIONS

ABBREVATION	DEFINITION
ACC™	Advanced Carbon Capture ™
AHTC	Area HTC (e.g. HTC Northern Europe)
AKSO	Aker Solutions
ALARP	As Low As Reasonably Practicable
APC	Air Pollution Control
Bara	Absolute Pressure - Pressure reading relative to absolute vacuum
BAT	Best Available Technology
BIM	Building Information Modelling
BLEVE	Boiling Liquid Expanding Vapor Explosion

ABBREVATION	DEFINITION
BOE	Basis of Estimate
BREF	Best Reference Document
CAR	Construction All Risk(Insurance)
CBS	Cost Breakdown Structure
CC	Carbon Capture
CCC	CO_2 Capture, Conditioning and temporary storage plant
CCCP	Carbon Capture and Conditioning with intermediate CO_2 storage
CCS	Carbon Capture and Storage
CCR	Central Control Room
CFD	Computational Fluid Dynamics
Clinker	Intermediate product leaving the cement kiln
CMS	Contract Master Schedule
Company	HeidelbergCement / Norcem
CPU	Central Processing Unit
CS	Carbon steel / mild steel
CSRF	Cross-Sectoral Reduction Factor (CO_2 allowances)
dBA	Decibel A
DCC	Direct Contact Cooler
DCS	Distributed Control System
DSB	The Norwegian Directorate for Civil Protection and Emergency
DG	Decision gate
ECRA	European Cement Research Academy (Headquarter in Düsseldorf)
EPC	Engineering, Procurement and Construction
EPCM	Engineering, Procurement and Construction Management
EPcma	Engineering, Procurement and Construction Management assistance
ESP	Electro Static Precipitator
ESP 3	Electro static Precipitator on String 2 after CT2
ESP 4	Electro static Precipitator on String 1 after CT1
EU – ETS	European Union - Emissions Trading Scheme
EWTP	Effluent Water Treatment Plant
EX	Explosive Atmosphere
FEED	Front End Engineering Design
FF1	Fabric Filter 1 (Bag filter String 1)
FF2	Fabric Filter 2 (Bag filter String 2)
FTO	Freedom to operate
GCT1	Gas Conditioning Tower 1 (on String 1)
GCT2	Gas Conditioning Tower 2 (on String 2)
GSA	Gas Suspension Absorption

ABBREVATION	DEFINITION
HAZID	Hazard Identification
HC	HeidelbergCement Group
HC GES	HeidelbergCement Group Environmental Sustainability
HCNE	HeidelbergCement Northern Europe
HMI	Human Machine Interface
HSE	Health, Safety & Environment
HSS	Heat stable salts
HTC	Heidelberg Technology Centre
HVAC	Heating, Ventilation and Air Conditioning
I/O	Input/ Output
ID Fan 1	Fan handling exhaust gas from Conditioning Tower 1 (CT1)
ID Fan 2	Fan handling exhaust gas from Conditioning Tower 2 (CT2)
IP	Intellectual Property
IPR	Intellectual property rights
ITP	Inspection and Test Plan
KP	"Koordinator Prosjektering" / Coordinator Engineering
KU	"Koordinator Utførelse" / Coordinator for project execution
LA clinker	Low Alkaline Clinker (previously called TYPE clinker)
LCI	Life Cycle Inventory
LCO_2	Carbon Dioxide liquefied by cooling and which is in a liquid state
m.a.s.l.	Meters above sea level
MC	Mechanical Completion
MDR	Master Document Register
MEA	Monoethanolamine
MPT	Multi-discipline Purchasing Team
MTO	Material Take Off
MTU	Mobile Test Unit
MW	Mega Watts
NCD	Norwegian CCS Demonstration Project
NDA	Non-Disclosure Agreement
NEA	Norwegian Environmental Agency
OED	Olje- og Energi Departementet (Ministry of Petroleum and Energy of the Norwegian government)
Offsite	"Offsite" constitutes other areas that will be affected by permanent installations or temporary facilities during the construction phase.
Owner	HeidelbergCement / Norcem
O&M	Operation and Maintenance
PAC	Powdered Active Carbon

ABBREVATION	DEFINITION
PAH	Polycyclic Aromatic Hydrocarbons
PCB	PolyChlorinated Biphenyls
PCS	Process Control System
PDRI	Project Definition Rating Index for Industrial Projects
PEM	Project Execution Model
PEP	Project Execution Plan
PFAS	Polyfluoroalkyl Substances
PFD	Process Flow Diagram
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctanesulfonates (salts of PFOA)
PH1	Preheater Tower at String 1 (Consisting of cyclone 1.1, 2.1, 3.1 and 4.1)
PH2	Preheater Tower at String 2 (Consisting of cyclone 1.2, 2.2, 3.2 and 4.2)
PID	Piping and Instrumentation Diagram
PLC	Programmable Logic Controller
PSV	Pressure Safety Valve
PMT	Project Management Team
QRA	Quantitative Risk Assessment
RFQ	Request for Quotation
RM	Raw Mill
RS	Round Sum
SC	Project Steering Committee
SHA	Safety Hazard Analysis
SIMOPS	Simultaneous Operations
SPOC	Single Point of Contact
SS	Stainless Steel
TBD	To be decided/defined
TBT	Tributyltin
TCM	Technology Centre Mongstad
TOC	Total Organic Carbon
Ton	Metric ton = Tonnes = 1000 kg/m^3
TQP	Technology Qualification Program
UPS	Uninterruptible Power System
VSD	Variable Speed Drive
WBS	Work Breakdown Structure
WHRB	Waste Heat Recovery Boiler
WHRU	Waste Heat Recovery Unit

Table 1 – Abbreviations and definitions

4 COMMERCIAL

4.1 HEAD OF TERMS AND COMMERCIAL PREREQUSITES (1a)

This chapter concerns contract terms and commercial conditions for the establishment and operation of the carbon capture plant at Norcem Brevik.

The head of terms and commercial pre-requisites are currently under negotiation between OED and Norcem and is not at a sufficient level of maturity for meaningful commentary to be made in this report.

The interfaces between the project partners in FEED used for establishing the current cost estimates (CAPEX and OPEX) are shown in Figure 5 and Figure 6 below.

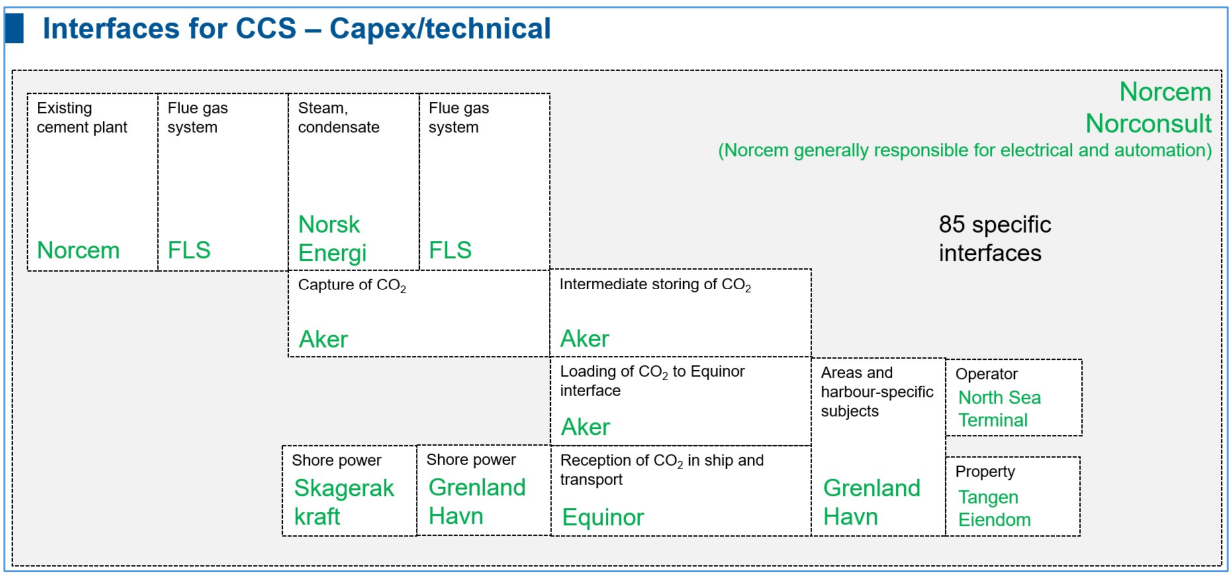


Figure 5 – Interface matrix for Capex

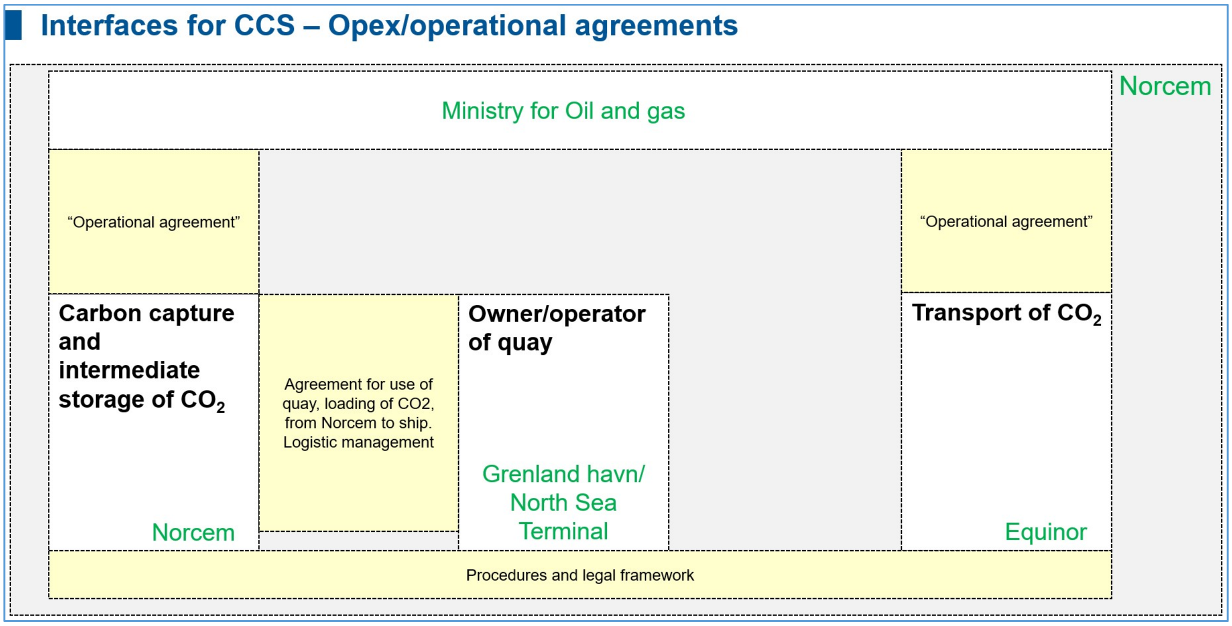


Figure 6 - Interface matrix for OPEX

The "Attachment H - Key Operating Principles" [2] outlines the operational principles and procedures for the loading of Liquid CO_2 cargo between Northern Lights and Capture Sites. This document is now under approval by the state and will be presented as a final document at the conclusion of the contract agreement.

All costs included in cost estimates must be dedicated to the CCS plant only, but in a few cases direct benefits for the cement plant are identified, relevant for both CAPEX and OPEX. Evaluation of "cross-subsidization" worked out during the FEED along with a procedure for the evaluation.

4.2 EXECUTION STRATEGY

The Project Execution Strategy [31] defines the strategic approach to project execution. The Project Execution Plan (Attachment 39) is based on the Project Execution Strategy and defines the basis of all project work and how the project will be managed. The project execution method is described in section 10.7.

4.3 PROCUREMENT STRATEGY (1i)

The following project requirements are defined in the FEED study agreement between Norcem and the Government:

- All novel technology elements shall be qualified according to DNV GL's recommended practices for qualification of new technology prior to investment decision by the Government.
- The maturity level of project definition deliverables shall meet the requirements set forth in AACE 18R-97 Class 2 by the end of FEED, to ensure that the accuracy in the cost estimates for project execution and operation are adequate for investment decision by the Government.

The Norwegian Government will only provide funding to projects complying with the above requirements.

Based on the above requirements and the development of Norcem's CO_2 capture project up until and including the FEED study, taking into specific consideration the need for experience and competence in relation to cement production, possible technology providers identified as qualified for realisation of the CO_2 capture project in Brevik are:

- Aker Solutions with respect to the design and delivery of CO_2 capture, conditioning, intermediate storage and loading
- Norsk Energi with respect to the design and delivery of waste heat recovery from the existing cement production process

These technologies include a significant portion of novel technology elements, which have been qualified by DNV GL during the FEED phase and also comply with the maturity requirements to project definition deliverables defined by the Government.

Norconsult as Norcem's civil engineering contractor for the FEED phase, has had a framework agreement with Norcem for decades and possesses unique knowledge of existing plant structures and soil conditions. Norconsult is therefore a possible civil engineering contractor for project execution.

FLSmidth has delivered numerous plant upgrades at Norcem Brevik and is therefore a possible supplier of cement plant modifications.

To benefit from the acquired maturity level in project definition deliverables, beyond what is normally required for a FEED, use of partners with sufficient experience and key competencies is vital. The required maturity level is obtained through the project partners unique combined competencies and experience, and close cooperation across process- and project interfaces throughout project development.

The current proposed contracting structure comprises the following:

- Norcem Plant & Infrastructure
- Civil Works

- CO_2 Capture Plant

Norcem Plant and Infrastructure will be responsible for engineering, procurement and construction of Norcem Plant Modifications

Civil Works will be responsible for engineering, procurement and construction of all civil works.

The CO_2 Capture Plant Contractor will be responsible for engineering, procurement and construction of the CO_2 capture plant, including CO_2 conditioning, intermediate storage and loading, as well as waste heat recovery from the existing cement production process.
These work packages are further detailed in section 10.7.

These will be managed and monitored by a Company Management Team consisting of a combination of Norcem / HeidelbergCement representatives and hired in resources from a management service contractor.

The proposed contract structure is illustrated in Figure 7 below.

Figure 7 - Contracting Structure

This structure is chosen to separate and distribute responsibilities and scope of work in a suitable manner, considering the following:

- Interface management
- Plant element location at Company`s Site
- Project schedule
- Health, Safety and Environment

In its project execution Norcem will apply the rules and procedures set forth in the Norwegian Act and Regulation on public procurement ("Lov og forskrift om offentlige anskaffelser") to the extent that the Act and the Regulation apply to Norcem's procurement under the agreement between Norcem and the Government. In this regard Norcem is aware of Section 1-3 of the Procurement Regulation which provides that the Procurement Act and the Procurement Regulation applies to certain subsidised works and services contracts. To the extent the Act and the Regulation do not apply Norcem will nevertheless apply the fundamental principles in the Act and use appropriate procurement procedures in connection with all contract awards, in accordance with good industry practice.

The procurement strategy is detailed in Procurement & Contract Strategy (Attachment 40). Procurement Management is described in the Project Execution Plan (Attachment 39).

4.4 BUSINESS CASE FOR THE BENEFICIARY (1b)

4.4.1 Overall purpose of the project

The cement industry is responsible for 5-7% of the total annual man-made CO_2 emissions [1]. The high level of emissions is due to the very wide use of cement and concrete, which is the most used construction material in the world. A high consumption of cement is regarded as a prerequisite for the improvement of living conditions for an increased total world population.

When producing cement more than 60% of the CO_2 emissions originate from the chemical process of calcining limestone, which is the main raw material for cement, and less than 40% originate from the energy consumption related to the manufacturing process. Even with a total shift to renewable energy sources, the CO_2 emissions related to cement production would still be considerable.

4.4.1.1 Norcem Zero Vision 2030

As part of HeidelbergCement Group sustainability targets, Norcem have developed a “Zero Vision 2030” which states an ambition to deliver products from 2030 that have zero CO_2 emissions over the lifetime of the building structure in a lifecycle perspective.

The Zero Vision focuses on all aspects of cement production including energy efficiency, utilization of biomass fuels, reduction of clinker content and concrete decarbonatization, in addition to, carbon capture.

HeidelbergCement Group will not be able to fulfil this ambition without carbon capture.
Specific emissions (CO_2 per tonnes cement) from cement produced by Norcem today is lower than the average level on the European cement market, due to the high level of alternative fuels (biomass). Cement from Brevik with CCS will outperform all other cements in the market on specific CO_2 emissions.

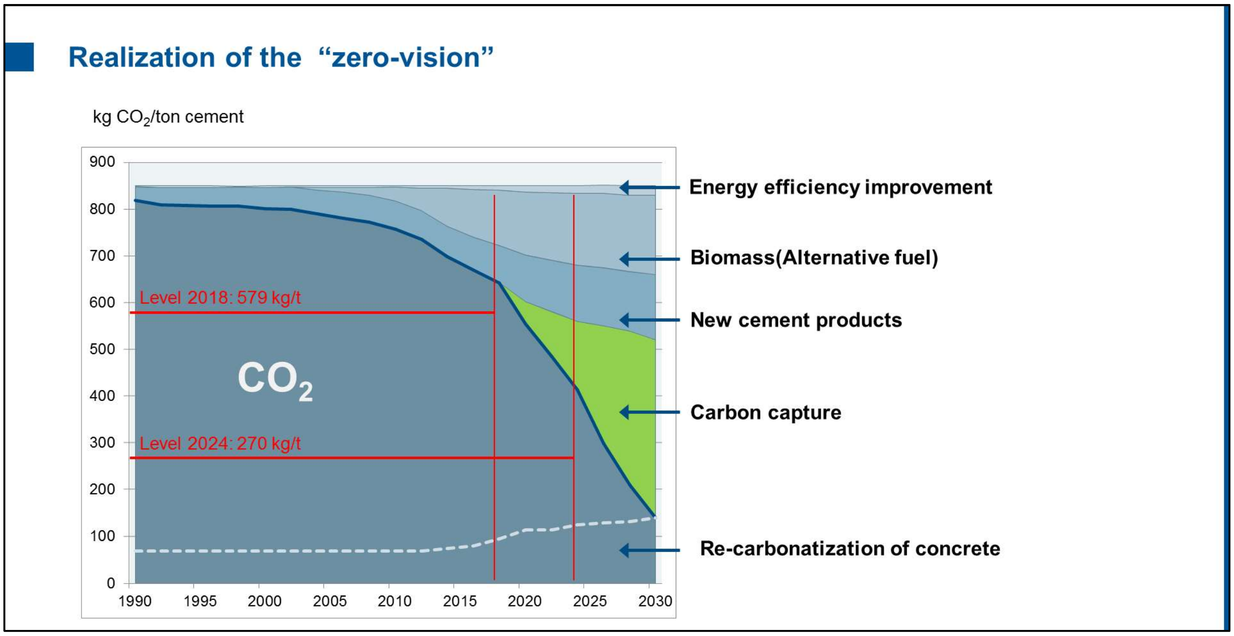


Figure 8 - Norcem Zero Vision 2030

4.4.2 The Norwegian Construction Market

The total cement consumption in Norway 2018 was 2,2 mill tonnes of which the Norcem market share was aproximately [redacted]%. The total market for cement can be divided in four different market segments with very different characteristics, as shown in Figure 9.

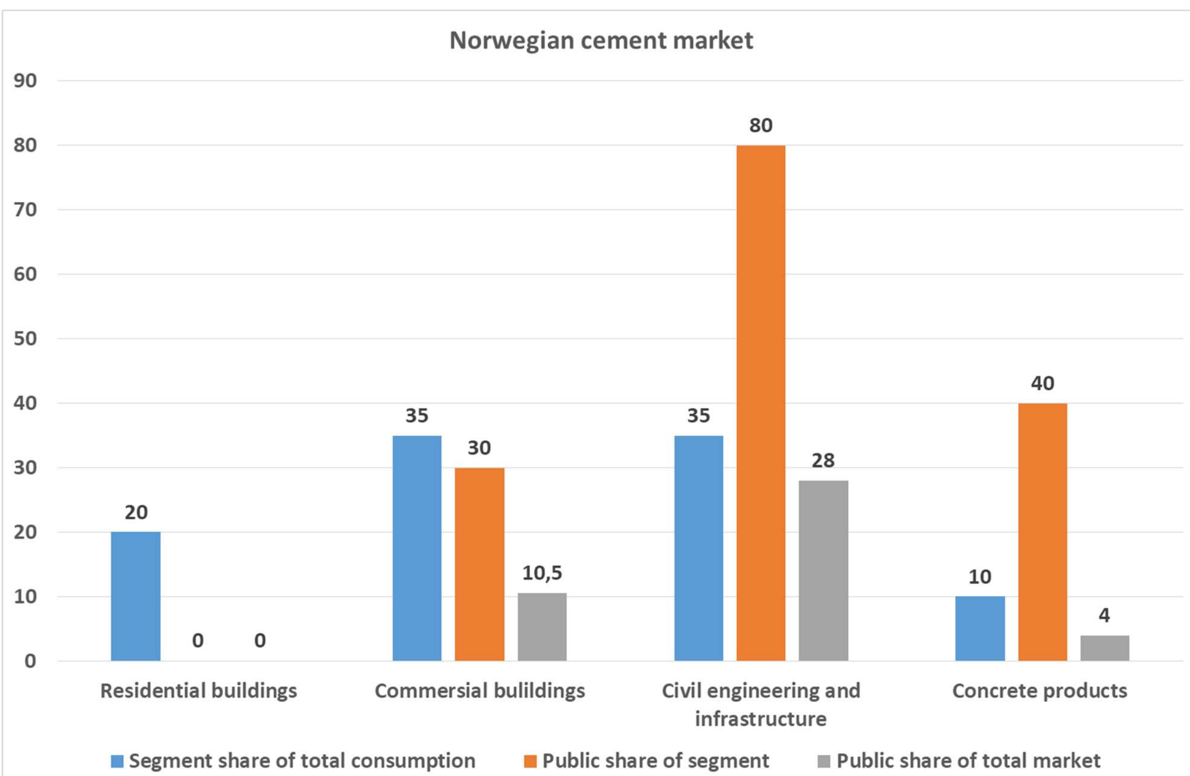


Figure 9 – Overview of the Norwegian cement market

Residential buildings represent 20% of the total market. In this market segment, cement and concrete are used in foundations for all types of residential buildings and for loadbearing structures like walls and slabs. For familiy homes in rural areas wood is the dominating construction material here the use of concrete is mainly in foundations and floors while in urban areas concrete is the dominating construction material in most multi-story apartment buildings. This segment is dominated 100% by private owners and the market driver in this segment is the demand for flats in the urban areas.

Commercial buildings represent 35% of the total market. In this segment cement and concrete are used for fundations and floors as well as loadbearing structures. In this market segment concrete has a substantial market share in competition with steel structures as loadbearing construction material. Public owners represent 30% of this market segment through public office buildings, schools, hospitals, nursing homes etc. The company Statsbygg is a very important actor in the segment who influences other public owners such as local municipalities and regional governments, through their priorities and practices regarding the use of construction materials. For private consumption in this segment the main driver for investments are the low interest rates. The public consumption in this segment is more driven by political decision making.

Civil engineering and infrastructure represent 35% of the total market. In this segment cement and concrete are used in structures like harbours, bridges, dams, tunnels and railway foundations. For many of these applications concrete is the dominating construction material due to the long service life in very harsh environment. This segment is dominated by public owners, 80%. The Norwegian road outhorities, Statens Vegvesen, is the most important actor who influences other public owners regarding the spesifications and use of concrete as construction material. Statens Vegvesen, Nye Veier and Bane Nor represent close to 80% of this market segment and the drivers for investments are completely dependent on political decision making.

Concrete products represent 10% of the total market. In this segment cement and concrete are used for products like sewage pipes, pavement blocks, roof tiles and others. Most projects are smaller and there is no dominating actors that have a significant impact on the use of concrete in the market. Concrete products are in constant competition with alternative solutions such as plastic pipes, asphalt, steelplates as well as imported concrete products. The privat consumption in this market segment is fully dependent on private purchasing power. Public owners like local municipalities represent 40% of this segment.

4.4.3 Impact on competitiveness

CCS, under current conditions, will have a significant impact on cement manufacturing cost. International studies show that capture costs will be in the same range as existing production costs for cement.

Cement cost impact on total project cost will vary to a very large extent depending on the type of structure and market segment.

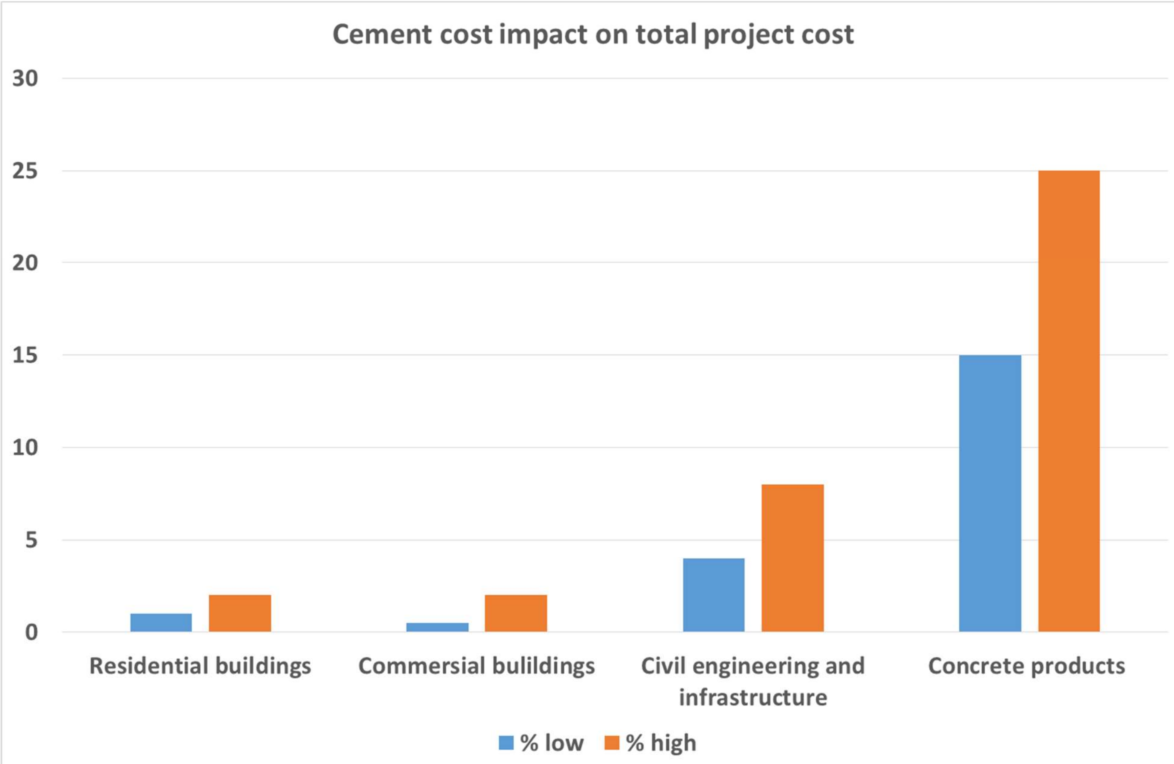


Figure 10 - Cement cost impact on total project cost

<u>For residental buildings</u>, the cement cost will typically impact 1-2% of the total project cost. In this segment most end customers are private single family owners and their willingness to compensate for increased cost due to CCS is at the moment very low. With increased cost on domestic cement due to CCS, this market will have an increased share of imported cement.

<u>For commercial buildings</u> the impact of cement on total cost is normally lower than for residential buildings. In this segment the private owners show very low willingness to compensate for extra cost due to sustainable solutions like CCS. In this part of the segment increased cost of domestic cement will increase the use of steel structures and increase the import of cement.
For public owners in this segment we see an increasing interest in sustainable solutions and to some extent an increasing willingness to compensate for this development.

<u>For civil engineering and infrastructure projects</u> the cement impact on total cost is higher than for buildings. The type of projects vary and the cement cost impact will be in the range of 4-8% of total project costs. The number of owners are limited and the alternatives to concrete as a construction material are also limited. The public owners in this segment show an increasing focus on sustainable construction solutions and have clear long term targets on reduction of CO_2 emissions. Even with a significant impact on total cost, this segment appears to be the most mature segment regarding willingness to compensate for increased CCS costs.

<u>For concrete products</u> cement cost have a significant impact on total cost. For these projects the concrete product is a major part of the total delivery and the impact of cement on total cost can be close to 25%. The private owners in this segment show no willingness to compensate for the increased cost of CCS. The public owners in this segment are mainly local municipalities with varying focus on sustainable construction solutions. Increased cost for domestic cement will in this segment to a very large extent increase the import of cement and concrete products.

The impact of cement on cost will also vary along the value chain for concrete construction, as shown in Figure 11.

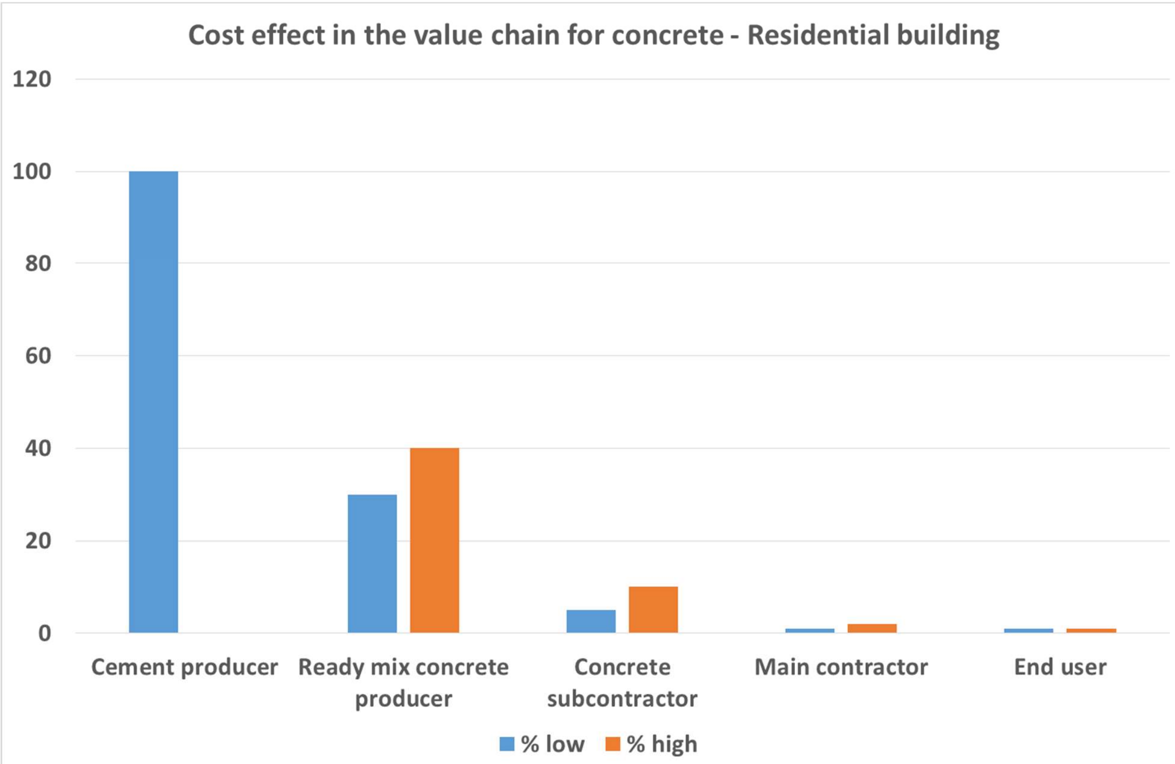


Figure 11 - Cost effect in the value chain for concrete – residential buildings

Cost increase on cement production due to CCS will have 100% impact on the cost of cement. For ‘Ready-mix’ concrete the impact of increased cost will be substantial since 30-40% of concrete cost is related to cement. Ready-mix concrete is normally supplied to a local contractor who has specialized in concrete construction and are normally subcontractor to a main building contractor. For these subcontractors cement represent 5-10% of their cost. For the main contractor and the end user 1-2% of the project cost are related to cement.

Even though the impact of cement cost on total project cost are rather low for many projects, the impact is always very high on the competitiveness of the ready-mix concrete producer. Cost increase of cement production due to CCS without losing competitiveness will not be possible without governmental incentives that transfer cost increases to the end user. The development of these incentive mechanisms will have to focus the competitiveness of CCS cement along the whole value chain for concrete construction, to secure the competitiveness against imported non CCS products and other less sustainable construction solutions in all supply decision processes along the value chain.

Distribution of cement in Norway is mainly based on truck transport from local depots along the coast. The depots are supplied from the plants by dedicated cement vessels. The incentives must focus on avoiding increased distribution costs and related CO_2 emissions from transport.

These incentives must prevent increased imports of cement and, especially, concrete products as this will increase the CO_2 emissions from transport in addition to using less CO_2 lean cement products.
Incentives must also make sure that the competitiveness towards other construction materials like steel, plastics and timber, are not affected in favour of less durable and CO_2 lean construction solutions.

4.5 BASIS OF ESTIMATE (1c)

4.5.1 Terminology and standards

The terminology used in this chapter is based on AACE International “Cost Engineering Terminology” Recommended Practice 10S-90 [3].

4.5.2 Basis and references

The overall basis of estimate is documented in document NC03-PERI-F-RA-0004 - Basis of Estimate [4], which in turn is based on the separate Basis-of-Estimate documents produced by each contributing partner. Contributions have been received from:

Partner	B of E doc. no.	Estimate doc. no.
Aker Solutions	NC03-AKER-F–RA–0003	NC03-AKER-F-RA-0002
Norconsult	NC03-NOCON-C-RA-0015	NC03-NOCON-F-TE-0001
Norsk Energi	NC03-NOEN-F-RA-0001	NC03-NOEN-F-TE-0001
FLSmidth	NC03-FLSM-F-RA-0001	NC03-FLSM-A-TE-0001 NC03-FLSM-A-TE-0002
Norcem WBS 100-399	NC03-NOCE-F-RA-0001	Included in B-of-E
Norcem WBS 500	NC03-NOCE-F-RA-0501	NC03-NOCE-F-TE-0501

Table 4 – Basis of estimate documentation

4.5.3 Cost breakdown structure

The cost breakdown structure was established in the CBS document, NC03-PERI-F-GL-0001, [5] and used by all contributors. For capital costs, the basic structure is a matrix with account numbers according to NS3453 [6] defining the rows, and physical building blocks defining columns. For details, please refer to “Norcem Kostnadsnedbrytningsstruktur (CBS)” - NC03-PERI-F-GL-0001 [5] (Attachment 1).

For operating costs, the structure established in “Norcem Kostnadsnedbrytningsstruktur (CBS)” - NC03-PERI-F-GL-0001 [5] (Attachment 1) is shown below:

Account	Specification
	Variable Costs
1	Electricity
2	Steam
3	Other variable costs
3.1	Solvent
3.2	Water
3.3	Ship loading cost (agreement with Grenland havn)
3.4	Hazardous waste costs
3.5	Other

	Fixed Costs
4	Manpower
5	Maintenance
6	Service Contracts
7	Other specified fixed costs
7.1	Administration
7.2	Insurances
7.3	Land lease Grenland Havn
	Total calculated OPEX
	Contingency
	Total OPEX including contingency

Table 5 - Operating costs structure

A list of exclusions is shown in section 4.8.

The CBS used to report capital and operating costs have been aligned with the standard cost structure required by Gassnova. There is, therefore, no further bridging calculation to go from one structure to the other.

4.5.4 Partner estimates

Partial estimates have been received from all contributing partners. Document references are given in table 4 in section 4.5.2 above. All partners have estimated in their own familiar format and then distributed the costs into the project CBS. This transformation is described in each partner's respective Basis of Estimate

4.5.5 Principles of consolidation

Although the consolidation has been done by a third party (Periti AS), this does not constitute a full independent review and validation as described by AACEI in their RP 31R-03 [7]. The guidelines given in RP 31R have been used to consolidate all estimates.

The consolidation has been done by importing and aggregating all the contributors' spreadsheets. The principles utilised, and detailed explanations are discussed in the cost model report, NC03-PERI-F-AA-0001 Cost calculations and tables (Attachment 59) [8] .

4.5.6 Traceability

As shown in the cost model report, Cost calculations and tables - NC03-PERI-F-AA-0001 [8], all numbers received from partners are fully traceable to the aggregate level reported. Where adjustments are made, e.g. to split a single number into several entries in the CBS, the factors used are documented in the reports from each partner.

4.5.7 Owner's costs

Owner's costs have been estimated by the Heidelberg/Norcem organization and reflect the execution strategy chosen for realization of the project.

The cost elements included in owner's cost are listed in Table 6.

OWNER'S COSTS ELEMENTS		
Item No.	Element	Typical Scope of Services
1	Project Management Team	Owner's personnel dedicated to the project including travel / relocation and subsistence costs. *Note: this item is strongly influenced by the selected contracting strategy.*
2	Insurance	Production interruption insurance. Necessary Insurance
3	Capitalised OPEX	Owners Pre-Operations personnel including spares, training, operator training and simulation equipment.
4	HSE Support	Sustainable development / Environmental / Safety Consultants / In Country Support.
5	Certification	Certifying / marine warranty surveyors / vendor and fabrication inspection / governmental / regulatory permits and approvals.
6	Project Support	Owner's personnel time writing to, not necessarily dedicated to the project, includes peer reviews and assists.
7	Communication / Documentation / PR Services	Translation / project publicity materials / documentation archiving / close out.
8	Office & Office Support	Office rental / equipment and services.
9	Miscellaneous Services	Includes loss of production for extra outage of plant and additional cost for Norcem due to unavailability of own workshops and buildings
10	Security	All costs associated with security – covering personnel / camps, vehicles communication equipment and training.
11	Project Financing	Costs associated with third party financing of the project in question
12	Parent Company Overheads	Owners non time writing personnel – senior management / legal / commercial etc.

Table 6 - Owner's cost elements as included in the project cost estimate

Owner's costs were calculated within WBS 100-399 and WBS 500. Details can be found in references [9], [10], and [11]. A complete breakdown of the cost estimate can be found in NC03-PERI-F-AA-0001 - Cost calculations and tables [8].

Total owner's cost is listed under building block 13 in the cost break down structure. All construction temporary facilities are included in owner's cost in the FEED estimate.

4.6 OUTLINE OF SCOPE OF WORK DOCUMENT FOR STATE SUPPORT AGREEMENT

See document NC03-NOCE-A-RA-0008 - Outline of Scope of Work Document for State Support Agreement (Attachment 2)

4.7 ESTIMATED CAPEX (1d)

The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

4.8 OPERATING COSTS

The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

4.9 COST CONTRIBUTION FROM BENEFICICARY (1f)

The capture project in Brevik has developed stepwise since 2011; with funding mainly by CLIMIT/Gassnova and Norcem.

The first discussions/negotiations with the Ministry of Petroleum and Energy (OED) regarding a funding agreement for realisation of a full-scale carbon capture plant started in 2016 but was put on hold in October 2017 when the Norwegian CCS Demonstration (NCD) project was paused. The negotiations started again at the beginning of 2019.

The negotiations on key financial figures in the agreement wrt. cost distribution between the Ministry and Norcem regarding investment costs, operating costs and the economic effect of the captured volume are ongoing. HeidelbergCement approval of the key figures and main principles in the agreement is necessary for Norcem / HeidelbergCement to give a final offer to the Ministry. According to the agreed schedule, an offer shall be submitted by Norcem to the Ministry in December 2019 or early January 2020. The agreement with the Ministry is planned to be finalised early 2020 and will be conditional to Parliament approval of project realisation in December 2020.

4.10 MATURITY ANALYSIS (1h)

4.10.1 Self-Assessment

The capital cost estimate has been reviewed with reference to estimate classes as defined by AACEI [12]. The methods used, and the results of this self-assessment are reported in detail in a separate document [13].

The assessment is based primarily on the maturity of specified project definition deliverables, covering both general project data and engineering deliverables. This is cross-checked against a number of other indicators of project maturity.

The engineering development of the project has a high level of maturity, consistent with a class 2 estimate. Some elements of the project execution plan are limited mainly by the lack of finalization of the financing agreement with the authorities. Reasonable drafts and frameworks have already been established. The remaining contracts are expected to be finalized well before the start of execution, and no major shifts are foreseen. In light of this, the exceptions noted are seen as non-significant with respect to the estimate.

In conclusion, the estimate is found to be a “class 2 estimate with exceptions”.

4.10.2 Estimate review

A benchmarking of the cost estimate has been conducted, by comparing costs for parts of the project to overall investment cost to find cost factors, where a relevant basis is available. These derived cost factors are compared to ranges of cost factors given in Compass International Front End / Conceptual Estimating Yearbook [14] and factors available in-house at Periti.

In addition, available man-hour rates are found to be in line with prices from local projects executed in 2018.

The total estimate was broken down into equipment cost, material and construction cost on disciplines as well as engineering, site supervision and owner’s cost. This is further described in the cost estimate document [8]

The total cost is high compared to a green field plant, but this is expected due to significant renovation of existing facilities and the complex heat integration. Additionally, the civil cost is high due to significant revamps and the new maintenance building. The instrumentation cost percentage is low, which may warrant attention during detailed engineering and execution.

4.10.3 Cost estimate quality assurance

Each partner has been responsible for their cost estimate and was required to do quality assurance according to AACE International [7]. This is documented in Basis of Estimate documents for each estimate. Periti has been responsible for consolidating all partners’ estimates into one and has reviewed the cost compilation, checking for completeness and spot-checking summation within the files. This compilation has been reviewed and checked as an internal quality assurance. Unit prices used for personnel have been reviewed against internal pricing data and knowledge of local pricing regime.

4.10.4 Reconciliation against the DG2 estimate

The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

4.11 COST RISK ANALYSIS (1h)

The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

4.12 CASH FLOW ANALYSIS (1g)

The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5 PROJECT DESCRIPTION

5.1 FUNCTIONAL DESCRIPTION OF EXISTING PLANT (2a)

The general manufacturing process for ordinary Portland cement is schematically illustrated in Figure 12.

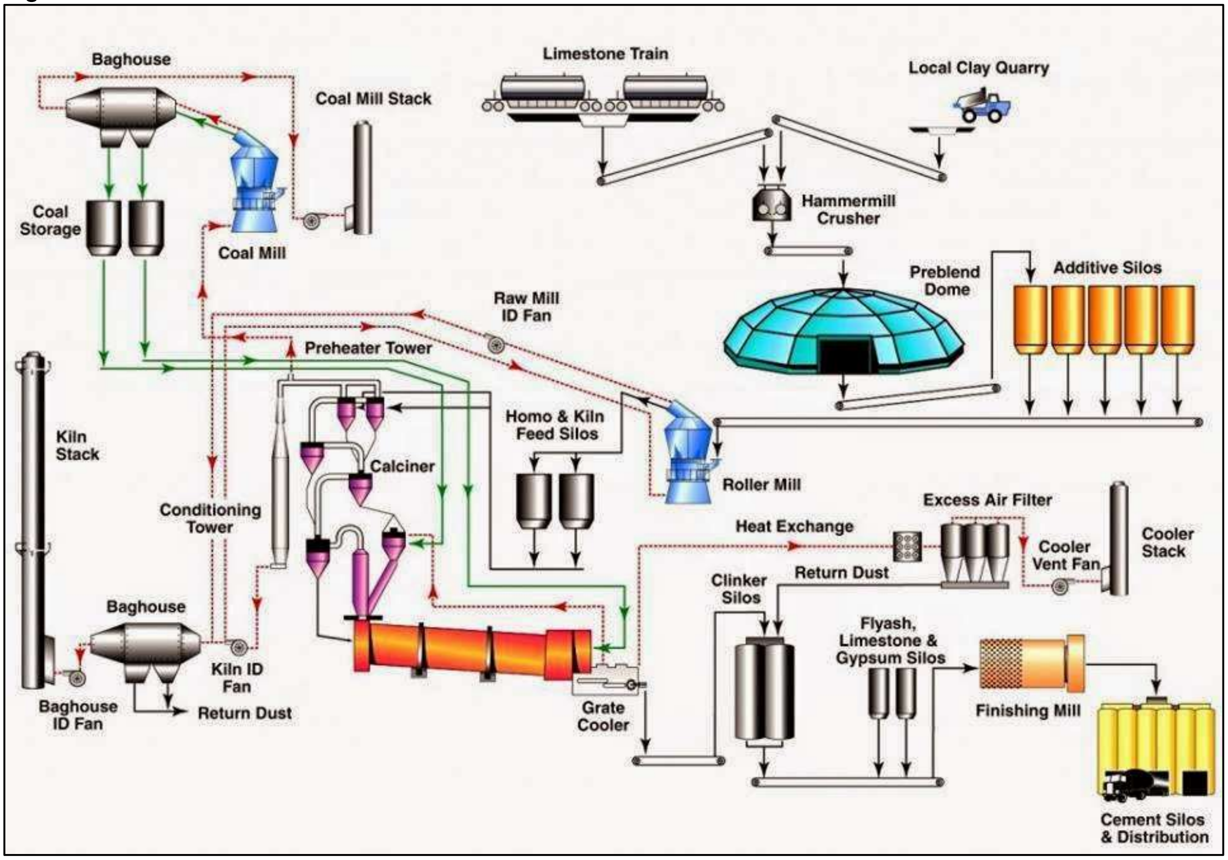


Figure 12 - General manufacturing process for Ordinary Portland Cement

More specifically for Norcem AS Brevik, the manufacturing process and key production data is shown in Figure 13 and Figure 14. The main production steps are as listed below:

1. Limestone is excavated from 3 sources and brought to plant pre-crushed to a size <240mm:
    a. Approximately 1/3 from underground mine
    b. Approximately 1/3 from Bjørntvedt quarry in Porsgrunn
    c. Approximately 1/3 from Verdal quarry
2. The limestone is mixed with corrective materials (SiO_2, Fe_2O_3 and Al_2O_3) and ground to fine powder called “raw meal” where ≈ 90% is below 90µm. The material is analysed and controlled on-line before entering the first grinding step. The material is dried during the first grinding stage using hot gas from preheater string No 2.
3. The raw meal is homogenized and then stored in storage silos (a buffer for 3-4 days of production)
4. The raw meal is conveyed to the top of the kiln preheater tower and added to the process between the upper two cyclones on each preheater string. The meal is then heat exchanged

in counter stream with the exhaust gas from the kiln process. The exhaust gas is by this heat exchange cooled to approximately 370 - 430°C before leaving the preheater tower. The meal is at the same time preheated to approximately 800°C before entering the calciner.

5. In the vertical static kiln, normally referred to as the “calciner”, the raw meal is dispersed with tertiary air and gases from rotary kiln. The temperature in the calciner is in the range of 900-1000°C, which is required for decomposing $CaCO_3$ to CaO + CO_2 (normally referred to as “calcination”). This process is very energy consuming and requires approximately 65% of the total thermal energy consumed in the kiln system. After the calcination process approximately 5-8% $CaCO_3$ remains in the raw meal
6. The calcined meal (normally referred to as “hot meal”), is now entering the rotary kiln. In the first (upper) half of the kiln, the materials are heated up towards the sintering temperature of 1450°C which occurs in the second half of the rotary kiln. During the sintering process, the substantial clinker minerals are formed:
   - Ca_3SiO_5 (simplified). Normally referred to as C_3S or “Alite”
   - Ca_2SiO_4 (simplified). Normally referred to as C_2S or “Belite”
   - $Ca_3Al_2O_6$ (simplified). Normally referred to as C_3A
   - $Ca_4Al_2Fe_2O_{10}$ (simplified). Normally referred to as C_4AF

   During the sintering process, approximately 25% of the material is liquid.
7. After sintering, the process enters the clinker cooler for quenching. Rapid cooling is important to “freeze” the mineral crystals before they decompose and deteriorate. The clinker cooler is a fluidized bed where ambient air is blown through a bed of clinker. The clinker is cooled while the air is preheated to 900-1000°C before it enters the combustion process in the rotary kiln and calciner. Cooling air used in the second half of the clinker cooler, while material is cooled from ≈ 500 to 100°C, is vented to air as excess cooling air. Finished clinker is then conveyed to clinker silos by steel conveyors
8. Clinker is then conveyed to cement mills. Norcem have 3 cement mills, all ball mills with closed circuit classifiers. The largest mill, CM No 7, also have a roller press for pre-grinding before the ball mill. Clinker is mixed with different types of additive materials, depending on which type of cement quality to be made. The mix is ground to the fine powder, cement.

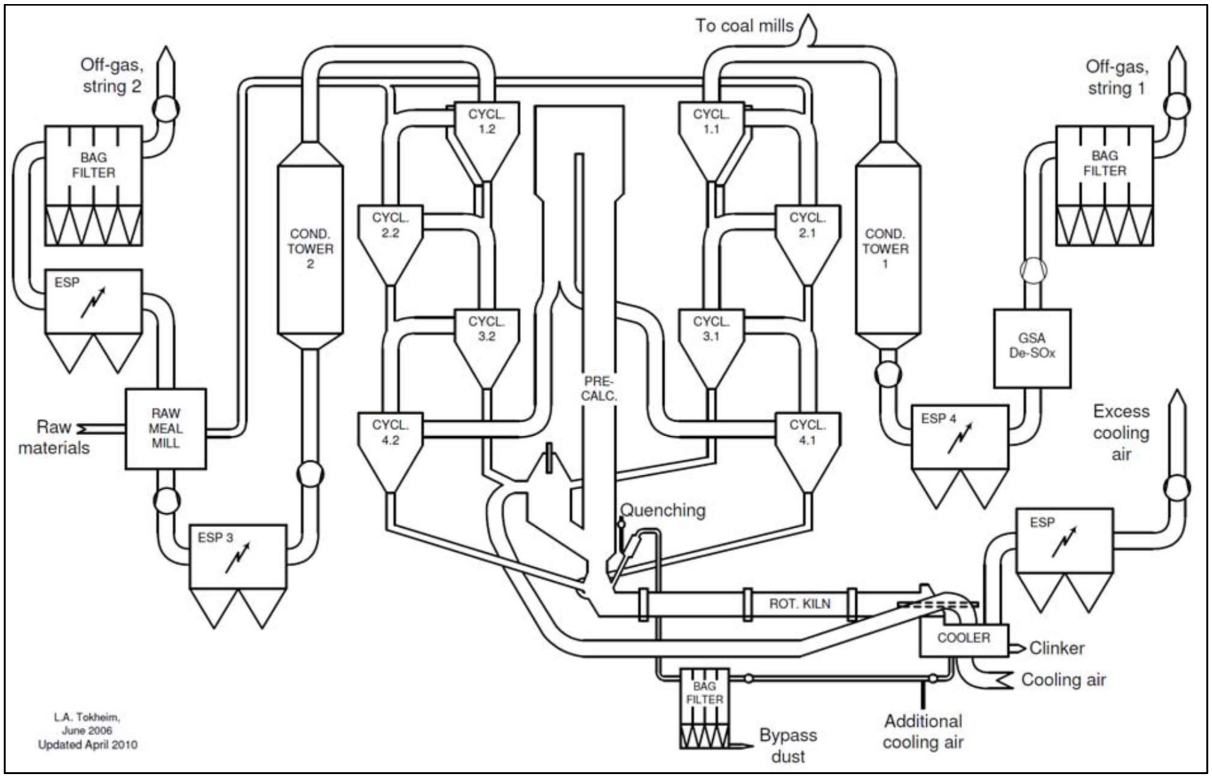


Figure 13 - The cement kiln (Kiln No 6) at Norcem Brevik

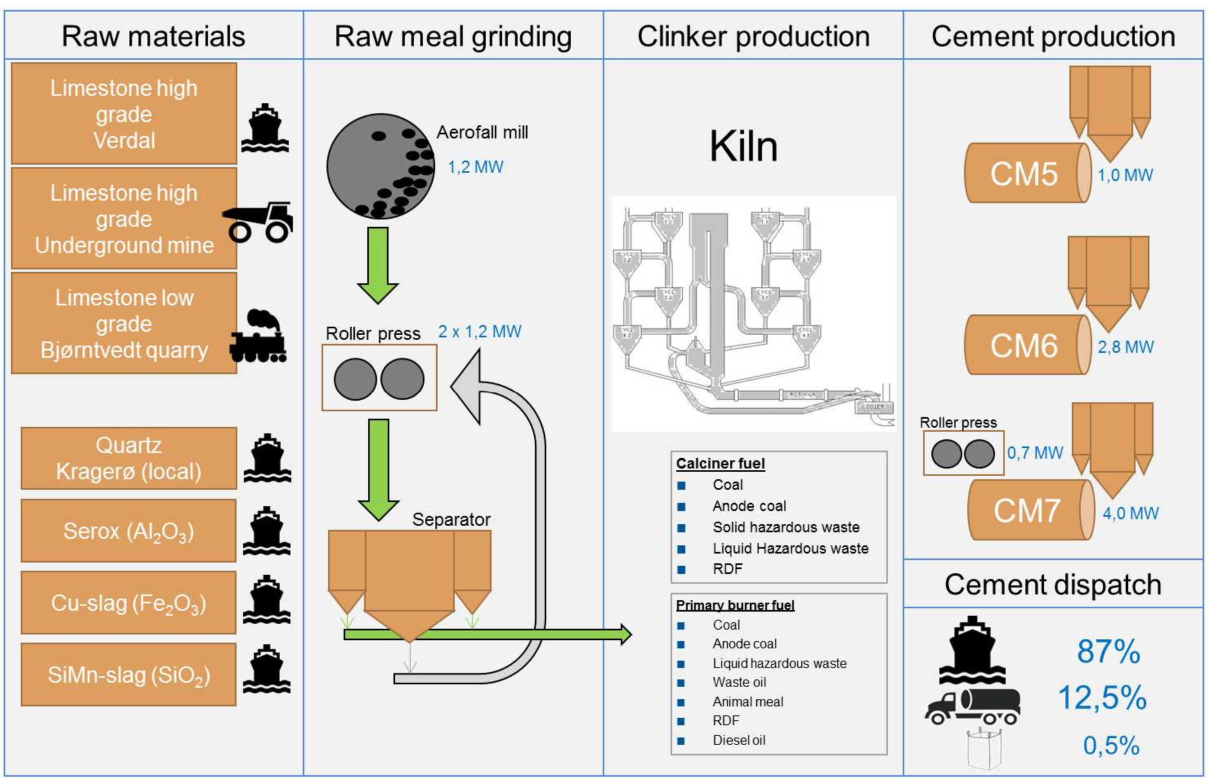


Figure 14 - General manufacturing layout and key data for Norcem AS Brevik

As a representative reference case for manufacturing of cement from clinker, average figures from 2017 are shown in Table 7 :

Material	Consumption (1000 tons)	Share	Comment
Clinker	1 080	78,9 %	
Gypsum	72	5,3 %	
Limestone	59	4,3 %	
Iron sulphate	4	0,3 %	
Fly ash	153	11,2 %	From coal fired power plants
SUM	1 370	100,0 %	

Table 7 - Reference case for manufacturing of cement from clinker

5.2 DESCRIPTION OF THE FLUE GAS (2b, 2c)

This chapter gives an updated description of the CO_2 source (composition, temperature, pressure, rate and regularity). In addition, the expected development / variation in the CO_2 source's rate over time is described (seasonal variations and variations over the plant's lifetime).
Cement cannot be produced without the simultaneous formation and release of CO_2. This is because the limestone, which is the main component in raw material, decomposes in the process and releases CO_2 ($CaCO_3 \rightarrow CaO + CO_2$). Approximately 2/3 of the carbon emissions are related to this process while 1/3 to the fuels used to maintain the required temperature in the process. Over many years, Norcem reduced the carbon footprint through substitution of raw materials and fuels, and this has resulted in the carbon emissions since 1990 being reduced from approx. 810-820 kg CO_2/t cement to a level around 600 kg CO_2/t of cement in 2017-2018.

The principles of the CO_2 balance in the kiln system are illustrated in Figure 15 based on approximate figures from 2017.

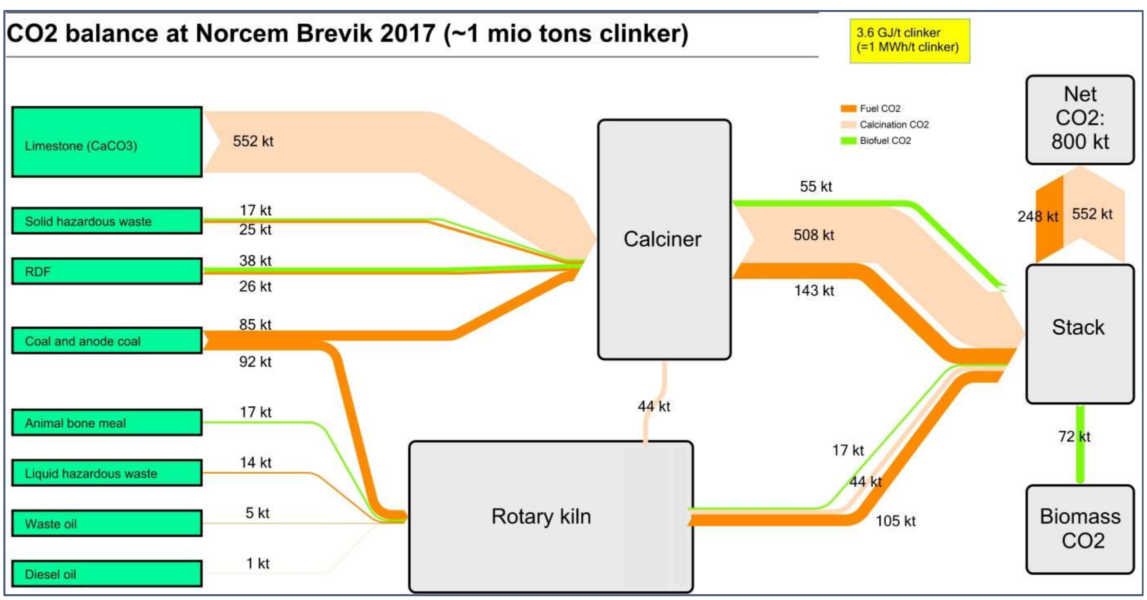


Figure 15 - CO_2 balance at Norcem Brevik 2017

5.2.1 Description of the CO_2 source (composition, temperature, pressure and regularity)

Typical composition of the flue gas in various interface points of the process, is thoroughly described in the reports NC03-AKER-P-RA-0008 - Estimated future process gas flows and conditions (Attachment 3) and NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4).

5.2.2 How the composition of the flue gas is affected by which clinker is produced.

Norcem Brevik mainly produces two types of clinker; STANDARD (STD) and Low Alkali (LA) clinker. STD clinker is manufactured approx. 50% of the time. In the production of STD clinker, limestone is used to a large extent from the open pit of Bjørntvedt which contains significant amount of sulphur as Pyrite (FeS_2), compared to limestone from Verdal and the Norcem underground mine. Therefore, to reduce the SO_2 level, the GSA is used during STD clinker production. The sulphur content is then reduced from a level around 450 mg/Nm^3 to 25 mg/Nm^3. Slurry of lime is injected into the GSA; additional water is supplied to the flue gas during STD production. The water content in the flue gas is increased while the temperature drops from approx. 150-180°C to approx. 85-105°C.

For manufacturing LA clinker; limestone is mainly used from Verdal and the Norcem underground mine, resulting in a SO_2 content in the flue gas in the range 30 mg/Nm^3. The SO_2 scrubber is therefore normally not in operation during LA clinker production.

The NOx concentration is not affected by which clinkers are produced, and the NOx reduction system is in operation regardless of which type of clinker is produced.

When the NOx reduction system (SNCR De-NOx) is in operation, the NOx concentration is reduced from the typical level of 350 - 800 mg/Nm^3 to typically 250 mg/Nm^3.

5.2.3 CO_2 concentration in the flue gas

The concentration of CO_2 in kiln gas leaving the preheater tower is high, around 22%, which is favourable for efficient carbon capture. Elimination of false air entering the kiln system is important to avoid dilution of the gas and to reduce the total gas volume through the fans and filter system. Continuous monitoring and maintenance are carried out to reduce false air leakages.

5.2.4 Expected development / variation in CO_2 source rate over time

This chapter describes expected development / variation in the CO_2 source rate over time, including seasonal variations over the lifetime of the plant.

5.2.4.1 Emissions covered by the Emissions Trading Scheme and allocation of allowances for Norcem Brevik

Norcem is subject to the Emissions Trading Scheme and extracts of emission-permissible emissions in CO_2 equivalents and allocated allowances for the period 2008 to 2020 are shown in Figure 16 (Source: The Norwegian Environment Agency's website (www.miljodirektoratet.no)).

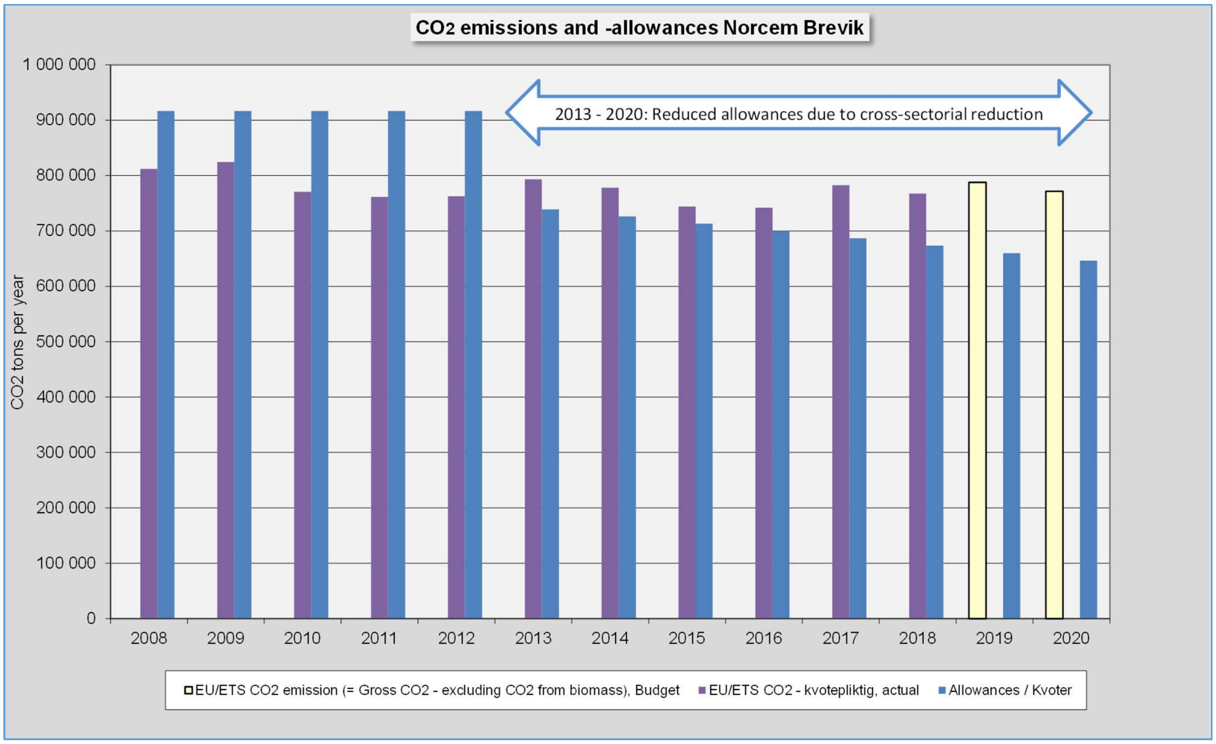


Figure 16 - CO_2 emissions and allowances; Norcem Brevik

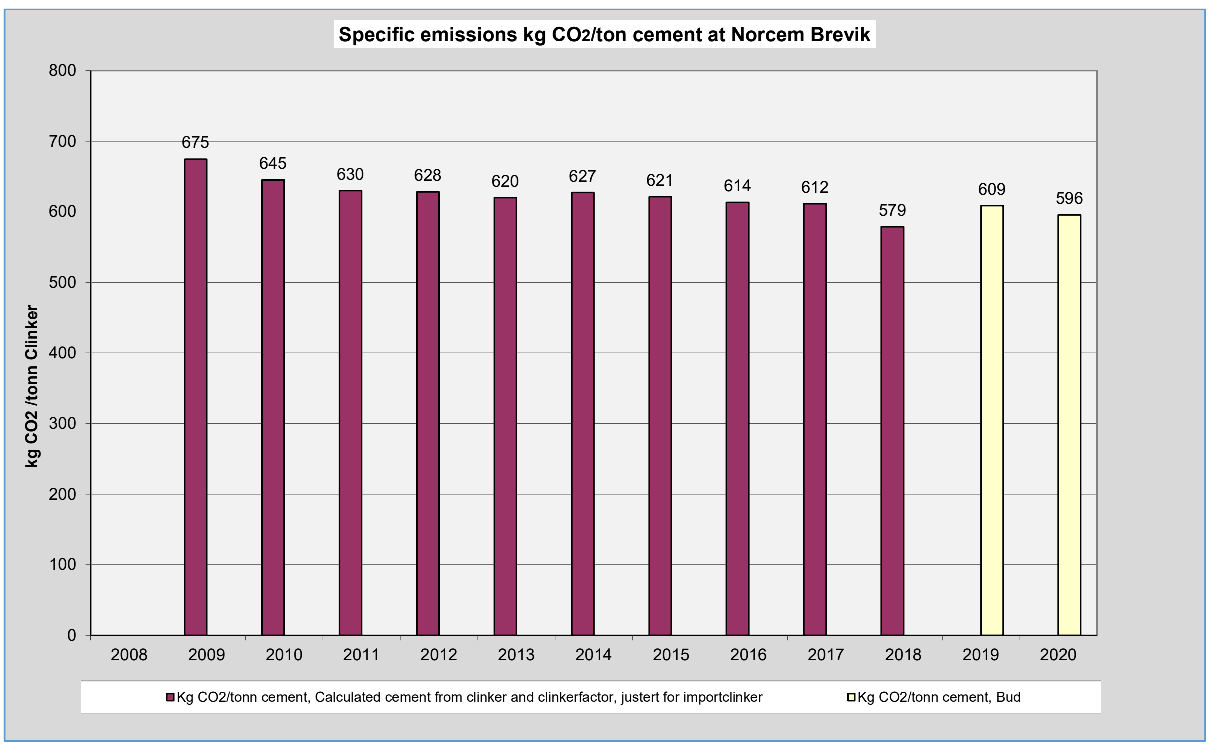


Figure 17 Specific emissions CO_2 / ton cement; Norcem Brevik

5.2.4.2 Norcem's own forecasts for future clinker production and CO_2 emissions (Figure 17)

The maximum production capacity in Brevik is at a level of 1 million tons clinker/year, and it is expected to remain at this level for many years still, as seen in Figure 16 - CO2 emissions and allowances; Norcem Brevik. No major changes are planned nor expected.

5.2.4.3 European Union Emissions Trading Scheme (EU-ETS)

Norcem is part of the European Union Emissions Trading Scheme (EU-ETS) and is now in the third period (2013 - 2020). In 2016, Norcem's two factories in Kjøpsvik and Brevik were in balance with the allowance allocated. For this trading period, the EU-ETS benchmark for the cement industry sector is 766 kg CO_2 / t clinker, where emissions at Norcem Brevik currently are in the range of 740-760 kg CO_2 / t clinker, still below the benchmark.
The number of allowances will be reduced for the next allocation period (2020), with the result that Norcem Brevik will be allocated quotas that fully cover the expected need. The current cross-sectoral reduction factor (CSRF) is at 1.74% but is expected to increase during the early 2020's.

5.3 TECHNICAL DESCRIPTION OF THE NEW PLANT (2e)

5.3.1 High-level plant description

This is a *first-of-its-kind* highly sophisticated carbon capture and conditioning plant; capturing CO_2 from the flue gas from Norcem's cement production plant in Brevik, Norway Conditioning CO_2 for ship transport and permanent storage below the sea bed on the Norwegian continental shelf.

The annual CO_2 capture capacity has been optimized (cost/ benefit) and mainly utilizes waste heat from existing cement plant and CO_2 conditioning for thermal energy production. As a result, only electricity and no additional heat or fuels are required to drive the CO_2 capture process.

The main connection points between the existing and the new plant are within the flue gas system as the flue gas contains both waste heat and CO_2. The new plant is installed in parallel to the existing flue gas system with focus on a safe, easy and smooth changeover between cement production with and without carbon capture and heat recovery, thus securing the integrity of the cement production.

The project comprises all necessary modifications of existing installations at Norcem.

The capture plant itself is arranged as *Green-field* installations, while the modifications to existing plant and providing the utilities are *Brown-field* installations.

5.3.2 Main design fundamentals

The main design fundamentals for the complete plant are:

1. The plant shall comply with all relevant HSE requirements
2. The construction and operation of the new plant shall not compromise the availability of the cement production in any way
3. CO_2 export quality requirements
4. Any interruptions or shutdowns in the cement production process shall not lead to any uncontrolled situations in the new plant
5. The plant is a demonstration plant aiming to demonstrate carbon capture from cement production processes while being part of a complete CCS chain
6. CO_2 capture capacity of 400 000 tons CO_2/ year (cost/ benefit)
7. CO_2 capture capacity to be based on available waste heat (thermal energy) recovered from existing cement process and from the capture and conditioning process itself

The NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4) (ODB), is based on these requirements and requirements stated in the Gassnova Design Basis, and it comprises all relevant design input for the complete plant. When needed, each WBS unit has established their own basis of design related to their own scope based on the principles set forth in the ODB.

5.3.3 Norcem site

The complete plant is located within Norcem's property in Brevik with three exceptions:

- The ship loading quay for CO_2 export, located at "Kastolkaia"
- The main grid station, which will be upgraded to handle the increased power demands
- The CO_2 storage tanks and pipeline culverts, which are partly located within Tangen Eiendom's area

Figure 18 shows site area allocation. This is further described in section 5.8, as well as in the NC03-NOCON-C-RA-0042 - CCS Plot plan (Attachment 5).

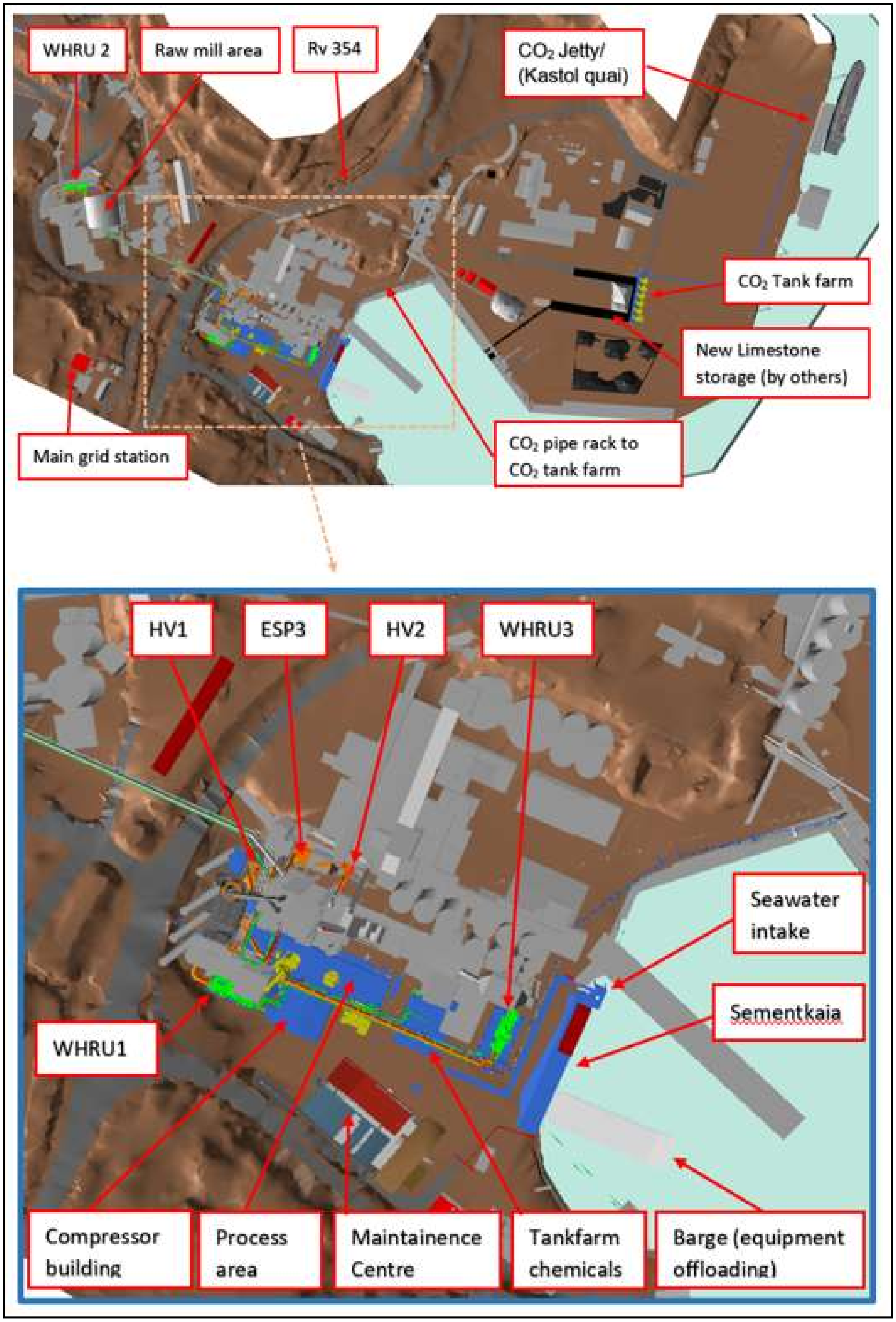


Figure 18 - Site Area Allocation

5.3.4 Main plant categories – introduction to plant description

The various elements of the new plant are divided into the following main plant categories being described in the following:

- Carbon capture, conditioning, intermediate storage and loading
  (Capturing CO_2 from the flue gas and conditioning it for export)
- Waste heat recovery from existing cement production process
  (Recovery of waste heat from the flue gas for use in the CO_2 capture process)
- Modification of existing flue gas system
  (All required modifications needed for highest possible waste heat recovery)
- Utility systems
  (All utilities like e.g. power needed for all new plant combined)
- Process consumables
  (All process consumables for all new plant combined)
- Civil works
  (Civil work needed for new plant and for required modifications/ relocation of existing)

In addition, separate sections are included for the following:

- Heat balance
  (Capture plant requirements vs. waste heat recovery)
- Plant operability, functionality and limitations
  (Functionality and limitations for all new plant combined)

5.3.5 Carbon capture, conditioning, intermediate storage and loading

5.3.5.1 Introduction

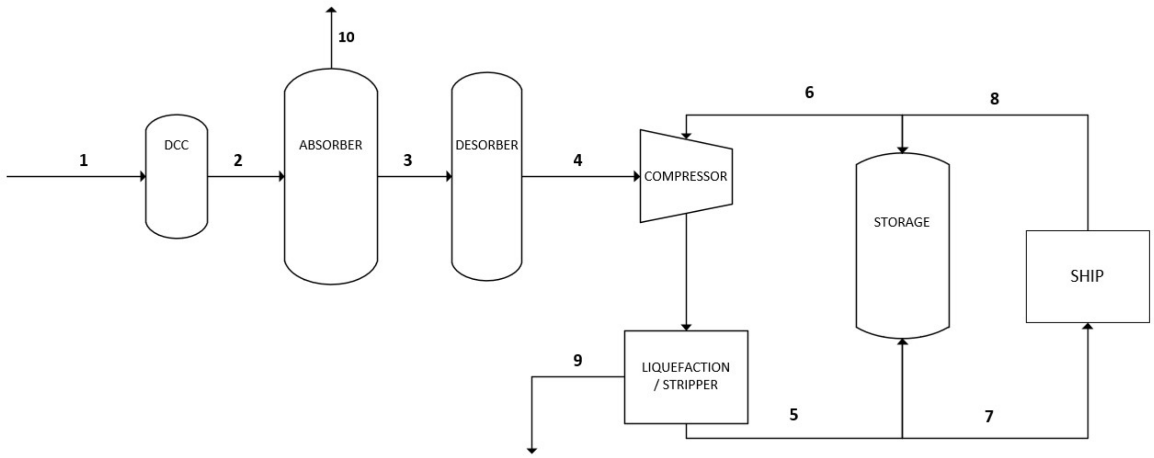
This plant category comprises all plant elements needed for separating the CO_2 from the cement production flue gas, conditioning it to meet export quality requirements and provide local intermediate storage.

Detailed descriptions can be found in NC03-AKER-A-RA-0006 - FEED study report (Attachment 6).

For better understanding, the following descriptions should be read in connection with the following flow diagrams:

- NC03-AKER-P-XA-0003 - Process flow diagram - Overall system diagram (Attachment 7) and
- NC03-AKER-P-XA-0008 - Process flow diagram – CO_2 tank farm and ship loading (Attachment 8).

Figure 19 below shows a simplified CO_2 flow diagram. It shows the main flows through each of the plant elements capture, condition, intermediate storage and loading. This flow presentation visualises capture rate, various capacities through the different plant elements and the effects coming from evaporation in the storage tanks and vapour return from CO_2 transport ship.



Flow line	CO_2 flow (tonnes/h)	Description/ comment
1	65	
2	65	
3	55	Net CO_2 loading.
4	55	
5	58	Liquefied CO_2
6	3	Vapour, estimated: • 1 tonnes/h from heat influx to CO_2 intermediate storage tanks, piping and transport ship • 2 tonnes/h from displaced volume in CO_2 intermediate storage tanks and transport ship
7	800	Liquid, Intermittent - during ship loading only
8	29 - 32	Vapour, Intermittent - during ship loading only, displaced volume in ship tanks which is returned to CO_2 intermediate storage tanks to replace extracted liquid volume. Range due to range in ship conditions.
9	0.04	Loss from inert stripper
10	10	To ambient

Figure 19 – Simplified CO_2 flow diagram with flow values

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.3.6 Waste heat recovery from existing cement production process

5.3.6.1 Introduction

This plant category comprises all plant elements needed for recovering waste heat from the cement production flue gas, converting it into steam at required quality and pressure for utilisation in the carbon capture process. It also comprises an aux. electrode steam boiler for reclaimer service and partial backup for fluctuations in the waste heat recovery.

For better understanding of the overall system, the following descriptions should be read while following the flow lines on the flow diagram NC03-NOEN-P-XA-0001Process flow diagram – Steam and condensate system included as attachment 9.

Detailed descriptions can be found in NC03-NOEN-A-RA-0001 - FEED study report WBS 550, in NC03-NOEN-P-RD-0001 - Technical Description, and in NC03-NOEN-P-TR-0002 - Technical specification, Waste Heat Recovery Boilers and Feed Water Tank.

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.3.7 Modification of existing flue gas system

5.3.7.1 Introduction

This plant category comprises all plant elements in the existing flue gas system which needs to be modified or replaced to integrate the CCC plant and waste heat recovery systems, and to meet the new operating conditions.

The planned modifications and replacements are based on a thorough inspection of the existing plant on site and extensive evaluations of the consequences of the new operating conditions.

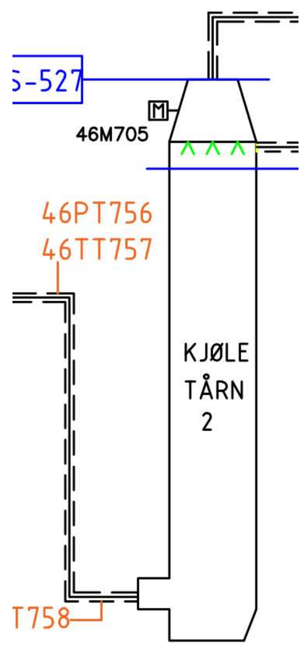
Detailed descriptions can be found in NC03-FLSM-Z-RA-0005 - FEED study report, WBS 540.

In this chapter, separate cut-outs from the Norcem PFD, NC03-NOCE-P-XA-0001 - Process Flow Diagram, 46PID page 1 and 2 are used to show how the new plant is integrated with the existing flue gas system.

Plant shown in black colour is the existing plant, green colour represents plant that must be modified or replaced, and magenta colour represents new plant. The boxes labelled “GS- “identify interface points.

NC03-NOCE-P-XA-0001 - Process Flow Diagram, 46PID page 1 and 2 is included as attachment 10.

5.3.7.2 Gas Conditioning Towers string 1 and 2 (GCT 1 and 2)



The Gas Conditioning Towers, GCT, must be modified to cover new roles. Today the towers are operated with a continuous steady water spray for cooling purposes when the cement production is running. As there currently is no heat recovery from flue gas, the outlet temperature from the GCTs are kept rather low to be on the safe side for protecting downstream equipment.

When the waste heat recovery system comes into operation the objective is to keep the GCT outlet temperature stable and as high as feasible with regards to downstream equipment to obtain maximum heat recovery.

To achieve this the GCT’s will be operating with a variable cooling service (water spray) based on variable incoming preheater gas temperatures in the range of 375-450°C providing a stable outlet temperature of approx. 375°C. In this operational mode the plant will be operating on narrow temperature margin between desired temperature and max. permissible temperature.

This new service requires that the cooling service (water spray) must be able to react immediately for changes in inlet temperature to the GCT to maintain max. allowable inlet temperature to downstream equipment. This means that the cooling water lances and nozzles must be protected against clogging due to heavy dust load in the GCTs when not in use, or in use on less than max service. This is achieved by upgrading the GCTs with a 2-phase spray system with permanent purge air to the lances and nozzles. This will prevent blocking of the nozzles during inactive periods.

A two-phase spraying system uses compress air for atomizing the water into very small droplets. Both water and air pressures are moderate, see Figure 36.

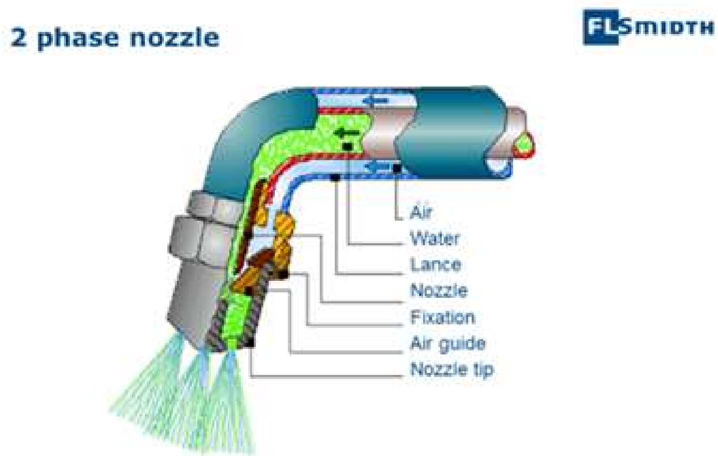
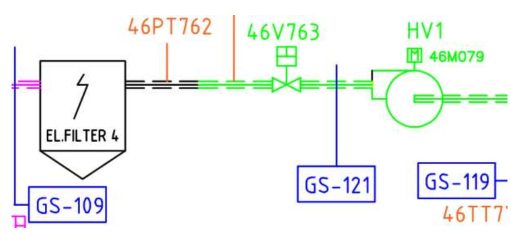


Figure 36 - Two-phase water/ air nozzle for cooling service in the GCTs

To get the best possible effect, both GCTs will be upgraded to a two-phase spray system including a two-phase forward control system. In addition, GCT1 will be upgraded with gas distribution screen as that already installed in GCT2.

5.3.7.3 Main flue gas fans/ Hovedventilator string 1 and 2 (HV 1 and 2)



These fans are downstream the GCTs and must handle flue gas with increased temperature. Therefore, both these fans must be replaced as the volume flow increases with the increased temperature. The fans with el. motor will be equal in size and model, and of centrifugal type with one impeller between bearings. Normal speed is approx. 1000 rpm, and corresponding shaft power is approx. 1750 kW. Installed power is 2000 kW, and the el. motors are controlled by variable speed drives (VSD).

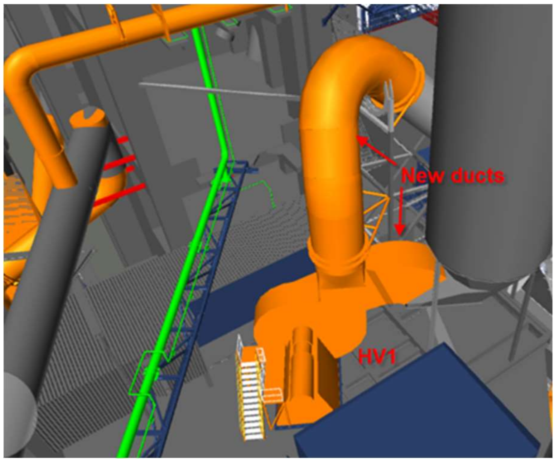
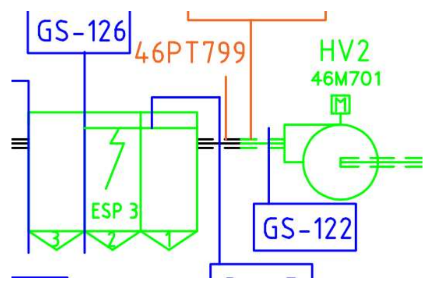


Figure 37 - HV1 (left) HV2 (right).
Legend: Orange: New flue gas fan and ducting, Blue: New structures/ buildings, Green: Steam/ condensate.

Operating on design flow, temp. and pressure the temperature increase for the flue gas within the fans will be approx. 15 - 20°C, thus increasing the outlet temperature of the flue gas towards 390-395°C. Max continuous operating temperature for the downstream ESPs are 400°C.

The fan housings are of welded non-alloy high temp. steel, the impellers are of high strength quenched and tempered steel and the shafts are of high temp alloy steel. The fans will be insulated with 100 mm mineral wool covered with cladding plate.

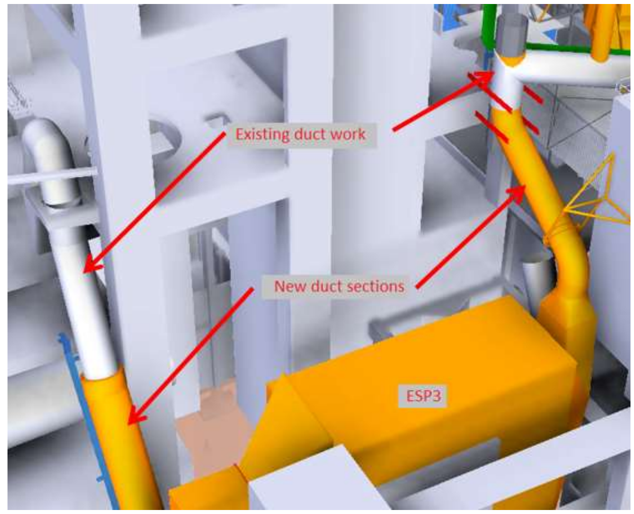
5.3.7.4 Electro Static Precipitator/ El. filter string 1 and 2 (ESP 4 and 3)



The current setup is characterized by each string ending up with a fabric filter (FF) ensuring a low and stable emission. This means that today the actual performance of the ESP 3 upstream the FF 2 is not critical, but the ESP 4 performance is linked to a max. acceptable dust content in GSA inlet which is upstream the FF 1.

However, with the planned installation of the waste heat recovery system, ESP 4 and 3 will play a more important role in reducing the dust load in the flue gas before entering the WHRU's and thereby reducing the risk of scaling with reduced heat transfer as a result. Both ESPs will therefore be upgraded to meet a dust outlet requirement of 0,1 g/Nm^3. One of the most efficient ESP improvements during the last 20 years is the development of fast reacting high voltage ESP controllers.

ESP 3 has only two electrical fields today and will be upgraded with a third electrical field as well an extension in height, and the new fast reacting high voltage controller, PIACS DC4.



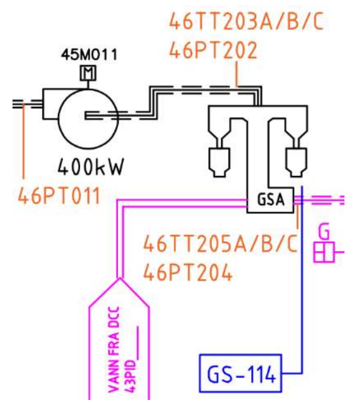
ESP 4 has three electrical fields and the required height, and during high temperature testing (~340 °C) March 14th – 16th 2016 ESP 4 showed very good performance with emission values around 30-50 mg/Nm^3. The ESP 4 performance is expected to be equivalent in the temperature range from 340°C up to 400°C. It will be upgraded with the new fast reacting high voltage controller, PIACS DC4.

The dust entering ESP 3 and 4 consists primarily of pulverized limestone.

5.3.7.5 Gas Suspension Absorption string 1 only (GSA)

The GSA requires no upgrades or modifications on the flue gas side as the future process conditions are inside the original design values.

The GSA will initially be operated at the same TAD (Temperature Above Dewpoint) as today to avoid moisture in the flue gas and consequently clogging of the fabric filter FF1 (bag filter) based on Norcem operational experience. This requires a higher lime consumption for SO_2 removal compared to operate on a lower TAD and hence meaning lower GSA outlet temperature. During operation, the TAD will be further evaluated, and most probably lowered as the flue gas contains less water when the GCTs are operating on reduced cooling service. This will again lead to reduce lime consumption.

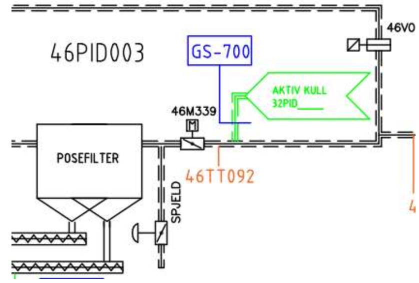


The water system supplying the GSA with spay water and diluting water for lime is modified to utilize process water coming from the DCC and the EWTP as make-up water thus reducing the consumption of potable water.

5.3.7.6 Injection system for Powdered Activated Carbon (PAC) on string 1

Due to the new flue gas operating conditions maintaining a higher temperature over a longer period there is a potential increased risk for formation of dioxins in the flue gas system (see section 6.3.1.3). The GSA and the Raw mill will, when operation, scrub the dioxin out of the flue gas as the present operation of the cement plant.

The GSA is not in operation when producing LA clinker (approx. 50% of the operating time), and therefore, a system for injection of powdered active carbon is installed between the GSA and FF1 handling possible dioxin formation during LA clinker production.

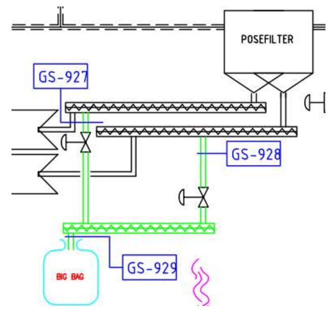


The system comprises a silo with a PAC capacity of 30 m^3 and an injection system

The active carbon will be effective for capturing both dioxin and mercury in the downstream fabric filter thus also reducing the total release of mercury from the combined plant compared to today. The PAC system together with the disposal of the dust coming from FF1 are important measures to allow return of process water from DCC and EWTP to the GSA.

A similar system may be installed on string 2 as well (currently an option) if future operational data will show that this is required. Such PAC systems have been installed several times by FLSmidth and is standard equipment proven to be quite efficient.

5.3.7.7 Fabric filters/ Bag filter string 1 and 2 (FF1 and 2)



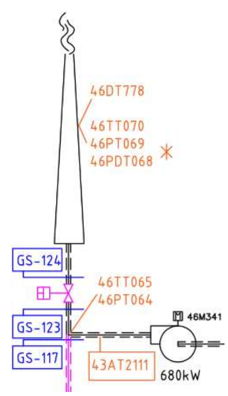
No modifications of the flue gas side of FF1 are foreseen to be necessary due to future operating conditions. On the FF2 the internal bypass damper is upgraded to be faster reacting (1 sec) becoming an additional temperature protection feature for the filter bags. This upgrade is in addition the existing cold air inlet protective feature.

In case of a WHRU fan 2 breakdown the water injection in the GCT 2 will be reactivated for cooling the hot flue gas from the preheating towers. However, due to the long physical distance between the GCT 2 and the FF2 there is a lot of hot flue gas in transit that will not be cooled by the GCT2. Therefore, the bags in FF2 must be protected from this hot gas by opening the cold air inlet and by diverting the hot flue gas from the bags by opening the FF 2 internal bypass.

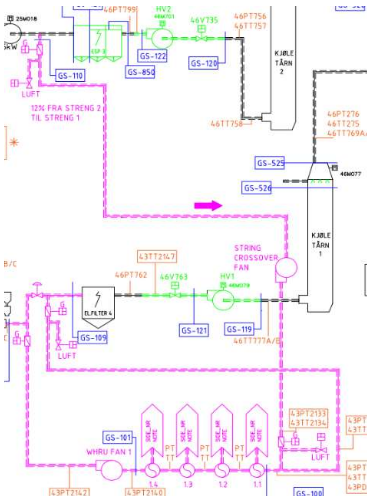
The dust handling system on FF1 is modified as this dust will no longer be returned to the cement process due to its possible content of dioxin, mercury and active carbon, see section above regarding PAC injection.. This dust will be extracted to a new big-bag system and go to final disposal.

5.3.7.8 Stack no. 3

This is the stack currently in use for flue gas from string 1, and its operation will be replaced by the new stack included in the capture plant. However, a damper will be installed upstream stack no. 3 making it usable in cases where both the capture plant and the capture plant by-pass is out of operation while the cement production is in operation.



5.3.7.9 Flue gas crossover from string 2 to string 1



Flue gas crossover from string 2 to string 1 is required as there is not enough CO_2 to be captured from string 1 alone to reach the yearly capacity of 400 000 tones CO_2. Flue gas must be added from string 2.

In addition, this ad operational flexibility dependent on final capture rate and heat transfer in the WHRUs as a variable flow of flue gas may be added from string 2 to capture 55 t CO_2/h. As the crossover fan is equipped with a variable speed drive (VSD), this is only limited by the crossover fan capacity reserves and turndown ratio.

The flue gas from string 1 and 2 is coming from the same kiln and is further mixed through string 1 securing a homogenous gas entering the downstream capture plant.

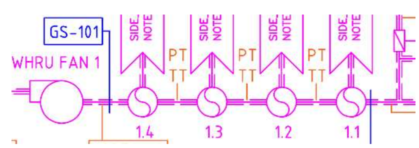
The fan will be insulated with 100 mm mineral wool covered with cladding plate.

5.3.7.10 WHRU fan 1, 2 and 3

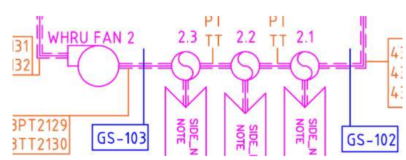
These are new fans serving the three WHRUs by compensating for the pressure drop in the flue gas caused by the boilers. The fans will be of centrifugal type with one impeller between bearings and the el. motors are controlled by variable speed drives (VSD).

The fan housings are welded of non-alloy high temp. steel, the impellers are of non-alloy high tensile steel and the shafts are of non-alloy structural steel. The fans will be insulated with 100 mm mineral wool covered with cladding plate.

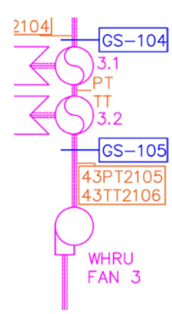
These fans are rather large power consumers:



<u>WHRU fan 1:</u>
Serving four boilers
Normal speed is approx. 1000 rpm
Shaft power is 820 kW
Installed power is 950 kW

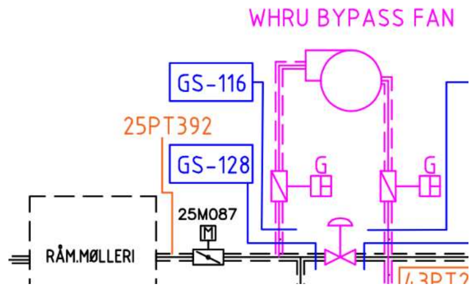


<u>WHRU fan 2:</u>
Serving three boilers
Normal speed, approx. 1000 rpm
Shaft power 600 kW
Installed power 710 kW.



<u>WHRU fan 3:</u>
Serving two boilers
Normal speed, approx. 1000 rpm
Shaft power 410 kW
Installed power 500 kW.

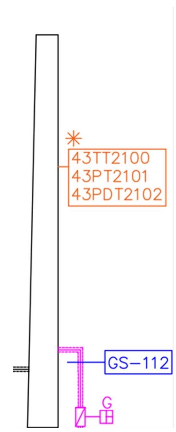
5.3.7.11 WHRU by-pass fan
This is a new fan used only when producing LA clinker and the WHRU 2 is in operation. The purpose of this new fan is to supply the raw mill with high-temperature flue gas in addition to the cooled flue gas coming from the WHRU 2 when producing LA clinker as a hot but rather small flow to the mill is required.



The fan will be of centrifugal type with one impeller between bearings and the el. motor is controlled by a variable speed drive (VSD).

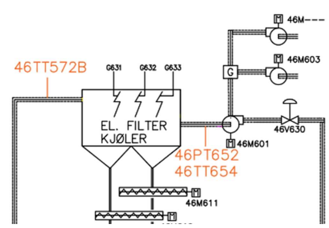
Normal speed is approx. 485 rpm, shaft power is 22 kW. Installed power is 30 kW. The fan will be insulated with 100 mm mineral wool covered with cladding plate.

5.3.7.12 Stack for clinker cooler hot air
This is the stack currently in use today for hot air from clinker cooler, and its operation will be replaced by the new stack in the capture plant during normal operation of waste heat recover unit 3. As this stack is to be used for clinker cooler hot air in case of WHRU 3 shutdown, it is kept warm by releasing some hot air through the stack also during WHRU 3 operation. The tie-in for the WHRU 3 will be above todays inlet to the stack from the hot air clinker cooler to avoid any change of hot air flow direction inside the stack when changing between WHRU 3 operation and WHRU 3 standstill.



The damper upstream the WHRU 3 is “locked open” to secure a smooth changeover of hot air flow direction and it will only be closed in case of maintenance requiring opening of the ductwork or boilers. This smooth changeover is important to avoid pressure fluctuations in the duct upstream the stack affecting the burner in the kiln.

5.3.7.13 Electro Static Precipitator/ El. filter Clinker Cooler hot air ESP
Only minor upgrades of the electrical fields of the filter are required for this unit to comply with the required dust content downstream the filter.



In addition, the ESP temperature protection will be upgraded by improved cooler control with either fresh air dampers or water injection activated above a certain temperature limit.

If needed to further secure performance, this ESP could also be upgraded with a new fast reacting high voltage controller. This is not included in the design at this point.

The dust entering the clinker cooler ESP consists primarily of cement dust.

5.3.7.14 Flue gas ducts and tie-ins
The new installations require both new ducting and modification of existing. In tight spaces old ducting is modified to gain space for new dampers and tie-ins. Generally, the new flue gas ducts are similar to the existing with regards to materials and supports.

Circular ducts are preferred as they minimise the amount of steel required and are less expensive to fabricate. However, in tight spaces ducting with rectangular cross section may be used. All ducts are made from mild steel with external stiffeners. A corrosion allowance of 1-2 mm is included.

When selecting actual cross section area, a flue gas design velocity in the range 15-20 m/s is used to avoid dust settling while maintaining an acceptable pressure loss. Pressure loss calculations are performed for all new ducts to establish flue gas velocity and thus duct dimensions.

Only surface treatment is a transport primer as the ducts will be insulated. To avoid heat loss and condensation of moisture in the flue gas inside the ducts they will be insulated with 100 mm mineral wool covered with cladding. To avoid corrosion in ducting dead-legs purging possibilities with air is included as on existing plant.

All tie-ins for the new plant are equipped with isolation dampers and mechanically designed to avoid dust build-up and high-pressure losses.

Expansion joints are added both to new ducts and to tie-ins where necessary to handle vibration and thermal expansion. Slide brackets, saddles and pendular supports will support the ducts in a way that allow, and control needed movement due to thermal expansion. Supports will where possible be attached to existing structures thus reducing the need for additional new foundations.

The ducts are equipped with manholes for internal inspection.

Stress calculations of ducts and supports wrt dust filling are based on HTC guidelines, Norcem's own operational experience in Brevik together with FLSmidth's experience from other comparable cement production plants.

5.3.7.15 Dampers
All new dampers, on-off and modulating, are of louvre type with two shafts and double acting pneumatic actuators and limit switches. All dampers which need to be 100% gas tight are equipped with sealing air to accommodate for manual inspection inside sealed off ducting while cement production is ongoing.

Sealing air is ambient air and is provided to each damper by installation of a local fan and air heater. The air heater will be put into operation if corrosion becomes evident in the dampers due to moisture in the sealing air.

All damper housings are made from mild steel, blade sealing from SS and shafts from SS.

5.3.8 Utility systems

5.3.8.1 Introduction

This plant category comprises all plant utility elements supporting the main process systems described above. Utilities are delivered both by new installations and from upgraded existing utility systems.

For each utility system it is denoted if it is a *New installation* or an *Upgrade/ extension* of the existing system

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.3.9 Process Consumables

5.3.9.1 Introduction

This chapter describes various process consumables being chemicals that must be supplied to and stored at the Norcem plant for use during normal operation. This chapters do not cover consumables like water, electrical power, compressed air, etc. as these are described as utilities in section 5.3.8

Detailed descriptions can be found in NC03-AKER-A-RA-0006 - FEED study report (Attachment 6).

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.3.10 Civil works

5.3.10.1 Introduction

The civil works needed for establishing the CCC plant are divided into the following main groups with sub-group number, each pointing to separate documents and drawings;

1. Modifications and relocation of existing facilities and structures:
    - 412 Demolition work
    - 413 Relocation of existing facilities
    - 414 Modification of existing structures
    - 415 Temporarily construction facilities

2. New installations:
    - 422 Main process areas, compressor building and drying unit
    - 423 Substations
    - 424 WHRU foundations
    - 425 Flue gas ducts supports and foundations
    - 426 Tank farms
    - 427 Jetties and sea water intake/ outlet
    - 428 Miscellaneous civil
    - 440 Underground installations
    - 430 HVAC

3. Ground surveys:
    - 406 Geotechnical

For group 1 Norcem is the main contributor wrt requirements and availability for alternative locations for the existing facilities and structures. Typically for the tasks in this group is that they are related to either mechanical or electrical work on existing installations where the changeover must be done during a yearly winter repair. They must also be completed before any other installation works for the new plant is initiated. Generally, all buildings/ functions are re-established having the same size/ capacity/ functionality as today's buildings/ functions. However, some upgrading must be expected to meet new governmental requirements, e.g. Tek17. There has also been high focus on environmentally sustainable solutions with regards to heating, ventilation, etc.

For group 2 it is the new process equipment that defines the requirements to the civil structures. This means that the new civil structures must comply with the requirements put forward by the process equipment. This applies not only to size and weight, but also to requirements like dust load, temperatures, noise, required maintenance area, etc.

As the CCC Plant is being integrated into an existing cement production plant a lot of existing civil structures will be affected by e.g. additional loads (static and dynamic) from new equipment. For all such cases, the existing structures have been examined wrt handling the additional loads and needed reinforcements. As such reinforcements may be substantial and therefore both be costly and affect the operation of the existing cement plant, there has been an extensive cooperation between the process equipment suppliers and Norcem with support from Norconsult to establish the best possible locations/ layout for the process equipment, and for the routing of ducts and piping between the various locations.

Group 3 is the various investigations that have been carried out to confirm that the preferred locations for new plant is feasible both from a technical and an economical perspective. In addition to soil investigations all existing installations that are affected in any way by the new plant has undergone a mapping wrt dangerous substances. This also includes the routing at the seabed for the main sea water cooling pipes.

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.3.11 Plant Operability

The operability understood as the plant's capabilities during operational modes as *start-up, normal operation, turn down, shutdown, emergency shutdown, standby, etc.* have been developed in parallel with the development of the Process Flow Diagrams (PFDs) and the Piping & Instrumentation Diagrams (P&IDs) for setting up system flexibility requirements, instrumentation, and defining the various equipment requirements.

All new plant is designed, arranged and equipped so the change-over between operating the cement production with or without the CCC plant and the waste heat recovery units in operation is smooth and can be done without stopping the cement production.

For the new plant, the CCC plant is the governing system and where the waste heat recovery system and the flue gas handling are responding to operational requirements coming from the CCC plant.

The normal operational range for all new plant is 100% with a turndown to 75% capacity.

For further details, please see NC03-AKER-P-FD-0001 - Process Control, Start-up and Shutdown Philosophy and NC03-NOCE-Z-RA-0027 - Functional Design Specification (FDS) Tie-ins.

5.4 RELIABILITY ANALYSIS FOR CO_2 PRODUCTION (2k)

5.4.1 CO_2 Product Specification

The CO_2 will be compressed and dried to the required specifications provided in the design basis, hence liquid CO_2 at approximately 16 bara and -26 °C will be delivered at the battery limit between the CO_2 capture plant and CO_2 transportation. The design requirements for the CO_2 purity are shown in Table 15.

Component	Concentration ppm (mole)	
Water, H_2O	*≤ 30*	*Required to avoid formation of hydrates (blockage) and free water (corrosion) in the pressure vessels and process systems used for interim storage and transportation.*
Oxygen, O_2	*≤ 10*	*Required to avoid formation of corrosive species in the lower well completion where the CO_2 mixes with reservoir brine containing chlorides.*

Sulphur oxides, SOx	*≤ 10*	*Required to avoid accelerated corrosion in presence of water. Value set conservatively to allow wider range of materials.*
Nitric oxide/ Nitrogen dioxide, NOx	*≤ 10*	*Required to avoid accelerated corrosion in presence of water. Value set conservatively to allow wider range of materials.*
Hydrogen sulphide, H_2S	*≤ 9*	*Toxic to personnel in case of accidental release.*
Carbon monoxide, CO	*≤ 100*	*Toxic to personnel in case of accidental release.*
Amine	*≤ 10*	*May react with and degrade several non-metallic materials*
Ammonia, NH_3	*≤ 10*	*Effects unknown*
Hydrogen, H_2	*≤ 50*	*May cause embrittlement of metals.*
Formaldehyde	*≤ 20*	*May react with oxygen to form formic acid. Other effects are unknown*
Acetaldehyde	*≤ 20*	*May react with oxygen to form acetic acid. Other effects are unknown*
Mercury, Hg	*≤ 0.03*	*Toxic to personnel entering vessels, replacing filters, etc. May cause embrittlement of metals.*
Cadmium, Cd Thallium, Ti	*≤ 0.03 (sum)*	*Toxic to personnel entering vessels, replacing filters, etc. May cause metal embrittlement of metals.*

Table 15 - Design CO_2 product purity specification at battery limit with CO_2 transport provider

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.5 RELIABILITY ANALYSIS FOR DELIVERY OF CO_2 (2i)

5.5.1 Production rate of liquid CO_2 at export conditions

As specified in the Design Basis, the CO_2 capture plant will be dimensioned for a capacity of 55 ton/h of CO_2. The downstream CO_2 conditioning plant will be dimensioned for slightly higher capacity as this plant needs to consider recycled CO_2 vapor from the liquefaction process as well as evaporated and displaced CO_2 from the tank farm and the CO_2 ship. Since all evaporated CO_2 is recycled back to the conditioning plant, the loss of "captured CO_2" in the downstream conditioning process and tank farm is very limited. Captured CO_2 is only lost from the inert stripper vent, during normal operation. According to process simulations 40 kg/h of CO_2 must be vented from the inert stripper to fulfil the <10 ppmv O_2 criterion in the CO_2 product. Thus, for all practical matters it can be assumed that the net production rate of liquid CO_2 (liquid CO_2 to the storage tanks subtracted the displaced and evaporated CO_2 gas) is equal to the CO_2 capture rate of 55 ton/h during normal operation. For further details regarding the heat and mass balance see NC03-AKER-A-RA-0006 - FEED study report (Attachment 6).

As described in section 5.3.5.9 CO_2 vent system, CO_2 will be vented from the CO_2 conditioning plant and/or the storage tank. Venting from the CO_2 conditioning plant only occurs during start-up and shutdown operation. On the other hand, loss of CO_2 due to venting from the CO_2 tank farm will occur during standstill of the CCC plant. In accordance with the Design Basis, the CCC plant is expected to be in operation for 7300 hours in an average year meaning that venting of evaporated CO_2 from the tank farm is expected for typically 1400 hours per year. The CO_2 evaporation due to heat ingress from ambient to the CO_2 tank farm and associated piping has preliminary been estimated to 1 ton/h, which will lead to an estimated maximum of 1400 tons/year of CO_2 venting.

5.5.2 CO_2 production regularity

To operate the CCC plant at a nominal output of 55 ton/h of liquid CO_2 for export requires that:

- the Brevik plant is in stable operation
- the flue gas flow rate and CO_2 content in the flue gas to the CCC plant is sufficient to reach 55 ton/h CO_2 capture
- the design amount of steam for the capture plant is available from the waste heat recovery units in the cement process

In the Design Basis it has been assumed that the Brevik plant is in operation for 7400 hours in an average year. Based on analysis of operating data from the Brevik plant [18]. it is concluded that the flue gas flow rate and CO_2 content are sufficient for capturing 55 ton/h of CO_2 in these 7400 operating hours. However, the waste heat availability is not always sufficient during all the 7400 hours to provide the required amount of steam. For this reason, an electric auxiliary boiler is installed to provide the balancing heat input required for the CCC plant.

In addition to the conditions above being fulfilled for the Brevik plant, the CCC plant must be available for capture of CO_2 at design capacity. The CCC plant will not always be available for capture of CO_2 at design capacity when the Brevik plant is in operation due to start-up time of the CCC plant, equipment trips, maintenance work, mechanical failures, etc.

The 7400 hours of operation at the Brevik plant means nearly 1400 hours of outage in an average year whereof 500 hours are planned (3-weeks winter repair) and 900 hours are unplanned. The long periods of outage will provide many opportunities to perform maintenance and repair work at the CCC plant when the Brevik plant is anyway out of operation. For this reason, it is reasonable to expect relatively high availability for the CCC plant even though it is designed without redundancy on most of the equipment.

The start-up of the CCC plant will always lag behind the start-up of the Brevik plant. The start-up time of the CCC plant will depend on the duration of the outage. For a plant trip, or short outage where the CCC plant and WHRU system is maintained in hot standby, the start-up time will be short. The ramp up of the WHRU system and hence steam supply will be determining for the start-up time of the capture plant. When capture plant load of 50% is reached, the compressor is started up. The compressor start-up is fast (minutes only), and if the CO_2 drying package is pre-pressurized and ready for inline operation, the liquefaction plant is started up as soon as the dry gas upstream of the CO_2 condenser is confirmed pressurised. If the dryer package has been de-pressurized, it takes another 15 minutes to re-pressurize it. If both dryer beds are wet, it takes almost 12 hours to dry one bed before the liquefaction process can start, the latter is however not a normal start-up case since an operating dryer bed will be isolated and maintain pressurized during a normal shut-down.

In Figure 46, stop statistics for the Brevik Plant are shown for 2016 and 2017(see NC02-AKER-A-RA-0006 - Concept Study Report). It appears that although there is significant variation between the two years, the majority of stops have relatively short duration. Based on the stop statistics and the start-up times, it is estimated that about 50-90 hours of start-up time lags (i.e. lost operating hours) per year is expected for the CCC plant.

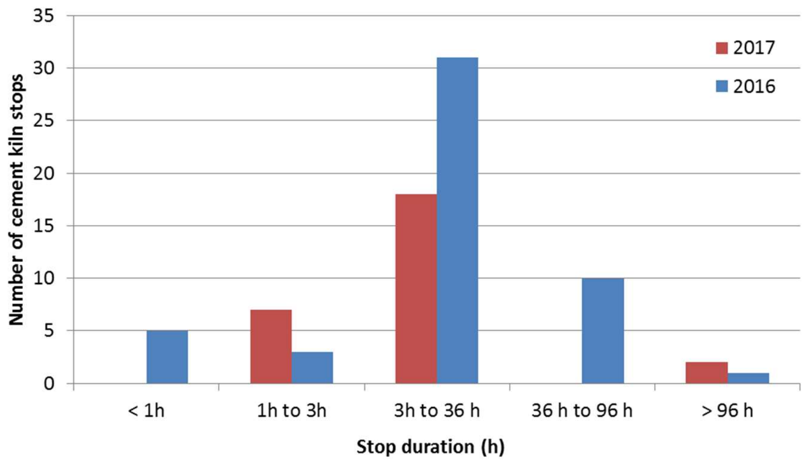


Figure 46 - Stop statistics for cement kiln at Brevik for 2016 and 2017

Considering approximate 1 hour start up time in average, the operating time lost on start-ups is less than 100 hours per year and it seems possible that the CCC plant may operate near design capacity for up to 7300 hours per year. With 7300 operating hours at design capacity in an average year it will be possible to reach the target of 400 000 tpa of CO_2 capture.

A detailed RAM analysis has been performed during FEED, where the whole train including WHRU system and CCC plant is assessed. The results of the RAM study are summarized in Table 16.

Value Chain Element	Availability	Production downtime
Availability of CCS	96.9% (not including planned shutdown)	11,3 days
Availability of kiln	83.3%	61 days
WHRU system, LP stream compressor, El Boiler, and condensate return pump and tank	99,5%	2 days
Availability of whole production chain	80,3%	72 days

Table 16 - Production Availabilities of CO_2

For details of methodology and assumptions, please see NC03-AKER-Z-RA-0005 - RAM Report (Attachment 12).

5.5.2.1 Seasonal variations

Except for the 3-weeks yearly winter repair at the Brevik plant, no planned stop or seasonal variation in the plant's load factor are expected. The yearly winter repair is typically located in the period March to April. All scheduled maintenance of the CCC plant is expected to be executed in this period as well. A three week stop of the CCC plant implies that the volume of liquid CO_2 for export is reduced with about 28 000 tons compared to if the plant had been in continuous operation in the period.

As there is nearly 900 hours of unscheduled stops per year at the Brevik plant in average, it is apparent that there will be variations in the volume of liquid CO_2 prepared for export. Nevertheless, as shown in Figure 46; the unscheduled stops are typically of short duration and it is unlikely to have long periods of outage in a row.

5.6 THE PROSPECTIVE OF THE EMISSION SOURCE (2d)

The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.7 TECHNICAL MATURITY AND TECHNOLOGY QUALIFICATION (2f, 2g, 2h)

This section provides a summary of the Technology Qualification activities performed in the project and the conclusions from DNV GL's independent assessment of technology performance.

The following technologies applied in and developed as part of the project are assessed to have new technology elements:

1) CO_2 capture technology (Aker Solutions)
2) CO_2 compressor with integrated heat recovery (Aker Solutions)
3) Waste Heat Recovery Units (Norsk Energi)

These technologies have all been qualified for full scale carbon capture in Brevik, in accordance with DNV GL's recommended practices DNV-RP-A203 - Qualification of new technology [19] and DNV-RP-J201 - Qualification procedures for CO_2 capture technology [20].

Based on the conclusions from completed FEED studies, the performed technology qualification activities and the technology performance assessments made by DNV GL, Norcem considers the residual project risk related to the performance of novel technologies to be low.

The following subsections provides a summary and conclusions from the Technology Qualification of each of the three technologies listed above.

The further contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

5.8 LAND USE AND PLOT PLANS (2j)

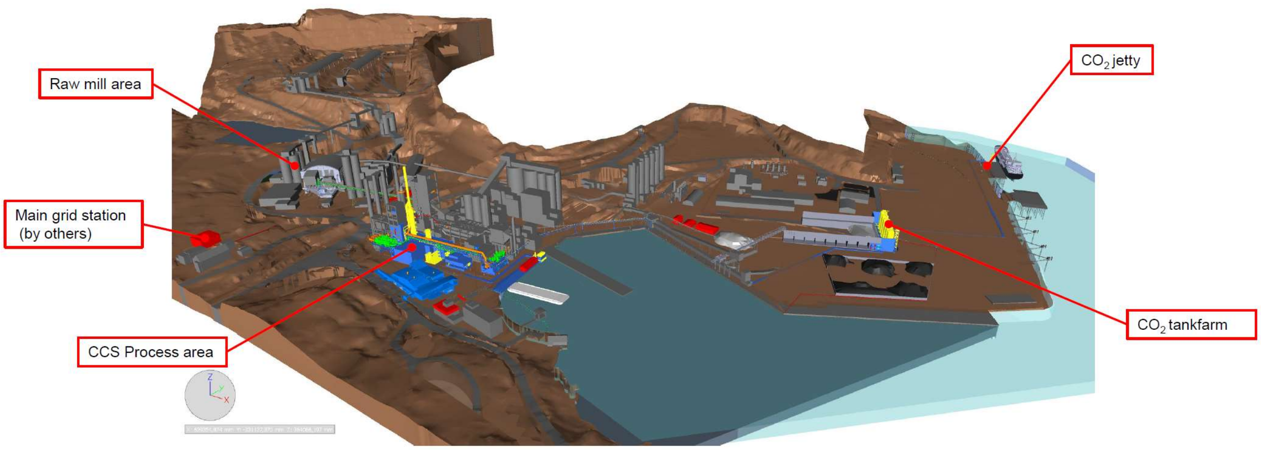
5.8.1 Presentation of new structures

During the Feed project there have been some changes in the Plot Plan. These main changes are:

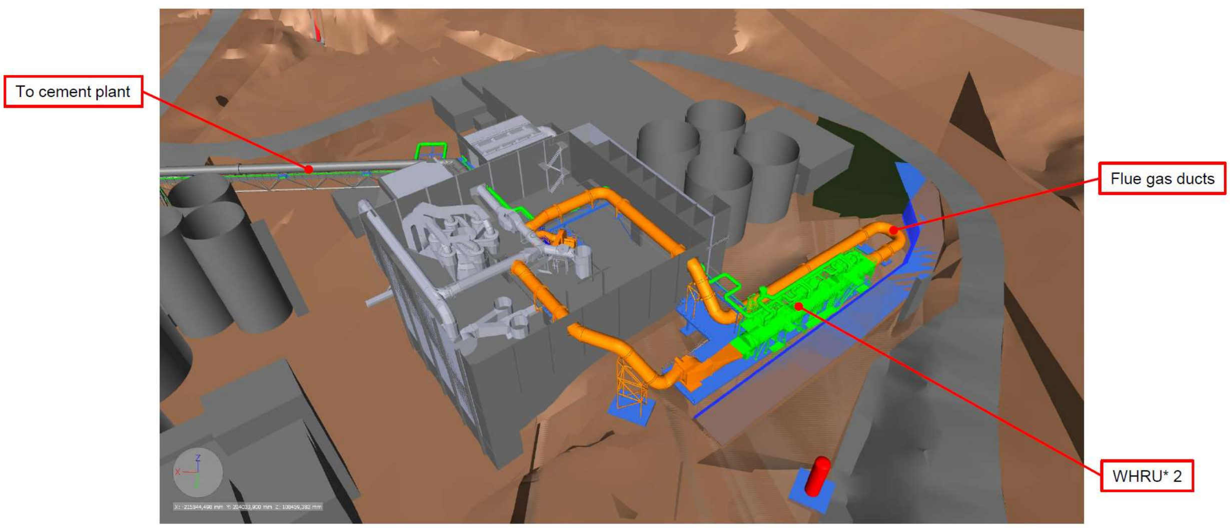
- Relocation of Main grid station
- Relocation of seawater intake
- Relocation of seawater pipes - onshore in culvert
- Relocation of CO_2 Tank-farm
- Rerouting of CO_2 pipes to storage
- Rerouting of CO_2 pipes to jetty

All significant changes to the Plot Plan have been handled according to Change Management procedures. A separate change log has been established: NC03-NOCE-A-RA-0007 - Change log Concept to FEED.

Overview, Norcem Brevik Cement Plant

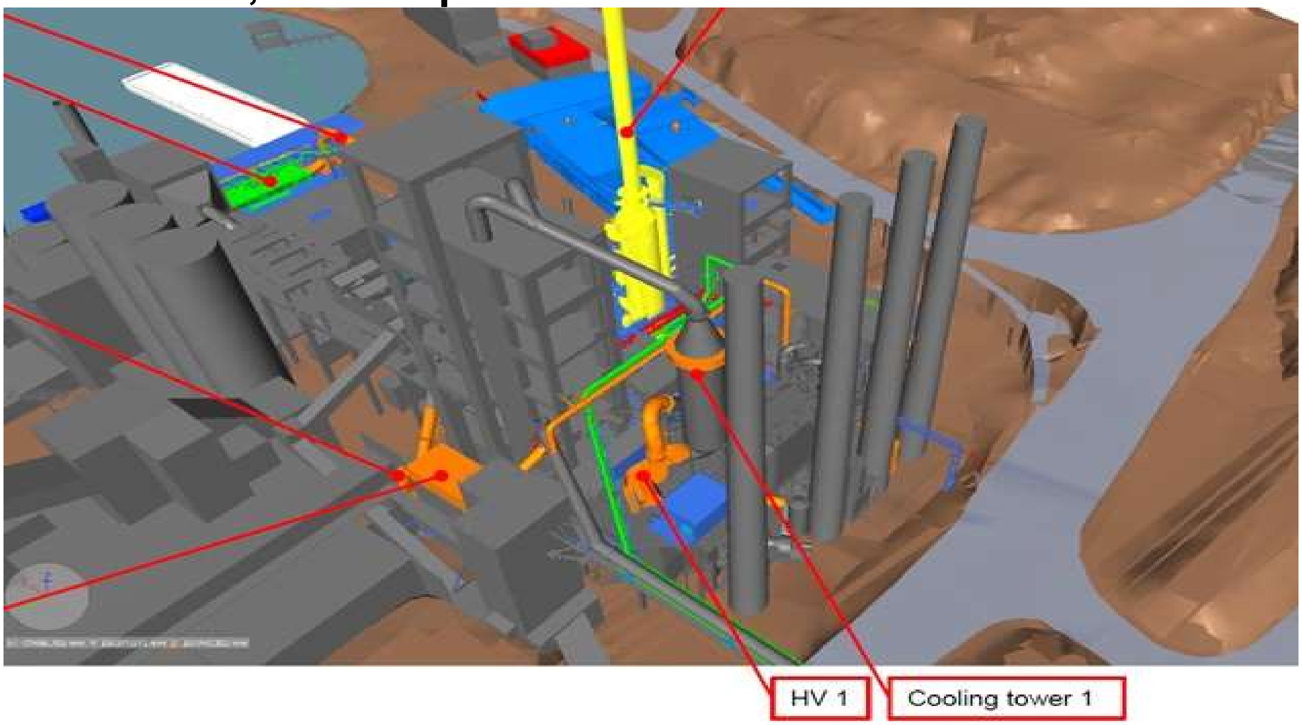


Overview, Raw mill area

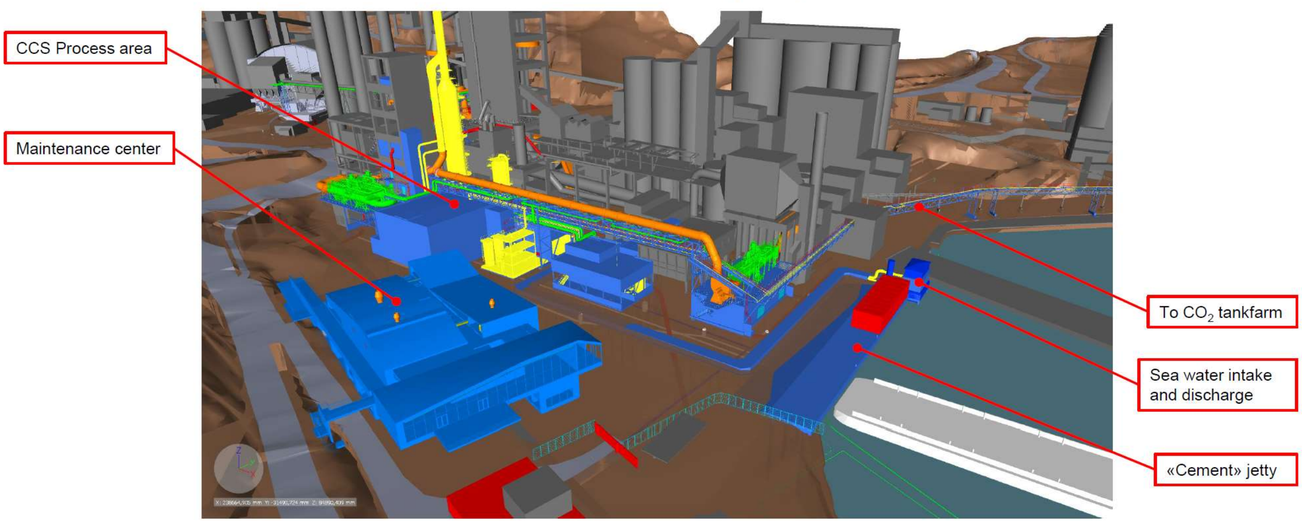


* Waste Heat Recovery Unit

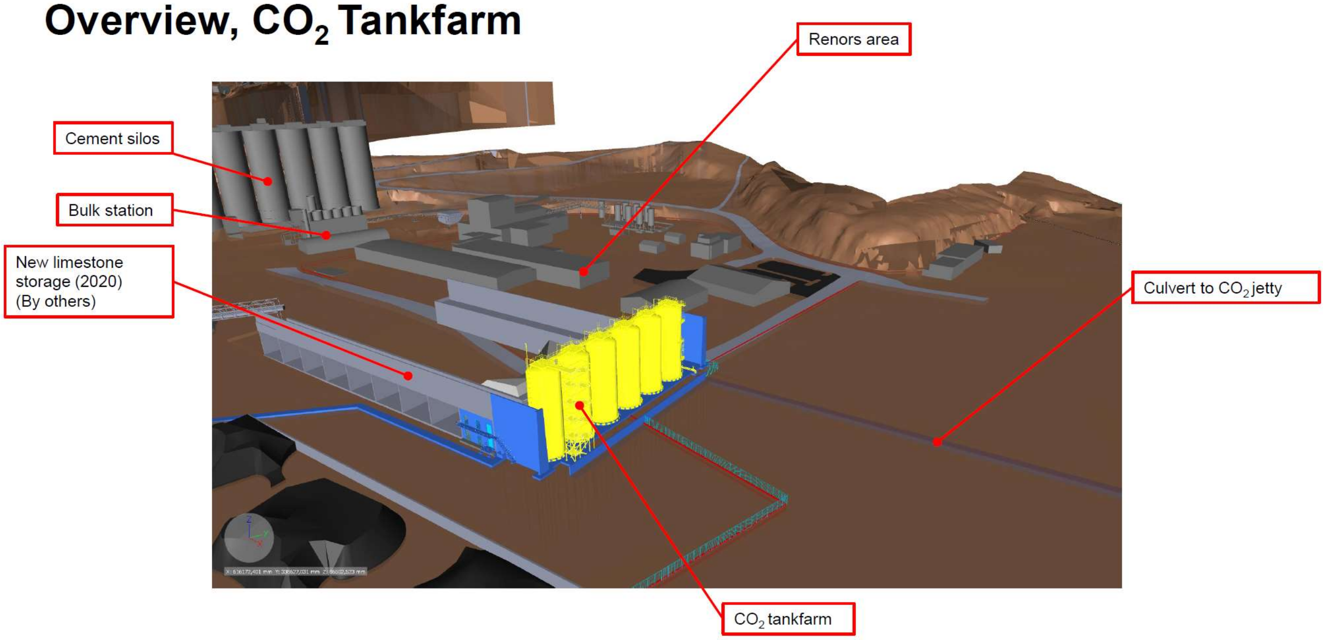
Overview, Cement process area



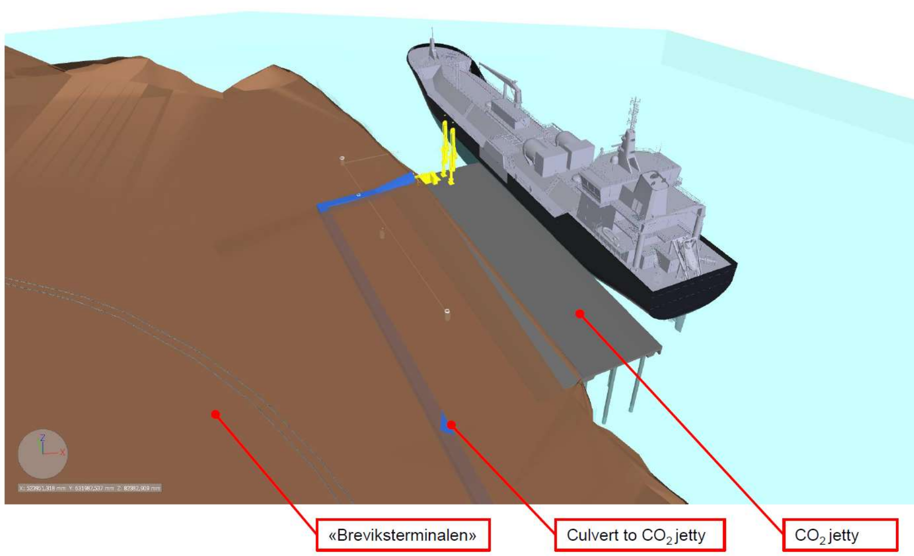
Overview, Maintenance center and jetty



Overview, CO_2 Tankfarm



Overview, CO_2 jetty



5.8.2 Norcem site

The site to be used for the carbon capture project lies within Norcem's property, with three exceptions:

- The ship loading quay for CO_2 export
- The existing main grid station that will be upgraded.
- The CO_2 tank farm, which is partly located within a property partly owned by Tangen Eiendom

The site is divided into 3 geographical areas, ref drawing NC03-NOCON-C-XF-0005 - Layout Area 1 – 3.

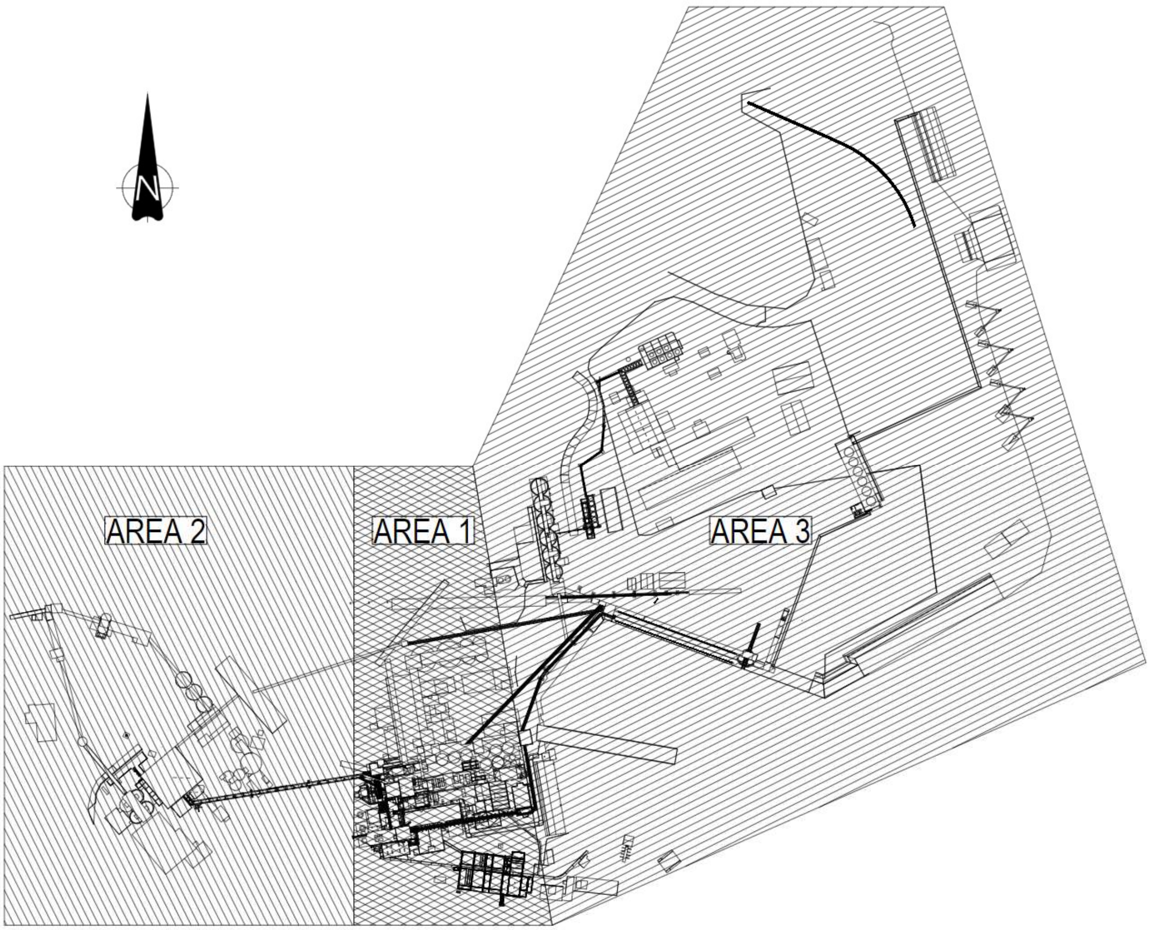


Figure 47 - Site geographical areas

Figure 47 shows the site geographical areas, ref. drawing NC03-NOCON-C-XF-0005 - Layout area 1-3.

Area 1 comprises the Process Area itself, which includes the Compressor Building, Absorber, Drying Systems, Water Treatment Plant and Amine Tank installations. Furthermore, we also find Heat exchangers WHRU #1 and #3, the main fans HV1 and HV2 as well as a new Maintenance centre in this area.

Area 2 is located on the west side of RV 354, where we find heat exchanger WHRU #2 and new electrical Substation from Skagerak Energi.

All other facilities related to the CCS project are located in Area 3 which includes the new Cement quay, Seawater intake station, CO_2 Tank farm and new electrical Substation.

Area 1 is in an area where both former and existing cement kilns lie and where some other constructions must be demolished.

To have the necessary physical space for Area 1, and facilitation of important rig areas for the construction of the CCS project, large parts of existing buildings consisting of workshops, warehouses, offices and canteen must be demolished. A new maintenance centre will be built as a replacement that takes care of these functions. The need for sufficient adjustment and storage area during the construction phase is arranged and is shown in the drawings NC03-NOCON-C-XE-0240, 0241, 0250 and 0251; "reserve areas" are provided which can easily be adopted when needed during the actual construction phase. An illustration of the new maintenance centre can be seen here and in the drawings; NC03-NOCON-C-XE-0925, 0926, 0927, 0928, 0929, 0933, 0934, 0935, 0936, 0937, 0938 and 0939.

Figure 48 - shows the new maintenance centre, ref. drawing NC03-NOCON-C-XE-0926

The existing Cement quay to be used for transporting equipment is generally in very poor condition. This must be demolished and rebuilt and adapted to its new features. The Cement quay will be used for the reception of large and heavy units that are transported via boat / barge to Brevik. The quay facility for the shipment of liquid CO_2 will be located in connection with Grenland Havnevesen's harbour facility east of the plant. In this area, CO_2 Tank farm will also be located with transport of CO_2 on pipe racks / culverts from the processing plant in Area 1.

Several areas have been identified that will facilitate important rig areas and storage areas. Primarily we will try to arrange these in close connection to a new road from the north which is under construction as part of an ongoing project at the plant. A detailed overview can be found in the document NC03-NOCON-C-RA-0042 - CCS Plot plan (Attachment 5) with attached overview drawings.

An overview and description of drawings depicting the land use and plot plans of the project area is provided in Table 18 below.

Drawing number	Title	Description
NC03-NOCON-C-XF-0001	Overall Plot Plan	Provides an overview of the entire Brevik cement plant and identifies the areas which will receive modifications through the CCS Demonstration project.
NC03-NOCON-C-XF-0002	Overall Plot Plan - Picture.	
NC03-NOCON-C-XF-0003	Plot Plan CCS - Process area	Provides an overview of the process area of the CCS plant.
NC03-NOCON-C-XF-0004	Main Civil Works	Overview of the main area.

<table>
<tr><th>Drawing number</th><th>Title</th><th>Description</th></tr>
<tr><td>NC03-NOCON-C-XF-0005</td><td>Layout area 1-3</td><td>Defining layout areas</td></tr>
<tr><td>NC03-NOCON-C-XF-0006</td><td>Roads and bridge crossings</td><td>Defines the dimensions of roads and bridge crossings</td></tr>
<tr><td>NC03-NOCON-C-XF-0010</td><td>Overall 3D view from south-east</td><td rowspan="5">Overall 3D views: Provides 3D views of the CCS plant facilities.</td></tr>
<tr><td>NC03-NOCON-C-XF-0011</td><td>Overall 3D view from south-west</td></tr>
<tr><td>NC03-NOCON-C-XF-0012</td><td>Overall 3D view from south</td></tr>
<tr><td>NC03-NOCON-C-XF-0013</td><td>Overall 3D view from north-east</td></tr>
<tr><td>NC03-NOCON-C-XF-0014</td><td>Overall 3D view from north</td></tr>
<tr><td>NC03-NOCON-C-XE-0240</td><td>Temporary construction facilities. Rig and laydown areas for preparatory works.</td><td rowspan="2">Rig and laydown areas for Preparatory works: Provides an overview of the planned rig- and laydown areas for first step of construction. This step includes the relocation of existing facilities needed to ensure plant operation during construction phase</td></tr>
<tr><td>NC03-NOCON-C-XE-0241</td><td>Temporary construction facilities. Rig and laydown areas for preparatory works - Picture.</td></tr>
<tr><td>NC03-NOCON-C-XE-0250</td><td>Temporary construction facilities. Rig and laydown areas for main contract.</td><td rowspan="2">Rig and laydown areas for Main contracts: Provides an overview of the planned rig- and laydown areas for the construction of the CCS plant at Norcem.</td></tr>
<tr><td>NC03-NOCON-C-XE-0251</td><td>Temporary construction facilities. Rig and laydown areas for main contract - Picture.</td></tr>
</table>

Table 18- Overview of land use drawings and plot plans

The site allocation is described in the NC03-NOCON-C-RA-0042 – CCS Plot plan (Attachment 5). This document is principally presenting the frozen locations of all key equipment and installations and the utilization of existing buildings, rooms and open areas.
Additionally, the report also contains a presentation illustrating rig and laydown areas for temporary installations.

Most drawings and illustrations are extracted from the 3D model which is under continuous development.
Content of the Plot Plan, was presented for Norcem Brevik plant management 18.10.2018, and generally approved. The plan was split in a list of 50 separate units/packages, individually discussed and approved. Some comments and suggestions were made, and all concerns related to the Plot Plan are implemented.

5.9 COMMISSIONING PHILOSOPHY (2I)

The intention with this chapter is to describe the commissioning philosophy for the Brevik Carbon Capture Plant, including

- Electrical power supply systems with accessories
- Process Control Systems
- Modifications of existing process units in cement plant (entire delivery from FLS)
- Heat recovery including accessories (Entire delivery from Norsk Energi)

- Carbon Capture Plant, intermediate storage for CO_2 and ship loading facilities for CO_2 (entire delivery from Aker Solutions)

The phases before, during and after the commissioning, the organization, the roles, responsibilities and time of hand-over of ownership of equipment and systems are described in the following subsections.

5.9.1 Commissioning Organization

The proposed commissioning organisation is described in Table 19 below.

<table>
<tr><th>Position</th><th>Superior position</th><th>Remarks</th></tr>
<tr><td>Commissioning Manager</td><td>Project manager</td><td rowspan="2">Engaged by Norcem/HC</td></tr>
<tr><td>Commissioning Supervisor</td><td>Commissioning Manager</td></tr>
<tr><td>Norcem Commissioning mobile team
• 2 operators working daytime
• 5 operators working shift (24/7)</td><td>Commissioning supervisor</td><td rowspan="2">During commissioning, the operators will report to Commissioning supervisor. Supervisors will presumably work only daytime, even though commissioning activities will commence 24/7.</td></tr>
<tr><td>Norcem Control room operators
• 5 operators working shift (24/7)</td><td>Commissioning supervisor</td></tr>
<tr><td>Electrical, instrumentation and automation commissioning team (Norcem scope)
• A total of 8 persons is planned during testing and commissioning</td><td>Commissioning supervisor</td><td>The team will have managers (part-time), supervisors (part-time) and operators (part-time) in the various disciplines.</td></tr>
<tr><td>Aker commissioning team</td><td>Superior position within Aker organization</td><td rowspan="4">For “Mechanical completion” and pre-commissioning (or “testing”) of deliveries within own scope. Then the teams will merge gradually with Norcem Commissioning team for the final stages.</td></tr>
<tr><td>Norsk Energi commissioning team</td><td>Superior position within Norsk Energi organization</td></tr>
<tr><td>FLS commissioning team</td><td>Superior position within FLS organization</td></tr>
<tr><td>Norcem plant</td><td>Superior position within Norcem plant organization</td></tr>
</table>

Table 19 - Commissioning Organization

An overview of the manning for the Norcem plant Commissioning team is shown in Table 20 below.

	2023												2024				
Position/function:	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Commissioning Supervisor						1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Commissioning team (including required training)						2.0	2.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Control room process operator								5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Electrical testing/commissioning Manager									0.2	0.2	0.2	0.2	0.1	0.1			
Electrical testing/commissioning Engineer									0.5	0.5	0.5	0.5	0.3	0.3			
Electrical testing/commissioning Craftsmen									3.0	3.0	3.0	3.0	1.5	1.5			
Instrumentation testing/commissioning Manager									0.2	0.2	0.2	0.2	0.1	0.1			
Instrumentation testing/commissioning Engineer									0.5	0.5	0.5	0.5	0.3	0.3			
Instrumentation testing/commissioning Craftsmen									3.0	3.0	3.0	3.0	1.5	1.5			
Automation testing/commissioning Manager									0.2	0.2	0.2	0.2	0.1	0.1			
Automation testing/commissioning Engineer									1.0	1.0	1.0	1.0	0.5	0.5			
Automation testing/commissioning Craftsmen																	

Table 20 - Norcem Plant Commissioning Team Manning

The Commissioning Manager will enter the organization at an early stage of the execution phase.

5.9.2 Phases of completion and commissioning

Table 21 defines the different phases from mechanical completion until start up:

Phase	Definition
Preparation	Required preparatory work for the upcoming phases: • The phases, roles and responsibilities are defined. • Overall level, and detailed plans and procedures are worked out • Documentation to be used for each task in each phase is established • Detailed commissioning schedule is worked out All commissioning preparations are under the responsibility of Commissioning Manager
Mechanical completion	Verification of installation MC includes pressure testing, signal testing and loop testing. Ready for hand-over to commissioning including punch list. The MC hand-over should be sub-system by sub-system Typically pressure testing, signal testing and loop testing, and check direction of rotation. To be performed during the MC stage The complete loop test consists of: • Checking the signal on the face plate in the control system. • Confirming the control system I/O interface is working, and it is correct according to documentation. • Confirming the entire cable route. The cables and all termination points (e.g. junction boxes and cross wiring cabinets), are working and are correct according to documentation. • Confirm that the field end is functioning, that it can send and transmit signals and that it works as intended. The field end can be a field device like a transmitter or a solenoid. Or it can be an equipment or cabinet. E.g. heater with temperature sensors. PLC logic testing (simulation)
Commissioning (or "cold commissioning")	Verification of function. A simplified function test of a system, sub system or equipment. A test with simplified process media, with the intent to verify that the process and logic is functioning as intended.

Start-up (or “hot commissioning”)	Prepare system/ equipment start-up. Taking the systems from empty state with ambient conditions, to a normal operational state with correct process medium. Verification of full function. A full function test of a system with all supporting systems and functions, including the logic in the control system.
Initial running	Get the individual systems to function together as one unit and to achieve stable and reliable operation of the whole plant.

Table 21 - Phases of completion and commissioning

Example of handover matrix from MC to commissioning shown in Figure 49 below (from Aker Solutions).

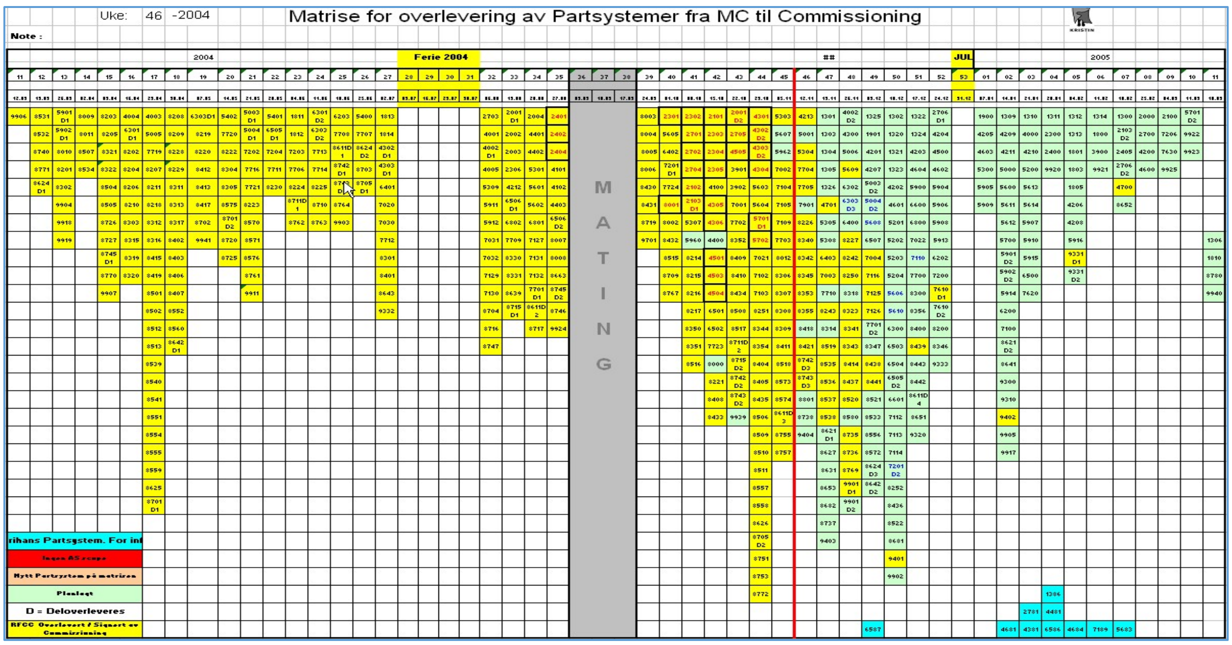


Figure 49 - Handover matrix from MC to commissioning

5.9.3 Execution

Commissioning takes place when mechanical completion (MC), pressure test and loop test are completed for all items/parts within a given commissioning system/package. Handover from Mechanical Completion to Commissioning should be documented by MCC (Mechanical Completion Certificate).

For systems with process media, the equipment shall be tested with a process media suitable for testing. These will be specified in the commissioning procedures for each system. The most common test media are potable water and air.

The function test consists of verifying that the media is flowing in the right manner through the right patches in the process, that the pumps are doing this correctly and that vessels are filled and emptied correctly. The primary elements are connected to the control system and the test is verifying that the control of the elements is correct. The control system runs the pumps correctly, it opens/closes and controls the valves correctly in the correct order. The set-up of measuring devices shall be verified. e.g. level measurements shall be verified against the actual levels in the vessels.

For the heat exchanges the test mediums are used to test the flows. The heating/cooling effect of an exchanger is not tested. This is part of the start-up testing. The commissioning procedure will describe in detail the test that shall be done for each system and sub system.

5.9.4 Process systems

The process systems are to be broken down into functional sub-systems for commissioning. Each sub-system will be further split into commissioning packages, which will be defined using P&ID drawings and reflected in the commissioning procedures prepared during detailed engineering.

In each sub-system there is a list of systems/equipment that belongs to the sub-system. For this equipment all instrumentation, process control systems and process safety systems shall be tested.

It is recommended that the sub-systems that have CO_2 as a process medium is commissioned after the CO_2 capture and compression started up. So that the CO_2 capture and compression system can supply the test medium for the CO_2 liquefaction, storage and loading system.
MC including loop test and pressure test will be done at the same time as these activities for the other systems/subsystems.

Special attention regarding the Heat Recovery Systems (If the Norsk Energi scope will be Aker responsibility it will most likely be treated as the rest of the Aker scope)

“Pre-commissioning” will mainly be:

- Inspection and acceptations of all equipment
- Control of all instrumentation signals
- Instrumentation loop test
- Start-up water treatment equipment and start producing of make-up water.
- Filling chemicals (typical ammonia, oxygen scavenger, etc.)

“Cold commissioning” is to be performed after NDT-control or other welding evaluation and consists of the following actions:

- Pressure testing
- Test of control system

5.9.5 Utility Systems

Commissioning will require use of Norcem’s utility systems at site, such as water and instrument air. Norcem is responsible for the functionality of these systems, while hook-up to the test plant at battery limit will be each “customers” responsibility. Hand-over to commissioning inside the battery limit as described under 5.9.2 MC hand-over.

5.9.6 References

Further information regarding the commissioning philosophy can be found in the following documentation:

- NC03-AKER-Z-FD-0001 - Commissioning and System Testing Philosophy (Attachment 14).
- NC03-NOCE-E-RA-0502 - Design Electrical report (Attachment 15).
- NC03-NOCE-F-RA-0501 - Basis of Estimate WBS 500 [10](Attachment 16).
- Guideline_for_project_management_2016_04 (Heidelberg Cement guideline) (Attachment 17).

5.10 CONSTRUCTION AND INTEGRATION (2o, 2q, 2r, 2s)

5.10.1 Construction and installation philosophy (2o)

This section describes the overall construction and installation philosophy for the CCC Plant at Norcem Brevik. This is to be understood as "*Which high-level requirements and limitations must the project adapt to during construction and installation*".

The higher-ranking requirement is, ref. section 5.3.2:

"Construction and operation of the new plant shall not compromise the availability of the cement production in any way".

Based on the above and looking at the construction phase alone, the following are key elements in the construction philosophy listed in random order:

- The construction shall be carried out without accidents, pollution or safety issues.
- A common detailed and realistic schedule for all construction, installation Mechanical Completion (MC) and commissioning activities shall be established covering all parties, and this schedule shall be approved by the Norcem Brevik plant
- Construction and installation work that requires the cement production to be out of operation must be concentrated to the yearly 3 weeks winter repair
- During the 3 weeks of winter repair the amount of construction and installation work in the centralized factory area should be limited to what is strictly required to avoid overcrowding the area
- Construction and installation work shall not block or limit access for operation and maintenance of existing plant/ equipment
- Where new infrastructure covering both existing and new plant shall be established, the new infrastructure must be operational before the existing is demolished
- For all buildings to be demolished and relocated/ rebuilt, suitable permanent or temporarily facilities shall be established before demolition takes place
- All electrical installation work shall be handled by Norcem El. Dept.
- All automation installation and programming shall be handled by Norcem El. Dept.
- Seek to limit manning and extensive need for scaffolding and temporary platforms on site by delivery of modules, skids and fully dressed equipment. This effort will be evaluated based on a total cost-benefit analysis.
- Finalise civil construction work as much as possible before starting installation of mechanical equipment to limit simultaneous manning requirements
- All parties to cooperate on the use of heavy-lift cranes in dedicated areas by heavy-lift campaigns to minimise cost
- Use of local work force for local site work to the extent possible to reduce the need for accommodation barracks

- Limit number of sub-supplier levels to secure quality and schedule fulfilment
- Focus on completing the construction and installation activities area by area to grant access for next discipline in a controlled and safe manner
- Focus on completing Mechanical Completion (MC) activities area by area, and carry out consecutively handover of area/ system/ sub-system to commissioning in a controlled manner by formal use of a MC status tool
- There shall be one Commissioning manager with overall commissioning management responsibility
- Facilitate for delivery of heavy and bulky material by sea by upgrading the "cement quay" and organize good transport routes on site

More details for some of the elements may be found in section 5.10.4

Note that some of these elements sets requirements to the design to be feasible during construction.

5.10.2 Integration philosophy (2q)

This section describes the principles and high-level design requirements for how the CCC Plant is to be integrated into the existing plant at Norcem. These requirements are based on both available plot, existing technical installations and established methods for design, operation and maintenance, and are responded to during the design of the plant.

The higher-ranking requirement is also here:

"Construction and operation of the new plant shall not compromise the availability of the cement production in any way"

Based on the above and looking at the design phase alone, the following are key elements in the integration philosophy listed in random order:

- The design shall fulfil the requirements in the future *Environmental operating permit*, relevant governmental laws and regulations, and comply with existing health and safety regulations at Norcem Brevik
- The actual carbon capture process has been tested at Norcem Brevik on the actual flue gas for an adequate period to secure correct setup and design of main process elements, selection of process parameters and amine composition
- The design of the waste heat recovery boilers is based on testing at Norcem Brevik on actual flue gas for an adequate period to verify main design parameters being the basis for the waste heat recovery potential (and thus the CO_2 capture capacity)
- All new plant is designed with focus on safe, easy and smooth changeover between cement production with and without carbon capture and heat recovery thus securing the integrity of the cement production
- All area utilization is approved by Norcem Brevik management and other relevant property owners

* Equipment that may cause larger CO_2 emissions in case of accidental incidents are located and arranged in such a way that the risk for 3rd party are within the acceptable limits set forth by governmental bodies

* Maximum noise level at nearby residential dwellings resulting from existing and new plant combined will be within todays noise requirements for Norcem Brevik

* The overall layout limits the amount of *Brown field* activities to the installations that must be distributed, e.g. modifications of existing flue gas system and the waste heat recovery units. The rest are, to the largest extent possible, arranged in such a way that it can be regarded as *Green field* installations

* The thermal energy requirements (corresponding to CO_2 capture capacity) of the new plant are primarily covered by waste heat recovery from existing cement production process and from the new capture process itself based on a total cost-benefit analysis

* The operational flexibility and security systems of the CCC Plant can handle "all" kind of normal planned shutdowns as well as sudden and unplanned shutdowns/ emergency shutdowns in the cement production plant without causing any undesirable situations within the CCC Plant

* All new plant is designed in accordance with Norcem El. Dept. requirements and standardized solutions and methods wrt electro, instrumentation and automation

* All new plant follows existing principles for maintenance and spare parts inventory, and adapt to existing material selection and surface treatment philosophy where relevant

* All new plant is designed in accordance with land-based industry practices as the existing plant

* All new plant is designed as a single train (1x100%) for all main equipment as for the existing plant

* Operation of all new plant are aligned with existing operational procedures and manning principles

* Physical investigation of ground and soil conditions are used as input to the plot plan and local arrangement of equipment

* All design target standardization of "*off-the-shelf*" components where practically and economically sensible

* The design utilize/ reuse excess process water from new plant in existing plant to reduce overall consumption of potable water

* The design utilizes excess process heat for heating of new and existing buildings

All requirements for the design of the new plant are included in the NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4) [17]. More details for some of the elements may be found in section 5.10.4

5.10.3 Tie-in points (2r)

The tie-in points between existing cement production facility and the new plant may be divided into the following groups or categories:

- Tie-ins to the existing flue gas system for the CCC plant and the waste heat recovery units
  - ⇨ – at various locations in string 1 and 2, and in the clinker cooler air system
- Tie-ins to existing closed loop cooling system based on water from local pond
  - ⇨ – at new utility station close to main process area
- Tie-ins for process water return from capture plant to existing flue gas cleaning replacing potable water
  - ⇨ – at Gas Suspension Absorber (GSA) water system
- Tie-ins for potable water
  - ⇨ – at new utility station close to main process area and raw mill area
- Tie-ins for fire water
  - ⇨ – at new utility station close to main process area and raw mill area
- Tie-ins for 22kV electrical power supply
  - ⇨ – at existing power grid station at Rønningen
- Tie-ins for automation system
  - ⇨ – at existing AS communication grid in existing cement production control and monitoring system
- Tie-ins for instrument air
  - ⇨ – at new utility station close to main process area and raw mill area
- Tie-ins for plant air
  - ⇨ – at new utility station close to main process area and raw mill area

The utility station in the main process area is shown in Figure 50. The utility station in the raw mill area is shown in Figure 51.

Figure 50 - Utility station in main process area

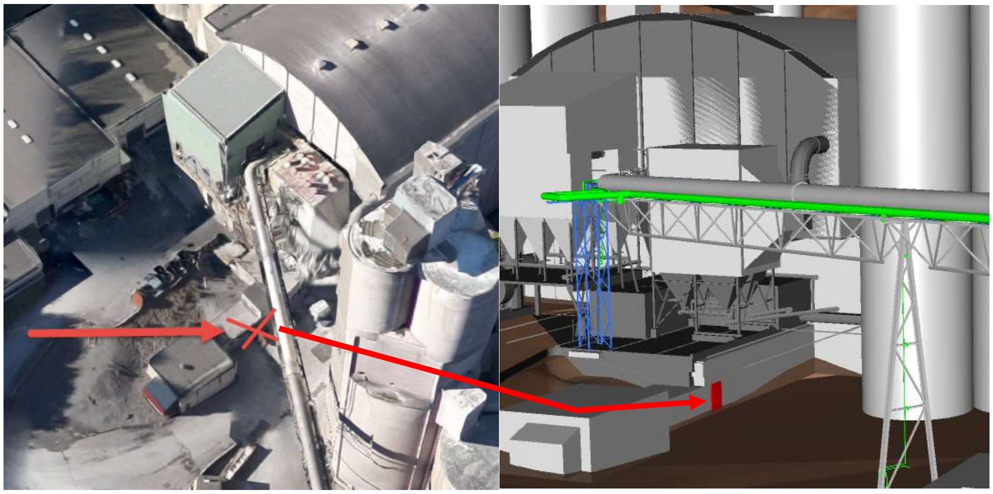


Figure 51 - Utility station in raw mill area

The new utility stations are connected to existing distributions systems both below and above ground.

Below ground, there will be connections to existing or converted infrastructure, such as fire-, process- and drinking water. The connections will be made in dedicated manholes, where flanged shut-off valves will be installed for connections. See drawings NC03-NOCON-L-XE-0770, -0771 and -0772 for detailed overview of connection points.

5.10.4 The integration (2s)

This section adds details, background and explanations to important bullet points listed in sections 5.10.1 and 5.10.2.

5.10.4.1 Main design topics

The Environmental operating permit for the combined existing plant and new plant will only be prepared and issued after the combined plant has shown that it fulfils the requirements set forth by the government for the actual plant. As this plant is a *first-of-its-kind* not all regulatory framework is not yet in place. Therefore, the design basis requirements for emissions to air of nitrosamines and nitramines are established based on operational experience from Test centre Mongstad (TCM), and the operating permit for the same. Regulations wrt other emissions to air and sea are known and incorporated into the design of the new plant.

The interim storage of the CO_2 is the largest potential accidental emission point for CO_2 within the new plant. For evaluating possible consequences for 3rd party in case of accidental release several dispersion analyses (Computational Fluid Dynamics - CFD analysis) have been carried out. Vital to the consequence of the dispersion of the CO_2 is the location of the source and the potential release rate. To limit the probability for affecting 3rd party, the CO_2 storage is located as far away from residential dwellings as practically possible still being within Norcem property. In case of an accidental emission the most likely point source are the pipe connection to the tanks, and to limit the release rate the size of the pipe connections is reduced by designing for simultaneous filling and emptying of all six tanks. A CO_2 release will be detected by the safety system and the actual tank will be isolated, and the storage has walls on three sides controlling the direction of a potential dispersion. This also protects against external fire loads causing heating and evaporation of CO_2 inside the tanks at a higher rate than manageable by the safety valves (BLEVE). See also section 6.3.

The CO_2 loading quay to be used is the most rarely used and remote quay in the harbour area wrt to exposure to harbour personnel. Several detection and shutdown functions are included in design in cooperation with Northern Light. These activities also include a HAZOP facilitated by DNV GL covering all activities connected to loading activities. The details of the safety systems, leak frequency, leak durations etc. found onboard the CO_2 transport vessel are not known at the time of writing. Nevertheless, the CO_2 transport vessel shall be “built for purpose” and a sufficient number of barriers is expected to be installed to ensure low risk for major leaks from the vessel itself. Since the vessel is only docked for loading every fourth day, the risk contribution is expected to be negligible compared to the CCC facility at Norcem.

To reduce the risk of leakages transport pipes for both liquid CO_2 and vapour return are fully welded (no flanges), and all pipes crossing open areas like the harbour area are arranged in underground culverts to reduce the risk of leakages caused by collisions.

All larger vent volumes of CO_2 from normal operation is routed to the new stack where it is mixed with the flue gas before released to air at 100 meters height.

To secure the fulfilment of the noise requirements a noise analysis is performed covering all noise generating equipment in the new plant together with the existing plant, all at correct locations. See also section 6.3.

The process design parameters are established through a chain of activities and developments at Norcem Brevik. The most important is the test campaign performed by Aker Solution using their Mobile Test Unit (MTU) covering some 7400 operating hours. Testing on actual flue gas in Brevik has been a strict requirement from Heidelberg to secure the correct amine composition for the flue gas in question. The thermal energy needed in the CO_2 stripping process will partly come from waste heat recovery in the existing cement production. The waste heat is currently cooled by water injection in the cooling towers and dumped. To recover the waste heat new operating modes for the existing cement production process are required.

The main operational change is reduced cooling of flue gas in the cooling towers. A complete data set of process design values for the complete flue gas system are established for flue gas cooling based on waste heat recovery instead of cooling tower operation. Separate sets of values are established for Standard and LA clinker production. See NC03-AKER-P-RA-0008 - Estimated future process gas flows and conditions for details. Operational values for process design representing tie-in points for the CCC plant and the waste heat recovery units are derived from these data sets and included in NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4). In the design basis these values are complemented with other relevant design values, and the values are further developed in the various interface schemes being part of the interface management system, see section 10.6.

The input data to *Estimated future process gas flows and conditions* being the operational data coming from the preheater towers and the cooling towers where verified at start of FEED against latest operational data and performed sampling campaign carried out at Norcem Brevik. Following common process verification meetings have been conducted to discuss any changes in current operation and to verify all the values in NC03-AKER-P-RA-0008 - Estimated future process gas flows and conditions (Attachment 3) document are still valid. During these discussions the current amount of false air leaking into the flue gas system was also evaluated, and measurements for reducing this amount thus maintaining the high CO_2 concentration in the flue gas going to the capture plant are included. Such verifications will be carried out again at start-up of detail design.

Based on the established set of design data all existing equipment in the flue gas system have been evaluated by the equipment suppliers to verify that the equipment can handle the flue gas both with and without (existing conditions) the waste heat recovery and the capture plant in operation (higher temp and higher volume flow). Necessary modifications or replacements to satisfy new operational mode with waste heat recovery and CO_2 capture are included.

HAZOPs on each partner scope and a common HAZOP focusing on the tie-ins and interfaces have been carried out to verify the completeness of the PFDs and the P&IDs wrt to operational safety and flexibility.

The waste heat recovery boilers are also tested on the actual flue gas at Norcem Brevik to verify main design data as the flue gas velocity for achieving self-cleaning effect and the heat transfer coefficient confirming the total heat recovery potential.

All new plant is installed in parallel to the existing cement production process thus maintaining full operational integrity of the cement production process regardless of the operational mode of the new plant. To reduce any pressure fluctuations in the flue gas system when starting up or shutting down the new plant that might disturb the kiln operation, the design work has been focusing on using fan regulation rather than dampers for controlling the gas flows. All existing and new fans are therefore equipped with variable speed drive (VSD).

The new plant may be regarded as a combination of a *Brown field* plant and a *Green field* plant. The waste heat recovery system including the required modifications of the flue gas system is typical *Brown field* activities together with modifications of existing utility systems. All these elements are linked to the existing 24/7 cement production operation. During design this has been addressed by designing technical solutions targeting installation of new or modified equipment, and tie-ins within the three weeks winter repair.

This implies that all work related to the new plant that requires the cement production to be stopped must be performed during the three-week yearly winter repair Only in very special cases will these stop periods be extended. This is especially relevant when establishing the various tie-ins (e.g. flue gas, water, drain, etc) and modifications of existing equipment (e.g. automation/ control system, electro distribution systems, cooling towers, HV fans, ESPs, etc).

Two examples;

- All tie-in points to be made into the existing flue gas system will be installed with dampers thus limiting the required installation to only the tie-in itself and the damper during the winter repair. Remaining ductwork may be performed at a later stage independently of winter repair periods.
- For the new main fans, HV1 and HV2, a steel support fundament frame is included as a “transition” between existing concrete fundament and new fan footprint to keep demolition and installation time within the three-week window.

The CCC plant itself is the Green field part as this consists of free-standing building blocks primarily limited by the plot. Steam, flue gas and utilities in general are delivered to these blocks as required thus limiting the degree of which these blocks are physically integrated into existing plant. In this way the most complex and time-consuming parts to construct of the new plant may be designed as compact as possible. This is favourable due to enclosure requirements and it opens for possible module-based construction.

A common 3D model is established for the project. This model comprises a background model showing all existing structures and landscape, and separate 3D models reflecting the scope of each project partner added on top creating one common model. In particularly tight areas a 3D laser scanning tool is used in the field to confirm dimensions given in old layout drawings for existing structures.

A "light" version called the "*Innsynsmodellen*" is derived from the rather "heavy" main 3D model. This lighter model runs in Navisworks Freedom with more than sufficient functionality for visualization and control, and it can run on all standard PCs. In this model each project partner is assigned a company colour making it easy to identify the owner of drawn elements in case of clashes etc. This model is a vital tool for coordinating layout and arrangement design which will be further developed during detail engineering.

There has been reviews of the 3D model together with the Maintenance Dept. at Norcem to discuss and secure that required and sufficient space is made available in the new plant for maintenance in accordance with Norcem requirements.

Not all project partners are familiar with cement production plants or land-based industry. Substantial effort has therefore been put into the design to have all parties adapt to the "*Way of doing things at Norcem Brevik*" to design the new plant to the same standards as for the existing plant, and to avoid "gold plating".

These standards are a mixture of technical and operational issues developed over time being in line with quality standards for land-based industry, technical guidelines from Heidelberg (HTC), and operational experience. All HTC technical guidelines have been evaluated considering the scope of the new plant being quite different to the regular cement production factory, and relevant elements are included into the design.

In addition, Norcem has standardized the way they carry out new electrical and automation installations since the late 80's. This has been done to simplify engineering, installation and commissioning, and to improve future maintenance work. These various standardised solutions cover everything from overall architecture and down to hook up drawings for an electrical motor or an instrument including PLC and man-machine interface programming, and they are well described. Generally, all new plant follows these standardized solutions.

It has been targeted to utilize as much as possible of existing structures, areas and space and convert these as needed to facilitate for the new plant. When doing so residual strength has been checked. When designing the main routing for ducting, piping and cables the residual strength of existing structures has been evaluated to see if suitable supporting structures can be established.

Civil work related to a new process plant is mainly defined by the process equipment installations as foundations, support structures and enclosures. During the FEED Study detailed documents have been prepared by each equipment package partner containing all necessary input data for each foundation, support structure or enclosure (area, space, load, utilities, etc) known at the time. These data together with the results from the geotechnical surveys are the main input to civil engineering together with relevant standards and requirements as Tek17, wind loads, earthquake calculations, etc.

A potentially large risk for any project including excavation on old industrial plots at sea side are the presence of contaminated masses both onshore and offshore. Another risk is insufficient ground loadbearing capabilities. Both topics has been addressed by physical investigations, drilling and mapping at site. See NC03-NOCON-S-RA-0039 - Environmental Assessment of Soil Contamination, NC03-NOCON-S-RA-0040 - Environmental Assessment of seabed sediment and NC03-NOCON-S-RA-0040 - Geotechnical Data report.

The environmental investigations show that the ground is free from contamination at some areas and in other areas moderately contaminated, with two hotspots with heavy contamination. The contamination is mainly in the depth 0 – 2 m. The silty, natural soil deposit, which is found at around 3 m, is clean, with only a few exceptions. The findings presented in these reports have been input to the design work wrt verifying location of equipment and deciding on routing for underground and subsea installations.

In addition, noise from all new plant have been mapped together with noise from existing plant to secure compliance with the environmental noise requirements. Results are found in NC03-NOCON-S-RA-0041 - Environmental Noise Calculations and have served as input with regards to evaluating the need for additional noise enclosures.

5.10.4.2 Main construction and installation topics

Demolition

All equipment removal and demolition work will take place with the cement production plant in operation. Some vital existing facilities, that always need to be in full operation, is planned to be relocated. This require new equivalent facilities to be constructed and made operable before the original structures can be demolished. If facilities are to be rebuilt in approx. the same area, temporarily facilities for use during construction shall be established at a different location. The demolition work includes removal of mechanical and electrical equipment, cables, piping, concrete, steel, wooden structures and their disposal. Parts of the work is at high elevation and will require extensive use of cranes and scaffolding which again restrict work operations below.

Before any demolition is initiated, Norcem will disconnect and conserve installations that are affected by the demolition work. For underground piping, it is assumed that all existing pipes which are no longer in use and not in conflict with new installations, will remain in.

The work and disposal of waste debris shall comply with all relevant national and local laws and regulations. A recent proposal from the Norwegian Environment Agency opens for re-use of concrete as fill material, when not heavy polluted. This should be followed up at the time of execution as a cost saving measure.

A total of 21 different structures have been identified for demolition, among them offices, workshops, storage facilities and jetties. Environmental surveys have been carried out on all these structures for mapping of hazardous waste. This is a preliminary survey, a more thoroughly survey will be performed in the next phase of the project.

The structures contain various amounts of hazardous waste, and the most important findings are:

- Asbestos: Pipe insulation, flooring, gaskets
- Lead: Paint, pipe joints
- Phthalates: Flooring, possible finds in gaskets
- Chlorinated paraffins: Insulated window
- Chemicals and oil
- PCB: Windows, light fixtures
- PAH: Creosote in quay pilings
- Electrical equipment

Several of the structures contains asbestos and were built in a period in which asbestos was widely used (1960s and 1970s). Even though a survey of asbestos has been performed, there might still be undiscovered asbestos in the structures, especially in closed building parts (inside walls, under floorings) and in areas which could not be reached. Asbestos awareness is therefore especially important during the demolition processes.

Most of the waste materials will be transported out by road.

See NC03-NOCON-C-RA-0003 - Demolition work and NC03-NOCON-S-RA-0018 - Grovmengdebeskrivelse - Saneringsrapport for details.

<u>Civil construction</u>
Buildings and structures are planned as site-builds with little degree of prefabrication except for steel structures.

<u>Equipment installation</u>
There is a target to limit the number of workers on site simultaneously and to reduce the amount of scaffolding and temporarily platforms which take up much space. Therefore, larger equipment as absorber, desorber, CO_2 storage tanks, DCC, etc. will be delivered fully dressed with only the need to finalise the areas that cannot be finalised due to transport.

Remaining equipment is planned to arrive as modules, packages, sections, prefabricated steel structures, separate items, prefabricated pipe spools and loose fittings. This means that there will be a substantial amount of stick-built activities on site with several disciplines involved in addition to hook-up of more pre-completed packages. The balance between stick-built and a more extensive use of larger complete modules has been discussed wrt pros and cons in separate common constructability workshops, and this philosophy will be further matured during detail design and supplier selections.

These topics are well described in the construction studies and the construction review. See also section 6.8.

Fabrication of modules or dressing of equipment may also be done elsewhere outside site to reduce the number of workers on site. Several industrial locations in Bamble (Rafnes, Ineos) have large areas with direct access to sea. Cargo can be transported by barge between the two locations, see Figure 52 - External possible rig areas. Rønningen (Rafnes industrial area) is 9 km by boat (along the blue line) from Norcem

Figure 52 - External possible rig areas. Rønningen (Rafnes industrial area) is 9 km by boat (along the blue line) from Norcem

<u>Schedule</u>
When setting up the schedule, an important constraint is the yearly winter repair as these stops are vital for doing installation works that requires the cement production to be out of operation. These yearly 3 week-periods are normally to be finished 1 week before Easter holiday placing the winter repair period in late February to early April.
During these stops some 200 – 230 external personnel are engaged for maintenance tasks in addition to the regular workforce at Norcem. In order to avoid further overcrowding of the site the

CCC plant construction work is kept to a minimum during these stops. To allow for a sufficiently long and uninterrupted construction phase for the main process area, the 2023 winter repair is planned to take place in January/ February to allow for a longer uninterrupted installation period between the 2023 and 2024

To be able to utilise the winter repair in 2021 making it a total of three stop periods, planning and engineering for the relevant activities to be done must commence well before planned project start-up date of January 20th, 2021.

An important issue in this respect is the total number of workers on site. The planned maintenance work for the cement plant during these stops requires a crew of approx. 200 people in addition to the regular staff, and the crew needed for the installation work for the new plant comes on top of that.

See section 9 for the complete schedule.

<u>Site accessibility</u>
Transportation of goods to the site might be with road trucks or by sea vessels.

The quay for off-loading the heavy equipment arriving by sea will be the “Cement quay”. The quay will be upgraded as a part of the project. Bulk and smaller components arriving by sea may also be unloaded over this quay.

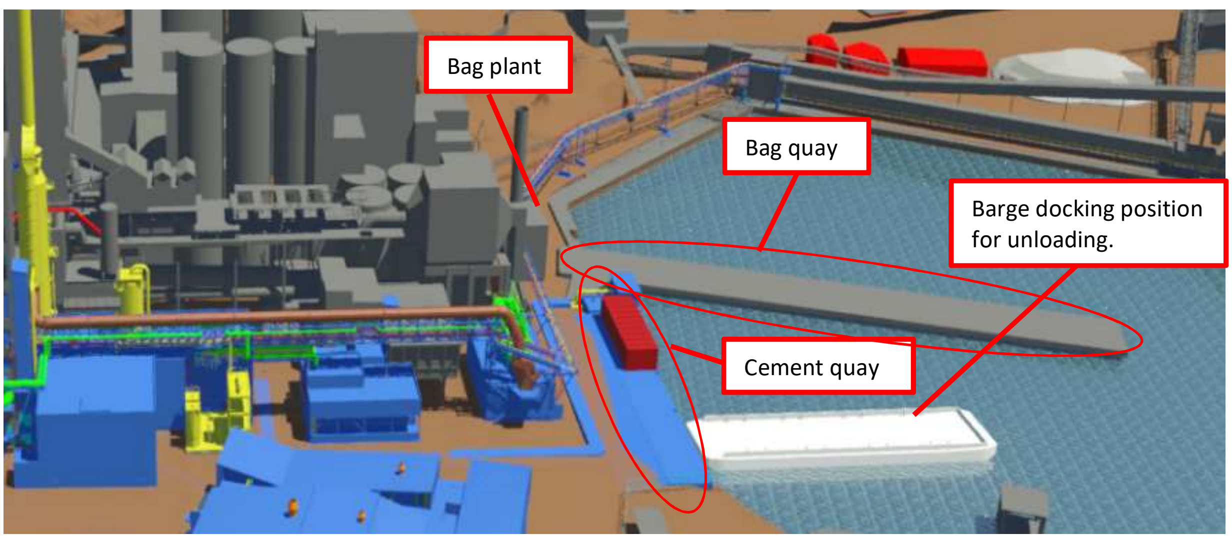


Figure 53 - Location of the Cement quay

With the barge in the position as indicated in Figure 53 there is a straight forward route for SPMTs to the main heavy-lift area for the larger equipment like absorber, desorber, compressor, DCC. etc.

The size of the barge shown in the figure is based on dimensions of the Boa Barge 31 (65 x 17,5 x 4 m).

The CO2 storage tanks can be off loaded at the Tangen quay. This quay is not on Norcem property and will not be upgraded. Alternatively, the tanks may be off loaded at the Ro-Ro quay. The final solution is dependent of the tank supplier to be and the mode of transportation.

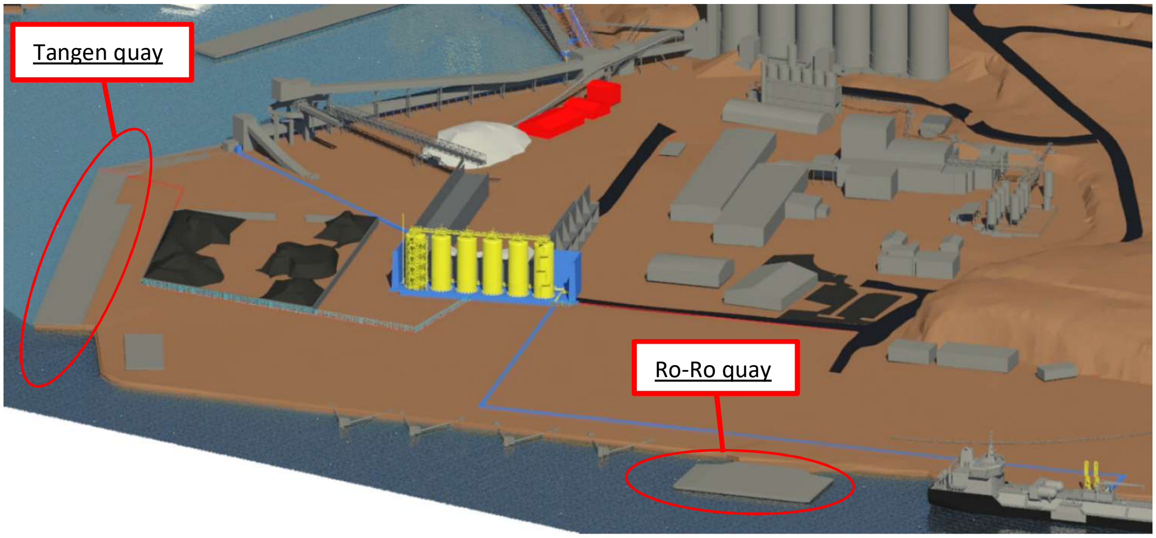


Figure 54 - Location of the "Brevik terminal" and the Ro-Ro quay

Internal site transport

The site transport from quay side will be performed by using ordinary flat truck transporters or fork lift for minor or less heavy equipment. For more heavy and large equipment, the use of Self Propelled Multi-Wheel Trailers (SPMT) will be used. These will be able to collect equipment on the barge and bring it all the way up to the cranes or on to the fundaments directly.

Figure 55 - Use of SPMT - Reference picture from Kårstø

The transport of the WHRU 2 is challenging due to the long distance from the quay and the need for crossing a main public rad and a rail road.

To provide adequate space for manoeuvring and positioning of mobile cranes alongside the quays, the part of the old cement bagging plant pointing towards the *bag quay* is demolished, see Figure 53.

Lifting

There will be several lifting operations during the installation of both technical equipment and during building erection.

Unloading equipment delivered by sea will be performed by a floating crane (400 t) either delivering directly to shore or to a barge.

The heavy-lifting on site will be performed by use of a crawler crane (600t) operating in a heavy-lift campaign. During this campaign all heavy-lifting requiring such lifting capacity is performed this crane has a long and expensive mobilization and demobilization period. Lighter loads will be lifted by use of various mobile cranes, truck cranes and fork lifts depending on the access and required capacity (weight, horizontal distance and height).

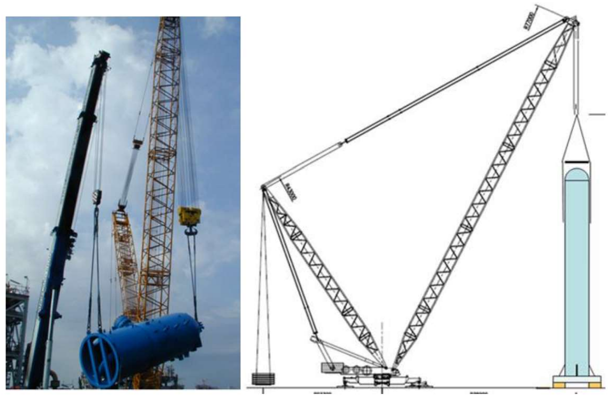


Figure 56 - Handling of large columns/ tanks including up-ending

Location of the crane for the lifting of the heavy equipment to be installed in the main process area will be in the area for the future CO_2 compressor building. When these lifts are finalized the crane will move and do the lifting of the CO_2 storage tanks. It is foreseen that the fans and the duct work for the flue gas arrangement may be lifted with the tower crane.

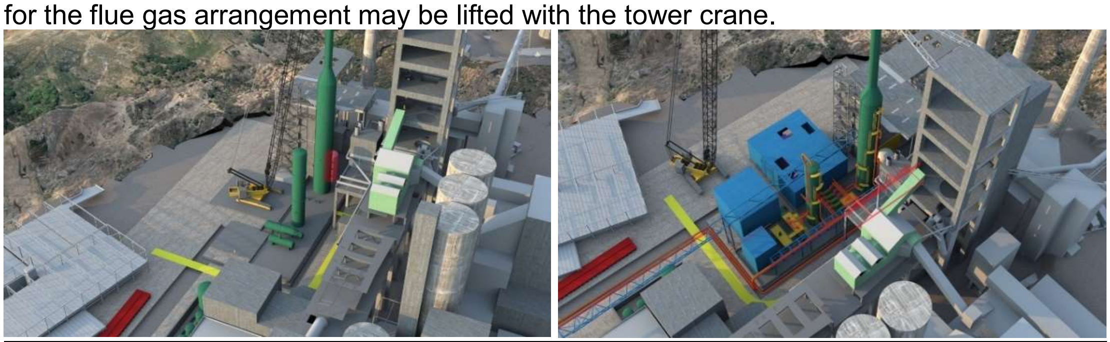


Figure 57 - Location of crane for lifting operations in the main process area

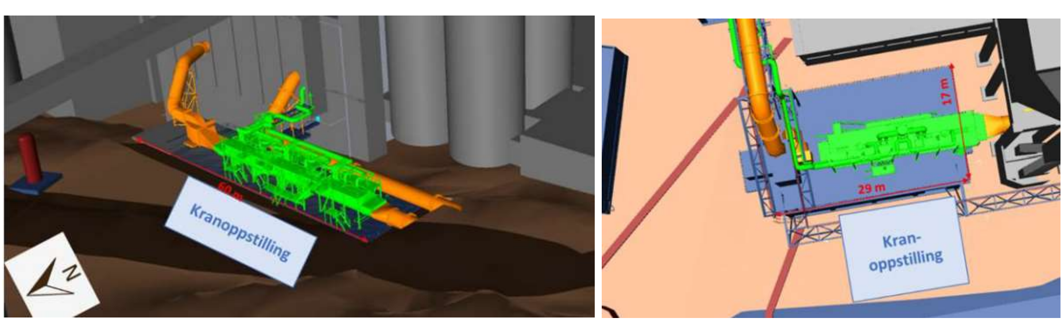


Figure 58 - Location of crane for lifting operations in the WHRU 2 (left) and WHRU 3 (right) area

Rig and laydown areas
In order not to block or limit access for operation and maintenance of existing plant/ equipment during the construction phase for the new plant several rig and laydown areas have been identified, both for the preparatory works and the process plant erection phase. Rig and laydown areas are shown on NC03-NOCON-C-XE-0240 and -0241 - Rig and laydown areas for preparatory works and NC03-NOCON-C-XE-0250 and -0251 - Rig and laydown areas for main contracts.

The required size for the rig and laydown areas are linked to the elected contractors, the contracts and the work sequence and schedule agreed upon. The rig and laydown areas available are somewhat limited and a thorough logistics management is needed to ensure efficient utilisation of the areas. Norcem has carried out larger reconstruction projects at the Brevik plant and is well acquainted with the logistics management required for this site.

It is planned for that larger items requiring much space for storage and handling (e.g. absorber, desorber, stack, CO_2 tanks, CO_2 compressor, etc.) will be installed directly to final location on arrival at site.

There is some additional space available at Norcem, and local depots may also be organized at other more remote locations with easy truck and sea transport to site. The barge may also be used as buffer area for incoming goods lining up for direct installation upon arrival.

The document NC03-NOCE-Z-RA-0025 Design Report, Temporary barrack facilities for construction phase, describes the various barrack facilities wrt location, functionality and capacity, duration, etc.

5.11 CONCEPT EVALUATIONS AND SELECTION (2t)

No concept changes have been made since the DG2 report was published.

5.12 OPERATION AND MAINTENANCE PHILOSOPHY

5.12.1 Key objectives for operation- and maintenance philosophy

The operation- and maintenance philosophy is intended to give a guide to the approach in which the CCS plant will be operated and maintained, to describe the operational conditions and specifications to be adapted during design, commissioning and operation.

This shall be achieved by defining operations and maintenance objectives which give rise to:

- High health, safety and environmental standard and in compliance with company policies and procedures
- Manage workers risk. This includes minimizing risk from transport, major accidents and occupational hazards
- Ensure capture of CO_2 to meet contractual obligations in the right quantity and quality
- Operation of the plant will be cost effective.
- Safeguard of the technical integrity of all assets in the plant
- Ensure appropriate technology is used in the facilities through providing tools and techniques.

Operation of the new CO_2 capture plant at the Norcem site will be based on achieving high plant availability with a minimum of manning. Day-to-day maintenance will be limited to first line routine maintenance with all other maintenance operations being planned and executed during outages, campaign maintenance periods, etc. Maintenance will as far as possible be condition based. Condition monitoring will be used to minimize maintenance work and downtime

To ensure high regularity, any maintenance activity that affects plant operation will be given careful consideration, and only carried out if completely necessary. In such instances, planning and preparation work will be carried out so that it can be performed as efficiently as possible with minimum downtime.

5.12.2 Maintenance strategy

Between the planned maintenance shut-down, it must be expected unplanned stops one- to two times per year for troubleshooting and equipment repairs. In addition, the equipment will experience stops due to unplanned shut-down of the cement plant, typically occurring once per week.

Table 22 illustrates the maintenance strategies that apply to the different equipment types:

Maintenance Strategy	Equipment Type
On-line condition based monitoring and remote assistance	Large and critical rotating equipment like fan-bearings, motor coil temperatures, mill bearings, kiln support roller bearings etc.
Off-line condition-based monitoring	Static equipment – vessels, tanks, heat exchangers, piping and valves
Non-intrusive monitoring	Static equipment - piping
Preventive maintenance	Instrumentation, electrical equipment (including motors) & rotating equipment
Corrective maintenance	All equipment following breakdown or condition assessment
Opportunity maintenance	All equipment provided maintenance routine is not unduly compromised
Operate to failure	Generally, not recommended on process integrated equipment.

Table 22 - Maintenance strategy

5.12.3 Maintenance System

The cement plant has a well working SAP-PM maintenance system for planning and registration of all maintenance. Basics methods for maintenance will be:

- **Conditioning Monitoring**: On-line and off-line monitoring of key equipment. Data will be automatically or manually collected from equipment and downloaded to adequate software for monitoring and evaluation.
- **Preventive Maintenance**: Carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of a component or equipment item.
- **Scheduled Maintenance**: Preventative maintenance carried out in accordance with an established time schedule or established number of units of use.
- **Corrective Maintenance**: Carried out after fault recognition and intended to place an item into a state in which it can perform its required function.

The work flow for ordinary day-to-day maintenance is illustrated in Figure 59 (directly copied from maintenance handbook, hence in Norwegian):

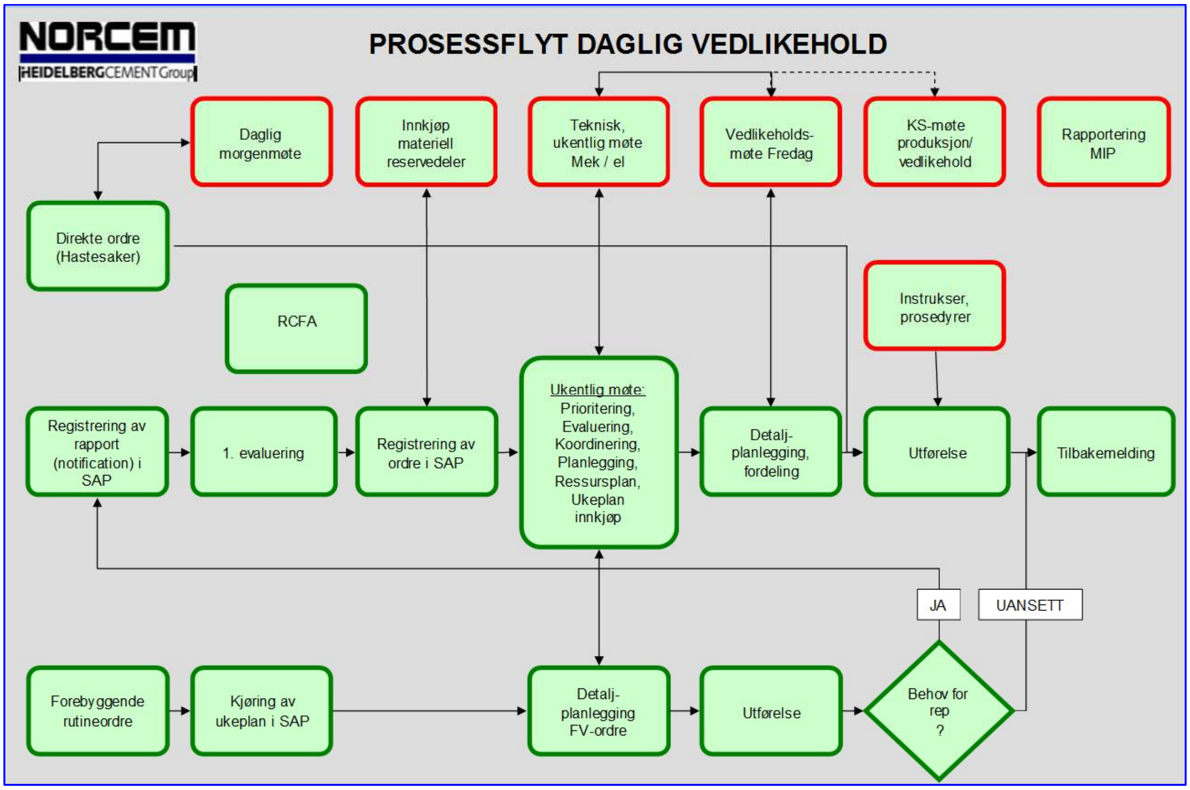


Figure 59 - work flow chart for daily maintenance operations

During the erection of the CCS plant, the maintenance system will be updated with all required data for maintenance of the new installations. For instance:

- Location
- Unit ID-number
- All new equipment including key data
- Individual control routines and intervals for all equipment
- Lubrication charts
- Spare parts linked to each unit/equipment, including minimum stock alarm set-points

5.12.4 Process Automation & Control

The operation of the CCS plant will be managed from the local CCR. The control system will be fully integrated DCS control system and its HMI will provide the control room operator full monitoring and remote start/stop and process-control capability of the whole process, from the flue gas source to export and loading.

The HMI and supervisory control system will provide full process mimic display of real-time process parameters. Remote capability is an option but will be decided at a later point in the project. With remote monitoring a third party can assist with control and monitoring of the CCS plant. Remote monitoring by supplier might apply for special units or components like for instance the CO_2 compressor.

Other parameters and systems will be integrated with Norcem control system, systems such as:

- Fire & Gas Systems
- Alarm Management
- Shutdown functions

- PA Systems

The process plant will be designed for minimum intervention and process control will be fully automated, to make sure the operation is highly efficient and cost effective. The routine work for process technicians will be limited to first line maintenance in the field. Considerations should be done to monitor key equipment (vibration etc.). This will be off-line monitoring which means operators will need to gather data from the equipment and upload this to the software that handles equipment performance monitoring.

5.12.5 Manual operations

The CCS plant will in general be equipped for a minimum requirement of manual operations. However, for maximum safety and optimal reliable operation some operations need to be made manually by process operators or maintenance operators. Manual operations which require manual manpower are listed below.

Daily inspections
Generally, the entire plant needs to be looked after on a continuous basis according to vendor recommendations and with routines specifying intervals and checklists.

Reclaiming
The thermal reclaimer will be operated in batch operations. 2-4 dedicated reclaimer campaigns (each with duration of approx. 2 weeks) are assumed to be performed each year. For every campaign approximately 80% of the solvent degradation products and impurities will be removed. The reclaimer vessel will need to be emptied after each campaign.

Filters
About 10% of the amine solutions is to be run through the filter package to remove particles and pollutants. This is done continuously by opening a slipstream trough the filter arrangement. As the particle and pollutant build up is creating pressure it’s important to monitor the filter package and change filter cartridges when needed.

Ship loading
Manual operations related to the ship loading activities will predominantly be made by Grenland Havn through an operational agreement. However, it is expected that the mobile operator from the CCS plant will play a role during the loading, and he/she probably needs to be present at least during start-up of loading.

Draining and preservation of boilers
In case of shut downs with expected long duration this may require some personnel for draining and dry preservation of boilers.

5.12.6 Competence and training

As this is a new process environment for Norcem operations a training program will be conducted during commissioning and handover. This will also include a handbook and an e-learning program for operators and supervisors. The operators should have as a minimum a chemical or process trade certificate to operate the plant. The process operator training will be delivered by the relevant contractor.

Operators handling the steam equipment should have specialized education to secure proper operation of the equipment. The requirements are given in «Forskrift om håndtering av farlig stoff». Thermal energy plants shall have certified “Kjelpasser” and “kjeloperatører”. The education consists of a one-week course. As a minimum the plant shall have one certified “Kjelpasser” and/or “kjeloperatør” on duty at the plant. One “kjelpasser” shall always be readily available (either on duty or standby). Certificates shall be renewed every 5 years.

Special training needs for maintenance personnel will be identified and conducted accordingly.

5.12.7 Spare parts

Spares are an integral part of any maintenance strategy because they can reduce some operating risks. This is typically achieved though reducing the consequences associated with item failures and in the process ensuring interruptions to production uptime are adequately managed. This is especially relevant for production dependent items that are likely to have significant lead times.

A spare part selection process should be developed in conjunction with O&M teams. Only items that can be justified as stocking via a risk base approach shall be ordered.

Where relevant, spare parts will be secured and stored at suitable locations to ensure they are available in a timely manner that limits the impact on production uptime when the need arises. All stored items must be adequately preserved to ensure degradation is minimized during their storage.

5.12.8 Plant organization

The CCS plant will be fully integrated with existing processing streams in the cement plant and the aim is to continue with existing personnel strategies to benefit the CCS operation. This means minimize any extra personnel to supervisory and manager positions and to either outsource or add extra personnel to the operations personnel.

A core team of maintenance staff will handle all routines maintenance requiring only specialized or contract maintenance personnel for the non-routine and any major maintenance activity (campaign maintenance etc.).

The below organization chart is showing the expected need for fixed manning during initial phase of the CCS plant. It is expected that the need for fixed manning will come down as process, maintenance and general routines are optimized.

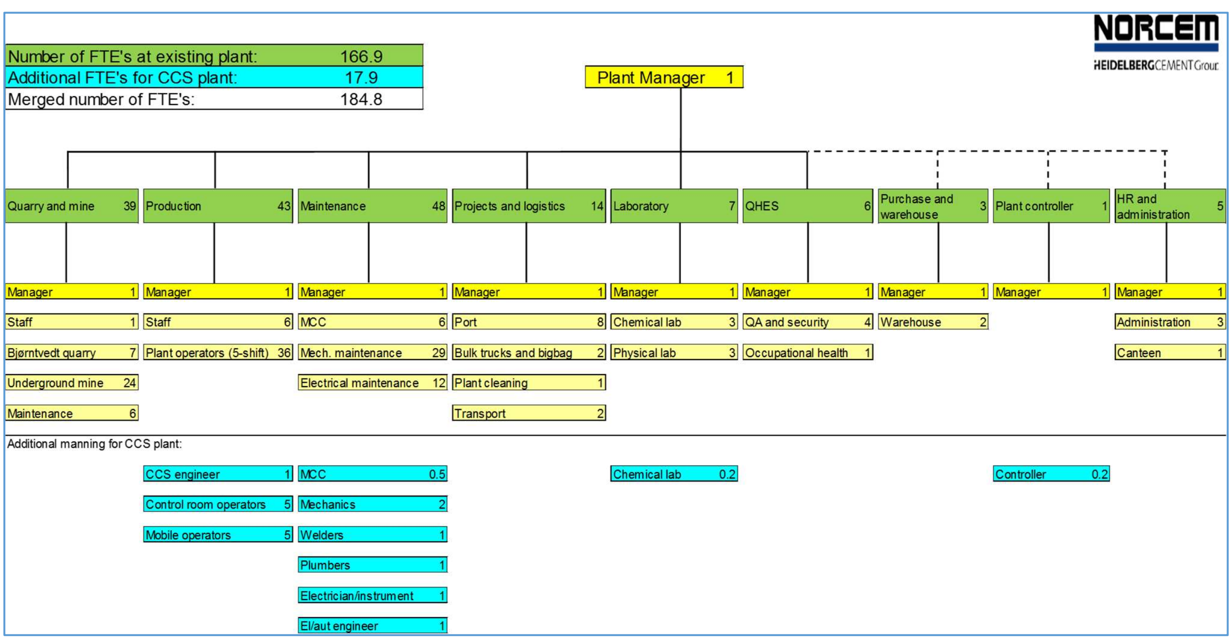


Figure 60 - Cement plant organization including CCS plant

5.12.9 References

- NC03-AKER-Z-FD-0002 - Operation and Maintenance Philosophy (Aker Solutions) (Attachment 19).
- NC03-NOEN-O-MB-0002 - Operation- and Maintenance Description (Norsk Energi) (Attachment 20).
- NC03-NOCE-A-MC-0001 - Spare parts philosophy (Norcem plant) (Attachment 21).
- NC03-NOCE-A-MC-0002 - Maintenance philosophy (Norcem plant) (Attachment 22).

5.13 TECHNICAL STANDARDS (2v)

An overview of the technical regulations and standards used for the work carried out in the FEED phase is listed in document NC03-NOCE-A-SA-0001 - Oversikt over tekniske forskrifter og standarder [24], which is included in the appendices (Attachment 23).

In addition to this list of national, EU and international technical regulations and standards, Heidelberg Cement has a considerable number of “Design Criteria and Standards” (DCS). A detailed assessment of these was performed during the FEED phase, to identify which of the standards should apply to the project and which should not due to the following:

- Norwegian laws and regulations overrules HC standards (especially HV power supply)
- Different setup is standardized at Brevik plant (especially in automation)
- Standardization of equipment and spare parts
- Dimensioning criteria from HC standards are carefully evaluated but not consequently followed, especially not where existing civil structures are being reused.

Following the assessment, a statement was issued by the project manager that the standards are to be interpreted as guidelines providing valuable information for design of buildings and process equipment to work in direct relation with a cement plant. Furthermore, that deviations from the design criteria mentioned in the evaluation reports, are to be considered as approved, unless specific feedback instructs otherwise. A notable exception is that any deviation from the mentioned documents where health and safety is in question shall be clarified with Project Manager in each case.

6 HEALTH, SAFETY AND ENVIRONMENT

6.1 HSE GOALS, PROCESSES AND RESULTS AT DG3 (3a)

This chapter describes up-to-date documentation of the project HSE objectives, processes and results at DG3.

In accordance with the HSE policy and identified risk conditions, the projects overall goal is that the project during FEED phase is carried out with a high focus on HSE in the design and that the projects activities are carried out based on systematic identification, implementation and follow-up of all HSE conditions.

Our goal for health, safety and environment:

- No injuries at work
- Ensure an HSE standard that helps to minimize risk exposure to persons, the environment and materials during the project implementation and later during construction and operation
- High focus on HSE in design

Our HSE goals for the project have been achieved through;

- Anchoring and involvement in project management
- Focus on HSE in organising, planning and implementing the work
- Project staff with a positive attitude towards and personal responsibility for HSE
- Zero tolerance for breach of factory safety regulations
- Good information and instruction / training of personnel when needed to achieve a safety-conscious attitude and good work routines
- Systematic identification of high-risk areas / activities
- The environmental aspect must be duly considered in the evaluation of design
- Design review and risk analysis techniques as well as experience transfer from comparable projects will be systematically used to identify problem areas and to propose improved solutions.

In particular, good communication with Norcem's HSE personnel and various project partners is important in all project phases. As part of risk management, it is also important to map current regulations and standards and to ensure that any deviations are handled. Goals and requirements are further described in NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4).

Both Norcem and the various project partners in the FEED study; Aker Solutions, FLSmidth, Norconsult and Norsk Energi, have carried out hazard identifications and HSE studies of their scope of work. Through meetings between project partners HSE responsible/Technical safety personnel and the Project HSE Manager they have evaluated the need for additional hazard identifications and HSE studies due to any changes or new information during the FEED phase. Examples of typical risk assessments performed during the FEED are HAZIDs, HAZOPs, Safety reviews, WEHRA (Working Environmental and Health Risk Assessments) and ENVID (Environmental Impact Identification). All the project partners have documented this in their respective action registers from these hazard identifications and it is available in Interaxo. Norcem specific HSE activities are documented in its own register called HSE Activity register. For details reference is made to NC03-NOCE-S-LA-0002 - HSE Activity register (Attachment 24). Actions that are not closed, in both Norcem´s and project partners action registers, are transferred to the next project phase. The rest of this HSE chapter in the DG3 report is mainly focused on the topics; pressurized refrigerated CO_2, discharges to air and water and noise.

No undesirable health, environmental and safety events have been recorded during the FEED phase. No unmanageable health, safety and environmental risks have been identified.

6.2 HSE PROGRAM (3b)

An overall HSE Program for the FEED phase have been developed.: NC03-NOCE-S-RA-0001 - HSE Program (Attachment 25). Each project partner has developed their own HSE Program which is in line with the overall program. The document NC03-NOCE-S-RA-0002 - HSE Activity Plan covers all the main activities with respect to HSE performed by Norcem and project partners during FEED (Attachment 26).

6.3 HSE STUDY RESULTS (3c)

This chapter present a summary of several HSE studies and risk evaluations carried out due to the introduction of carbon capture and intermediate storage of CO_2 at Norcem Brevik. For details reference is made to NC03-AKER-A-RA-0006 - FEED study report (Attachment 6) and Norconsult´s NC03-NOCON-A-RA-0022 - Input to Norcem's DG3 Report - Civil WBS 400 (Attachment 27).

Both Norcem and the various project partners in the FEED study; Aker Solutions, FLSmidth, Norconsult and Norsk Energi, have carried out hazard identifications and HSE studies (HAZOP´s, HAZID´s, WHERA, ENVID and safety reviews) of their scope of work. All documents are available in Interaxo and the last reversion of the specific reports also includes close-out descriptions.

Based on risk evaluations during FEED the main topics further investigated are:

- Risk associated with pressurized cooled CO_2
- Emissions from the capture plant
  - to air
  - to water
    - DCC effluent
    - Evaluation of heat release to recipient
    - Drain water (spills leakages and accidental release)
- Contaminated soil / sediments
- Noise

6.3.1 Risk associated with pressurized cooled CO_2

6.3.1.1 General

<u>CO_2 exposure and personnel risk</u>

CO_2 is a colour- and odourless gas with mole weight 44 kg/kmol. At standard temperature and pressure, the density is 1.98 kg/m^3, about 1.5 times heavier than air. CO_2 is present in the atmosphere at a concentration of around 385-400 ppm. The gas exhaled by humans typically contains 4-5 vol% CO_2 (40 000-50 000 ppm).

In the event of an uncontrolled release, a portion of the escaping fluid will quickly expand to CO_2 gas. The temperature of the released gas will fall rapidly due to the pressure drop and phase changes. Some of the released CO_2 will form solids ("dry ice snow", similar to when a hand-held CO_2 extinguisher is emptied). The solid will eventually sublimate, so after some time all the released CO_2 will be dispersed as gas. Because of the low temperature of the CO_2, the surrounding air will also be cooled down. This could cause the water vapor in the air to condense locally, which will resemble a thick fog.

Concentrated CO_2 is hazardous since it can displace oxygen in the air, and since inhalation of elevated concentrations of CO_2 can increase the acidity of the blood triggering adverse effects on the respiratory, cardiovascular and central nervous system. CO_2, like nitrogen, will displace oxygen, but unlike nitrogen, which does not have a neurological impact on humans, people would be at severe threat from increasing CO_2 concentrations well before they were from the reducing oxygen concentrations.

The Norwegian Directorate for Civil Protection and Emergency (DSB) has in their "*Retningslinjer for kvantitative risikovurderinger for anlegg som håndterer farlig stoff*", suggested to use the following probit function for CO_2 in risk analysis:

$$\mathrm{Pr} = -90.8 + 1.01\ \ln(\mathrm{C}^{8}\ \cdot \mathrm{t})$$

where C is the CO_2 concentration in air measured in ppm, and t is the exposure time in minutes.

Figure 61 is derived from the probit function and shows how mortality likelihood varies with concentration and exposure time.

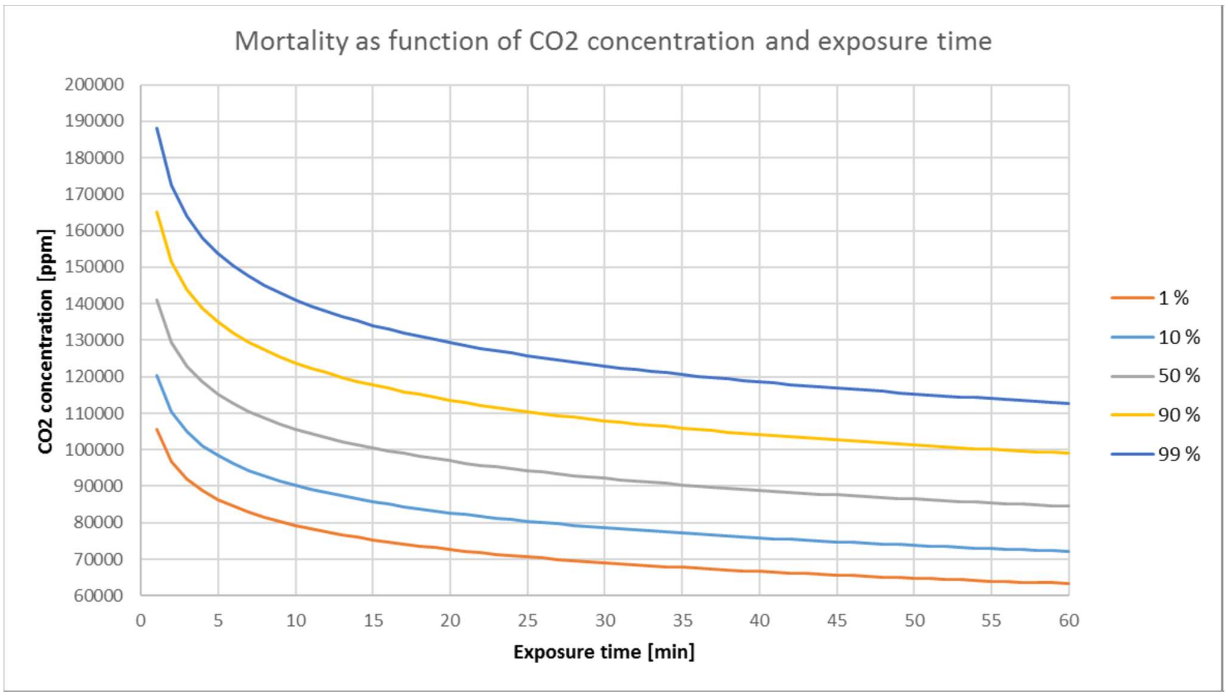


Figure 61 - Mortality as function of CO_2 concentration and exposure time

<u>Iso-risk contours</u>

The Concept Phase CO_2 release risk assessment study established a set of iso-risk contours for individual risk, as input to land planning and the ongoing impact assessment. These iso-risk contours, see Figure 62, are better known as "hensynssoner" and were based on a storage tank arrangement with the tanks located inside the Renor property. During the FEED phase the storage tank arrangement was changed and relocated outside the future limestone storage protected with high walls on the south, west and north side. Based on the FEED risk analysis, and on the results from the updated CFD simulations, it is assessed that the risk level for 3rd person areas will be similar or lower than what was estimated in the Concept Phase. 3rd person areas with potential to be exposed for hazardous concentrations of CO_2 in a major leakage scenario is mainly the small craft marina (småbåthavna) south of Norcem including private housing near the sea level and the scattered private housing north of Breviksterminalen. The requirements from DSB is that risk for 3rd person shall be in the outer zone or outside this zone. The main drivers in terms of the risk for 3rd person are large leaks from the storage tanks and updated CFD simulations indicate compliance with the requirements from DSB.

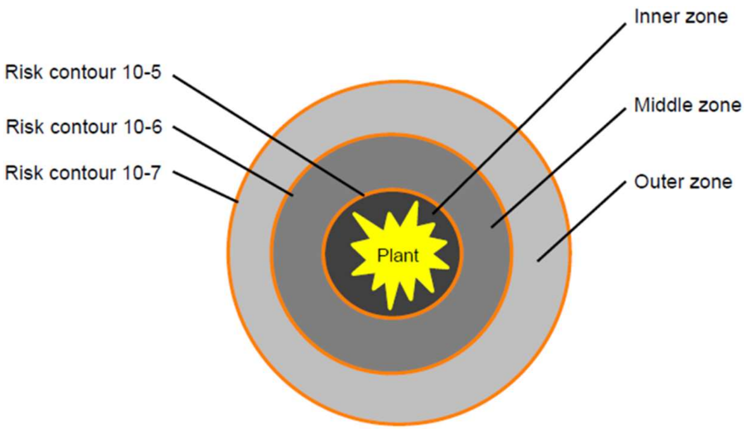


Figure 62 - Illustration DSB zones requiring special consideration ("hensynssoner") based on individual risk contours

6.3.1.2 Risk analysis of loss of containment (LOC) and process releases of CO_2

Pipeline with liquified CO_2 from the capture plant is routed in air (placed in truss constructions) to the quayside of the north side of Dalsbukta as shown in Figure 63. From this point, the pipelines are laid down in culverts in the ground via the CO_2 tank farm and out to the quay for CO_2 loading to transport vessels. Pipeline for return gas (CO_2) follow the same path back from the quay to the capture plant.

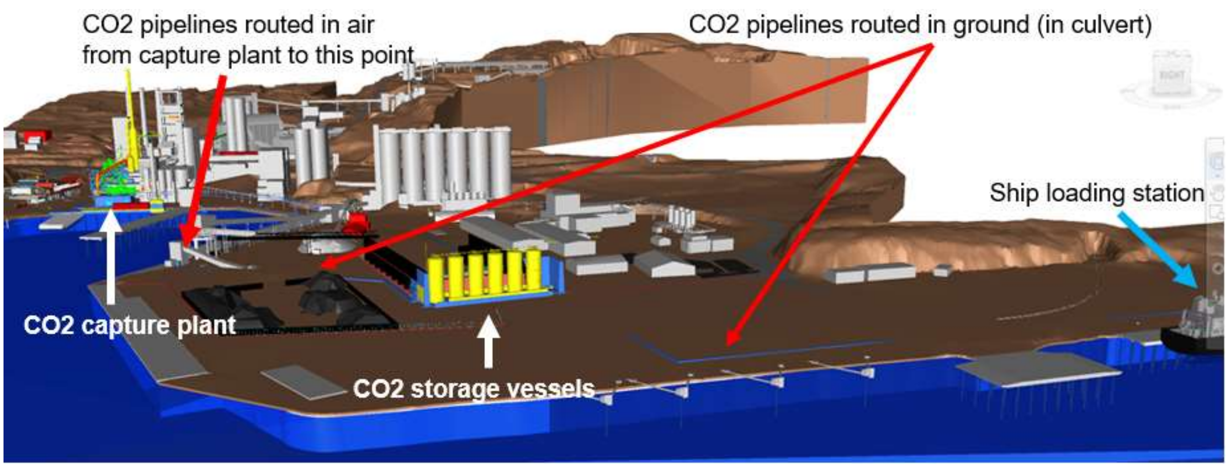


Figure 63 - Overview of the CCS plant at Norcem

As seen in Figure 63 the CCC facility extends over almost 1 km in length, from the capture and liquefaction process in the south-west, to the offloading to CO_2 transport vessel north-east of the current Norcem facilities. To be able to assess how this affects the risk, the CCC facility is split into smaller subareas with similar characteristics (type of equipment, location, etc.):

- Carbon capture and liquefaction process
- CO_2 pump and piping between process and storage tanks
- CO_2 storage tanks
- CO_2 export

This summary of the CO_2 risk analysis shall serve as decision support in the design development, input to the safety strategy and as input to emergency and preparedness planning for Norcem, Renor and Breviksterminalen. For details reference is made to NC03-AKER-S-RA-0007 - Risk Analysis Report (Attachment 28).

Carbon capture and liquefication process
The carbon capture and liquification process area has a high leak frequency, compared to the rest of the CCC facility, with about 80 % of the total leak frequency. The leak frequency is calculated to be one leak every 7 years. The leak frequency is dominated by leaks in the compressor segment and by small leaks (< 50 mm hole resulting in < 30 kg/s release rates with duration less than 10 min). Most of the leaks will be inside the mechanically ventilated compressor building or will be too small to have the potential to expose large areas to dangerous CO_2 concentrations.

CFD dispersion simulations show that the dispersion of accidental LOC releases in most cases are limited to the process areas themselves or to the areas directly outside the process areas. Leaks in the process areas are not likely to expose any 3rd person areas, Renor or Breviksterminalen. CO_2 leaks inside the process areas could potential expose Norcem personnel located inside or outside the process area. This risk must be handled through site specific emergency preparedness routines and training.

CO_2 pump and piping between process and storage tanks
Leak frequency for the CO_2 pump and the piping pathway from the process to the storage tanks is calculated to one leak every 170 years which is about 3% of the total leak frequency for the CCC facility. The leak frequency is dominated by small leaks. Basis for the calculations of leak frequencies have been flanged connections which gives a conservative approach since piping in the pathway are planned to be fully welded.

Releases along the piping pathway, in the elevated pipe rack or when the piping is hanging below the conveyor belt structure will have the potential to expose workers at Norcem and the mine entry. The largest leaks are assessed to have the potential to expose Renor, Breviksterminalen and the private houses close to the sea on the south side of Dalsbukta. However, the leak duration is short if the emergency shutdown valves towards the storage tanks close (based on detection of sudden change in
pressure or flow), so the risk for injury or death is assessed to be low. In case the emergency shutdown valves towards a
storage tank fails to close the entire tank content could be emptied through the hole (long leak duration). However, the leak rate will be limited by the 2-inch liquid tank connection. This limits the supply of CO_2 to about 74 kg/s, which is assessed to not expose any 3rd person areas. Renor and Breviksterminalen could see a minor exposure. Another barrier that limits the supply of CO_2 from the storage tanks is the check valve upstream the tanks.

When the CCC facilities are in place and in operation, no heavy lifting is planned to take place above CO_2 containing equipment. Most of the equipment and piping containing CO_2 are protected by inside/behind protective barriers that will hinder trucks, forklifts etc. to crash into them.

CO_2 storage tanks
The total leak frequency for the storage tanks is estimated to one leak every 67 years. The by far largest contributor to leak frequency is valves (93 % of total frequency). The tanks themselves only contribute with 2 % of the frequency. Leaks from the tanks can occur both from the connection points on the top of the tanks (gas leaks) and from the liquid connections on the side and bottom.

The extent of gas leak from the top of the tanks is small and the risk associated by gas leaks from the storage tanks are assessed to be low. If one of the liquid connections to the tanks starts to leak, the result could be a large and long-lasting release of CO_2. There is no blowdown arrangement for the storage tanks, so the contents of the entire tank will be emptied through the rupture. Hence, leak durations will vary from about 20 minutes to more than an hour.

Renor and Breviksterminalen are likely to become exposed to above dangerous CO_2 concentrations in case of a large liquid release (rupture of 6-inch outlet piping, > 500 kg/s) from the storage tanks. Some part of Norcem process area and entry to the mines is also expected to be exposed. The worst-case scenario is major release downwards due to rupture in a 6-inch outlet piping in calm weather conditions. Figure 64 shows a CO_2 gas cloud spread with concentration of 7% due to a rupture in a 6-inch outlet piping 10 minutes after the leakage has started. Based on the probit function presented in Figure 61, the risk for personnel exposed is a morality of 1% for 25 minutes of exposure.

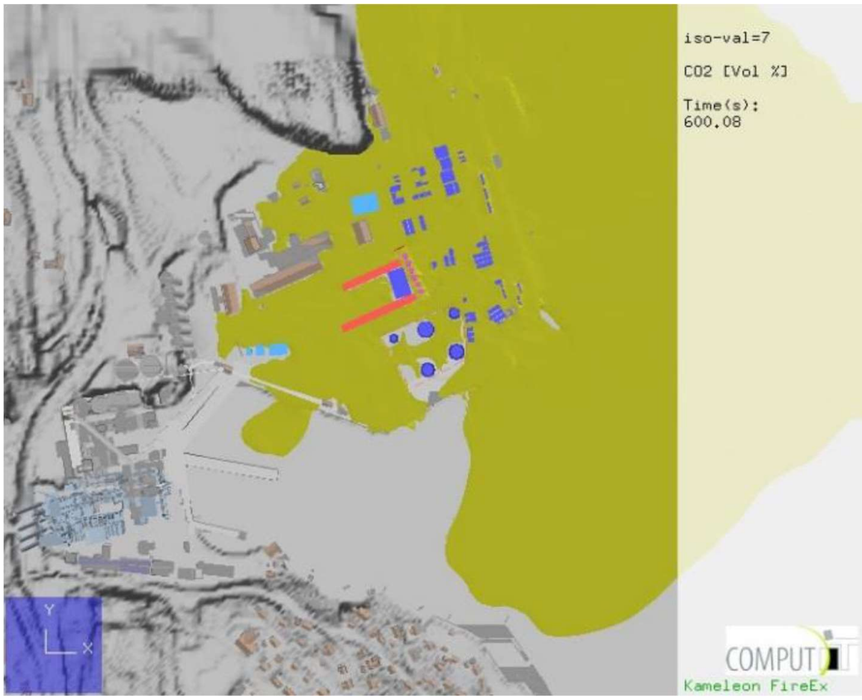


Figure 64 - Release rate of 500 kg/s and directing downwards, windspeed 1 m/s from North

The private houses and the small boat marina on the south side of Dalsbukta are not likely to become exposed to CO_2 concentrations above dangerous levels, neither the private houses located close to the sea, north of the offloading area in such a leakage scenario. Already with a wind speed of 4 m/s, the gas cloud will be about half the size compared to Figure 64. This confirms that the risk is low to expose 3rd persons to harmful concentrations of CO_2 due to large leakage from the tank farm. 1st and 2nd person personnel (working at the Norcem facility or at any of the neighbouring businesses (Renor and the harbour)) are assumed to be able to escape to safe location within 10 minutes after an accidental CO_2 release starts. The risk for employees at Norcem, Renor and Breviksterminalen will be handled through the emergency preparedness plan for the area.

BLEVE (Boiling liquid expanding vapor explosion) is an explosion caused by a catastrophic rupture of a pressure vessel containing a liquefied gas. The sudden depressurization will lead to an explosive vaporization inside the bulk of the liquid. Blast waves and even shock waves can be generated to have destructive impact on the surroundings and human bodies as well as the projectiles. There are reported accidents in the literature that show that BLEVEs can occur in CO_2 storage tanks. A BLEVE in one of the storage tanks at Norcem is probably the most sever accident - in terms of potential for destruction, injury and death in the surroundings that could occur in connection with the CCC facility. Potential consequences are high blast loads, high energy projectiles and sudden release of large quantities of CO_2. The possibility for a BLEVE cannot be ruled out. However, there are several barriers in place that will reduce the likelihood of a BLEVE to occur. Examples of planned barriers that will be in place to reduce the likelihood for BLEVE at Norcem are listed below:

- Two Pressure Safety Valves (PSV) per tank. The valves are connected to the gas filled side of the tank (on the top)
- Tank design pressure is 21 barg, while the operation pressure is 15 barg.
- The tanks are protected/shielded by walls on the north, west and south side of the tanks. This means that fires at Renor, in the stone storage building or in the coal piles will only give low heat loads on the tanks. The same walls also serve as impact protection.
- Pressure and level indicators in the tanks that will shut down the supply if the alarm levels are exceeded.
- The tanks have thermal insulation to slow down the heating of the content caused by the ambient air and the sun. The insulation is not designed to withstand an external fire load.
- The tanks are also equipped with a vent line to atmosphere (PV0012) that allow evaporated CO_2 due to heating of the tank content, to be released. The vent is sized to relief the evaporation of the tank content in case of a production stop at a sunny summer day with 50 °C ambient temperature. This vent comes in addition to the PSVs.
- The tanks have impact protection on the east side that hinders passing trucks and other heavy machinery to bump into and potentially damage the tanks.
- There are connection points for firewater nearby the tanks. This allow for setting up cooling of the tank content if an external heat source is exposing the tanks.

For details regards introduced barriers reference is made to NC03-AKER-S-RA-0007 - Risk Analysis Report (Attachment 28). In addition, there will be several warning signs that will appear before a tank goes to BLEVE (external fire, pressure increase inside the tank, too high filling degree in tank, etc.). This will, if responded to correctly, provide time to carry out evacuation of personnel at Renor, Norcem and Breviksterminalen, before the tank explodes. All in all, it’s assessed that the risk associated with BLEVE is low.

<u>CO_2 export</u>
The total leak frequency for the export segment (excluding the CO_2 transport vessel) is estimated to one leakage every 71 years.

Piping between the storage tanks is placed inside a culvert that is routed below Breviksterminalen. This means that it is well protected from impact loads and other above-ground activities at Breviksterminalen. Small to medium leaks inside the culvert are likely to be contained by the culvert walls and therefore exit the culvert either close to the storage tanks or close to the loading arm. Large leaks (ruptures) could potentially damage the culvert structure so that a crater in the ground appears close to the leak point. In this case the CO_2 will disperse to the surroundings from the leak point. The gas that exits the culvert next to the storage tanks will have a similar dispersion pattern as for leaks from the tanks.

In case of leaks from the north end of the culvert, from the loading arm or from the CO_2 transport vessel, most of the CO_2 is assessed to disperse either out on the sea, or south towards Breviksterminalen and Renor. The small hill to the west and the earthen barrier to the north will in most cases limit the spread of CO_2 in those directions. However, with a large leak and with wind towards north, some CO_2 could go over or around the earthen barrier, and then disperse towards the private houses located further north. If the emergency shutdown valve towards the ship and towards the storage tanks close, the duration of large leaks will be short (a few minutes). However, should the XV fail to close, the result would be a long duration leak with the potential to expose the private houses to the north (given unfavourable wind conditions).

The safety systems, leak frequency, leak durations etc. found onboard the CO_2 transport vessel are not known at the time of writing. Nevertheless, *the vessel will be designed according to the IGC code and relevant class rules,* and we expect that a sufficient number of barriers will be installed to ensure low risk for major leaks. Since the transport vessel is only docked for a limited period over a year (approximately 8%), the risk contribution is expected to be low compared to the CCC facility at Norcem. The Risk analysis will be updated after the QRA for the transport vessel has been received from the Northern Lights project.

6.3.2 Emissions from the capture plant

Aker Solutions has throughout project development been the technology provider for the CO_2 capture process as well as the contractor for providing the system design for the CO_2 conditioning, CO_2 intermediate storage and CO_2 export facilities. Aker Solutions has applied their Advanced Carbon Capture™ (ACC™) process using the ACC™ S26 solvent. The ACC™ process is an energy and cost-efficient process with minimal environmental impact.

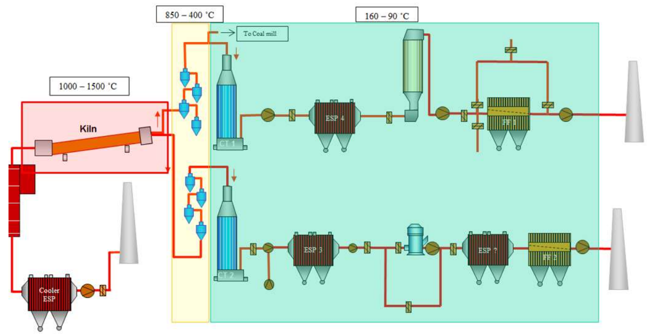
The design, construction and operation of the new CCC plant shall comply with relevant laws and regulations, and Environmental operating permit, permission 2004.057.T, last updated June 2018. Environmental operating permit for Norcem Brevik gives emission limits for dust, hydrochloric acid, hydrofluoric acid, NO_X, SO_2, TOC, some metals, chlorinated dioxins and furans. The emissions of amine and amine degradation products (particularly aldehydes and ketones) contribute with some additional TOC and this should be considered when the emission permit for Norcem Brevik is updated to include the CCC plant.

There are currently no specific national regulations or guidelines for the emissions from the CCC plant and this risk are identified in the project risk register. The Norwegian Environmental Agency (NEA) has previously indicated that new CO_2 capture plant in Norway are likely to face similar regulation and limits with respect to nitrosamines and nitramines that is currently applied at Test Centre Mongstad (TCM). The capture plant operation permit will be part of Norcem's existing permit and the work with a draft operation application for evaluation by the Environmental Agency has started during FEED.

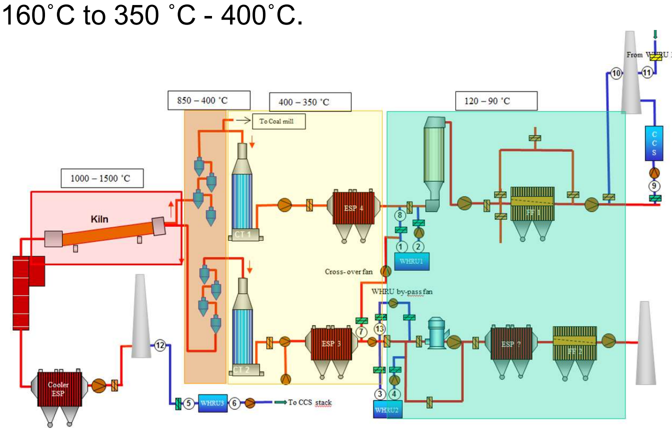
6.3.2.1 Emissions to air

Introduction of the capture plant will due to the cleaning of the smoke gas before removal of CO_2 result in reduced emissions of several components i.e. SO_2, HCL and HF. In particular for SO_2, there is significant positive environmental effect of adding a CCC plant. Emissions to air from existing cement production and the capture plant shall be measured in the new stack at representative points with regards to emissions. This shall be arranged in such a way that all emissions to air is monitored for all operational variants. Continuous emission monitoring system (CEMS) shall be applied, for analysis of the same elements as analysed by existing Norcem CEMS today including new compounds such as solvent amines and aldehydes. In addition, manual emission measurement campaigns shall be conducted on a regular basis, to verify compliance of new permit regulations and to verify performance of CEMS and quantification of trace elements not detectable by CEMS.

Dioxins are believed to form when the precursors are present, and the temperature is in the range from 250˚C to 450˚C. Dioxin can be found in the dust and in the process gas depending on the temperatures in the individual process sections. When the process gas is cooled in conditioning towers and the temperature in the rest of the process is below 250˚C, dioxin will not form.



When implementing the CCS, the temperatures in the conditioning towers and ESP 3 and 4 changes from around 160˚C to 350 ˚C - 400˚C.



Therefore, a system for injection of powdered active carbon is installed between the GSA and FF1. All the flue gas from string 1 and 12% of the flue gas from string 2 will be cleaned with activated charcoal (PAC) before bag filter prior the carbon capture process. The effect of treating the flue gas with activated charcoal (PAC) is expected to reduce the content of dioxins down to 100 pg/Nm^3. Emissions of dioxins from the flue gas after carbon capture are therefore significantly reduced. The rest of the flue gas from string 2 could contain higher amounts of dioxins than before due to above mentioned changes operating conditions. However, total emissions of dioxins from the plant will be reduced after the introduction of the carbon capture facility. Any need for extra cleaning of flue gas in string 2 (same system as for string 1) will be considered by measurements after the capture plant is put into operation.

Some reaction products of amines have been shown to have carcinogenic effect. The CCC plant is currently designed with Aker Solutions ACC™ Emission Control system and Anti-Mist design to minimize emissions of amine and amine degradation products from the CCC plant. The viability of the ACC™ emission control technology has been successfully demonstrated on the actual flue gas from string 1 of the Brevik plant as part of the MTU test campaign at Norcem Brevik. Expected trace level emissions are included in NC03-AKER-S-RA-0001 - Environmental Report (Attachment 29).

Sintef Molab performed dispersion analyses of the flue gas in the feasibility study. The flue gas dispersion study from previous phase is regarded as still valid and has not been updated in the FEED phase. Based on the emission rates and dispersion analyses, NILU calculated the expected environmental impacts of nitrosamines and nitramines in air and water using S26. The maximum total concentration of nitrosamines and nitramines is just above 0.001 ng/m3. This is less than 0.4% of the recommended guideline of 0.3 ng/m3. Furthermore, it should be mentioned that the direct emissions are conservatively chosen (e.g. use of detection limit for nitramines), hence the real emissions are likely to be even lower. NILU calculated the freshwater concentration in the lakes with maximum deposition, “Stokkevann” to the south of the stack and “Bamblevann” to the southwest of the stack. The resulting combined concentrations of nitrosamines and nitramines are 0.0121 ng/l for “Stokkevann” and 0.0126 ng/l for “Bamblevann”. This is far below the guideline of 4 ng/l.

Based on the emission rates, the dispersion model results and calculation of formation and degradation of nitrosamines and nitramines in this study indicates that emission and atmospheric formation of nitrosamines and nitramines from the CCC plant are well below the conservative guidelines established by authorities. This is amongst other things because the amines present in the ACC™ S26 solvent do not form nitrosamines and nitramines to significant extent, and due to the efficient emission control system of Aker Solutions’ ACC™ process.

6.3.2.2 Emissions to water

The identified discharges to water from the CCC plant are:

- DCC effluent
- Heat release to recipient

In addition, there is a possibility for discharges of contaminated drain water (spills, leakages and accidental releases) to sea.

DCC effluent

Except from the cooling water return and boiler blow down, the only continuous liquid stream from the CO_2 capture plant will be the Direct Contact Cooler (DCC) effluent. The DCC condenses water from the flue gas and potentially washes out some of the pollutants from the cement plant flue gas that is today emitted to air. The net DCC discharge flow rate will be approximately 6 m^3/h, independent on GSA operation. When GSA is in operation, the DCC bleed rate will increase from 6 to 11 m^3/h, but 5 m^3/h will be routed back and reused in the GSA. 5 m^3/h is the calculated GSA water consumption with new GSA inlet gas condition and flow rate.

Effluent Water Treatment Plant (EWTP)/Package treating effluent water from the DCC is included in the FEED design. The EWTP will consist of ultrafiltration units (for particulate removal) followed by activated carbon bed for removal of dissolved mercury and dioxins.

Estimated release to sea has been calculated based on assumed capture rate in DCC and the expected removal rate in the Effluent Water Treatment Package. A requirement has been given in the package specification that the concentration of mercury in the cleaned water going to sea shall be maximum 1 µg/L (< 0.04 kg/year). Further requirements are that > 95% of suspended solids, other heavy metals and dioxins shall be captured in the EWTP.

Heat release to recipient

Heat dissipation and local warming of the “Eidangerfjord” as result of the cooling water emitted from the capture plant was thorough investigated during the concept phase by COWI, ref. NC03-AKER-S-RA-0001 - Environmental Report (Attachment 29). The total cooling demand is approx. 61 MW and the cooling water flow rate is 3400 m^3/h with delta T of 15 °C. The routing of cooling water intake (in red) and outfall (in green) is displayed in Figure 65.

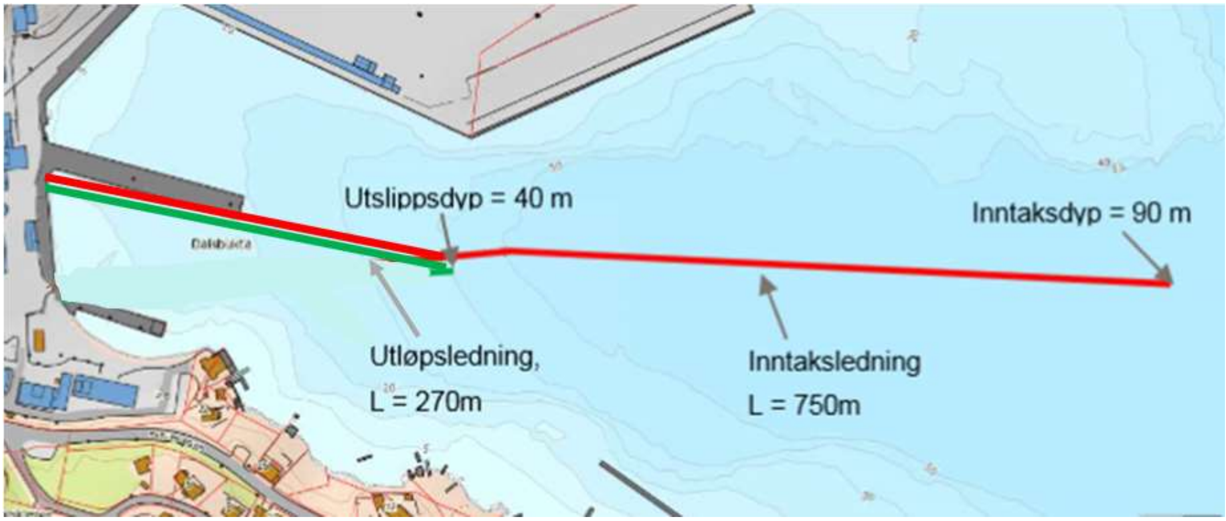


Figure 65 - Proposed routing of cooling water intake (in red) and outfall (in green)

The cooling water outfall consist of a 270 m long submerged Ø1000 mm PE pipeline down to a depth of 40 meter, where a horizontal 46-meter-long diffusor (perforated pipe section) is located. The diffusor ensures efficient mixing of tempered cooling water into the recipient. According to the COWI study, a primary mixing ratio of 9 is obtained immediately above the diffusor, resulting in a local temperature increase of 1.3 °C at a water depth of 37 meter. There is no risk of warm water breaking through to surface water, instead the study shows that the intermixed cooling water at a depth of approx. 37 meters is transferred horizontally southwards and merges with the “Frierfjorden” outgoing current. At this point, the secondary mixing will have reduced the temperature difference to non-detectable limits. According to COWI, the proposed cooling water system is feasible and should fulfil any environmental requirements. It is hence decided that the discharge of the seawater coolant will be as described in the concept study, with a diffusor to improve the mixing with surrounding seawater.

<u>Contaminated drain water (spills leakages and accidental release)</u>
Evaluation of risk of spills, leaks and accidental discharges of amine and caustic containing equipment have been analysed in several workshops and analysis during the FEED. Mitigation actions have been included where required.

The amine and caustic containing equipment will be in bunds covered by roofs. Rainwater and potential spills, leaks and accidental discharges will flow by gravity to a pit. The destination of the liquid in the pit will be manually controlled based on amine/chemical contamination or not. Uncontaminated water can be further pumped to area surface drain while contaminated water can be picked up by a road truck. The roofs will reduce the amount of rainwater to the bund and avoid mixing of potential spills, leaks and accidental discharges with rainwater.

Areas designed for offloading of amine and chemicals and onloading of waste are areas where spills are most likely to occur. These areas are designed to collect spills. It’s recommended that one person observes the filling process to ensure that overfilling doesn’t occur.

Contaminated drain water can be transported off-site for treatment as waste or to the reclaimer package.

6.3.3 Contaminated soil / sediments

An environmental investigation of the ground at Norcem's plant in Brevik was conducted by Norconsult in December 2018. For details reference is made to NC03-NOCON-S-RA-0039 - Environmental Assessment of Soil Contamination (Attachment 30).

The environmental investigations show that the ground is free from contamination at some areas and in other areas moderately contaminated, with two hotspots with heavy contamination. The contamination is mainly in the depth 0 – 2 m. The silty, natural soil deposit, which is found at around 3 m, is clean, with only a few exceptions.

The results show that the analysed parameters are in contaminant class 1 in the Norwegian Environment Agency's guideline "Health based classifications of contaminated soil", TA-2553/2009, in the main part of the samples. Concentrations above contaminant class 1 are detected in 10 of 16 boreholes. This is mainly organic parameters. In samples from 4 boreholes, different metals are detected in contaminant class 2 and 3. A few samples contain dioxins and chromium (Cr_6+) in contaminant class 2 and 3. The PFOS-concentrations are in contaminant class 1 in all samples analysed for PFAS.

An assessment plan needs to be made for the ground affected by the construction plans.

The environmental investigation of the sediments was conducted on the 14th of January 2019. For details reference is made to NC03-NOCON-S-RA-0040 - Environmental Assessment of Seabed Sediment (Attachment 31). The investigation was conducted by two environmental advisors from Norconsult. The sediments in the bay have been investigated several times in earlier years. The results from those investigations were taken into consideration when planning this investigation. Sediment samples were collected from one sediment station. The station represents samples from four different positions along "Cementkaia". The seabed was mostly too hard for the corer to penetrate the seabed. The deepest, collected sample was close to the "Kullkaia" and about 17 cm deep.

The analysis of the samples show that the sediments are heavily contaminated with PAH, TBT, and dioxins. The concentrations are in contamination class 3 and 4, and class 5 for TBT. When it comes to PAH and dioxins, the results are very similar at both sampling depths in the substrate. TBT showed higher contamination level in the deeper layer and heavy metals had slightly higher concentrations in the upper sediment layers.

The PFOS and PFOA concentrations are below the detection limit for the analysis method, but above contaminant class 1 in the guideline.

As the sediment is heavily contaminated, a risk assessment and an assessment plan are required by the guideline M-409. This must be reviewed and approved by the Norwegian Environment Agency.

6.3.4 Noise

The cement plant has existed in Brevik for more than 100 years and before today's settlement was established. Norcem has ongoing dialogue with the authorities, which has shown understanding that the opportunities to achieve a noise level down to 45 dBA at the nearest home residents are currently very demanding. Against this background, Norcem will initially seek to reduce noise from the factory at the nearest home residents down to 50 dBA. If the CCC facility had emitted a noise level of 45 dBA, this would not have been audible at the nearest home residents as today's cement production is close to 10 dBA above this. The reason why the CCC project has worked to reduce the noise level from the CCC facility to 40 dBA is because it will contribute to make it easier for the cement plant to reduce the noise level below 50 dBA in the future. During the project period, Norcem have also worked to reduce the current noise from the cement plant. By introduction of noise reducing measures on kiln 6, calculations have shown that the noise level of the nearest home residents will be reduced by 3 -5 dBA compared to the current noise level. After the introduction of CCC facility and noise reducing measures on kiln 6, the target down to 50 dBA at the nearest home residents will be almost reached.

In today's emission permit for noise, it is stated that Norcem must reduce the noise level as much as possible and in the first instance work to reduce noise at the nearest home residents down to 50 dBA. According to State guideline T-1442 "*Retningslinje for behandling av støy i arealplanlegging*" the night noise requirement from industrial companies of this type is $L_{night} \leq 45$ dBA. In NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4) it is stated that the noise level at nearby residential dwellings resulting from equipment/ installations/ operations introduced by the CCS project, including CO_2 ship loading activities at quay side shall not exceed 45 dBA.
Norconsult has prepared noise calculations for the area from the CCS facility based on expected noise levels from different equipment and operations, ref.: NC03-NOCON-S-RA-0041 - Environmental Noise calculations (Attachment 32). In order to meet requirement listed in guideline T-1442 for the cement plant in the future, Norconsult suggests that the project target for noise from the new CO_2 plant at the nearest neighbours does not exceed Leq ≤ 40 dBA. Based on noise calculation Norconsult has prepared noise maps for the area. Different noise levels are indicated with several colours as displayed in Figure 66.

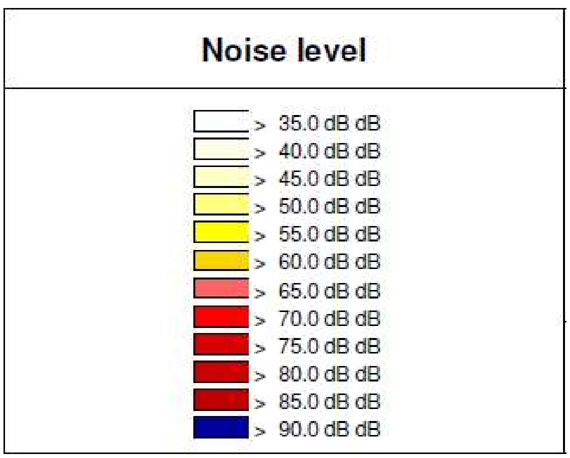


Figure 66 - Colour coding used in noise maps

Equivalent noise level from new equipment in connection with CO_2 capture are calculated with and without noise-reducing measures. As seen in Figure 67, the noise levels from the CCC facility alone will not exceed 40 dBA for nearby residential dwellings (i.e. “Sementvegen 23”) if recommended noise reducing measures are implemented. Neither CO_2 loading operations result in noise levels for nearby residential dwellings above 40 dBA, see Figure 68.

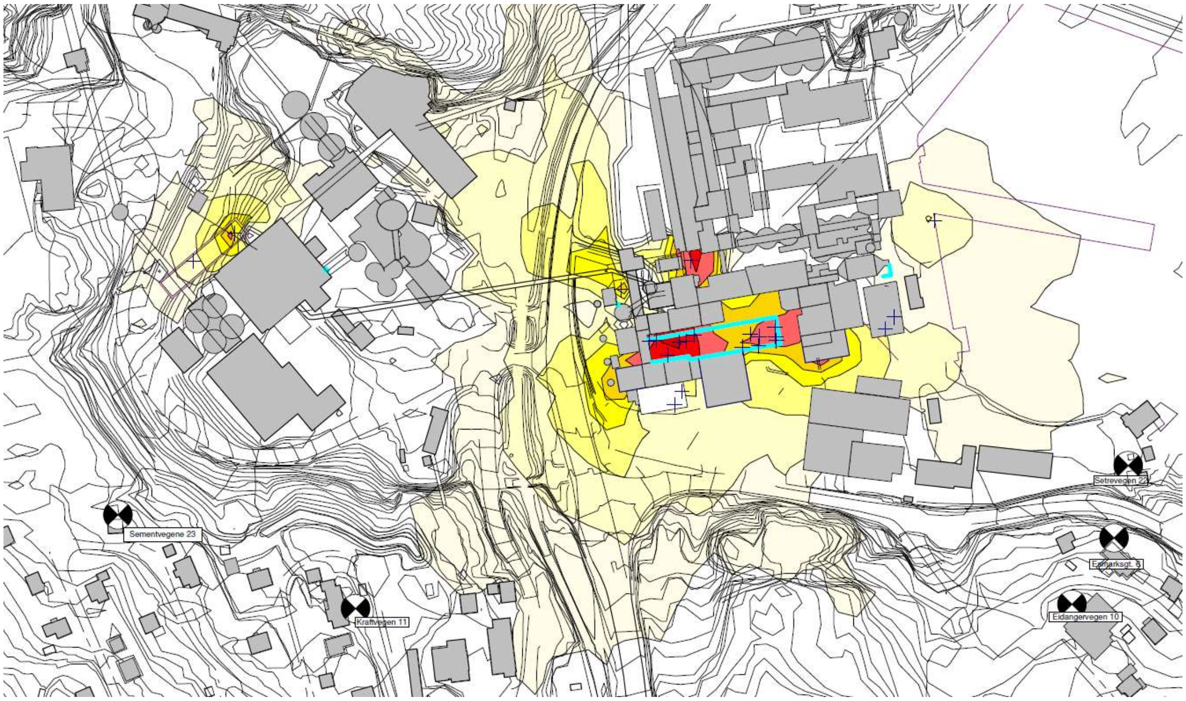


Figure 67 - Equivalent noise level from new equipment in connection with CO_2 capture with noise-reducing measures

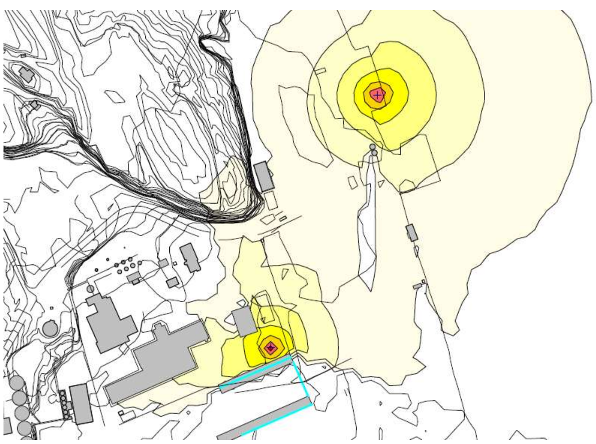


Figure 68 - Equivalent noise level from storage tanks area and CO_2 loading area at the quay

The contribution to noise after introduction of a CCC plant at Norcem will be negligible if recommended noise reducing measures are implemented. In connection with the construction of the capture plant, Norcem also plans noise reducing measures on kiln 6. Calculations performed by Norconsult (NC03-NOCON-S-RA-0049 - Noise calculations for CSS and Norcem plant incl. noise abatement for kiln 6) indicate reduced noise levels at nearby residential dwellings with 3-4 dBA compared to today's noise levels from the plant.

6.4 HSE REGULATIONS OVERVIEW (3d)

This chapter gives an overview and description of relevant HSE regulations and how this is addressed in the study work up to DG3.

For the catch part of the CCS chain, executive authorities are the Norwegian Environment Agency, the County Governor, Porsgrunn Municipality, the Norwegian Directorate for Civil Protection (DSB) and the Norwegian Labour Inspection Authority. During the FEED phase Norcem have had frequently contact with Norwegian Environment Agency and Norwegian Directorate for Civil Protection (DSB).

In connection with the environmental impact assessment, the list of relevant regulations is reviewed in relation to the areas considers relevant for the investigation and it will be revealed through meetings with executive authorities (the Norwegian Environment Agency, the Norwegian Directorate for Civil Protection, the Norwegian Labour Inspection Authority, Porsgrunn Municipality and possibly the County Governor). Norcem has engaged Multiconsult to assist with the environmental impact assessment which is expected to be sent for consultation during September 2019.

Regulatory requirements by Authorities can be split in 3 main groups:

- Approvals and permits
- Laws and regulations
- Exceptions

The regulatory requirements impose several activities on the company. This chapter primarily describes government-related activities in the health, environment and safety area.

6.4.1 Approvals and permits

Approvals and permits are linked to the individual production plant. They are obtained by the individual plant and are described in the plant QA/QC documentation.

6.4.2 Laws and regulations

To protect the employees' health and safety, the CCC Plant design, construction and operation shall comply with requirements set in the laws and regulations defined in Ch.8.1.1.

Both emission components originating from the cement plant and emission components generated by the CCC Plant have been evaluated in the FEED phase. The emission monitoring and control shall comply with the following:

- Norwegian regulation about pollution, "Forurensningsforskriften" – FOR-2004-06-001-931
- "Lov om vern mot forurensninger og om avfall", "Forurensningsloven" - LOV-1981-03-13-6
- IED regulation: Industrial Emission Directive X. Directive 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control)
- BREF/BAT Cement: BAT Reference document for Cement and Lime Manufacturing X. 213/163/EU: Commission Implementing decision of 26th March 2013 establishing the best available techniques (BAT) with conclusions under directive 2010/75/EU of the European parliament and of the Council on industrial emissions for the production of cement, lime and magnesium oxide.
- The Norwegian Institute of Public Health (NIPH) and the Norwegian Environmental Agency (NEA, in Norwegian MD) have reviewed literature about different air pollution components and unwanted health effects and have updated the air quality criteria [25] based on this knowledge.

- "Forskrift om kvoteplikt og handel med kvoter for utslipp av klimagasser -FOR-2004-12-23-1851"
- In ″Stortingsmelding nr. 26″ from 2006-2007 [26] goals for local air quality are given.
- National recommendations for air quality management in municipal area planning are described in ″Retningslinjer for behandling av luftkvalitet i arealplanlegging″ (T-1520).
- Environmental operating permit, permission 2004.057.T, last updated June 4th, 2018.

Regelhjelp.no has an overview of current laws and regulations in the HSE area in our industry and relevant to our activities. We have considered that this portal responds to our need for an overview of current legal requirements in the HSE area. Overview of current legal requirements for the cement industry:
http://www.regelhjelp.no/no/Finn-HMS-krav-til-din-bransje/Produksjon-av-glass-sement-gipsbetong-med-mer/

The document "Procedure for Identifying Requirements in Laws and Regulations" (PD0015) describes the responsibility for identifying new relevant legal requirements for our activities.

6.4.3 Exceptions

The Company shall always comply with the requirements and limitations given by the authorities. If such a claim appears inappropriate or impossible to follow, exemption from the competent authority must be obtained before the claim can be set aside. It is the responsibility of the plant manager / marketing manager to ensure that necessary dispensations are obtained. The dispensation must be documented.

6.4.4 Norcem's project partners

In the FEED phase Norcem's project partners have followed their own internal HSE procedures and systems in carrying out their work. This is stated in contracts with our partners.

6.4.5 Standards

- Environmental Management; ISO standard 14001
- Occupational Health and Safety Management: OHSAS standard 18001

6.5 CLIMATE FOOTPRINT

Gassnova will calculate the CO_2 footprint for the complete CCS chain, using a calculation tool developed for the NCD project in cooperation with DNV GL/Carbon Limits. The tool is based on the ISO standards 14040, «Life Cycle Analysis – principles and framework», and 14044, «Life Cycle Analysis – requirements and guidelines».

As input to the CO_2 footprint calculation for the complete CCS chain, performed by Gassnova, ÅF Advansia has performed a life cycle inventory (LCI) for the CO_2 capture plant in Brevik. In collaboration with Gassnova, all inventory data has been gathered from the relevant project partners and aggregated to a complete LCI for the CO_2 capture plant.

6.5.1 Life Cycle Inventory Methodology

The CO_2 footprint calculation tool was used as a structure and for the documentation of LCI data. For the purpose of the LCI, the CO_2 capture plant was divided into the following life cycle phases and activities:

- Construction phase
    - Preparation of the site / clearing
    - Buildings / Roads construction
    - Equipment – Material of construction – Transport to site
        - Capture

        - Liquefaction
        - Transport to the shore
        - Storage tanks – Quay – Loading arms
        - Modifications to existing facility and integration
    - Mobile vehicles for construction
- Operational phase
    - Chemicals and utilities
    - Grid electricity purchases
    - Waste and wastewater handling
- Decommissioning phase
    - Clearing
    - Fuel consumed in mobile vehicles
    - Waste disposal

The LCI was performed in cooperation with project partners and Gassnova. according to Table 23.

Date	**LCI Activity**
15.01.2019	Presentation of LCI methodology in monthly project meeting, establish contact person(s) for data collection
January – February 2019	Meetings with project partners, presentation of method and LCI data delivery plan
13.03.2019	Status meeting between Gassnova and Norcem
31.03.2019	Deadline for delivery of LCI data from project partners
10.05.2019	Deadline for delivery of final LCI data from project partners
February – May 2019	Continuous aggregation of data and quality check
15.05.2019	Meeting with Gassnova, review of final data, findings and quality check
17.05.2019 – 24.05.2019	Draft LCI data for review to all project partners and Gassnova
29.05.2019	Delivery of LCI data for the CO_2 capture plant in Brevik (MS Excel)

Table 23 - LCI activities for CO_2-footprint assessment.

The data collection, sources (project partner and document references), level of confidence, transport mode, origin etc. are documented with comments in the CO_2 footprint calculation tool.

6.5.2 Assumptions and comments

All assumptions and comments have been made directly in the CO_2 footprint calculation tool. This section aims to further explain and clarify important parts of the LCI.

Construction phase

- All floors are counted for in clearing/construction/buildings with units in m^2 (3 floors á 200 m^2 = 600 m^2).
- The tables of equipment have limited space in calculation tool. Therefore, phases with long lists of equipment have been aggregated. This is the case for “Capture” and “Modifications to existing facility and integration”, where the final main item is a lump post named “various” and contains materials with known content and origin.
- “Mobile vehicles for construction” is highly uncertain and can differ +/- 50-100%. Norconsult’s estimate is based on project cost, while Norsk Energy is based on hour

estimate. Remaining project partners made rough guesstimates, which were improved by extrapolating the fuel consumption per kg installed equipment based on Norsk Energi's hour estimate, as the installation activities are more similar to each other than e.g. the civil works by Norconsult.

Operational phase
Grid electricity purchases are not strictly limited to the capture and liquefaction phases but are documented here of technical reasons. Residual filter waste containing heavy metals is considered to be treated as hazardous waste and landfilled at Langøya or similar waste treatment facility. Reclaimer waste will most likely be handled by neighbour waste company in Brevik and incinerated as hazardous waste.

Decommissioning phase
The decommissioning phase is highly uncertain, because of uncertainties in future technologies and conditions. Fuel consumption is assumed to be the same as for installation of equipment, which is highly uncertain. For waste disposal and waste types, the weights are well in line with ingoing weights for equipment installations in the construction phase. The types of waste treatment, transportation modes and distances are more uncertain.

Level of confidence and representativeness of LCI-data
A level of confidence is filled in under each table (high, moderate, low). In the comments field under each table, the detailed level of confidence per project partner is further explained. For each table with mixed confidence levels, the lowest confidence level will as a rule determine the total level. E.g. moderate mixed with high level of confidence, the total confidence level will be only moderate.
The comment fields to the very right of each activity or main item also contain information about uncertainties, together with references to project documents.

Calculation of specific emission factors
For calculation of emission factors, the following conditions and assumptions are made:

- Background database Ecoinvent 3.5.
- Calculations were made with SimaPro 8.5.2.0.
- The life cycle impact assessment method IPCC 2013 (100 years) was used to calculate the CO_2-footprint.
- For emission factors based on market processes (GLO) in Ecoinvent, transports are already included. For all other emission factors, transports need to be added.
- Allocation at point of substitution (APOS).

6.5.3 Deliverables

LCI data for the CO_2 capture plant in Brevik included in the CO_2 footprint calculation tool LCI in MS Excel format, document no.: NC03-NOCE-S-CA-0001 - CO_2 footprint (Attachment 33).

6.6 ACCREDITATION AND QUALITY PLAN (4a, 4b)

6.6.1 Accreditation

Norcem is certified according to the NS-EN ISO 9001:2015 quality management standard and requires that all project partners are certified according to ISO 9001 or equivalent and that this is reflected throughout their business operations.

6.6.2 Quality Plan

NC03-NOCE-Q-AD-0002 - Quality and Risk Management Plan (Attachment 35) outlines the quality and risk related processes (activities) required to ensure that the quality of the project deliverables meet the project requirements. This is a governing project document, and a live document which will be updated as needed throughout the project.

The activities outlined in this plan are in accordance with the requirements in ISO 9001:2015 and are based on the project scope and risk assessments.

The Quality & Risk Management Plan describes the quality management system structure, the project organization, roles and responsibilities, quality management procedures and project audit and verification activities.

NC03-NOCE-A-KM-0001 - project manual (Attachment 34) has been established for the project. The project manual describes the project management systems and routines and outline the project scope and activities, as well as project communication, meetings, reporting and documentation.

In addition, the project quality management procedures in the NC03-NOCE-Q-AD-0002 - Quality and Risk Management Plan (Attachment 35) covers project planning, interface management, quality assurance and control of project deliverables, cost estimation, communication and meetings, stakeholder management, document control, resource management, training and awareness, reporting, change management and continuous improvement based on knowledge sharing and experience exchange.

Project audits and verification activities are covered in section 6.7.

6.7 PERFORMED QUALITY CONTROL AND ASSURANCE (4c, 4d)

Project quality control and assurance have been performed in accordance with NC03-NOCE-Q-AD-0002 - Quality and Risk Management Plan (Attachment 35)

Project audits and other verification activities are important means to ensure and verify that the project deliverables meet the required quality.

Project audits and verification activities performed in the FEED phase include:

- Regulatory Processes
- Technology Qualification (TQ)
- Audits of project partners
- HAZID & HAZOP
- Design reviews
- Verification of cost estimates
- Constructability review

A detailed plan for audits and verification activities for the FEED phase (NC03-NOCE-QA-TA-0001 - Plan for Quality Audits) was established. Gassnova was invited to planned project audits as an observer.

An Impact Assessment will be performed by Multiconsult in accordance with governing regulations for impact assessments.

6.7.1 Regulatory processes

An Impact Assessment has been performed by Multiconsult in accordance with governing regulations for impact assessments. For a more detailed description of the current status of the Impact Assessment, see section 8.2

6.7.2 Technology Qualification (TQ)

The following technologies applied in and developed as part of the project are assessed to have new technology elements:

- CO_2 capture technology (Aker Solutions)
- CO_2 compressor with heat recovery (Aker Solutions)
- Waste Heat Recovery Units (Norsk Energi)

These technologies have been qualified in accordance with DNV GL's recommended practices DNV-RP-A203 - Technology Qualification [19] and DNV-RPJ201 - Qualification procedures for CO_2 capture technology [20].

For a more detailed description, see section 5.7.

6.7.3 Quality audits of project partners

The project audits completed in the FEED phase are shown in the Table 24.

Activity	Date
Review of Norcem's quality- and project- management systems and procedures	24. January 2019
Audit of **Aker Solutions** quality management systems and procedures	6. December 2018
Audit of **Norconsult** quality management systems and procedures	24. April 2019
Audit of **FLSmidth** quality management systems and procedures	28. February 2019

Table 24 - Performed quality audits

In addition, Gassnova conducted an audit of Norcem's quality management system in November 2018. No major findings were identified.

Individual reports were written from each of these audits, documenting the findings.

All findings from the audits were registered and followed up in NC03-NOCE-Q-LA-0001 - Quality Audit Register. All audit findings have been closed in a satisfactory manner.

6.7.4 HAZID & HAZOP

For an overview of performed Hazard Identification (HAZID) workshops and Hazard and Operability studies as part of the FEED study, please see section 6 of this report.

6.7.5 Design reviews

Good engineering practice is important to ensure good quality in the engineering deliverables (see section 5.10).

A 3D model of the carbon capture and conditioning plant integrated with the existing cement plant in Brevik, has been actively used by the project partners throughout engineering, and has been updated weekly with the latest changes in design.

The plot plan, generated from the project 3D model, was presented to and approved by Norcem plant management and employee representatives in October 2018.

Common design reviews with all project partners were performed with particular focus on interfaces and tie-ins for the Plot Plan, PFDs and P&ID prior to finalising these.

The document NC03-NOCE-Q-AD-0003 - Level of detail / maturity for engineering deliverables in FEED (Attachment 36) provided guidance with examples per document type to the level of detail required for each of the main engineering deliverables.

In addition, common HAZOPs with particular focus on the interfaces and tie-ins (ref. section 6 of this report) have been performed.

Changes to the plot plan, PFDs and P&IDs after design freeze points have been subject to change control in accordance with NC03-NOCE-A-KA-0002 - Change Management Procedure.

6.7.6 Verification of cost estimates

Performed verification activities or quality assurance of cost estimates, including cost risk analysis are described in sections 4.9 and 4.10 of this report.

6.7.7 Constructability Review

An overall Constructability review was performed by Kværner (NC03-NOCE-Z-RA-0028 - Constructability Review Report (Kværner) - Attachment 37).
In addition, Norconsult and Aker performed constructability reviews for their scope of work (NC03-NOCON-C-RA-0038 - Constructability review report and NC03-AKER-Z-RA-0002 - Construction Method Study Report). For a more detailed description, see section 6.8.

6.8 CONSTRUCTABILITY REVIEW

Kværner was contracted by Norcem to perform a Constructability Review of the FEED study executed for the CO_2 Capture and Conditioning plant at Norcem cement plant in Brevik. The objective of the review was to assess the constructability methods, philosophy and strategy applied in the FEED study work, for both the construction and installation scope of the complete plant, including civil works.

The performed constructability review is summarised in NC03-NOCE-Z-RA-0028 - Constructability Review Report (Attachment 37).

Kværner has assessed, based on given input and conducted interviews, whether the work has been defined to support optimized construction and installation methods, where SIMOPS, sequencing, infrastructure logistics and schedules are essential with regards to supporting a safe and efficient installation and construction phase. Kværner has related the review to their construction and fabrication execution experience, and also to their methods for implementing a construction- and installation friendly design. They have based the report on their understanding of the current status of the CCS project, and the report includes their observations with proposed improvements or updates of planned methods, in addition to highlighting what is well defined in the existing methods and work.

In addition to the overall Constructability Review performed by Kværner Norconsult and Aker Solutions have performed constructability reviews for their scope of work, ref. documents NC03-NOCON-C-RA-0038 - Constructability Review Report and NC03-AKER-Z-RA-0002 - Constructability Method Study Report.

The recommendations made by Kværner in the overall Constructability Review, were reviewed in a workshop with project partners in June 2019, where Kværner presented their recommendations, these were discussed and evaluated with a cost benefit perspective. Based on these discussions, some elements of the current construction and installation plan will be further evaluated to ensure safe, timely and cost-efficient construction and installation. These are detailed in minutes from the constructability review workshop held in June 2019 [32].

Local construction contractors engaged by Aker Solutions in the FEED study have most experience with stick-built, and so far Aker Solutions has not challenged these contractors in terms of modularization.

The local construction contractors will be invited to tender for the construction and installation work of the CCC plant, and will, among other things, compete on construction method, including degree of modularization. The construction method review will continue throughout contract negotiations and conclude prior to award of critical Purchase Orders (first priority packages).

6.9 VALUE IMPROVEMENT PRACTICES AND COST REDUCTION ASSESSMENT (2u)

A Value improvement (VIP) process was carried out during the feed. This was conducted in a workshop with all partners present as well as personnel from Gassnova.

A detailed review of the project was carried out according to Value Engineering principles with the aim to find possibilities for increasing the value on the project and reduce the total cost. Possible improvements were discussed and brainstormed. The resulting outcome was a list of possible improvement containing 53 points.

All points have been further evaluated during the FEED and a decision has been made either to implement or disregard each point.

For further details of the VIP evaluation see NC03-PERI-F-RA-0002 - Value Improvement Workshop report and NC03-NOCE-Z-LA-0001 - VIP Action list FEED.

6.10 FREEDOM TO OPERATE ANALYSIS (2m)

A freedom to operate (FTO) analysis concerning the ACC™ technology and other important technology aspects applied in the CCC plant design has been executed as part of the Concept and FEED studies. The FTO has been conducted for Aker Solutions by an external IPR consultant.

The FTO analysis has focused on the following 7 areas:

1. Mist control including applied water-wash configuration and heat integration within the ACC™ technology
2. Concept for CO_2 compression with integrated heat recovery
3. Heat integration in the CO_2 liquefaction and inert stripping processes
4. Heat integration of a CO_2 capture plant with a cement production facility
5. Use of the CO_2 absorber as vent stack for concentrated CO_2 e.g. during transient and off-spec. operation
6. Use of the S26 solvent
7. Flue gas tie-in

These focus areas were selected based on an assessment of all major subsystems within the overall carbon capture, conditioning and interim storage scope with respect to characteristics such as Aker Solutions protection, technology maturity, availability, importance, implications of infringement, status of Aker Solutions' design. The assessment includes an evaluation of the probability of possible infringement before and after the FTO analysis.

Aker Solutions FTO analysis concludes, that the findings from the FTO analysis do not pose a significant threat to the intended process solutions for the CCC plant at Norcem, Brevik.

The FTO analysis has focused on technology elements and process solutions that are critical to the design of the CCC plant and that would introduce large changes to the project if needed to be circumvented at a later stage. It is not believed that the choice of detailed solutions will result in any problems related to patents, provided that the relevant patent rights identified and discussed in the FTO are taken into account.

It should be noted that no FTO analysis will be final, as patent applications in early phase are not publicly available. Additionally, pending patent applications may be amended, and divisional applications filed, during prosecution in a way which is impossible to predict, changing the scope of protection.

Based on the FTO analysis, all subsystems of the total Aker Solutions scope are considered to have low probability of possible infringement, and low risk with respect to Freedom to Operate.

See the redacted version of the IP3 classified document NC03-AKER-A-RA-0004 - Freedom to Operate Report (Attachment 61), for further details.

Apart from Aker Solutions' technology, the waste heat recovery system design developed by Norsk Energi have elements of novel technology. Norsk Energi has confirmed that there is low probability of possible infringement, and low risk with respect to Freedom to Operate related to their technology.

The FTO analysis will be reviewed and updated as required in time for any necessary modifications due to possible patent infringements to be made to the detailed design. The updated FTO analysis will include the waste heat recovery system design.

Norcem will through project execution contracts seek indemnification from the technology providers for any costs incurred or workarounds required as a result of breach of third party patent rights concerned with implementation of the technology at Norcem Brevik.

7 RISK MANAGAMENT

The project Risk Management procedures are described in NC03-NOCE-Q-AD-0002 - Quality & Risk Management Plan (Attachment 35). The project Quality & Risk Management Plan describes how project risks are identified and evaluated, how mitigating measures are identified and how this is followed up and documented in NC03-NOCE-S-LA-0001 – risk register (Attachment 38).

The project risk management procedures are described in more detail in section 7.2.
The high risks included in the project risk register is shown in section 7.3 with reference to the current project risk register.

7.1 RISK MANAGEMENT AND -PROCESSES (8a)

The project Risk Management procedures are described in NC03-NOCE-Q-AD-0002 - Quality & Risk Management Plan (Attachment. 35)

Project risks are risks that may affect factors such as project execution (progress), quality, HSE, production capacity or regularity, operating costs and profits and corporate reputation. Both opportunities and threats have been considered. Both project risk in connection with operations and maintenance (OPEX) and expected investment costs (CAPEX) are included.

The QA/QC and Risk Manager has been responsible for documenting identified project risks in the risk register and making sure that identified risks are evaluated and followed up with risk mitigation measures (where possible).

Throughout the FEED phase, both Norcem and their project partners have regularly evaluated their own project risk and implement risk mitigation measures in areas of high risk. The project partners have provided input, at least monthly, to project management on project risk and risk mitigation measures related to their areas of responsibility.

The project risk register has been updated at least monthly throughout the FEED-phase and the main risks have been shared with Gassnova as part of the monthly report and reviewed in monthly project meetings, both in the project team and with Gassnova.

Project risk in this context does not include uncertainties related to calculus work and statutory requirements in health, safety and the environment. Risk management related to HSE and environment is described in more detail in section 6.

7.2 METHOD FOR DETERMINATION OF PROJECT RISK

The risk management process in the project can be divided into the following steps:

- Identify the risk of an event (hazard or opportunity)
- Assess the probability and consequence of the event occurring
- Find relevant risk mitigation measures
- Evaluate residual risk after action has been taken

Risks are typically identified and assessed, and risk mitigating actions identified in project meetings with the relevant project team members.
Risks are categorized as high, medium or low based on the assessed likelihood and consequence. Conditions considered to represent high risk require immediate action, or any measures that can be implemented in a later phase if it is not critical to the FEED phase.

At medium risk, risk mitigation measures should be proposed, and measures considered to be implemented if it is not unreasonably costly.
Low risk is considered acceptable and does not require risk mitigation measures. If measures that further reduce risk free of charge are revealed, such measures will still be implemented.

7.3 RISK MATRIX (8c)

NC03-NOCE-S-LA-0001 – Project Risk Register (Attachment 38) includes a risk matrix used for categorization of risk as high, medium or low based on the assessed likelihood and consequence.

All risks relevant for the project FEED phase only have now been closed, as this phase is completed. The remaining open risks are relevant for Project Execution and/or Operation, as defined in the Project Risk Register for each risk.
The risk matrix is shown in Figure 69 below (in Norwegian):

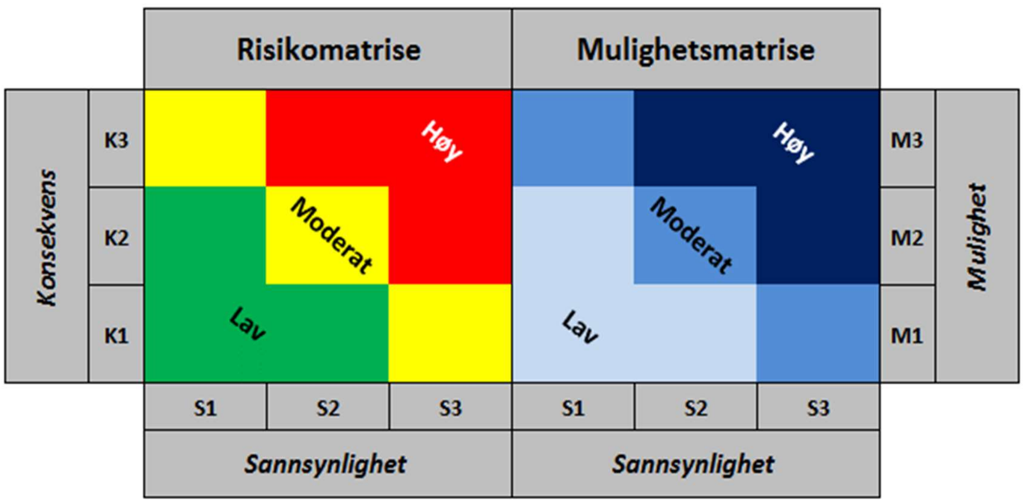


Figure 69 - Risk Matrix

The risk acceptance criteria for the risk and opportunity analysis is shown in the Figure 70:

ACCEPTANCE CRITERIA RISK-/OPPORTUNITY ANALYSIS
Acceptance criteria should be defined specifically for the project. This is an example.

Consequence classes		Low — Consequence — High			Low — Opportunity — High		
		K1	*K2*	*K3*	*M1*	*M2*	*M3*
Describe target areas for the project	SHA	First aid injury	Sick leave- / permanent injury	Fatality			
	Financial	Cost < 10 mill.	Cost 10-100 mill.	Cost > 100 mill.	Saving < 10 mill.	Saving 10-100 mill.	Saving > 100 mill.
	Progress	Delay < 1 month	Delay 1-3 months	Delay > 3 months	Progress advance < 1 month	Progress advance 1-3 months	Progress advance >3 months
	Quality	Insignificant impact on functionality	Medium impact on functionality	Significant impact on functionality	Minimal improvement in functionality	Significant improvement in functionality	Very large improvement in functionality
	Environment	Recovery time pollution < 1 år	Recovery time pollution 1-10 år	Recovery time pollution > 10 år			

Likelihood classes		Low — Likelihood — High			Low — Likelihood — High		
		S1	*S2*	*S3*	*S1*	*S2*	*S3*
Describe target areas for the project	SHA	Once per 10-100 years	Once per 1-10 years	Once per year or more often			
	Financial	10% (qualitative)	50% (qualitative)	80% (qualitative)	10% (qualitative)	50% (qualitative)	80% (qualitative)
	Progress	10% (qualitative)	50% (qualitative)	80% (qualitative)	10% (qualitative)	50% (qualitative)	80% (qualitative)
	Quality	10% (qualitative)	50% (qualitative)	80% (qualitative)	10% (qualitative)	50% (qualitative)	80% (qualitative)
	Idriftsettelse	10% (qualitative)	50% (qualitative)	80% (qualitative)			
	Environment	Has happened in the industry	Has happened in Heidelberg / Norcem	Has happended in Norcem Brevik			

Figure 70 - Risk Acceptance Criteria

In project execution, a 5*5 risk matrix will be used, replacing the 3*3 risk matrix used for FEED, to allow for a more detailed assessment and thereby clearer prioritisation of the project risks.

As shown in Figure 71 below, there are currently 1 high, 37 moderate and 26 low risks in the project risk register.

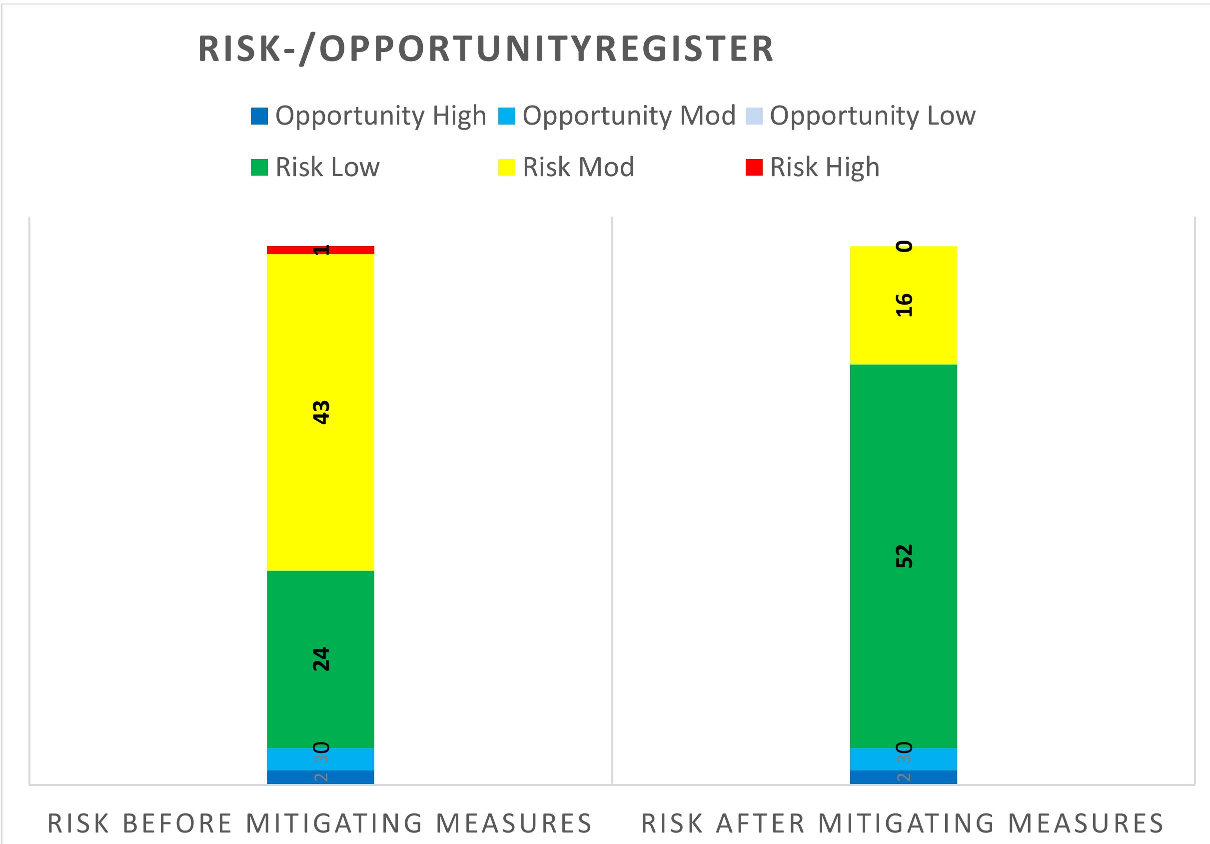


Figure 71 - Project Risk by Category

The remaining high risks in the project risk register is shown in Table 25.

Table 25 - High Project Risk

Risk ID	Project phase	Risk Element	Cause	Consequence	Risk Level per end of FEED
NOCE-11	Project Execution & Operation	Project cost for Heidelberg Cement / Norcem higher than anticipated, due to unclear contractual conditions between Norcem and relevant authorities on support for construction and operation.	Unclear contractual conditions between Heidelberg Cement / Norcem and relevant authorities on support for operation.	Project cost higher than anticipated	Risk High

This risk is due to the fact that the contractual conditions between Heidelberg Cement / Norcem and relevant authorities on financial support for project execution and operation are not yet clarified, as the contract negotiations between the State and Heidelberg Cement / Norcem are ongoing. Heidelberg Cement / Norcem cannot move forward with internal management approval of the project or contract negotiations with potential project contractors and suppliers until the contractual conditions with the State have been clarified.

The main principles in the financial support agreement between Heidelberg Cement / Norcem and the State, and project approval by HeidelbergCement must be landed before Heidelberg Cement / Norcem final offer to the State.

The risk mitigating actions for the remaining high risk with deadline and status is shown in Table 26 below.

Table 26: Risk Mitigating Measures for High Risk

Risk ID	Mitigating Measures	Deadline	Responsible	Status
NOCE-11-M1	Conclude finance model (Investment and operations) with authorities (prior to HeidelbergCement final offer to ministry)	15.10.2019	Per Brevik	Ongoing
NOCE-11-M2	HeidelbergCement commitment to project realisation (Vorstand recommendation) (given State approval)	22.10.2019	Per Brevik	Ongoing
NOCE-11-M3	Supervisory Board approval of Vorstand recommendation	18.11.2019	Per Brevik	
NOCE-11-M4	HeidelbergCement final offer to ministry	31.12.2019	Per Brevik	
NOCE-11-M5	Parliament approval of project realisation	31.12.2020	Per Brevik	
NOCE-11-M6	Proper project risk distribution to main contractors	31.12.2020	Per Brevik	

8 REGULATORY STRATEGY (5a)

8.1 OVERVIEW OF REGULATIONS

8.1.1 Laws and Regulations for Norcem

Public laws and regulations should be a guide to Norcem's activities. The following laws are relevant for the CCS project and ensured through Norcem's HSE and Quality System (*The laws in Norwegian language*):

- Forurensningsloven:
  - Lov av 13. mars 1981 nr. 6 om vern mot forurensninger og avfall. Kontrollinstans er *Miljødirektoratet*.
- Plan- og bygningsloven.
  - Lov av 27. Juni 1971. Lov om planlegging og byggesaksbehandling (plan- og bygningsloven).
- Internkontrollforskriften
  - Lov av 12. Juni 1996
- Arbeidsmiljøloven:
  - Lov av 4. februar 1977 nr. 4 om arbeidervern og arbeidsmiljø m.m. Kontrollinstans er Arbeidstilsynet.
- Brann- og eksplosjonsvernloven:
  - Lov av 14. juni 2002 om vern mot brann, eksplosjon og ulykker med farlig stoff og om brannvesenets redningsoppgaver. Kontrollinstans er Direktoratet for Brann og eksplosjonsvern (DBE).
- Lov om tilsyn med elektriske anlegg og – utstyr.
  - Lov av 24. mai 1929 nr. 4 og § 9 om tilsyn med elektriske anlegg og elektrisk utstyr. Kontrollinstans er Elektrisitetstilsynet.
- Produktkontrolloven.
  - Lov av 11. juni 1976 nr. 79 om produktkontroll. Kontrollinstans er Enhet for produktsikkerhet i Barne- og familiedepartementet.
- Forskrift om industrivern.
  - Lov av 20. Desember 2011
- Forskrift om sikring av havneanlegg (+ The International Ship and Port Facility Security Code, ISPS).
  - Lov av 29. Mai 2013. Kontrollinstans er Kystverket)
- Forskrift om organisering, ledelse og medvirkning
  - Lov av 6. Desember 2011
- Arbeidsplass-forskriften
  - Lov av 6. Desember 2011. Forskrift om utforming og innretning av arbeidsplasser og arbeidslokaler (arbeidsplassforskriften)
- Forskrift om utførelse av arbeid
  - Lov av 6. Desember 2011. Forskrift om utførelse av arbeid, bruk av arbeidsutstyr og tilhørende tekniske krav (forskrift om utførelse av arbeid)
- Maskinforskriften
  - Lov av 20. Mai 2009. Forskrift om maskiner

Regelhjelp.no has an overview of current laws and regulations in the HSE area in our industry and relevant to our activities. We have considered that this portal responds to our need for an overview of current legal requirements in the HSE area. Overview of current legal requirements for the cement industry:
http://www.regelhjelp.no/no/Finn-HMS-krav-til-din-bransje/Produksjon-av-glass-sement-gipsbetong-med-mer/

Requirements that the individual department has found necessary for their own business should be specified in departmental manuals. Head of Department is responsible for ensuring that regulations are available and that requirements in the regulations are announced to the employees in this regard.

The document "Procedure for Identifying Requirements in Laws and Regulations" (PD0015) describes the responsibility for identifying new relevant legal requirements for our activities.

8.2 STATUS ENVIRONMENTAL IMPACT ASSESSMENT

This section presents a brief summary of the Environmental Impact Assessment (EIA). For more specific information about the topics mentioned below, reference is made to chapter 6.3 HSE Study Results in this report.

The draft EIA was issued by Multiconsult on 30. September 2019, and has been sent to NEA for comments. Feedback from NEA has been received, and the EIA will be submitted for consultation (public scrutiny) by the end of November. The consultation deadline is 6 weeks. The EIA will be updated based on consultation comments by 31. January 2020, and is expected to be approved by the end of March 2020.

Based on risk evaluations during FEED the main topics related to environmental impact are;

- Emissions from the capture plant
  - to air
  - to water
- Contaminated soil / sediments
- Noise

8.2.1 Emissions to air

Introduction of the capture plant will due to the cleaning of the flue gas before removal of CO_2 result in reduced emissions of several components i.e. SO_2, HCL and HF. In particular for SO_2, there is significant positive environmental effect of adding a CCC plant. Emissions to air from existing cement production and the capture plant shall be measured in the new stack at representative points with regards to emissions. This shall be arranged in such a way that all emissions to air is monitored for all operational variants.

The CCC plant will be equipped with Aker Solutions ACC™ Emission Control system and Anti-Mist design to minimize emissions of amine and amine degradation products from the CCC plant. The viability of the ACC™ emission control technology has been successfully demonstrated on the actual flue gas from string 1 of the Brevik plant as part of the MTU test campaign at Norcem Brevik. Based on the emission rates and dispersion analyses, NILU calculated the expected environmental impacts of nitrosamines and nitramines in air and water using S26. The maximum total concentration of nitrosamines and nitramines in air is just above 0.001 ng/m3, which is less than 0.4% of the recommended guideline of 0.3 ng/m3. NILU also calculated the freshwater concentration, due to precipitation of contaminated flue gas, in the lakes with maximum deposition, “Stokkevann” to the south of the stack and “Bamblevann” to the southwest of the stack. The resulting combined concentrations of nitrosamines and nitramines are 0.0121 ng/l for “Stokkevann” and 0.0126 ng/l for “Bamblevann”. This is far below the guideline of 4 ng/l.

Due to changes in operating temperatures, increased formation of dioxins will probably occur. All the flue gas from string 1 and 12% of the flue gas from string 2 will be cleaned with activated charcoal before bag filter prior to the carbon capture process. The effect of treating the flue gas with activated charcoal is expected to reduce the content of dioxins to 100 pg/Nm^3. Emissions of dioxins from the flue gas after introduction of the CCC plant are therefore significantly reduced due to treating the flue gas with activated charcoal before the bag filter.

8.2.2 Emissions to water

Norcem has no direct emissions to seawater today. After introduction of the CO_2 capture plant there will be emissions to sea from the Direct Contact Cooler (DCC) which is mixed with cooling water (seawater used for cooling purposes) before discharge to Eidangerfjorden. The DCC condenses water from the flue gas and potentially washes out some of the pollutants from the cement plant flue gas that is today emitted to air. An Effluent Water Treatment Plant (EWTP)/Package treating effluent water from the DCC is included in FEED design. The EWTP will consist of ultrafiltration units (for particulate removal) followed by an activated carbon bed for removal of substances such as dissolved mercury and dioxins.

In connection with the Environmental Impact Assessment (EIA), the Norwegian Institute for Water Research (NIVA) was asked to consider discharges of purified process water (after EWTP) from the carbon capture plant to Eidangerfjorden. Parts of the summary in the NIVA report states the following;
"The process water contains mainly dust, total organic carbon (TOC), SO_2, NO_x, metals (including mercury) and dioxins. Supplies of dust, TOC, SO_2, NO_x and acidifying substances are considered to have a marginal effect on the water quality in the Eidangerfjord and Langesundsfjorden. The concentration of mercury from the diffuser will be well below the limit values (AA-EQS) given in the water regulations. There are elevated concentrations of dioxins in the aquatic environment in the Eidangerfjord and Langesundsfjorden today, and previous measurements of dioxins in the fjords indicate that AA-EQS in the water column has been exceeded. The emission of dioxins from Norcem will not be diluted to concentrations below AA-EQS if these background concentrations are used as calculations. Injections of 0.9 mg / year from Norcem amount to approx. 0.09% of calculated inputs to Langesundsfjorden from Frierfjorden."

Input to NIVA from Aker Solutions is based on an EWTP cleaning effect of 90% of the water from DCC regarding dioxins. According to specialists in Aker Solutions, the efficiency of EWTP is probably better than a cleaning effect of 90 % with respect to dioxins. The work to document a better efficiency of EWTP based on specific information of the dioxins in question, will continue after delivery of this DG3 report.

Heat dissipation and local warming of the "Eidangerfjord" as result of the cooling water emitted from the capture plant was thoroughly investigated during the concept phase by COWI. According to COWI, the proposed cooling water system is feasible and should fulfil any environmental requirements. Reference is made to NC03-AKER-S-RA-0001 - Environmental Report (Attachment 29).
The amine and caustic containing equipment will be in bunds covered by roofs. Rainwater and potential spills, leaks and accidental discharges will flow by gravity to a pit. The destination of the liquid in the pit will be manually controlled based on amine/chemical contamination or not. Uncontaminated water can be further pumped to area surface drain while contaminated water can be picked up by a road truck.

8.2.3 Contaminated soil / sediments

An environmental investigation of the ground at Norcem's plant in Brevik was conducted by Norconsult in December 2018. The environmental investigation of the sediments was conducted on the 14th of January 2019. As expected, concentrations above contaminant class 1 were measured in 10 of 16 boreholes. These contaminants are mainly organic compounds. In samples from 4 boreholes, different metals were detected in contaminant class 2 and 3. A few samples also contained dioxins and chromium (Cr_6+) in contaminant class 2 and 3. A remediation plan needs to be made for the ground affected by the construction plans. Contaminated soil must be delivered to an approved site for cleaning / disposal.

Samples of sediments from four different positions along “Cementkaia” revealed that the sediments are heavily contaminated with PAH, TBT, and dioxins among others. A risk assessment and a remediation plan are required by the guideline M-409 for sediments affected by construction plans. This must be assessed and approved by the Norwegian Environment Agency.

8.2.4 Noise

In today's emission permit for noise, it is stated that Norcem must reduce the noise level as much as possible and in the first instance work to reduce noise at the nearest home residents down to 50 dBA. According to State-guideline T-1442 "Retningslinje for behandling av støy i arealplanlegging" the night noise requirement from industrial companies of this type is Lnight ≤ 45 dBA. In NC03-NOCE-Z-RA-0001 - Overall Design Basis [17] (Attachment 4) it is stated that the noise level at nearby residential dwellings resulting from equipment/ installations/ operations introduced by the CCS project, including CO_2 ship loading activities at quay side shall not exceed 45 dBA.

The contribution to noise after introduction of a CCC plant at Norcem will be negligible if recommended noise reducing measures are implemented. In connection with the construction of the capture plant, Norcem also plans noise reducing measures on oven 6. Calculations performed by Norconsult (Noise calculations for CSS and Norcem factory incl. noise abatement for oven 6, Doc. No.: NC03-NOCON-S-RA-0049) indicate reduced noise levels at nearby residential dwellings with 3-4 dBA compared to today's noise levels from the Norcem Plant.

8.3 STATUS EMISSION PERMIT

The design, construction and operation of the new CCC plant shall comply with relevant laws and regulations, and the Environmental operating permit, permission 2004.057.T, last updated June 2018. The Environmental operating permit for Norcem Brevik gives emission limits for dust, hydrochloric acid, hydrofluoric acid, NO_X, SO_2, TOC, some metals, chlorinated dioxins and furans. The emissions of amine and amine degradation products (particularly aldehydes and ketones) contribute with some additional TOC and this should be considered when the emission permit for Norcem Brevik is updated to include the CCC plant.

During both the concept phase and the FEED phase Norcem have had frequently contact with Norwegian Environment Agency (NEA). Emissions of amine and amine degradation products have had special focus since emission limit values have not yet been set by the authorities. Nevertheless, the Norwegian Environmental Agency has previously indicated that new CO_2 capture plant in Norway is likely to face similar regulation and limits with respect to nitrosamines and nitramines to that currently applied at Test Centre Mongstad (TCM).

The content of the Environmental Impact Assessment (EIA) prepared by Multiconsult is central to the work on emission application to the Norwegian Environmental Agency.

Norcem will start the work to prepare the discharge permits for NEA during the EIA consultation period. To include all input from the consultation period, a discharge permit will be applied for within the second quarter of 2020.

8.4 STATUS OTHER PERMITS AND CONSENTS

This section gives an overview of necessary authorizations from the Norwegian Directorate for Civil Protection (DCP) and building permit application to municipality of Porsgrunn.

8.4.1 Application for consent to Directorate for Civil Protection (DCP)

During both the concept phase and the FEED phase Norcem have had frequently contact with the Norwegian Directorate for Civil Protection (DCP). The work with the application for consent according to *Theme Guide from DCP, chapter 8 on obtaining consent,* will among other things be based on the Environmental Impact Assessment (EIA) prepared by Multiconsult and Quantitative Risk Assessment (QRA) of pressurized cooled CO_2 prepared by Aker Solutions. Work on the application to DCP will start in November 2019. Norcem has received input from DCP for what the application must contain. Comments included in the updated EIA will also be implemented in the application for consent which is scheduled to be sent to DCP in Q1 2020.

8.4.2 Building permit application to municipality of Porsgrunn

The area affected by the CCC is regulated for industrial purposes in accordance with the regulation plan. New constructions and / or significant changes to existing structures depends on the application and permission from the building authorities, cf. Planning and Building Act 1. § 20-1. Norconsult will take the responsibility for the building permit application to municipality of Porsgrunn. The height of the new flue stack will be above the maximum height stipulated in the regulation plan for the area and a deviation request from the maximum height must be included in the building permit application. The work with the building permit application will start in the beginning of 2020.

As earlier described, contaminated soil / sediments have been proven in several places on Norcem. Norconsult will perform risk assessment and an assessment plan according to the guideline M-409 for soil/sediments affected by construction plans. This must be assessed and approved by the Norwegian Environment Agency. This work has started.

9 SCHEDULE

9.1 GENERAL

This document presents the collated EPC schedule for all partners participated in the FEED study. The presentation is divided into several levels of schedule details:

- Overall EPC schedule – Level 1
- Overall EPC schedule – Level 2
- Detailed EPC schedule – Level 3 and partly Level 4
- Milestone Schedule
- Schedule Risk histograms

The presentation layouts are grouped differently, based on the level of details (Level 1 – 4). To differentiate between the partners, the bars in the bar chart are using different colours based on the colours from the 3D model of the plant (BIM model).

Norconsult

Aker Solutions

Norcem

FLSmidth

Norsk Energi

For further details on each partners schedule please see:

- NC03-AKER-F-TA-0001 - Project Execution Schedule – EPC
- NC03-FLSM-A-TA-0003 - Detailed Engineering, Fabrication and Delivery Schedule
- NC03-NOCON-A-TA-0001 - Gjennomføringsplan for bygging og drift (AACE RP 38R-06)
- NC03-NOEN-A-TA-0002 - Project Execution Plan
- NC03-NOCE-A-TA-0501 - Project Execution Schedule for WBS 500 - Electro

9.1.1 Schedule Methodology

Safran Project Software has been used to collate all five partners schedules. Partners have used different tools to make their own schedule. Microsoft Project, Excel and Safran Project is among these tools. User fields and calendars from each partner has also been aligned.

The Engineering, Construction and Commissioning calendars has used 7,5 hours pr. day, 5 days per week. Norwegian public holidays (Christmas and Easter) has also been used. Vacation days has been statistically spread throughout the year with the majority grouped in July.

One of the major advantages in the Project Environment we will be using, is the connection between both the Document System and Time registration system, and Safran Project:
Almost all the documents have a "profile" which indicate the maturation or the progress in each document's lifespan.

All the documents are tagged with an Activity-ID from the corresponding Activity-ID in the Planning system. There is a Many-To-One relationship between documents and activities - i.e several or one document can belong to only one activity in Safran. So when the documents develops, the actual

progress reflects in the planning system and creates the basis for progress reporting on the related cut-off.
The same principles is valid for the time collecting system, where the time-collector strings also have a corresponding string in Safran. The relationship will typical be a One-To-Many from "time-system" to Safran. And this will again be the basis for reporting at each cut-off.

For details on how the project environment will be established In the next phase (EPCC) we refer to information given in the DG3 report chapter 10.7 “Project Execution Method”.

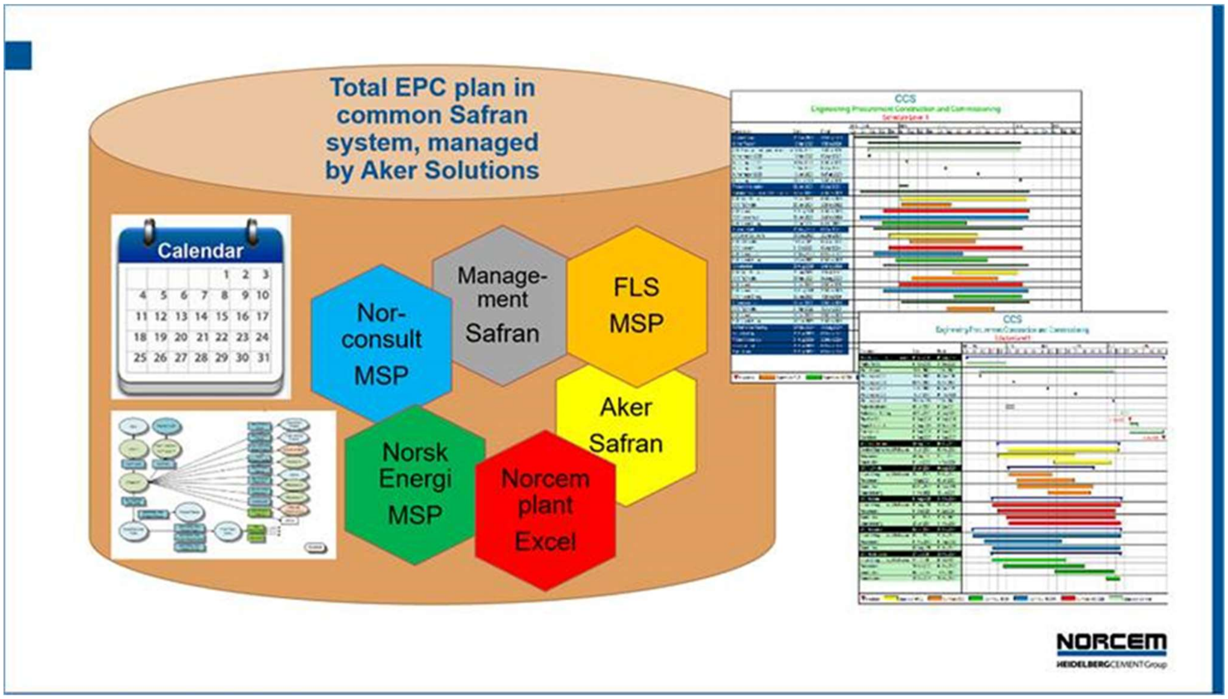


Figure 72 – Total project technical overview using Safran

9.1.2 Benchmarking

As the CCS is a demonstration project, there is no direct similar benchmark project to use as comparison. However, both Aker and some of the other partners have performed numerous EPC projects of different processing facilities both on and offshore and have used comparable details to size the schedule. We consider the schedule to be robust with a pessimistic approach when estimating the activities. However, we would like to emphasize that almost every activity is at a schedule level 3 and a prerequisite for this schedule is a planned start-up for some of the critical activities already in the interim period.

9.1.3 Abbreviations

AKSO – Aker Solutions
CCS – Carbon Capture and Storage
EPC - Engineering Procurement and Construction
FLSM – FLSmidth
NOCE – Norcem
NOCON – Norconsult
NOEN – Norsk Energi
WBS – Work Breakdown Structure

- WBS100 – CCS Management
- WBS400 – Norconsult

- WBS500 – Norcem
- WBS540 – FLSmidth
- WBS550 – Norsk Energi
- WBS600 – Aker Solutions

9.1.4 Planning Assumptions

In order to meet the project's end date in May 2024, it is a prerequisite that the project starts in January 2021. In addition, the engineering and purchasing period for most of the Long Lead Items must start in the interim period.

Norcem has several preparatory activities essential for the CCS project that must start and be completed before the winter repair (WR) period begins. The first two winter repair periods start in 2020 and 2021, and much of the preparatory work therefore starts in the interim period. That includes all EPC phases, as well as commissioning.
In chapter 9.2 – the overall schedule, you will find project phases starting before project initialization due to the above mention facts.

9.2 DELIVERY SCHEDULE FOR ENGINEERING PROCUREMENT CONSTRUCTION AND COMMISSIONING (6c)

9.2.1 Overall Schedule (Level 1) – Grouped by main phases and partners

CCS
Engineering Procurement Construction and Commissioning
Schedule Level 1

Description	Start	Finish
Interim Period	01.Nov.2019	31.Dec.2020
Winter Repair	16.Mar.2020	17.Mar.2024
CCS Management, general and com	16.Mar.2020	17.Mar.2024
Winter repair 2020	16.Mar.2020	05.Apr.2020
Winter repair 2021	08.Mar.2021	26.Mar.2021
Winter repair 2022	14.Mar.2022	03.Apr.2022
Winter repair 2023	16.Jan.2023	04.Feb.2023
Winter repair 2024	26.Feb.2024	17.Mar.2024
Project Initialization	02.Jan.2021	01.Apr.2021
Detailed Engineering & Follow-on	03.Jan.2020	30.May.2024
CCS Aker Solutions	18.Jan.2021	06.May.2024
CCS FLSmidth	25.Jan.2021	20.May.2022
CCS Norcem	01.Aug.2020	30.May.2024
CCS Norconsult	03.Jan.2020	24.May.2024
CCS Norsk Energi	27.Jul.2020	07.Oct.2022
Procurement	01.May.2020	01.Apr.2024
CCS Aker Solutions	30.Sep.2020	23.Jan.2023
CCS FLSmidth	19.Apr.2021	06.Jan.2023
CCS Norcem	01.Oct.2020	01.Apr.2024
CCS Norconsult	01.May.2020	01.Sep.2022
CCS Norsk Energi	30.Nov.2020	04.May.2023
Construction	03.Aug.2020	24.May.2024
CCS Aker Solutions	01.Jun.2022	14.Feb.2024
CCS FLSmidth	03.May.2021	04.Aug.2023
CCS Norcem	04.Jan.2021	31.Mar.2024
CCS Norconsult	03.Aug.2020	24.May.2024
CCS Norsk Energi	06.Jun.2022	19.Mar.2024
Commissioning	25.Jan.2021	31.May.2024
CCS FLSmidth	31.Mar.2022	30.Jun.2023
CCS Norcem	25.Jan.2021	31.May.2024
CCS Norsk Energi	22.Dec.2023	20.May.2024
Performance Testing	30.May.2024	31.Aug.2024
Plant Start-Up	01.Sep.2024	01.Sep.2024
Project Close-out	31.Aug.2024	29.Nov.2024
Run-in period	01.Sep.2024	01.Sep.2025
Operations	01.Sep.2025	01.Sep.2025

Milestone | Summary FLS | Summary NOEN | Summary NOCON | Summary NOCEM | Summary General

Figure 73 - Overall Schedule (Level 1) – Grouped by EPC and Partners

As described I chapter 9.1.4 will some of the activities start before Contract Award in January 2021.

9.2.2 Overall Schedule (Level 1) – Grouped by partners and main phases

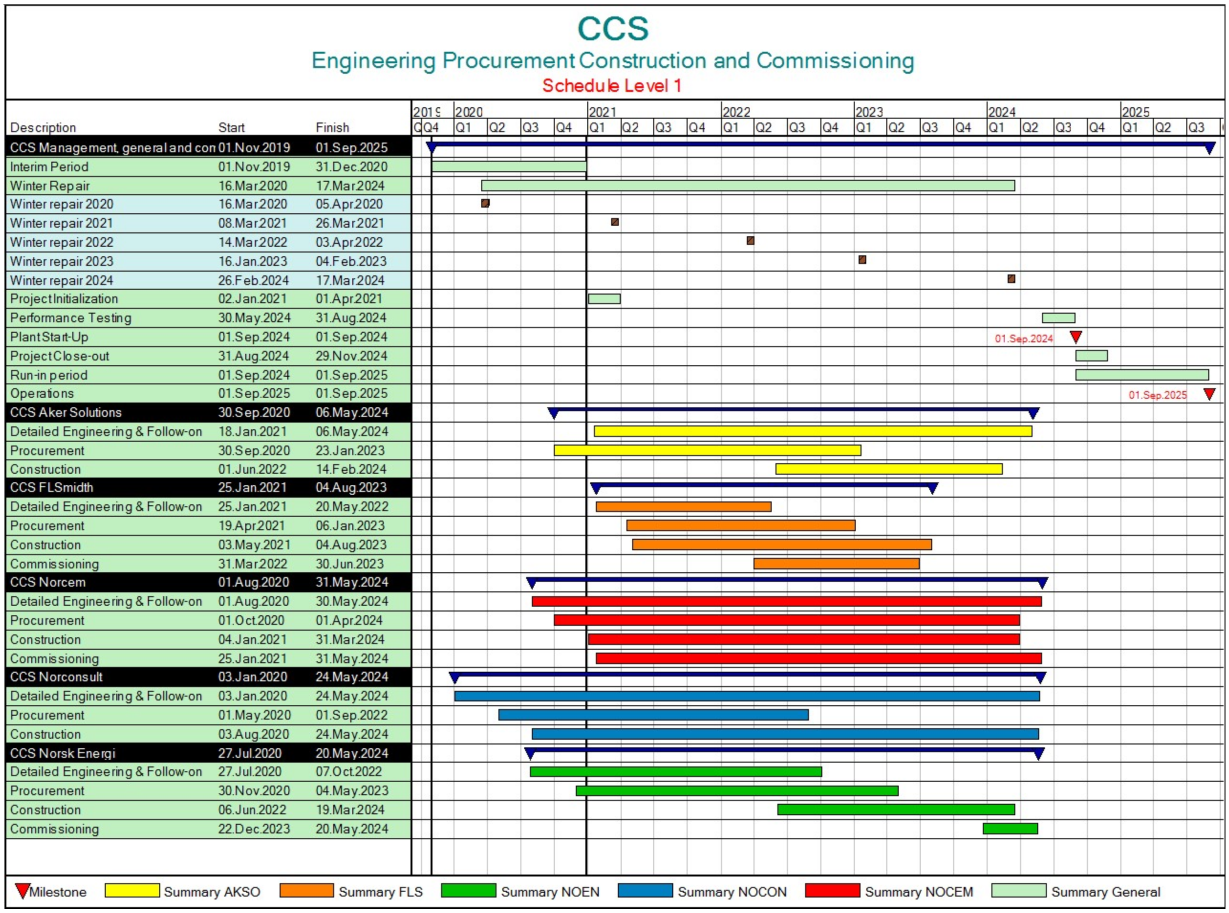


Figure 74 - Overall Schedule (Level 1) – Grouped by Partners and EPC

As described I chapter 9.1.4 will some of the activities start before Contract Award in January 2021.

9.2.3 Overall Schedule (Level 2) – Grouped by main phases, main area and discipline

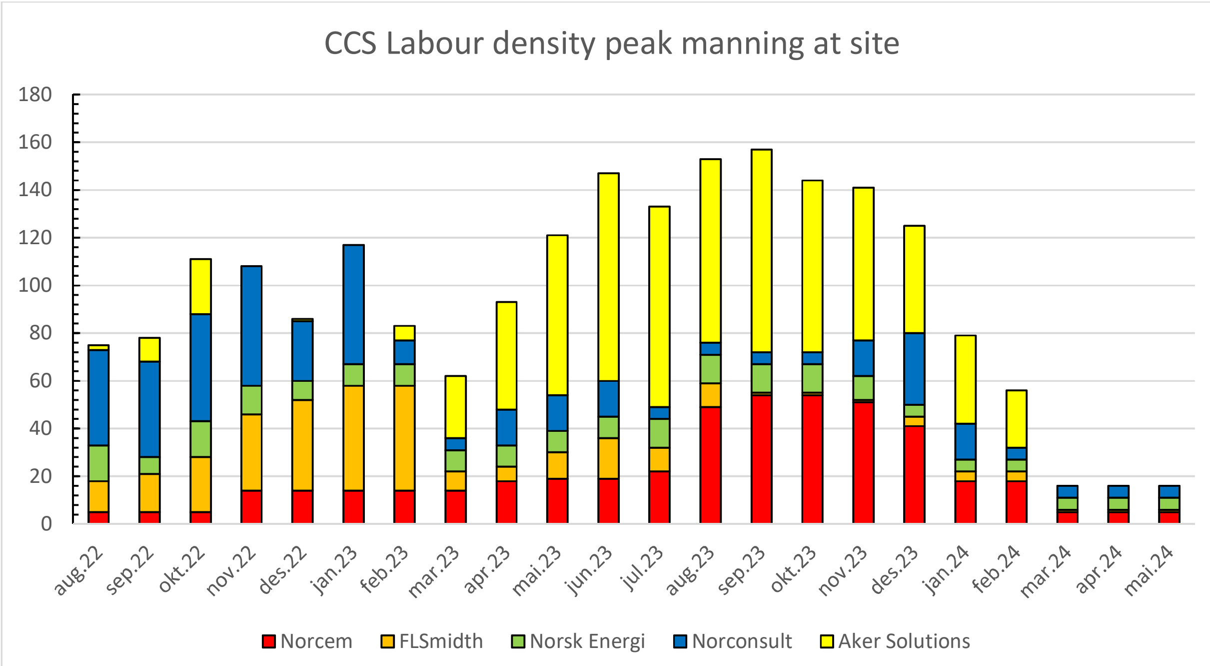
The contents of this section has been removed in this redacted version of the FEED study (DG3) report due to confidentiality.

9.2.4 Detailed schedule (Level 3 and 4) – Grouped by main phases, main area, discipline and sub-phases

For a detailed schedule level 3 and partly level 4, reference is made to document NC03-NOCE-A-TB-0002 - Delivery Schedule for Engineering Procurement Construction and Commissioning, page 9, chapter 1.6.1 (Attachment 11).

9.2.5 Labour density peak manning at site

The histogram below shows a peak manning at site of 157 persons based on 7.5 hours pr. day. If this should cause any problems, the project will consider working longer hours per day to reduce this number. The average manning in the period is around 122.



Date	aug.22	sep.22	okt.22	nov.22	des.22	jan.23	feb.23	mar.23	apr.23	mai.23	jun.23	jul.23	aug.23	sep.23	okt.23	nov.23	des.23	jan.24	feb.24	mar.24	apr.24	mai.24
Norcem	5	5	5	14	14	14	14	14	18	19	19	22	49	54	54	51	41	18	18	5	5	5
FLSmidth	13	16	23	32	38	44	44	8	6	11	17	10	10	1	1	1	4	4	4	1	1	1
Norsk Energi	15	7	15	12	8	9	9	9	9	9	9	12	12	12	12	10	5	5	5	5	5	5
Norconsult	40	40	45	50	25	50	10	5	15	15	15	5	5	5	5	15	30	15	5	5	5	5
Aker Solutions	2	10	23	0	1	0	6	26	45	67	87	84	77	85	72	64	45	37	24	0	0	0
Total	**75**	**78**	**111**	**108**	**86**	**117**	**83**	**62**	**93**	**121**	**147**	**133**	**153**	**157**	**144**	**141**	**125**	**79**	**56**	**16**	**16**	**16**

Figure 76 - Labour Density at site

9.2.6 Critical Path Analysis

The critical path goes through

- Procurement of equipment
- Implementation of vendor information in design
- Release of Structural and Piping fabrication drawings
- Prefabrication of Structural and Piping
- Installations at site
- Installation in the Main Process Area/Compressor area
- Mechanical completion
- Commissioning

Another critical path goes from the completion of the civil base slabs in Process Area/Compressor area before start of Installation at site.

9.3 MILESTONE SCHEDULE

Please find the main milestones below. These and all other project milestones are listed in NC03-NOCE-A-TB-0002 - Delivery Schedule for Engineering Procurement Construction and Commissioning, page 9, chapter 1.6.1 (Attachment 11).

- Interim period starts 01.Nov 2019
- Pre-Engineering starts 03.Jan 2020
- Pre-Procurement LLI starts 30.Sep 2020
- Pre-Construction (Demolition) starts 03.Aug 2020

- Winter Repairs
  - W20 16.Mar 2020 - 05.Apr 2020
  - W21 08.Mar 2021 - 26.Mar 2021
  - W22 14.Mar 2022 - 03.Apr 2022
  - W23 16.Jan 2023 - 04.Feb 2023
  - W24 26.Feb 2024 - 17.Mar 2024

- EPCC Project starts 02.Jan 2021
- Critical PO's Awarded (E2A) 02.May 2021
- Construction Finished (incl. MC) 24.May 2024
- Commissioning finished 31.May 2024
- Ready for Performance Testing 30.May 2024
- Plant Start-up 01.Sep 2024

- Project Close out 31.Aug 2024 - 29.Nov 2024

- Run in period starts 01.Sep 2024
- Operations 01.Sep 2024

9.4 SCHEDULE RISK ANALYSIS (SRA)

9.4.1 Risk Settings

A Schedule Risk has been performed for all activities. It is important to be aware of the fact that this schedule also contains activities where the start-dates are set manually i.e. not linked. These activities will not have major influence on the resulting statistical results.

The set-up for the Schedule Risk Analysis is as follows:

Deterministic duration = duration as is.
Optimistic duration = 75% of the deterministic.
Pessimistic duration = 125 % of the deterministic.

Start date is 01.01.2021
Activities from start of Project Close out period, are not included.

Monte Carlo method - Number of iterations is 1000

This SRA is not a detailed analysis due to limited functionality in the tool that we used. It was not possible to evaluate single activities. A more comprehensive analysis will be performed in the next phase.

9.4.2 Risk Histogram

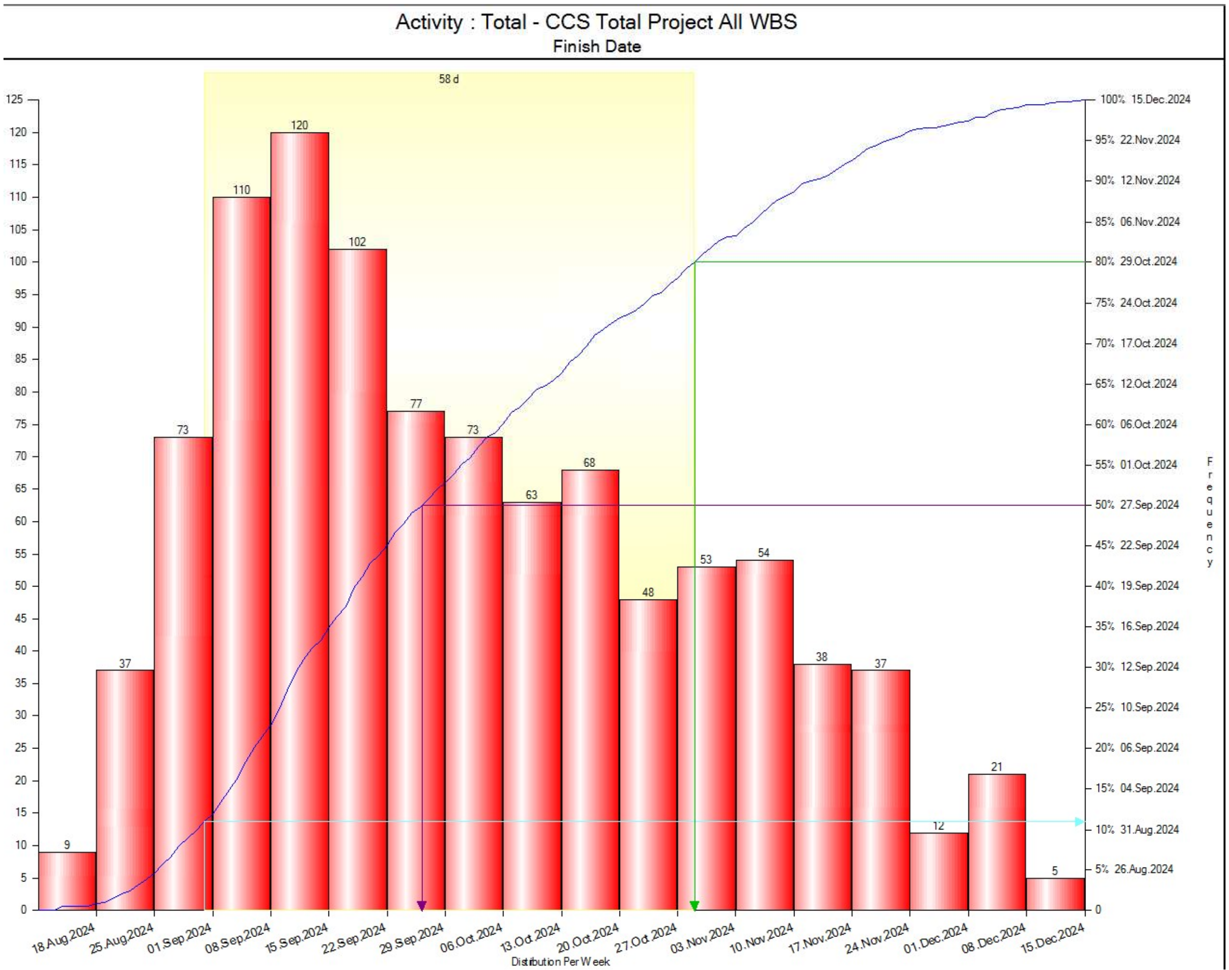


Figure 77 - Risk histogram

The Risk histogram shows a 50% (P50) probability for a finish date no later than 27th September 2024 and an 80% (P80) probability for a finish date no later than 29th October 2024. As stated I chapter 9.4.1 it It is not possible to determine which activities are involved in a probable finish date, nor what cost effects this will have, since we do not know what phase in the project this occurs in.

9.4.3 Top 5 schedule Risks

- Inadequate power supply, due to delay in capacity extension delivered by Skagerak Nett (NOCE-2)
- Delay in project execution, due to claims as a result of inadequate adherence of the public procurement legislation directive (NOCE-25)
- Inadequate quality and/or delay in execution phase, due to long interim period (for investment decision) and inadequate funding for interim period activities (NOCE-33)
- Inadequate quality and/or delay in execution phase, due to inadequate owner management (and ownership), organisational setup and resource capacity, competence and experience (NOCE-34)
- Delay in construction and completion (MC, Commissioning, start-up, performance testing) due to different understanding of scope of work (scope split and -magnitude) within electrical and instrument disciplines (AKSO-17)

10 PROJECT EXECUTION – CONSTRUCTION AND OPERATION

10.1 ENGINEERING EXPERIENCE AND REFERENCE LIST (7a)

Heidelberg Cement (HC) is one of the world's largest building material companies with 58.000 employees at 3100 sites in 60 countries. With respect to production volumes, Heidelberg Cement is world's No.1 in aggregates (309 Mt/year), No.2 in cement (130 Mt/year) and No.3 in ready-mix concrete (49 Mm^3/year). A large part of the activities in HC is naturally related to the continuous upgrade and renewal of production facilities required to keep up with the increasing demands related to competitiveness and sustainability.

Norcem belongs to the branch of Heidelberg Cement called NEECA, which is short for Northern/Eastern Europe - Central Asia, covering the following countries: Denmark, Estonia, Iceland, Latvia, Lithuania, Norway, Sweden; Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czechia, Georgia, Greece, Hungary, Kazakhstan, Poland, Romania, Russia, Slovakia.

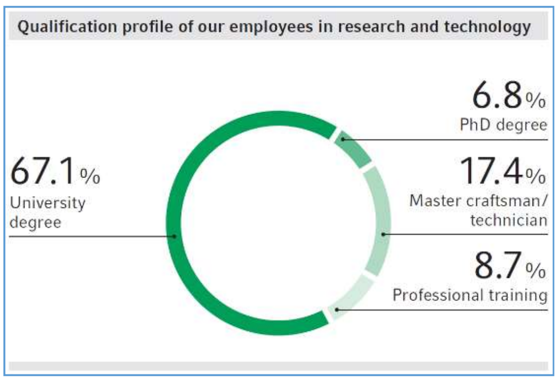


Figure 78 – Employee qualification profile

Technical centres support our national companies in each Group area. In the cement business line, these are the Heidelberg Technology Centres (HTC) with three area organizations. The HTC-unit covering Norcem is located in Germany and supporting Europe, the Mediterranean Basin, Africa, and Central Asia.

The more than 1100 employees in HTC holds a high level of expertise in research and technology as a key competitive factor, and the qualification requirements are correspondingly high. 67.1 % of the employees. In our technical competence centres have a university degree and 6.8% have a PhD (see Figure 78). Intensive on-going training and a systematic exchange of knowledge in expert networks across the Group ensure a high level of qualification.

With respect to project management experience from large and complex projects, the following reference projects are selected as representative for HTC Germany (Leimen):

- 2019: Schelklingen, Germany: Brownfield cement kiln line with related plant modifications, EURO 125M
- 2019: Burg Lengenfeld, Germany: Brownfield cement kiln line with related plant modifications, EURO 115M
- 2018: Kaspi, Georgia: Brownfield cement kiln line with related plant upgrades, EURO 80M
- 2018: Citeureup, Indonesia: Brownfield cement kiln line with related plant upgrades, EURO 410M
- 2017: Tula, Russia: Brownfield clay grinding/drying plant, EURO 20M

- 2014: Port Kembala, Australia: Greenfield cement grinding plant, AUD 165M
- 2012: Tula, Russia: Complete greenfield cement plant: EURO 272M

Norcem will represent the role of sub-supplier in the CCS-project and hence, references are listed under chapter 10.5.5.

Project execution is thoroughly planned with a lean, yet experienced and highly competent project organisation, led by HeidelbergCement and supported by advanced technology providers and well reputed civil engineering contractors. For sub-supplier's qualifications and relevant experience, please see section 10.5

10.2 DESCRIPTION OF SCOPE OF WORK (7b)

A complete description of the scope of work is provided in NC03-NOCE-A-TA-0003 - Project Execution Plan [27](Attachment 39) and chapter 4.5 of this document.

10.3 ORGANISATION (7c)

The proposed project organisation for project execution is provided in Figure 79.

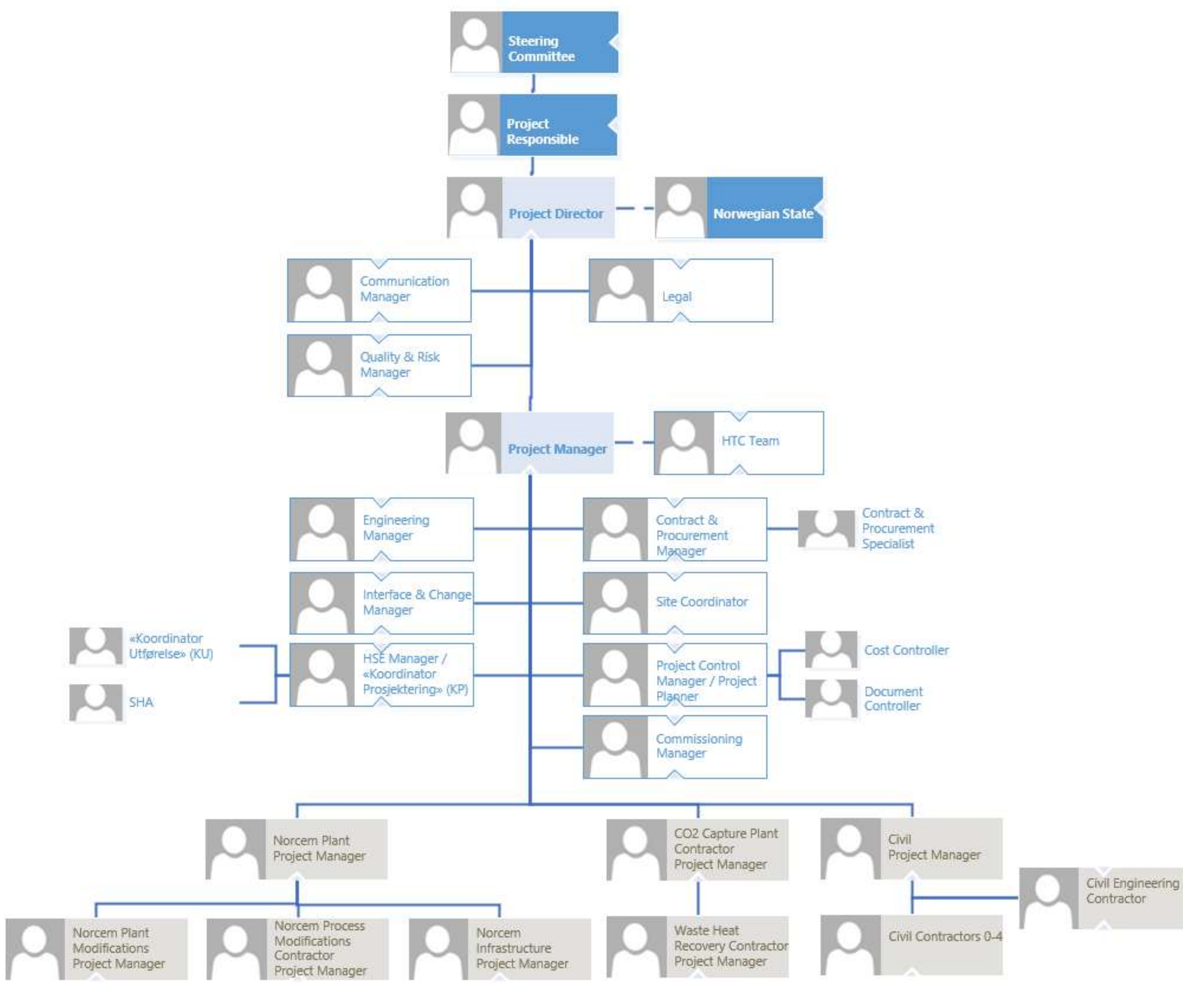


Figure 79 - Proposed Project Organisation Execution

The current project steering committee is headed by HeidelbergCement Northern Europe's director; Giv Brantenberg and the committee members come from HeidelbergCement Northern Europe (HCNE), HeidelbergCement Technology Centre (HTC), Group Environmental Sustainability (HC GES) and European Cement Research Academy (ECRA). The project is well anchored with the HeidelbergCement Group and the European cement industry.

A description of the project management roles required, and their main responsibilities are listed in Table 27

Table 27 - Project Management Roles and Responsibilities

Project Role	Main Responsibilities
Steering Committee (SC)	Guide project management in all major decisions and monitor project performance. Serves as the highest decision-making authority within the project management organisation.
Project Responsible	Directly responsible to Heidelberg Cement (HC) for the overall performance of the project, overall responsible for sufficient and competent project resources, project finances, project benefits realisation and senior stakeholder management, responsible for selecting the Project Director and for organising and leading the SC meetings.
Project Director	Overall responsible for project management in accordance with project requirements and governing documents with particular focus on schedule, cost and risk, responsible for project reporting to the State and Steering Committee and for follow-up and documentation of project benefits realisation and lessons learned.
Project Manager	Responsible for managing the project and leading the project management team in accordance with project requirements and governing documents. The Project Manager is deputy to the Project Director.
HTC Team	Securing experience and concentrating knowledge in the management, design and construction of large capital projects, optimise project management practices and increase value creation in the execution of major CAPEX projects.
Communication Manager	Overall responsible for project communications planning & execution, responsible for project stakeholder analysis and stakeholder management plan.
Engineering Manager	Responsible for overall coordination of Detailed Engineering and construction method management
Interface & Change Manager	Overall responsible for management of changes and project interface in accordance with project requirements and governing documents.
Quality & Risk Manager	Overall responsible for project quality planning and follow-up, risk management planning and follow-up (risk assessment and mitigation) in accordance with project requirements and governing documents.
HSE Manager / "Koordinator Prosjektering" (KP)	Overall responsible for project HSE management (planning and follow-up). "Koordinator Prosjektering" (KP) (Coordinator Engineering) according to "Byggherreforskriften"
"Koordinator Utførelse" (KU)	"Koordinator Utførelse" (KU) (coordinator for project execution) according to "Byggherreforskriften", Safety Coordinator according to Heidelberg Cement Guideline for Project Management (Ref. 9).
SHA	SHA according to "Byggherreforskriften"
Contract & Procurement Manager	Overall responsible for contracts administration and claims, and management of project procurement in accordance with project requirements and governing documents.

Project Role	Main Responsibilities
Legal	Overall responsible for project legal and insurance
Contract & Procurement Specialist	Responsible for project contract & procurement execution and advise
Commissioning Manager	Overall responsible for project commissioning (planning and execution), including performance testing
Project Control Manager / Project Planner	Overall responsible for project control (cost and documentation), responsible for project planning (master schedule), progress follow-up and reporting in accordance with project requirements and governing documents.
Cost Controller	Responsible for project cost monitoring, control and reporting, invoicing and payment
Document Controller / Project Admin	Responsible for project document control in accordance with project requirements and governing documents, project administration
Site Coordinator	Site Management and administration on behalf of the Project Manager, assist contractors with all requests related to site activities, monitor the work progress and supervise the work quality on site, direct contact for contractors site managers.
Norcem Plant Project Manager	Responsible for managing Norcem Plant's scope of work in accordance with project requirements and governing documents
Norcem Plant Modifications Project Manager	Responsible for managing Norcem Plant Modifications in accordance with project requirements and governing documents
Norcem Process Modifications Contractor Project Manager	Responsible for managing Norcem Process Modifications Contractor's scope of work in accordance with project requirements and governing documents
Norcem Infrastructure Project Manager	Responsible for managing Norcem Infrastructure scope of work in accordance with project requirements and governing documents
CO_2 Capture Plant Contractor Project Manager	Responsible for managing the CO_2 Capture Plant Contractor's scope of work in accordance with project requirements and governing documents
Waste Heat Recovery Contractor Project Manager	Responsible for managing the Waste Heat Recovery Contractor's scope of work in accordance with project requirements and governing documents
Civil Project Manager	Responsible for managing the Civil scope of work in accordance with project requirements and governing documents
Civil Engineering Contractor	Responsible for managing the Civil Engineering Contractor's scope of work in accordance with project requirements and governing documents
Civil Contractors 0-4	Responsible for managing their scope of work in accordance with project requirements and governing documents

Norcem holds the main builder ("Byggherre") responsibilities in accordance with Construction Client Regulations ("Byggherreforskriften"). [28]

As illustrated in the project organisation above, the project management team will follow up the main contractors (Norcem Plant, Civil Works and CO_2 Capture Plant) in accordance with the Project Execution Plan (Attachment 39).
A lean (cost effective) project organisation is planned for, without duplication of functions.

Each contractor will have a Project Manager, reporting to the Project Manager, as shown in the project organisation chart above. Each contractor will also have an engineering manager (for detailed engineering) and an interface manager coordinating the interfaces internally and towards other project partners.

Construction Managers, SHA, KU and KP are included by each contractor in accordance with Construction Client Regulations (“Byggherreforskriften”) [28].

The Project Responsible, Project Director and Project Manager roles will be filled by representatives from the HeidelbergCement Group. The other roles in the project management team will be filled by resources from Norcem, HeidelbergCement Group and hired-in individuals. Since Norcem / HeidelbergCement is largely built up based on the expertise needed for the design, construction and operation of cement plants, it is necessary to contract some of the expertise and experience required for the project management team. The project will be managed under HeidelbergCement Group project management systems and procedures.

Since the operations of the CO_2 capture plant will be owned by the Norcem cement plant in Brevik and the cement plant will be in (around the clock) operation throughout the realisation phase, it is critical to successful project execution to include a Site Coordinator in the project organisation to coordinate interfaces between project partners and Norcem operations in Brevik during construction.

The project organisation for the project FEED phase is described in NC03-NOCE-A-RA-0003 - Organisation chart Norcem (Attachment 51) and the accompanying functional descriptions in NC03-NOCE-A-RA-0004 - Functional descriptions including project staff register.

Aker Solution’s proposed EPC organisation is described in NC03-AKER-A-RA-0006 - FEED study report (Attachment 6), section 18.9.

The proposed organisation of the civil work packages is provided by Norconsult in their document” NC03-NOCON-A-RA-0037 - Procurement and Contract strategy - Attachment 2: Site Construction Organisation-Provisional (Attachment 40).

10.4 KEY PERSONNEL (7d)

The proposed project organisation for project execution and a description of the key project management roles required and their main responsibilities is found in section 10.3.

It is critical to successful execution of the project that a base of key technical expertise and other key personnel who have been engaged in the FEED phase are continued for the project execution phase, to ensure adequate continuation of both relevant experience and technical competence. Additional resources will be involved as needed to fill the roles required for proper execution of the project (ref. section 10.3).

It is however not reasonable to expect commitment of named resources at this point in time, as the assumed project start date is January 2021 (nearly two years from now), provided that a decision to realise the project is made by the Norwegian Government by the end of 2020.

10.5 SUBSUPPLIERS (7e,7f, 7h)

This section provides an overview and descriptions of the current project partners or sub-suppliers.

An overview of the project partners in the FEED phase is provided in Table 28.

Table 28: FEED Project Partners

Project Partner	Work Package(s) (WBS no.)	Overall Scope of Work in FEED phase
Aker Solutions	600	CO_2 capture plant (including conditioning, intermediate storage and loading of CO_2).
DNV GL	600, 550	Technology Qualification of CO_2 capture technology, CO_2 compressor (including heat recovery) and Waste Heat Recovery Units
FLSmidth	540	Modifications to cement plant for integration of capture plant
Kværner	100	Constructability Review
Multiconsult	300	Environmental Impact Assessment (KU)
Norcem	500	Modifications to cement plant for integration of capture plant (infrastructure, electro, instrumentation and control system)
Norconsult	400	Civil engineering
Norsk Energi	550	Waste heat recovery from the cement plant
Periti	700	Cost estimation, VIP and maturity assessment
ÅF Advansia	100-399	Project management

The project partners' participation in the project feasibility study, concept and FEED phases are illustrated in Table 29.

Table 29: Project Partners' participation in Feasibility study, Concept and FEED

Project Partner	Feasibility Study	Concept	FEED
Aker Solutions			
DNV GL			
FLSmidth			
Kværner			
Multiconsult			
Norconsult			
Norsk Energi			
Periti			
ÅF Advansia			

To benefit from the acquired maturity level in project definition deliverables, use of partners with sufficient experience and key competencies is vital. The required maturity level is obtained through the project partners unique combined competencies and experience, and close cooperation across process- and project interfaces throughout project development.

Possible technology providers identified as qualified for realisation of the CO2 capture project in Brevik are:

- Aker Solutions with respect to the design and delivery of CO2 capture, conditioning, intermediate storage and loading
- Norsk Energi with respect to the design and delivery of waste heat recovery from the existing cement production process

These technologies include a significant portion of novel technology elements, which have been qualified by DNV GL during the FEED phase and also comply with the maturity requirements to project definition deliverables defined by the Government.

Norconsult as Norcem's civil engineering contractor for the FEED phase, has had a framework agreement with Norcem for decades and possesses unique knowledge of existing plant structures and soil conditions. Norconsult is therefore a possible civil engineering contractor for project execution.

FLSmidth has delivered numerous plant upgrades at Norcem Brevik and is therefore a possible supplier of cement plant modifications.

Norcem will be responsible for engineering, procurement and construction of electrical, instrumentation and automation, as well as some modifications to existing plant installations. Norcem will be responsible for commissioning and performance testing of the complete new plant with assistance from the contractors.

With respect to the critical interface between Norcem and the technology providers on engineering, installation and commissioning of electrical, instrument and automation, the technology providers will deliver the primary elements such as instrumentation, controlled valves, motors and other consumers. The technology providers will also deliver a functional description and FAT procedures for automation programming and testing and will participate in the FAT testing to confirm that their requirements are fulfilled.

A summary of current sub-supplier's qualifications and relevant experience is provided in the following subsections.

10.5.1 Aker Solutions qualifications and relevant experience

Aker Solutions has been engaged in Carbon Capture and Storage (CCS) projects and activities for more than 20 years. First, with the design and delivery of the Sleipner platform and its CO_2 injection facility in the North Sea for Statoil, which has injected about one million tons of CO_2 per year into an aquifer since 1996. Another important milestone started in 2008 with Aker Solutions' Mobile Test Unit (MTU), a small-scale CO_2 capture plant which comprises their Advanced Carbon Capture (ACC™) Technology. The MTU has successfully tested carbon capture from various flue gases for more than 20 000 operating hours at different industrial plants in Norway, UK and USA.

Also, in 2008, Aker Solutions started a comprehensive Carbon Capture R&D program (SOLVit) with partners (332 MNOK spent). The main objective of the program was to develop a cost-effective and more environmentally friendly capture process. The SOLVit project included solvent screening, development of analytical methods, development of a dedicated process simulator (CO2SIM), material testing and pilot plants operation. The scope included developing and testing of cost-efficient solvents (based on amine blends) with improved energy efficiency, minimized degradation and HSE emission performance. About 90 solvents were tested. Six different pilot plants were engaged and operated for about 45 000 hours in total. During the program, an energy saving of about 35% was achieved. The selected solvent has an improved HSE performance (non-toxic, non-hazardous for aquatic organisms, ready biodegradable, etc.). The solvent is very robust and generate minimum emission, corrosion and waste products. The SOLVit program was completed in January 2016.

In 2009, Aker Solutions was awarded the contract for the Technology Centre Mongstad (TCM) amine plant. The contract included engineering, procurement, fabrication, construction and installation, commissioning and two years operation. The amine plant was designed, delivered and commissioned in cooperation with Aker Solutions' sister company Kværner. TCM was started up in 2012. Aker Solutions established a comprehensive test program at TCM and were operating the plant in collaboration with the TCM team for about two years. Two alternative proprietary solvents and one standard amine (MEA) solvent were successfully tested. The MTU was operating on the same solvents in parallel with the main amine plant, to demonstrate control of scale-up.

In 2013 – 2015 the MTU was operated at Norcem's cement plant in Brevik, supported by the CLIMIT-program. The MTU was operated successfully with actual flue gas from the cement plant for 7400 operating hours over a period of 18 months.

Aker Solution's ACC™ technology and their CO_2 compressor with integrated heat recovery has now been qualified by DNV GL for full scale carbon capture at Norcem's cement plant in Brevik, according to their recommended practices DNV-RP-A203 "Qualification of new technology" [19] and DNV-RP-J201 "Qualification of CO_2-capture technology" [20]. For more detailed information on the technology qualification program and conclusions, see section 5.7

For more information see Aker Solutions homepage (https://akersolutions.com/) and web-site for CCUS (https://akersolutions.com/what-we-do/products-and-services/carbon-capture-utilization-and-storage/#)

A list of selected project references for Aker Solutions can be found in Attachment 43.

10.5.2 Norsk Energi's qualifications and relevant experience

Norsk Energi has long term and extensive experience with engineering and commissioning of shell boilers and water-tube boilers for waste heat recovery from off-gases with high dust content. Typically, waste heat recovery boilers have been installed and utilized for industrial application at brown-field smelting plants. The main challenges with the smelting processes is process fluctuations, rapid energy peaks and high dust content that the boiler are exposed to and are required to handle.
Shell boilers installed in smelting plants have a unique design that ensures self-cleaning effect of heat transfer surfaces and resulting in low fouling and high boiler efficiency. Through a number of boiler projects Norsk Energi have gained a unique know-how on the design of shell boilers.
Norsk Energi's Industry Department consists of 20 leading specialists within the field of thermal energy production and steam boiler systems. A large number of the department's projects are heat recovery projects where off-gas heat exchangers or boilers are retrofitted to existing plants.

For more information see Norsk Energi's homepage: http://www.energi.no/

A list of selected project references for Norsk Energi can be found in Attachment 44.

10.5.3 FLSmidth qualifications and relevant experience

FLSmidth is a major equipment supplier of high standing for new cement plants, as well as capacity increase and productivity improvements of existing cement plants. FLSmidth is a full flowsheet provider with more than 135 years of experience in the cement industry, assisting customers through the entire life-cycle of their plant(s).

FLSmidth has a long-term relationship with Norcem as one of their main suppliers of both new cement plants and capacity increase and productivity improvements to existing plants.

FLSmidth also has substantial experience in helping customers improve their environmental footprint without limiting plant performance and delivers solutions to reduce emissions of dust / particulate matter, Hydrogen Chloride (HCl), Mercury (Hg), Nitrogen Oxides (NOx), Sulphur Dioxides (SO2) and Total Organic Carbons (TOC).

For more information see FLSmidth homepage: https://www.flsmidth.com/

A list of selected project references for FLSmidth can be found in Attachment 45.

10.5.4 Norconsult qualifications and relevant experience

Norconsult is Norway's largest and one of the Nordic region's leading interdisciplinary consultancy firms, with activities spanning several continents. We offer services in regional planning, design and architecture. Norconsult engages in projects involving Buildings, Transport, Energy, Industry, Water, Oil and Gas, Environment, Planning, Architecture, Risk Management and IT. The Group is headquartered in Sandvika near Oslo. Norconsult has approximately 3 600 employees and is owned by its employees.

For more information see Norconsult's homepage: www.norconsult.com

Norconsult has long and broad experience from newbuilding and modification work within land-based industry. At Norcem's factory in Brevik, Norconsult has been the main supplier of construction technical consulting services for a number of years and knows the factory back to the 1970's.

Norconsult has gained experience with CO_2 handling through several large projects in Norway. Through Norconsult's participation in Norcem's various studies in connection with CCS Demonstration project, we have acquired additional experiences with CO_2 handling, although this is more directly linked to construction work.

Norconsult has gained experience with CO_2 handling through several large projects in Norway. Through Norconsult's participation in Norcem's various studies in connection with CCS Demonstration project, we have acquired additional experiences with CO_2 handling, although this is more directly linked to construction work.

A list of selected project references for Norconsult can be found in Attachment 46.

10.5.5 Norcem qualifications and relevant experience

Since 1985, the Norcem electro department has had the overall responsibility for complete electrical, instrument and automation installations. They have standardized the way they carry out new electrical and automation installations since the late 80's. This has been done to simplify and improve efficiency in engineering, installation and commissioning, and to ease future maintenance work. The various standardised solutions cover everything from overall architecture to hook-up drawings for an electrical motor or an instrument, including PLC and man-machine interface programming, and the solutions are well described.

In project execution, the electrical, instrument and automation team consists of highly qualified Norcem personnel and hired-in skilled experts as relevant, working closely with the relevant discipline experts from project partners. Norcem's ability and expertise to establishing a competent team, is shown over several years on major installation projects.

Norcem's plant is located in Grenland, one of the largest industry clusters in Norway. This gives great access to a local skilled supplier industry.

A list of selected project references for Norcem can be found in Attachment 47.

10.5.6 ÅF Advansia

ÅF Advansia is a part of ÅF, formerly "Aktiebolaget Ångpanneföreningen", a multinational technical consulting company. In February 2019 ÅF and Pöyry merged into one Company with 16.000 employees globally.

ÅF Advansia is Norway's largest professional environment within project and construction management.

With more than 300 well qualified employees with substantial project- and construction management experience, ÅF Advansia ensure solid and safe execution of projects, tailored to the customer and the project's distinctive character.

ÅF Advansia can take full responsibility for execution of large and complex projects throughout all project phases, from concept development throughout engineering, procurement, construction and commissioning, and has good experiences with delivering complete project management teams, qualified to lead all phases and processes in the project.

ÅF Advansia also offer special expertise through dedicated specialist environments for risk management, progress planning, cost management, quality management, environmental management, HSE management and document management.

ÅF Advansia is ISO 9001 and 14001 certified.

A list of selected project references for ÅF Advansia can be found in Attachment 48.

10.6 INTERFACE MANAGEMENT (7g)

Interface activities in the FEED study have been managed by the Interface coordinator. This function has been responsible for establishing relevant systems as required to fulfil the level of detail that the project phase requires, as well as any special requirements for the individual project partners.
There are two main categories of interface:
• Local - between the project partners within the project,
• Global - between the project and external actors e.g. Gassnova, HeidelbergCement, Northern Lights Skagerak Nett, etc.

Systems for managing the local interfaces were established during the concept study and have received positive feedback. A common understanding of the importance and necessity of an effective, agreed system of interface management has matured throughout the concept study, this work has continued during the FEED phase. The FEED study has seen a further refinement and depth introduced to the interface management system.

Global interfaces are handled through various own systems such as Gassnova's system for interface management utilising PIMS; a separate interface system for exchanging technical information regarding the loading and distribution of CO_2. Aker Solutions has contributed to the interface discussions and design related to the liquid CO_2 transfer between Norcem and the transport scope through regular interface meetings in a working group consisting of representatives/experts from Norcem, Northern Lights, Fortum and Gassnova.

Local interfaces have been divided between the project partners in accordance to the Work Breakdown Structure as defined here;

- WBS400 – Norconsult
- WBS500 – Norcem
- WBS540 – FLSmidth
- WBS550 – Norsk Energi
- WBS600 – Aker Solutions

The total scope of work is divided into job packages that are defined according to the individual project partner's competence area and type of delivery, this reduces the number of critical interfaces.
The job packages have been defined to include that:

- Norconsult deliver engineering and cost-estimates for all the infrastructure/civil works excluding electricity,

- Norcem delivers design and cost-estimate for all main electro. / aut. / instrumentation, as well as any stand-alone modifications required by the new facility.
- FLSmidth (FLS) deliver engineering design and cost estimates for all necessary upgrades to the existing cement process and handling of flue gas in connection with the new plant.
- Norsk Energi produces engineering and cost-estimating regarding steam production and condensation handling, including heat recovery from the cement process.
- Aker Solutions (Aker) develop engineering and cost-estimating related to CO_2, - from capture, through conditioning and loading.

Clarifications on job packages and interfaces have been carried out in the form of workshops including representatives from all the project partners. Identification of specific interface points has been aided by the development of the project's joint BIM model, each project partner has been assigned its own colour, which is then applied to all equipment from this partner in the model. A presentation of the BIM model is shown in Figure 80. In the model, grey colour indicates existing buildings, yellow, red, orange, blue and green represents new elements introduced by the CCS-project (each partners contribution is coloured differently) and the violet colour represents other ongoing projects at Norcem. In connection with specific interface discussions, it has thus been easy to identify the parties involved, aiding communication and defining ownership. Many design changes have been initially implemented in the BIM model with technical data in the interface register being completed later once the technical design is agreed upon. All interface points have been integrated in the flow diagrams and P&ID’s produced.

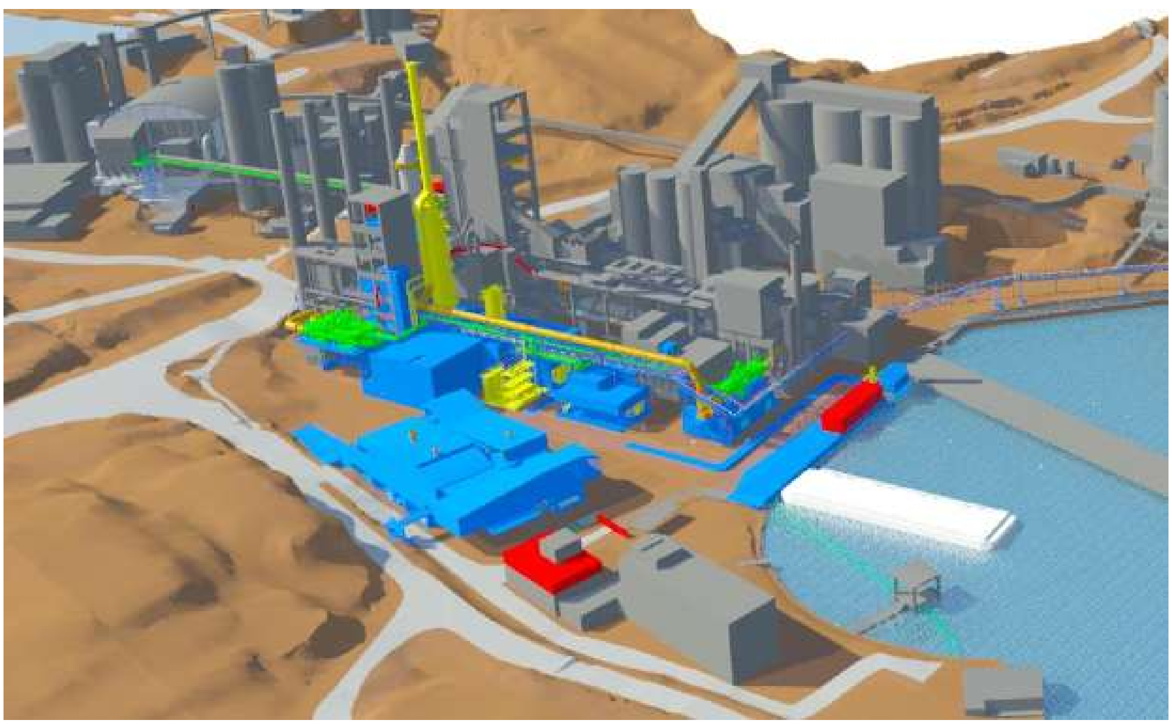


Figure 80- Presentation of BIM model

The local interfaces are divided into three main categories:

- Process interface,
- Electro / aut. / instrument interface
- Infrastructure / building (Civil-related works) interface

Different philosophies have been chosen to handle these categories. This is because the process interfaces are linked as a common theme throughout the production process, changes in data at one point can create a subsequent reaction later in the process. The process interfaces are therefore handled separately and in somewhat greater detail. The two remaining categories are treated as packages with a more general detailing level.

All local interface descriptions, forms and documents are openly available in Interaxo (project web hotel) for all project partners. The interface register is a high-level catalogue of the various interface points; each of these points is further defined in an interface form. The interface register has operated as a living document cataloguing the scope and status of interface work throughout the project. An overall goal within interface management has been to minimize the number of interface forms to those that are functionally necessary with the purpose of maintaining a targeted and effective database. The interface forms have been adapted as necessary with the common goal of providing a single meeting point for all information associated with a specific location. New interface forms being established only as and when necessary. The division of interface points for the detailing of components has been discouraged with a preference for referring to documentation / drawings which specify further details that are relevant to the interface point.

The ownership of each interface has been clarified between the involved partners and the owner of the interface has been subsequently responsible for updating the interface register and establishing an interface form, when necessary.

The civil interface has been specified directly between the civil contractor and each partner as this is central information that has direct influence upon project planning. These interfaces have been categorised and detailed slightly differently to the other interface points; this is due to the different nature of the interface and the level of detail required. Each partnership has produced a document detailing the Interface Information relevant to the Civil Contractor; these are referred to in the interface register.

All interface forms have been the subject of substantial update during the course of the FEED project. The resultant data has been verified and controlled by the relevant partners. A record of which is maintained in Interaxo. All interface forms have been controlled by both involved parties before the end of the FEED project. Documentation referred to or replacing interface points has been subject to the project document control system and has been verified by both involved parties before the end of the FEED project.

The document NC03-NOCE-Q-AD-0001 – “Grensesnitts-håndteringssystem” defines the interface management system and should be consulted for further details.

NC03-NOCE-Z-IR-0001 - Interface register, (Attachment 36), is also published at the end of the FEED project and included as an appendix to the DG3 report.

For details of the project document control system see document NC03-NOCE-Q-AD-0004 - Document control system.

10.7 PROJECT EXECUTION METHOD

10.7.1 Introduction

The Project Execution Strategy [31] (attachment 60) defines the strategic approach to project execution. The Project Execution Plan (Attachment 39) is based on the Project Execution Strategy and defines the basis of all project work and how the project will be managed.

The Project Execution Plan defines how the project and the various project phases are initiated, planned, executed, monitored and controlled, and closed, and integrates and consolidates all of the subsidiary project management plans and baselines, and other information necessary to manage the project.

The Project Execution Plan is an agreement between the Steering Committee, Project Responsible, Project Director, Project Manager, the project team and key senior enterprise management stakeholders associated with and/or affected by the project.

This Project Execution Plan covers all phases of the project investment period from Project Initiation until Project Close-out (including Completion Confirmation by the State and handover to operations).

10.7.2 Project Development

The CO_2 capture has developed since 2005, when a desktop study on full-scale carbon capture was initiated. In 2011-2012, Norcem received support from the ECRA (European Cement Research Academy) for further studies. From 2013 to 2017 Norcem received funding from CLIMIT to test alternative CO_2 capture technologies. Four alternative CO_2 capture technologies were tested on actual fuel gas, of which only Aker Solutions' amine technology was found to be sufficiently mature to be able to build a full-scale CO_2 capture plant by 2020, which was the time perspective at the time. Norcem therefore chose to continue their project development with Aker Solutions' technology.

In, the Norwegian CCS Demonstration Project (NCD) was initiated, and Norcem received funding from the State to perform Concept and FEED studies on CO_2 capture from the cement plant in Brevik, under a study agreement with the State (Gassnova).

Figure 81 below shows the NCD project timeline.

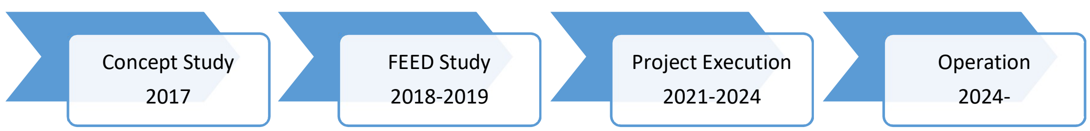


Figure 81 - NCD project timeline

10.7.3 Project Execution phases

The project phases are shown in Figure 82 below:

Figure 82 - Project phases

The main activities and deliverables included in these phases are described below.

Project Initiation

During the project initiation phase, project authorisation is obtained, project contracts are finalised and signed, the project resources are mobilised, the initial project scope, budget and schedule baselines are defined, the Project Execution Plan is updated based on governing documents (e.g. contracts) and management decisions and project team members and other stakeholder are informed of the project purpose, scope and objectives to align expectations.

The main deliverables from this phase are an approved project charter and updated Project Execution Plan and underlying project management documents.

Detailed Engineering
The Detailed Engineering phase comprises detailed engineering of the complete new plant at Norcem Brevik.

The deliverables from this phase are documentation of the complete plant design as required for procurement and construction.

Procurement
The Procurement phase includes procurement, manufacturing, Factory Acceptance Testing (FAT) and transportation from manufacturers site to Norcem Brevik site or pre-fabrication site.

The deliverables from this phase are complete equipment packages and construction materials needed for construction of the complete plant.

Construction
The Construction phase includes demolition, civil construction, pre-fabrication, installation and mechanical completion.

The end deliverable from this phase is the complete new plant ready for commissioning (mechanical complete).

Commissioning
The commissioning phase comprises cold and hot system testing of the complete plant.

The main deliverable from this phase is the complete new plant ready for start-up and performance testing.

Performance Testing
After mechanical completion and commissioning, performance testing of the complete plant is performed.

In this phase Acceptance Test of the plant shall be performed. The purpose of the Acceptance Test is to demonstrate that the plant satisfies the agreed performance requirements in “Avtale om tilskudd til fangst av CO_2”, Appendix A. The Acceptance Test is subject to consent (Completion Confirmation) by the State.

The main deliverable from this phase is documentation of confirmed completion of performance testing and fulfilment of the performance requirements in “Avtale om tilskudd til fangst av CO_2”, Appendix A, as input to Completion Confirmation by the State.

Project Close-out
The purpose of project close-out is to formalise acceptance of the product, service or result and bring the project or project phase to an orderly end.

Project Close-out comprises Completion Confirmation by the State, handover to operations, issue of a Final Project Report including Lessons Learned, Final Invoice and Cost Report to the State, Final Settlement Statements, Benefits Realisation and Knowledge Sharing Report, project archiving and a Post Investment Design Review.

10.7.4 Project Scope

The project scope is described in the Outline Scope of Work Document for State Support Agreement (Attachment 2).

The Work Breakdown Structure (WBS) shown in Figure 83 below is a hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables.

The WBS shall provide the necessary framework for the overall planning and control of the work, and shall be broken down to a low enough level for the work to be detailed, planned and followed up throughout project execution. The WBS shall be used for planning, cost control, invoicing, reporting and forecasting.

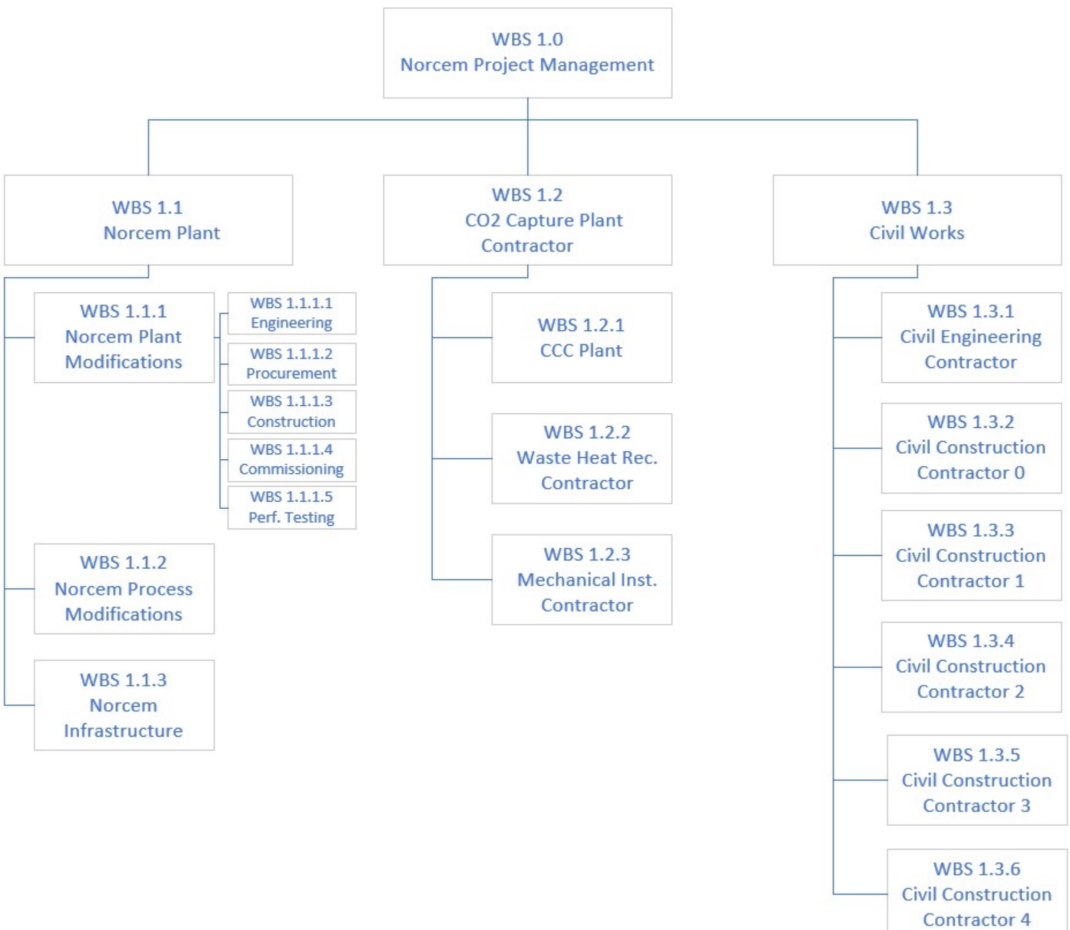


Figure 83 - Work Breakdown Structure

The WBS is based in the Procurement & Contract Strategy (Attachment 40). The procurement strategy is also described in section 4.3.

Norcem Plant (WBS 1.1) is responsible for engineering, procurement and construction of Norcem Plant Modifications (WBS 1.1.1), Norcem Process Modifications (WBS 1.1.2) and Norcem Infrastructure (WBS 1.1.3).
Norcem Plant Modifications (WBS 1.1.1) is responsible for engineering, installation and commissioning of electrical, instrument and automation, and necessary modifications to some existing facilities.
Norcem Process Modifications (WBS 1.1.2) is responsible for the necessary modifications to the existing flue gas system.
Norcem Infrastructure (WBS 1.1.3) is responsible for follow-up of Skagerak Nett wrt. the capacity extension for high voltage power supply, CO_2 supply to Northern Lights, agreements with harbour owner and operator (Grenland Havn), agreements with Tangen Eiendom as part land owner for CCS installations and plant internal traffic and logistic matters.

The CO_2 Capture Plant Contractor (WBS 1.2) is responsible for engineering, procurement and construction of the CO_2 capture plant, including CO_2 conditioning, intermediate storage and loading, as well as waste heat recovery from the existing cement production process.

The Waste Heat Recovery Contractor is responsible for engineering and procurement of waste heat recovery from the existing cement production process, as a sub-supplier to the CO_2 Capture Plant Contractor.

Civil works (WBS 1.3) is responsible for engineering, procurement and construction of all civil works.
The Civil Engineering Contractor (WBS 1.3.1) is responsible for civil engineering.
The Civil Construction Contractors' (WBS1.3.2 – WBS1.3.6) primary scope of work are:

- Civil Construction Contractor 0: Early relocation
- Civil Construction Contractor 1: Maintenance Center / CO_2 capture plant buildings
- Civil Construction Contractor 2: Jetties
- Civil Construction Contractor 3: Structural steel
- Civil Construction Contractor 4: Supplementary civil, landscaping

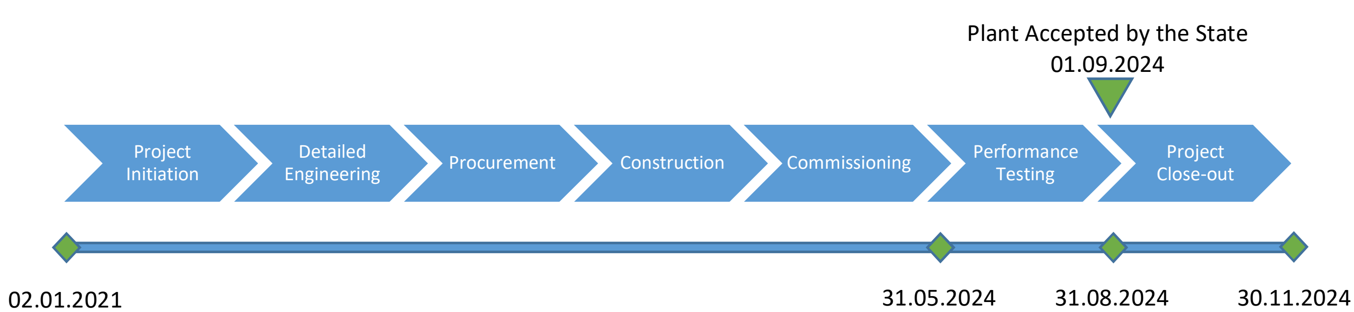
Norcem is responsible for commissioning and performance testing of the complete new plant.

10.7.5 Project Organisation

The project organisation for project execution is described in section 10.3.

10.7.6 Project Schedule

The overall project timeline is shown below:



The project schedule is divided into five levels:
Level 1) Main project phases (ref. timeline above) and milestones
Level 2) Disciplines (for Detailed Engineering) and plant areas (for the other main phases)

Level 3) Summary activities
Level 4) Activities
Level 5) Tasks or documents

The current schedule for project execution has three levels.
A five-level schedule for project execution, including all activities and tasks, with start-up date, duration and completion date, as well as dependencies and critical line, shall be established during project initiation.

11 BENEFITS REALIZATION

This chapter summarises Norcem's contributions to benefit realisation, including knowledge sharing, lessons learned and technology development.

Communication and sharing of knowledge in the project is described in section 11.2, Lessons Learned are summarised in section 11.3 and technology development is described in section 11.4.

11.1 BENEFITS REALISATION

Norcem has issued document: NC03-NOCE-A-TA-0002 - benefit realisation plan. This plan outlines the societal and business benefits and effect-oriented goals expected to be realised by the project, as well as the defined measures planned to support benefits realisation, and describes how the full-scale CO_2 capture project at Norcem in Brevik will contribute to benefit realisation.

Norcem has issued a Benefits Realisation Report for the FEED phase (document number: NC03-NOCE-A-RA-0002), summarising the benefits realisation activities performed in the project FEED phase. The accompanying NC03-NOCE-A-LA-0007 - Benefit Realisation Register includes an overview of activities contributing to benefit realisation, responsible person (s), targeted stakeholder(s), location and topics covered, as well as a reference to the relevant benefit realisation measure(s), for each activity.

Through the Norwegian CCS Demonstration Project, the Norwegian Government wants to contribute to the development of cost-effective technology for capture, transportation and storage of CO_2, and has the ambition to realise a cost-effective solution for full-scale CO_2 handling in Norway, given that this provides technology development in an international perspective.

Norcem has completed a solid FEED phase in good cooperation with the project partners (Aker Solutions, Norsk Energi, Norconsult, FLSmidth and ÅF Advansia) and Gassnova.
Excellent cooperation between the partners throughout the FEED phase have resulted in thoroughly discussed, matured, well defined and optimised technical solutions.

Three novel technologies are applied and have further developed through the project. Aker Solutions' carbon capture technology, Aker Solutions' CO_2 compressor with integrated heat recovery [21] [22] and Norsk Energi's waste heat recovery units have been qualified by DNV GL for full scale carbon capture at Norcem in Brevik [23], leaving low residual risk for unwanted failure mechanisms related to these novel technologies in operation of the CO_2 capture plant.

Norcem CCS FEED has been invaluable as an ongoing major engineering project demonstrating a potential new market and visualising actual possibilities for working "green" within the oil & gas industry. For Aker Solutions, being a major engineering house of Norway, it is of uttermost value to present the CCS technology and the engineering possibilities within this field, to attract talented engineers for working with carbon capture and hence facilitate further technology development and implementation in the future.

The project has had high focus on continuous improvement and possible simplifications, and to challenge the costs and achieve cost reduction, numerous improvements, simplification and cost reduction activities have been identified and implemented during both the Concept and the FEED phase, resulting in significant cost reductions, which will benefit this and upcoming projects.

A third-party Constructability Review of the complete plant (Ref. 6), to review, verify, and optimise construction and installation methods and schedule have been performed in the FEED phase.

Norcem has formulated a zero vision for CO_2 emissions over the product's life cycle and has acted towards this goals in continuous improvement of energy efficiency, using biomass as energy source and developing new cement types with a lower CO_2 footprint. The important last step to realising the zero vision is however the carbon capture and storage (CCS). More information on this can be found on Heidelberg Cement and Norcem's homepage (https://www.norcem.no/no/CCS). Concrete is one of the most used building materials worldwide, and the cement industry is accountable for more than 5 % of the world's manmade CO_2 emissions. it is therefore invaluable to be able to show that CO_2 can be captured from cement production in a safe manner, and that cement can be produced with zero CO_2 emissions over the product's lifecycle.

An Environmental Impact Assessment has been performed in the FEED phase, to give account for the environmental impacts of the project, and open for input from and dialogue with parties with an interest in the project and the general public. As Norcem's cement plant in Brevik is regulated for industrial purposes, an Environmental Impact Assessment is not an absolute requirement, but Norcem has chosen to go through the process to ensure transparency and an open dialogue with neighbours and interested parties to obtain their support and buy-in to the project.

The CO_2 footprint of the CO_2 capture plant in Brevik, including CO_2 condition and intermediate storage for transportation, has been thoroughly mapped by Norcem and their project partners in the FEED phase. The mapping is delivered to Gassnova as part of the DG3 delivery for Gassnova to perform a complete analysis of the CCS chain, using their purposed built tool developed by DNV GL.

Proper project management is essential to ensure that the planned project benefits are realised. Proper management of key stakeholders, both external and within the HeidelbergCement Group is a critical success factor to the project and this has been an important focus area also throughout the project FEED phase.

Norcem has had several meetings with Heidelberg Cement Group management, technical directors and plant managers, as well as other cement industry actors, throughout the FEED phase, to present the project and its status, and discuss future opportunities. Norcem has initiated a study with Cementa AB in Slite, Gotland, one of Europe's most modern cement plants, and part of the HeidelbergCement Group, to investigate the possibility of them being the next possible cement plant to implement CO_2 capture. In addition, HeidelbergCement are looking into the possibilities for CO_2 capture from their cement production plants in Lengfurt, Germany and British Columbia, Canada.

Norcem is one of four industrial partners in the CO2stCap (Cutting Cost of CO_2 Capture in Process Industry) project managed by SINTEF. The overall aim of the project is to suggest a cost-effective carbon capture strategy for future CCS systems in industry. This project has engaged 4 PhD's and Chalmers and USN are partners in the project.

Heidelberg Cement is a partner in the LEILAC CO_2 capture project in Belgium. This project is based on a technology called Direct Separation. The pilot plant, built at the HeidelbergCement plant in Lixhe, Belgium, was recently commissioned.

Norcem has also discussed electrification of the calcination process with CLIMIT, specifically related to two alternative projects (one in Norway and one in Sweden). Electrification of the calcination process means that CO_2 from limestone will not mix with off-gas from other fuels, as the calcination oven will be fuelled by electricity.

Norcem is part of the Prosess21 Steering Committee, and a board member of the CCS network in Norsk Polyteknisk Forening and has through these presented the project to and discussed the project with potential subsequent projects in other industries.

Norcem has been active in the public debate on financial incentives and regulatory mechanisms for CCS and has in cooperation with others performed and presented several analyses of the cost elements of the CCS chain, to provide insight into the cost elements of CCS, available to the public.

Norcem has throughout the project FEED phase provided consultation input to regulations and laws through hearing rounds and negotiations with relevant authorities.

Project risks for the FEED phase and future project phases have been identified and mitigated throughout the FEED phase, to reduce project risk to an acceptable level and ensure successful project delivery (on time, within budget and with the required quality). A Project Execution Plan outlining how the project will be managed throughout project realisation is delivered.

To ensure that the project is realised within the framework of time, cost and quality, given by investment decision, it is crucial that the interim period between the project FEED phase and realisation decision by the authorities, is utilised in an efficient manner, to ensure that all critical contracts are ready, long lead items will be delivered on time and key project personnel are mobilised in time for start-up of the realisation phase.

11.2 COMMUNICATION AND SHARING OF KNOWLEDGE (9a)

Norcem's Communication Plan (Attachment 52) for the project describes how all stakeholders will be informed about the project development during the project. This plan includes a stakeholder analysis, describes planned internal and external communication channels, research and development activities, collaboration initiatives, participation in conferences and planned communication activities.

Communication activities and sharing of knowledge is also described in Norcem's documents: NC03-NOCE-A-TA-0002 - Benefit Realisation Plan and NC03-NOCE-A-RA-0002 - Benefits Realisation Report.

Carbon capture is the central element in HeidelbergCement Northern Europe and Norcem's "zero-vision", a central part in the company's strategic priorities and part of the Groups sustainability communication.

Project information is communicated through the company's intranet (Unite), information screens, internal newsletters, and through "Insight" (Internal company print/digital magazine). Norcem also actively communicates project information in informal arenas across the Heidelberg Cement Group.

Norcem's homepage has a designated CCS-area, where stakeholders can find updated information regarding the project status.

Norcem has two Facebook-pages; one general for Norcem AS and one for the Brevik plant and the local community in Brevik; both used for communication on the project. Norcem uses YouTube for sharing videos from the project. As an example, a cartoon-video on the project, illustrating the process of carbon capture and storage is shared on social media, and showcased on internal events/presentations to create awareness about the holistic process of CCS. Specifically designed to be simple and understandable to the public. Norcem and Aker Solutions launched a new video presenting the project in connection with the high-level CCS conference in Oslo, September 2019.

Gassnova has established a communication network connected to the «Norwegian CCS-cluster», where Norcem participates.

Norcem has launched a new CLIMIT-project with focus on the possibilities to electrify the calcination process and collaborates closely with a similar Swedish project where among others Cementa (Norcem's sister company in HeidelbergCement group) and Vattenfall participate.

In 2016 Norsk Industri submitted their road map for the process industry to the government Expert committee for low-emission with the subtitle "Increased value-creation with zero-emission in 2050". The document focuses on new technology-solutions that are necessary in order to reach the target. CCS and especially Norcem's project in Brevik, is pointed out as essential, and an example of the active focus. Norcem has contributed and will continuously contribute to Norsk Industri through knowledge sharing with other industries where carbon capture can be an option and is an active partner in working groups within these areas (CCS, Climate change, sustainability, circular economy and international regulations).

SINTEF has over a 4 years period (2014 – 18) organised and executed CEMCAP, an international research project financed by EU (Horizon 2020). Main partners have been SINTEF, Alstom (now GE), Thyssen Krupp, IFK University of Stuttgart, ETH Zurich, TNO, VdZ and HeidelbergCement. In the work packages (WP's) one has discussed and assessed many important issues, and the project has delivered an impressive list of publications and received a lot of interest and public focus.

In ALIGN CCUS (Accelerating Low Carbon Industrial Growth through CCUS) with all together 29 partners including universities, research organisations, industries and test centres, one of the tasks, where Norcem together with Yara and SINTEF are the main contributors, is to evaluate the possibilities to establish an Intermediate storage (hub) in the Grenland region to facilitate the transportation of captured CO_2 to the western part of Norway. The project funded partly by EU (Horizon 2020) and partly by Gassnova, has a timeline/schedule for final reporting in 2021.

Norcem partners with the newly established research centre Norwegian CCS Research Centre (NCCS), established in 2016. The centre aims to enable fast-track CCS-deployment through industry-driven science-based innovation. The centre will contribute to fulfilment of the Paris-agreement, and that Norway still will be world leading in CCS. They will contribute to the CO_2-storage in the North Sea and support the Governments ambition to realise a complete CCS-chain within 2022. The program will run until 2024.

Norcem / Heidelberg Cement has conducted targeted international communication in conferences, EU network meetings and meetings with the cement industry and organisations throughout the project FEED phase, to share relevant knowledge and experience from the CO_2 capture project in Brevik.

Norcem has a great opportunity through the Heidelberg Cement Group, with its many factories, and through the European Cement Research Academy (ECRA), to share relevant knowledge and experience in the cement industry globally.

During the project FEED phase, Norcem has presented the project in several international arenas, and had several visits to the Brevik plant from international CCS stakeholders.

Norcem is part of the Prosess21 Expert Group for CCS, and a board member of the CCS network in Norsk Polyteknisk Forening and has through these roles engaged in discussions and knowledge sharing sessions on the project and CCS in general. An expert group on CCS will be established as part of Prosess21 from August 2019, where Norcem is a central contributor.

Norcem has presented the project to and discussed the project with educational institutions, doctoral programs, FMEs, technology mergers etc. on numerous occasions throughout the FEED phase. A Master study of heat recovery from cement production has been proposed to NTNU by Norsk Energi for 2019 to 2020.

Norcem has been pro-active throughout the project FEED phase in sharing knowledge and experience from the project with potential subsequent projects, actors, academia and the public debate, both through media, in conferences and seminars, and in meetings with national and international stakeholders, organisations and authorities. The complete CCS chain infrastructure including the storage facility is promoted by Norcem in every presentation given on the project.

Norcem has throughout the project FEED phase been pro-active in publishing experience and learning from the project on websites, in seminars, conferences and industry venues, and has had several publications in Norwegian newspapers, technical and industry magazines on the topic.

Norcem has maintained close contact with the European Commission throughout the FEED phase, contributed to ensure that relevant information and knowledge is communicated and understood, thereby increasing the likelihood that this is adopted when regulations are revised.

Norcem has also regularly met with relevant Norwegian DGs (Directorate-General) to share knowledge and experience and discuss necessary measures and incentives to implement CCS.

11.3 LESSONS LEARNED (9b)

A lessons-learned report was produced in the concept phase of this project and this has been followed up and reported also throughout the FEED phase.

Several Lessons Learned workshops have been held in the project FEED phase, with each of the project partners, with the project management team and with Gassnova. Valuable lessons Learned have also been captured through internal audits or reviews.

The goal has been to capture important learnings and identify areas for improvement and to ensure continuous improvement in project execution; to ensure a successful delivery of the FEED phase and future project phases.

Systematic sharing of knowledge and experience based on Lessons Learned has focused on the following areas of interest:

- Technical set-up and performance
- Costs (investment and operation)
- Project management and execution
- Business model (including project contract and execution)
- Environmental impact (emission reduction and other effects)
- Health and safety

All areas have been covered, as relevant for the current phase of the project.

The aligned lessons learned are summarised by knowledge area in the Lessons Learned Report from the FEED phase (Attachment 42)

11.4 TECHNOLOGY DEVELOPMENT (10a, 10b)

11.4.1 Elements in the project considered to contribute to technology development (10a)

If the CCS demonstration project in Brevik is realised, this will be the first cement plant in the world to be fitted with full-scale CO_2 capture. This will be a unique opportunity to demonstrate a full carbon capture and storage value chain in connection with modern and efficient cement clinker production. Of the few large-scale carbon capture plants currently in operation worldwide, only two of them (Boundary Dam and Petra Nova) capture CO_2 from flue gases (post combustion capture) and none from cement plants.

The potential for technology development and learning is significant in case of a realisation in Brevik. As the cement industry accounts for more than 5% of the man-made carbon emissions in the world, a successful carbon capture demonstration at Norcem will represent a major technology milestone that may significantly impact on global CO_2 mitigating efforts.

As of today, a full CCS chain with ship transportation of CO_2 to geological storage site and with such large volumes has not yet been demonstrated. It is likely that considerable technological and operational learnings will result from handling of the interface between CO_2 capture and ship transportation. Successful demonstration of this CCS chain with ship transportation could also lead to the development of CCS projects on smaller and more distributed CO_2 emission sources.

For the CCS project in Brevik, the proposed carbon capture plant will also be substantially integrated with the cement plant and will provide valuable knowledge and experience on this integration. The capture plant will predominantly operate on steam generated from waste heat recovered from the cement plant flue gas, and excess low-grade heat from the cement plant will be used for reheating of the flue gas from the capture plant.

Aker Solutions design includes a novel concept for CO_2 compression and liquefaction with integrated waste heat recovery from the Brevik plant. The proposed solution will result in a significant reduction in thermal energy required to operate the capture plant. To the best of our knowledge a solution like this has not been realised before. This technology is particularly interesting to industries where no heat (steam) source is available for the capture plant and new heating plant/boiler installation is required. The CO_2 compressor with integrated heat recovery has now been qualified by DNV GL, according to their recommended practice for qualification of new technology [22].

Aker Solutions' CO_2 capture technology has been developed over several years, and has further developed throughout this project, from pilot testing in Brevik on real flue gas with 7400 operating hours over a period of 18 months in 2013 – 2015 to further optimisation throughout the project concept and FEED phases. The technology has now been qualified for full scale carbon capture at Norcem Brevik by DNV GL, according to their recommended practices for qualification of new technology [19] [20].

The technology designed for waste heat recovery (shell boilers) has not previously been operated with the same type of cement off-gas which is found at Norcem Brevik. The only other known reference plant with shell boilers is Aalborg Portland Cement in Denmark, who has installed vertical shell boilers for hot water production. However, neither boiler concept or off-gas properties are comparable to the shell boiler concept and flue gas at Norcem Brevik. The shell boiler concept that is planned for Norcem is interesting for future projects on CO_2-capture from industrial processes, especially cement plants. At Norcem approximately 60 % of the heat demand in the CO_2-capture process is covered by the waste heat recovery boilers. Steam may be produced at very low cost when applying shell boilers. Also, the steam-from-power ratio is high (COP=6-7) and significantly higher than the COP of an industrial heat pump (COP=3-4). If successful waste heat recovery and

steam production with shell boilers may prove to be an important element in obtaining cost effective CO_2-capture at industrial plants with waste heat sources. The waste heat recovery units (shell boilers) have now been qualified for full scale carbon capture at Norcem Brevik by DNV GL [23], according to their recommended practice for qualification of new technology [19], through theoretical studies and pilot testing. Additional valuable practical experience with this technology will be gained in operation.
For more detailed information from the Technology Qualification activities mentioned above, see section 5.7.

11.4.2 Opportunities and possible obstacles to standardisation of the selected solution (10b)

The proposed solution for CO_2 capture at the Brevik plant with Aker Solutions' ACC™ technology is a post combustion capture technology. One key advantage of the post combustion capture technology is that it can be applied to a variety of different processes and emission sources in different industries. In addition, the post combustion technology has very low impact on the primary production process and hence is very suitable for retrofitting.

Unlike post combustion capture, other technologies/solutions for carbon capture in the cement industry, such as oxyfuel combustion, calcium looping, or indirect calcination, will interfere with the cement kiln/clinker burning process and such solutions will therefore be much more site specific not least because the composition of raw materials, fuel quality, produced type of cement etc. vary from site to site. It is therefore not unlikely that a carbon capture process similar to the one proposed for the Brevik plant may form a basis for a standardised solution for carbon capture in the cement industry and other industries with large CO_2 emissions.

Some aspects of the selected solution are, however, site-specific. As no cement plant or production plant is the same, this will always be the case. For instance, the design CO_2 capture capacity of 400 000 tons per year may not be the proper capacity at other sites. It is difficult to imagine that the size of the capture plant can be standardised as the emission size will vary from site to site. As many cement plants in the world are much larger than the than the Brevik plant, i.e. many million tons per year of CO_2 emissions, the Brevik capture plant must be regarded as a demonstration plant or "first step on the way" to demonstrate that large scale CO_2 capture is viable.

Experience from the pilot-testing in Brevik with Aker Solutions mobile test unit (MTU) in 2013-2015 has given Norcem valuable experience with regards to necessary equipment for cleaning of the flue gas prior to carbon capture. The principles and type of cleaning equipment can be standardised for future facilities. Nevertheless, some adjustments will likely be needed depending on local conditions. On the other hand, since the flue gas pre-treatment unit largely handles the variations, the pre-treated flue gas to the CO_2 capture process will be more comparable. This may allow for greater standardisation of the capture process itself.

The selected solution for CO_2 conditioning (purification and liquidation) in Brevik and the infrastructure for ship transportation will be specific to Norcem, while the equipment used (storage tanks, loading arms, measurement systems, etc.) can be standardised for the next plant.

For plants with waste heat in off-gas, the shell boiler concept is competitive and may prove to be the preferred technical and economical solution for steam production for CO_2 capture, provided that the waste heat in off-gas is not already used for other purposes.

Although the selected solutions for the CO_2 capture plant in Brevik cannot be 100% standardised, the facility will contribute to valuable learning for future carbon capture projects, both in the cement industry and other industries.

11.5 NEXT IN-KIND CAPTURE PROJECT (10c)

An implementation of the carbon capture project in Brevik will be important for the cement industry, but also other land-based industries with large carbon emissions. A realisation in Brevik will form a whole new BAT level for sustainable cement production in the future. The upcoming quota regime (after 2020) will require the cement industry to take further action, in addition to fuel and product optimisation, to reduce its carbon footprint. The future quota regime will ensure that only the most modern cement factories will survive, and it is only at the modern facilities that carbon capture can be implemented.

In the HeidelbergCement group, there are 140 cement plants with an annual cement capacity of almost 200 million tons. The potential for implementation of CO_2 capture is great, provided that the infrastructure for transportation and storage of CO_2 is in place and that CO_2 capture is viable based on willingness to invest, long-term investment support and political and regulatory incentives.

As of today, a complete CCS chain with ship transportation of large volumes of CO_2 to geological storage site has not yet been demonstrated. An establishment of a complete CCS chain in Norway will be ground-breaking for Norway, but also globally. Norway will be a pioneer in the development of technology, systems and regulatory conditions, in a long-term perspective, which will make CCS feasible elsewhere.

HeidelbergCement wants to be at the forefront in the development of carbon-reducing solutions and a realisation in Brevik, will provide valuable knowledge and experience on how the Group will continue to invest.

A realisation in Brevik will provide important knowledge and experience, which the cement industry and other CO_2 intensive industries need to understand and appreciate the efficiency of the technology, and will provide insight into the cost of full scale carbon capture as a valuable basis for future projects.

Norcem has a great opportunity through the HeidelbergCement Group, with its many factories, and through the European Cement Research Academy (ECRA) and Cembureau (European cement producers), Work Group A Climate, to share relevant knowledge and experience in the cement industry globally and has had several meetings throughout the FEED phase, to present the project, its status and discuss future opportunities.

Norcem has initiated a study with Cementa AB in Slite, Gotland, one of Europe’s most modern cement plants, and part of the HeidelbergCement Group, to investigate the possibility of them being the next possible cement plant to implement CO_2 capture. Based on what we have learned in Brevik, the plan is to build up a team in Slite to start looking into a possible solution and apply for financial support from the Ministry of Petroleum and Energy. Based on maturity, the most likely solution to evaluate is post-combustion capture technology, but Oxyfuel technology is an alternative option. In addition, Heidelberg Cement are looking into the possibilities for CO_2 capture from their cement production plants in Lengfurt, Germany and British Columbia, Canada.

Norcem has also discussed electrification of the calcination process with CLIMIT, related to two alternative projects (one in Norway and one in Sweden). Electrification of the calcination process means that CO_2 from limestone will not mix with off-gas from other fuels, as the calcination oven will be fuelled by electricity.

Heidelberg Cement is a partner in the LEILAC CO_2 capture project in Belgium. This project is based on a technology called Direct Separation. The pilot plant, built at the HeidelbergCement plant in Lixhe, Belgium, was recently commissioned. The project’s results will be shared widely through ongoing publications, conferences and the project website. To accelerate further development, LEILAC will deliver a techno-economic roadmap, and comprehensive knowledge sharing activities including a visitor centre at the pilot.

12 INTELLECTUAL PROPERTY AND PATENTED TECHNOLOGY (11a)

In the following subsections, intellectual property and background knowledge as well as patented technology/confidential information related to Aker Solutions' Advanced Carbon Capture™ (ACC™) technology are presented.

12.1 INTELLECTUAL PROPERTY/CONFIDENTIAL INFORMATION

Aker Solutions' Advanced Carbon Capture™ technology contains business secrets within the following areas:

- The composition of the amine solvent used in the CO_2 capture process, including all physical data and chemical properties of the amine solvent, as well as the structure of the specific decomposition products that might reveal the composition of the amine solvent.
- Design information for Aker Solutions' emission control technology, including the quantity of washing sections, type and dimensions of internals, process connections between washing sections, operating/design conditions (temperatures, washing water quantity and washing water composition), heat integration between washing sections and amine solvent.
- Technology for heat integration between CO_2 compression/liquefaction and CO_2 capture processes. This includes information about the design/operating conditions for CO_2 compressor and integrated heat recovery units. Process connections between heat recycling devices and CO_2 desorber.
- Technology for reclaiming of the amine solvent. This includes information about the choice of process equipment and process connections as well as design/operating conditions (temperature, pressure and composition) of the reclaimer process.
- Technology for energy conservation in the capture process through the use of "Energy Saver".
- Detailed design information about tailored process equipment including flue gas pre-treatment (DCC), CO_2 absorber, CO_2 desorber and reboiler.
- Mass and energy balances on business process flows within the CO_2 capture process.
- Material selection of process equipment and components exposed to amine solvent.
- The information listed under the following section "Patented Technology (and Background Knowledge)", apart from information that is publicly available in patent databases.

12.2 PATENTED TECHNOLOGY (AND BACKGROUND KNOWLEDGE)

Aker Solutions' ACC™ technology for CO_2 capture from flue gases is an amine-based CO_2 capture technology that has been developed, tested and qualified since 2005. Through the development of ACC™ technology and execution of engineering projects for full scale CO_2 capture Aker Solutions has established extensive background knowledge of CO_2 capture technology and how this integrates with industrial facilities with large emissions of CO_2.

The following items under the ACC™ technology are patented or under patenting:

- WO2009035340 "Improved method for regeneration of absorbent"
- WO2008108657 "Improved CO_2 absorption method"
- WO2008063079 "Absorber regeneration with flashed lean solution and heat integration"
- WO2008063082 "Absorber regeneration with compressed overhead steam two provide heat"

- WO2009108064 " CO_2 absorbent and method for CO_2 capture"
- WO2010102877 "Amine emission control"
- WO2010142716 "Method for reclaiming of CO_2 absorber and a reclaimer"
- WO2010037825 "Amines"
- WO2011036171 "Carbon dioxide absorbent"
- NO20121540 "Improvements by absorber for CO_2 capture"
- WO2013004731 "Method for mist control"
- WO2013004797 "Construction element for CO_2 capture"
- WO2014086988 "An aqueous CO_2 absorbent"
- WO2014102186 "Method and device for drainage and detection of leakage"

In addition to the previously mentioned technology items that are patented or in the patenting process, the following projects and experiences are considered of particularly relevant background knowledge in relation to the present project:

- All technical solutions for CO_2 capture, compression and liquefaction that is established in connection with other CO_2 capture projects, including pre-engineering of CO_2 capture at Norcem's plant in Brevik, including:
  - Heat integration solution between CO_2 compression/liquefaction and CO_2 capture processes
  - Solutions for reheat of the flue gas from the CO_2 absorber using hot air from the cement plant's clinker cooler
  - All experience and test results about Aker Solutions ACC™ technology that were obtained from the 18 months of testing with Aker Solutions' Mobile Test Unit (MTU) at Norcem's cement plant in Brevik
- All CO_2 capture solvents and technologies developed through Aker Solutions' SOLVit project. This includes all test results, physical data and the characterization of the developed solvents
- Construction experience through the delivery of amine plant on CO_2 Technology Centre Mongstad (TCM).
- Technology qualification of ACC™ technology that is performed according to DNV-RP-A203 - Qualification Procedures for New Technology and DNV-RP-J201 - Qualification Procedures for CO_2 Capture Technology.
- ACC™ reclaiming technology and operational optimization developed through the project "Amine Reclaiming"
- Knowledge and test results about the atmospheric degradation and transformation of Aker Solutions amine components that are achieved in the project "Experimental investigation of atmospheric amine degradation"
- Aker Solutions' simulation software for CO_2 capture processes "CO2SIM" and all other developed calculation and "design tools"
- Aker Solutions' design guidelines and Technical Requirements for ACC™ technology "
- Design and erection of Aker Solutions' mobile test unit (MTU), including operational experiences and test results obtained in previous MTU test campaigns.

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15 LIST OF ATTACHMENTS

The attachments will not be made available to the public, due to confidentiality.

Attachment no.	Title	Document number
1	Norcem Kostnadsnedbrytningsstruktur (CBS)	NC03-PERI-F-GL-0001_03
2	Outline Scope of Work Document for State Support Agreement	NC03-NOCE-A-RA-0008_01
3	Estimated Future Process Gas Flows and Conditions	NC03-AKER-P-RA-0008_C01
4	Overall Design Basis	NC03-NOCE-Z-RA-0001_05
5	CCS Plot Plan	NC03-NOCON-C-RA-0042_03
6	Feed Study Report	NC03-AKER-A-RA-0006_04C
7	Process System Diagram - Overall System Diagram	NC03-AKER-P-XA-0003_C04
8	Process Flow Diagram – CO2 Tank Farm and Ship Loading	NC03-AKER-P-XA-0008_C04
9	Process flow diagram – Steam and condensate system,	NC03-NOEN-P-XA-0001_C02
10	Process Flow Diagram, 46PID Page 1 And 2	NC03-NOCE-P-XA-0001_C06
11	Delivery Schedule for Engineering Procurement Construction and Commissioning	NC03-NOCE-A-TB-0002_02
12	RAM Report	NC03-AKER-Z-RA-0005_C02
13	Technology Qualification Report	NC03-AKER-A-RA-0010_C02
14	Commissioning and System Testing Philosophy	NC03-AKER-Z-FD-0001_C01
15	Design Electrical Report	NC03-NOCE-E-RA-0502_04
16	Basis of Estimate - WBS 500	NC03-NOCE-F-RA-0501_06
17	Guideline for Project Management 2016_04 (HeidelbergCement Guideline)	Edition no. 04
18	Change Log: Concept To FEED	NC03-NOCE-A-RA-0007_05
19	Operation and Maintenance Philosophy / Procedure	NC03-AKER-Z-FD-0002_C02
20	Operation- and Maintenance Manual	NC03-NOEN-O-MB-0002_C03
21	Spare Part Philosophy	NC03-NOCE-A-MC-0001_01
22	Maintenance Philosophy	NC03-NOCE-A-MC-0002_01
23	Oversikt Over Tekniske Forskrifter og Standarder	NC03-NOCE-A-SA-0001_03
24	HSE Activity Register	NC03-NOCE-S-LA-0002_06
25	HSE Program	NC03-NOCE-S-RA-0001_04
26	HSE Activity Plan	NC03-NOCE-S-RA-0002_06
27	Input to Norcem's DG3 Report - Civil WBS 400	NC03-NOCON-A-RA-0022_03
28	Risk Analysis Report	NC03-AKER-S-RA-0007_C02
29	Environmental Report	NC03-AKER-S-RA-0001_C03
30	Environmental Assessment of Soil Contamination	NC03-NOCON-S-RA-0039_C02

Attachment no.	Title	Document number
31	Environmental Assessment of Seabed Sediment	NC03-NOCON-S-RA-0040_C02
32	Environmental Noise Calculations	NC03-NOCON-S-RA-0041_C04
33	CO_2 Footprint	NC03-NOCE-S-CA-0001_02
34	Project Manual	NC03-NOCE-A-KM-0001_05
35	Quality & Risk Management Plan	NC03-NOCE-Q-AD-0002_04
36	Level of Detail / Maturity for Engineering Deliverables In FEED	NC03-NOCE-Q-AD-0003_03
37	Constructability Review Report (Kværner)	NC03-NOCE-Z-RA-0028_02
38	Risk Register	NC03-NOCE-S-LA-0001_04
39	Project Execution Plan	NC03-NOCE-A-TA-0003_03
40	Procurement & Contract Strategy	NC03-NOCE-A-FD-0001_05 Not to be included. Rev. 06 to be issued with legal assessment 07.11.2019.
41	Interface Register	NC03-NOCE-Z-IR-0001
42	Lessons Learned Report	NC03-NOCE-A-RA-0006_03
43	Aker Solutions reference list	
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45	FLSmidth reference list	
46	Norconsult reference list	
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48	ÅF Advansia reference list	
49	TQ Report Waste Heat Recovery Units	DNV GL Report No. 2019-0604_00
50	VOIDED	
51	Project Organisation Chart - FEED	NC03-NOCE-A-RA-0003_07
52	Communication Plan	NC03-NOCE-A-TA-0004_02
53	FTO report from Aker Solutions	
54	Assessment of completely or partly subsidized cost elements in DG3 estimates	NC03-NOCE-F-RA-0002_01
55	Gjennomføringsplan for bygging og drift	NC03-NOCON-A-TA-0001_09
56	Technology Qualification Plan	NC03-NOEN-A-RA-0002_B02
57	Basis of Estimate	NC03 PERI-F-RA-0004_03
58	Cost estimate	NC03-NOEN-F-TE-0001_C04
59	Cost calculations and tables	NC03-PERI-F-AA-0001_03
60	Project Execution Strategy	NC03-NOCE-A-FD-0003_01
61	Freedom to Operate Report (redacted version)	NC03-AKER-A-RA-0004_B02
62	Master Document Register FEED	NC03-NOCE-A-LA-0001_15