PROJECT CCS
CARBON
CAPTURE
OSLO

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1 EXECUTIVE SUMMARY

Fortum Oslo Varme (FOV) has performed the FEED Study "Project CCS Carbon Capture Oslo". The study is part of the Norwegian full-scale CCS Project for the overall CCS chain. The scope includes capturing CO_2 in a full-scale plant with liquefaction and conditioning of the CO_2, transport to harbour, intermediate harbour storage and export facilities.

1.1 Carbon Capture and Storage for the Waste-to-Energy Industry

Every year the world dumps more than 2 billion tons of waste, and waste handling is a major contributor to Green House Gas (GHG) emissions. Management of household waste (Municipal Solid Waste, MSW) is alone accounting for 5 % of the global GHG emissions.

An estimated 1.6 billion tons of CO_2-equivalent GHG emissions were generated from MSW alone in 2016, growing to 2.6 billion tonnes of CO_2 equivalents in 2050. The transition from landfills to sorting, recycling and incineration of residual waste significantly reduces greenhouse gas emissions and environmental impact. Improving waste management is one of the most important measures contributing to meet the goals of the 2017 Paris agreement.

Waste-to-Energy (WtE) plants' most important role is to burn waste that could not be prevented or recycled, and generate energy in the form of steam, electricity or hot water. WtE is the most sustainable solution today for residual waste that cannot or should not be recycled, and an important part of a circular waste system. WtE is not a contradiction to sorting and recycling, but a necessary addition that removes unwanted, toxic components from the material cycles. In effect, WtE plants act as pollutant sinks for the society.

The link between WtE, carbon capture, and district heating is important from a resource perspective. The available excess heat from the capture process can be utilized in the district heating systems.

Waste incineration with energy recovery will by itself result in more than 75% GHG reduction compared to landfilling the same waste. The transition from landfills to WtE also enables the capture of the still significant point sources of CO_2 emissions from the incineration and forms the basis for the development of Carbon Capture and Storage (CCS) in the waste industry.

WtE is also the best way of treating plastics that cannot be recycled at all or has been recycled a number of times and is no longer possible to recycle. The amount of plastics in the world is growing, and is expected to triple over the next 30 years. This presents major challenges in both a short and long term perspective, even with extensive research and development of sorting systems, recycling technology and the development of more recyclable packaging solutions. By establishing CO_2 capture from incineration of plastics that can no longer be recycled, this challenge can be dealt with in a sustainable way.

WtE plants with CO_2 capture can significantly contribute to achieve negative emissions. Approximately 50% of the incinerated waste is of non-fossil (biogenic) origin. Thus, half of the captured CO_2 from the WtE flue gases will in effect remove CO_2 from the atmosphere, which is often referred to as "negative emissions", i.e. reductions that have a greater benefit than reducing emissions from fossil fuel combustion. With waste being one of the few worldwide established value chains that produces energy from biomass, this gives a significant BIO-CCS (BECCS) potential for the WtE industry. Negative CO_2-emissions will also help neutralizing other emissions that are much harder to reduce or remove in a short-to-medium term perspective.

Capturing CO_2 from waste incineration is the natural next step towards a sustainable and circular waste treatment. The FOV CO_2 Capture Project at Klemetsrud demonstrates how cities can cut large emissions, utilize local resources and mitigate climate change from waste handling as a part of sustainable city solutions. CO_2 capture from WtE plants can be an important part of cities' emissions reductions, as WtE is in many cities the single largest point of CO_2 emissions.

There is a growing demand for WtE capacity in Europe as EU moves away from landfills and towards increased sorting and recycling. 142 million tons of residual waste treatment capacity will be needed in EU by 2035 in order to fulfil EU targets (65% material recycling and a reduction to 10% landfilling). With the current capacity of 100 million tons for WtE, around 40 million tons of new WtE capacity with prospects for CCS has to be established in the EU.

Fortum recognizes the unique potential that FOV CO_2 Capture Project represents for Norway. Oslo and Fortum together, have a strong interest in developing the technology in the direction of cost-effective, safe and qualified solutions for decarbonization. Fortum aims to be at the forefront of developing both the industry, the technology and new green jobs. The FOV CO_2 Capture Project at Klemetsrud will generate great learning and international transfer value as well as an opportunity to develop carbon capture to become a shared European initiative.

FOV is selected as leader of Fortum's own CCS Centre of Excellence. FOV has potential to reach out to multiple CCS industrial clusters to develop technology and new solutions together. With its large portfolio of WtE and energy plants, Fortum can help creating a future where new facilities will be built with integrated CO_2 capture as part of the flue gas cleaning process.

Liquefied CO_2 transportation by CO_2 neutral trucks between Klemetsrud and Oslo harbour is a first world-wide. Continuous transportation of CO_2 between Klemetsrud and Oslo harbour will generate knowledge which is valuable for other inland CO_2 capture sites.

There are several CO_2 capture projects already in the planning within the WtE industry both internally in Fortum and by external partners. The realisation of the FOV CO_2 Capture Project will give reassurance and produce valuable knowledge for the realisation of these projects.

1.2 Project Execution and Operating Excellence

Fortum's project execution method and procedures are utilised in the project execution. The project execution phases are identified in the Fortum procedures with the support of separate flowcharts, decision gates and procedures:

- Project establishment;
- Project start-up;
- Project execution;
- Verification of readiness for commissioning;
- Commissioning and taking over;
- Project closing.

Relevant procedures and systems like quality assurance (QA), risk management, document and data management, change management are based on Fortum procedures. Health, safety and environment (HSE) management is a top priority in Fortum, with Fortum's Safety and security handbook [1] implemented as basis for the project and the Project Manager as responsible for the HSE management.

Fortum has selected TechnipFMC as the main contractor with Shell as Licensor of the technology. The parties form a strong team for the realisation of the project with extensive experience in project execution of large-scale projects.

Fortum has since 2006 executed 11 large scale Combined Heat and Power projects with a total value of more than [redacted]. Fortum has a continuous investment program with currently ongoing and planned projects. Experience from the projects are continuously used for further improvement of the project execution methods and procedures.

TechnipFMC has a vast experience in design and build of a number of gas treatment plants worldwide.

Shell as the licensor of the technology already has two full-scale CCS plants in operation using their proprietary technology and their DC-103 absorbent for capturing CO_2.

FOV is the owner and the legal entity for the FOV CO_2 Capture Project. FOV appoints a Steering Group with representatives from both Fortum and the City of Oslo which will ensure that project goals are met.

The appointed Project Director has the overall responsibility for the FOV CO_2 Capture Project as well as the communication with Ministry of Petroleum and Energy (MPE) and for external communication including the benefit realisation activities.

The appointed Project Manager is responsible for the overall management of the project including time, cost, change and risk management and HSE activities. The Project Manager will be supported by the Project Management Office and the Owner's Engineer team.

The Project Management Office will also utilise resources from Fortum for support activities as IT support, support in HSE and QA, procurement, and human resources. The support is both in terms of available personnel, procedures and systems.

The Owner's Engineer team is a contracted consultant providing the required technical supervision services to the project. This includes follow-up of works of TechnipFMC and all other contractors included in the project and necessary engineering of own scope of supply. The Owner's Engineer will provide main part of the resources in the Project Management Office.

FOV's Operation and Maintenance (O&M) team will be mobilised prior to pre-commissioning and take part in all commissioning activities lead by TechnipFMC. The O&M team will operate the Carbone Capture (CC) Plant after the final acceptance of the plant.

TechnipFMC will establish their own project organisation and the project will be managed from their Lyon office in France. When the construction works start at Klemetsrud, a TechnipFMC Site organisation is mobilised at Klemetsrud with a dedicated Site Manager reporting directly to the TechnipFMC Project Manager.

1.3 Project description

The project has developed a robust and integrated solution ready for execution, with focus on major cost drivers, quality, HSE and risk. In the development of the project some main changes from the Concept Phase solution have been adopted as follows:

- The CO_2 transportation concept was revised, and truck transport (including liquefaction) is the base concept. The use of truck transport presents a significant reduction in investment cost and schedule risk for the project;

- A new location at Port of Oslo (Kneppeskjær) with a more suitable fixed quay is selected for the harbour facilities;
- Heat integration options have been evaluated during the FEED phase and a base case with 60 MW heat pumps has been chosen;
- Due to growth in required plot space, the entire hill east of the WtE plant need to be levelled out;

The project has been organised as an integrated project team working with TechnipFMC as the main contractor. Fortum project execution methods are adopted and including a dedicated Fortum Project Director and Project Manager. The FOV CO_2 Capture Project has a strong support from Fortum Oslo Varme owners and the Fortum organisation.

The current operations at the Klemetsrud WtE include three separate waste incineration lines and two steam turbines for electricity production and district heating. Currently the WtE plant emits about 400 000 tons/year of CO_2. The incineration capacity will increase in the coming years to achieve the treatment of 410 000 tons of waste and the emission of 460 200 ton/year of CO_2. This is defined as the design capacity (flue gas inlet) for the CC Plant.

The new CC Plant will be integrated with the Klemetsrud WtE plant so that the primary task of WtE plant, incineration of waste and delivery of heat to the district heating network, is not negatively impacted.

TechnipFMC is, in addition to being responsible for the CC Plant, also responsible for the truck loading/unloading stations, temporary storage at Klemetsrud, and intermediate storage and export facilities at the export terminal.

The CC plant consists of the following main elements:

- Pre- and post- treatment of the flue gas;
- Absorption of CO_2 from flue gas;
- Stripping of CO_2 and regeneration of the amine;
- CO_2 conditioning (Liquefaction);
- Utility systems;
- Transport and intermediate storage at Klemetsrud;
- Export terminal, including storage, for transfer to ship transport;

All elements have been detailed out during the FEED phase of the project to ensure a maturity of the design and cost estimates according to AACE-RP 18R-97 class 2.

The design also includes the export terminal at Port of Oslo. The export terminal includes the following main elements:

- Storage tanks for 5400 m^3 of liquefied CO_2;
- Export pump system and pipelines including loading arm with capacity of loading 800 m^3/h liquid CO_2;
- Unloading bays for unloading of trucks with liquid CO_2 from Klemetsrud.

The transport of liquified CO_2 from Klemetsrud to port will be done by CO_2 neutral trucks. Expected number daily loading and unloading transport operations are approximately 45, depending on the trailer payload.

TechnipFMC will carry out pre-commissioning and commissioning activities after mechanical completion. The FOV Operation and Maintenance team will be trained during these activities. Following the successful completion of the Commissioning, the Plant will be ready for Start-up. Final acceptance by FOV will follow, after a successful Trial-run period.

A technology qualification program including Pilot testing have been performed and a Statement of Qualified Technology is issued by DNV GL for the absorption process with Shell DC-103 amine capturing CO_2 from the Klemetsrud WtE plant flue gas.

FOV is committed to maintain and achieve a high standard towards health, safety and environment in all phases of the FOV CO_2 Capture Project in line with Fortum corporate policies and guidelines. Several HSE studies have been performed through the FEED phase to reduce the risk and improve the reliability of the technical solution.

The FOV CO_2 Capture Project quality system is based on FOV quality system, accredited according to ISO 9001:2015 and ISO 14001:2015. Quality Assurance activities during the feed included subcontractors' audits, internal audits follow up of the pilot plant fabrication and thorough documentation review.

Risk management is a key feature and integral part of project management in the FOV CO_2 Capture Project. The objective of the risk management system is to systematically and periodically identify, classify and mitigate risks and opportunities in the project.

Regulatory and zoning activities are ongoing, including issuing Zoning plan and EIA to political handling with an anticipated approval during 2019. Plan for obtaining all the necessary authorizations from the relevant authorities is ongoing, in order to have all permits approved by the start of the full-scale project.

The plot plans and layouts of technical equipment have been continuous areas of development during the FEED phase of the project. The CC Plant will be located next to the existing WtE facility, while the intermediate storage and truck loading is located at the former bus parking area. A 3D illustration of the CC Plant is shown in figure below.

Figure 1-1: 3D illustration of Klemetsrud CC plant [2].

1.4 Operation and Maintenance

During normal operation, the automation system of the WtE plant will control the existing systems. A new automation system will control the operation of the CC Plant. Required interfaces between existing and new system will be established to ensure safe operation. All systems will be monitored and controlled from the WtE plant Central Control Room (CCR).

The operation of the export terminal at Port of Oslo will be fully automated. All systems will be monitored and controlled from the CCR at Klemetsrud.

Yearly maintenance of the CC plant at Klemetsrud and related equipment will be coordinated with the yearly scheduled shutdown of the WtE lines.

1.5 Cost and schedule

The main elements of the contracts with MPE and TechnipFMC are agreed. The agreement with MPE is not yet completed, hence aligning the TechnipFMC agreement with MPE requirements is also not finalised as some details are still pending.

The cost estimates presented are based on the current status of the negotiations. FOV do not see the outstanding issues with MPE to have significant effect on the cost estimates and the schedule.

1.5.1 Cost Estimates

The cost estimates are established in accordance with AACE-RP 18R-97 class 2. The accuracy of the estimates is +/-20%.

The prices are based on 2019 prices and are exclusive VAT, finance cost and price escalation. The cost estimates are based on exchange rates given by Gassnova, presented in Table 1-1, and the currency risk is not included in the estimates other than for the Fortum financed part of the estimated cost.

Table 1-1: Exchange rates for cost estimate, summary.

Currency	Exchange rate	% CAPEX estimate	% OPEX estimate
EUR	EUR-NOK: 10	[redacted]	[redacted]
USD	USD-NOK: 9	[redacted]	[redacted]
NOK	-	[redacted]	[redacted]

The CAPEX estimate includes all costs from final investment decision until completion/commencement of the operation period.

Estimates for CAPEX and OPEX are presented in Table 1-2 and Table 1-3 respectively.

Table 1-2: CAPEX estimates, summary.

Base Estimate (MNOK)	P50 Estimate (MNOK)	P85 Estimate (MNOK)
[redacted]	[redacted]	[redacted]

Table 1-3: OPEX estimates, summary.

Base Estimate (MNOK)	P50 Estimate (MNOK)	P85 Estimate (MNOK)
[redacted]	[redacted]	[redacted]

1.5.2 Schedule

The schedule is developed based on the assumption that the Final Investment Decision by MPE will be taken in Q4 2020. Assumed project start is January 2021. Total project duration until plant ready for operation is 46 months. The following main milestones are defined:

Milestone	Milestone date
Project Start-up	04.01.2021
Foundation ready (Klemetsrud) for first equipment	01.04.2022
Mechanical Completion	29.02.2024
Commissioning finished and Ready for Start-up	[redacted]
Plant ready for operation	[redacted]
Delivery Acceptance Certificate signed & commencement of normal operation	27.10.2024

1.6 Conclusion, findings and recommendations

Through the course of the FEED Study several findings and conclusions have been identified. The main conclusions summarized below:

- The technology for capturing carbon to be implemented at Klemetsrud is fully qualified. This statement is based on an extensive technology qualification process including pilot testing of the actual technology on the Klemetsrud flue gas. DNV GL has issued a statement of Qualified Technology for the process.
- The FEED study confirms that the designated plot areas at both Klemetsrud and Port of Oslo will be sufficient for the new plant. However, the plot area for the CC Plant has increased and the entire hill east of the WtE plant need to be levelled out.
- Learnings from the execution of the project at Klemetsrud will enable potential for cost reduction, industrialization and standardization of coming CCS projects in the WtE industry.
- Emissions from waste handling are a growing global challenge. Moving waste from landfills towards sorting, recycling and WtE with carbon capture will give huge reductions in global GHG emissions. The WtE industry has a great potential for adopting the CO_2 capture technology, and several new WtE plants will be required in Europe in the coming years.
- Since approximately 50% of the incinerated waste is of non-fossil (biogenic) origin, WtE with CO_2 capture can significantly contribute to achieve negative emissions. WtE is also the best way of treating plastics that cannot be recycled at all, or has been recycled a number of times and is no longer possible to recycle. CO_2 capture from WtE plants can be an important part of cities' emissions reductions, as WtE is in many cities the single largest point of CO_2 emissions.
- Establishment of carbon capture at Klemetsrud has broad support from Fortum Oslo Varme owners (The City of Oslo and Fortum).

- Carbon capture at Klemetsrud is a safe choice: The WtE plant will be in operation for many years to come, waste will still be an available resource even though recirculation and re-use of materials is improving in the future. Fortum has extensive experience with the establishment and operation of advanced energy plants, and the plant design maturity is supported by a number of studies that improves its robustness.

2 UTVIDET SAMMENDRAG

Dette kapittelet er et sammendrag av rapporten som er skrevet på engelsk. Figurer som det refereres til her finnes i den engelske delen av rapporten i det relevante kapittelet.

Dette kapittelet skal være en norsk gjengivelse og et sammendrag av den engelske teksten i dokumentet. Referanser finnes i den engelske delen av rapporten. Der det kan være uklarheter eller uoverensstemmelser mellom norsk og engelsk tekst er det den engelske teksten i det enkelte kapittel som er gjeldende.

2.1 Introduksjon

Forprosjektet for FOVs CO_2-fangst etablerer en basis for gjennomføring av et fullskalaprosjekt med hensyn på teknisk og kommersiell modenhet.

Dette inkluderer fangstanlegg, flytendegjøring, transport fra Klemetsrud til Oslo Havn og utskipningsterminal på Oslo Havn. Det er også gjennomført et teknologikvalifiserings-program som inkluderer pilottesting på Klemetsrud.

Tekniske løsninger og mengdeberegninger er utviklet til et nivå som dokumenterer et kostnadsestimat innenfor ±20% i henhold til AACE RP 18R-97.

2.2 Kommersielt

Det pågår fortsatt forhandlinger med Olje- og energidepartementet (OED) når det gjelder avtalen om tilskudd til fangst av CO_2. Avtalen skal regulere bygging, drift og avvikling av CO_2-fangstanlegget. Avtalen forutsetter at FOV vil dekke en del av de påløpte kostnadene.

FOV vil bli gitt muligheten til å tjene inn sine investeringen ved å levere CO_2 til karbonfangstkjeden.

En del grunnleggende prinsipper om hvordan OED og FOV skal dele kostnadene i forbindelse med bygging og drift av CO_2-fangstanlegget er imidlertid på plass.

2.2.1 Investeringskostnader

Avtalens fordelingsmekanismer tar utgangspunkt i to investeringsnivåer, henholdsvis nivå 0 og 1. Nivåene er ennå ikke fastsatt, men blir definert i FOVs tilbud til staten som skal leveres innen 2. desember 2019. FOV har mulighet til å tilby dekning av kostnadene opp til investeringsnivå 0. OED dekker alle kostnadene mellom investeringsnivå 0 og investeringsnivå 1. Partene skal så dekke kostnadene som overstiger investeringsnivå 1 i henhold til fordelingen: OED [redacted]% og FOV [redacted]%.

Partene forhandler om et øvre tak på investeringskostnadene. Detaljer rundt dette er fortsatt ikke avklart.

2.2.2 Driftskostnader og besparelser

FOV vil motta ett fast og ett variabelt driftstilskudd i driftsperioden. Partene skal dekke driftskostnader som overskrider et visst nivå, driftskostnadsnivå 1, som følger: OED [redacted]% og FOV [redacted]%.

CO_2-utslipp fra FOVs energigjenvinningsanlegg på Klemetsrud er ikke underlagt CO_2-avgift og utslippene er ikke en del av EU ETS-systemet. [redacted]

2.2.3 Videre drift og avvikling

FOV vil ha en plikt til å fange og levere CO_2 etter at driftsperioden på 10 år utløper, forutsatt at det finnes transport- og lagringstjenester for CO_2 samt at videre drift er kommersielt forsvarlig.

2.2.4 Anskaffelsesstrategi

FOV har delt inn anskaffelsene i etableringsfasen i tre hoveddeler:

1. Komplett prosessanlegg for fangst av CO_2. Kontrakten er basert på NTK2015, og omfatter prosjektering, innkjøp, bygging og idriftsettelse av CO_2-fangstanlegget. Kontrakten omfatter nødvendige fasiliteter for mellomlagring av CO_2 på havneområdet og lasting av skip.
2. Grunnarbeider og fundamenter. Denne kontrakten omfatter utsprenging og utgraving av tomt, arbeider under bakkenivå samt prosjektering og bygging av fundamenter for prosessanlegget. Kontrakten er basert på NS8407.
3. Integrering mot eksisterende forbrennings- og fjernvarmeanlegg. Dette er et omfang som igjen deles inn i en rekke mindre kontrakter som er nødvendig for å knytte CO_2-fangstanlegget opp mot FOVs energigjenvinningsanlegg på Klemetsrud.
4. Eiers ingeniørteam som del av prosjektleders kontor. Et konsulentteam vil bli engasjert for å bistå Fortums organisasjon i prosjektgjennomføring og ha ansvar for oppfølging av underleverandører inklusive kvalitetsledelse, grensesnitt og rapportering til prosjektleder.

I forbindelse med drift av CO_2-fangstanlegget tildeles det tre større kontrakter:

1. Transport av CO_2 fra Klemetsrud til havneområdet med utslippsfire kjøretøy;
2. Vedlikehold og drift av CO_2-fangstanlegget;
3. Leveranser av proprietær absorbentløsning (Cansolv DC-103).

2.2.5 Estimerte kostnader

Investeringskostnadene dekker alle kostnadene fra startdagen fram til ferdigstillelse av CO_2-fangstanlegget, og dekker alt arbeidet som er beskrevet i Gassnovas og FOVs designbasis.

Kostnadsestimatet er utarbeidet henhold til AACE-RP 18R-97 Class 2. Estimatet har en nøyaktighet på +/- 20%.

Prisene er basert på prisnivået i 2019, og er eksklusiv MVA, finansieringskostnader og prisjusteringer. Valutakurser som angitt i Tabell 2-1 er benyttet.

Tabell 2-1: Valutakurs brukt i estimerte kostnader.

Valuta	Valuta kurs	% Investeringskostnader	% Driftskostnader
EUR	EUR-NOK: 10	[redacted]	[redacted]
USD	USD-NOK: 9	[redacted]	[redacted]
NOK	-	[redacted]	[redacted]

2.2.5.1 Estimerte investeringskostnader

		MNOK
Komplett prosessanlegg for fangst av CO_2		[redacted]
Grunnarbeider og fundamenter		[redacted]
Integrering mot eksisterende forbrennings- og fjernvarmeanlegg		[redacted]
Andre kostnader		[redacted]
Byggherrens kostnader		[redacted]
Totalt netto kostnader		[redacted]
«Contingency»	[redacted] %	[redacted]
CAPEX P50		[redacted]
«Management reserve»	[redacted] %	[redacted]
CAPEX P85		[redacted]

2.2.5.2 Estimerte årlige driftskostnader

		MNOK
Variable kostnader		[redacted]
Faste vedlikeholdskostnader		[redacted]
Faste driftskostnader		[redacted]
Faste driftskostnader – prosjekt stab		[redacted]
Totalt netto kostnader		[redacted]
«Contingency»	[redacted] %	[redacted]
OPEX P50		[redacted]
«Management reserve»	[redacted] %	[redacted]
OPEX P85		[redacted]

2.3 Prosjektbeskrivelse

2.3.1 Beskrivelse av eksisterende anlegg og røykgassammensetning

FOVs energigjenvinningsanlegg på Klemetsrud består av tre individuelle linjer som utnytter energien i restavfall fra husholdninger og næring. Linje 1 (K1) og 2 (K2) ble etablert i 1985 og linje 3 (K3) ble etablert i 2011. Pågående vedlikeholdsprogrammer for K1 og K2 sikrer planlagt levetid på disse linjene utover støtteperioden for drift av CO_2-fangstanlegget.

Avfall mottas i en felles bunker/lager hvor det blir mikset med kraner og matet inn til hver forbrenningslinje. Gjennom god kontroll av prosessen, herunder mating av avfall, lufttilførsel i fyrrommet (primærluft under forbrenningsristen og sekundærluft over selve brennsonen) sikres god utbrenning av avfallet og fullstendig forbrenning av røykgassen med et minimum av utslipp.

Røykgassen gjennomgår flere ulike rensetrinn før den blir analysert og innhold av stoffer kontrollert. Deretter slippes den ut via en 80 meter høy skorstein. Alle utslipp skal til enhver tid være innenfor anleggets utslippstillatelse.

Linje 1 og 2 har følgende rensetrinn:

- SNCR (Selective Non-Catalytic Reduction) av NO_X med tilførsel av urea;

- Tilførsel av aktivt kull/HOK for å binde tungmetaller, dioxiner med mer;
- Tilførsel av kalsiumhydroksid for å binde sure komponenter i røykgassen;
- Posefilter for å fjerne støv inkludert aktivt kull og kalk med ovennevnte stoffer og komponenter.

Linje 3 har et litt annet oppsett for røykgassrensingen:

- Elektrostatisk filter for å fjerne støv;
- Tilførsel av aktivt kull/HOK for å binde tungmetaller, dioxiner med mer;
- Våtvasker (skrubber) med tilførsel av lut (NaOH) for å fjerne sure gasser samt vaske ut tungmetaller;
- Katalysator (SCR = Selective Catalytic Reduction) med tilførsel av ammoniakk for fjerning av NO_X.

I energigjenvinningsanlegget blir forbrenningsenergien i avfallet overført til varmt vann og damp ved ca. 40 bar /360 °C. Overføringen skjer delvis i panelvegger (sammensveisede rør hvor vann sirkulerer) i fyrrommet og første del av anlegget samt i varmevekslere som er plassert inne i røykgasskanalene.

Dampen og det varme vannet utnyttes i de to fjernvarmenettene i området (Sentrums-nettet og Holmlia/Bjørndalen) samt ved produksjon av grønn elektrisitet i to dampdrevne turbingeneratorer. De to fjernvarmenettene er i utgangspunktet separert, men energi kan overføres mellom dem via en kryssvarmeveksler. Produsert grønn elektrisk energi leveres til Oslos innbyggere via det lokale kraftnettet.

CO_2-fangstanlegget skal designes for å kunne håndtere den røykgassmengde og sammensetning som forventes å komme fra den enkelte linje separat, samt alle linjer totalt. Tabell 2-2 viser dimensjonerende røykgassmengder med temperatur, oksygeninnhold samt CO_2.

Tabell 2-2: Røykgassmengder og designdata[1].

Beskrivelse	Sum K1 & K2	K3	Totalt
CO_2 mengde	201 900 tonn/år	258 300 tonn/år	460 200 tonn/år
Røykgass (FG) mengde[2]	157 600 Nm³/t	199 200 Nm³/t	356 800 Nm³/t
FG (v/mål O_2, dry)	112 200 Nm³/t	132 400 Nm³/h	244 600 Nm³/t
FG O_2 mål	7 %-vol (tørr)	6 %-vol (tørr)	-
FG CO_2 innhold (11 % O_2)	8.1 %-vol (tørr)	8.1 %-vol (tørr)	-
FG CO_2 innhold (v/ mål O_2)	11.4 %-vol (tørr)	12.2 %-vol (tørr)	-
FG H_2O innhold			-
Vinter	Mettet v/ 35-45 °C	Mettet v/ 35-45 °C	-
Sommer	Mettet v/ 60 °C	Mettet v/ 60 °C	-
FG temperatur			
Vinter	35-45 °C	85-100 °C	-
Sommer	60 °C	85-100 °C	-
Organisk andel i avfallet	50-60 %	50-60 %	50-60 %

[1] Data oppgitt per år hensyntar driftstimer, data oppgitt per time er momentane verdier
[2] Nm³/h: tørr gass, 0 °C, 101.3 kPa, 11 %-vol O_2.

Det er omfattende krav til kontinuerlig måling og overvåking av røykgass og av utslipp. Det utføres periodiske målekampanjer, herunder av røykgassen, og kjennskapen til røykgassens sammensetning er derfor god. Som følge av et litt ulikt oppsett på røykgass-renseanleggene på K1/K2 og K3 er sammensetningen litt forskjellig. Tabell 2-3 angir sammensetningen av røykgassen for de tre linjene separat og den resulterende blanding av alle tre linjene.

Tabell 2-3: Dagens røykgassammensetning for linje K1, K2, K3 separat samt kombinert (ved 11% O_2 dersom annet ikke er angitt).

Komponent	Konsentrasjon (mg/Nm³) K1 (Gj.snitt.)	K2 (Gj.snitt.)	K3 (Gj.snitt.)	Kombinert røykgass (mg/Nm³)
Online målte data				**Gjennomsnitt**
Støv	2.2	5.2	0.7	2.0
TOC/VOC	1.2	1.3	0.4	0.8
HCl	1.4	1.2	0.1	0.6
HF	0.05	0.05	0.08	0.07
CO	31.9	34.6	7.4	18.4
SO_2	14.5	8.7	1.9	6.0
NOx	117.7	111.2	14.4	57.0
NH_3	1.9	N/A	1.3	2
Kampanjemålinger				**Gjennomsnitt**
Acid mist (SO_3)	10.7	8.7	1.3	4.9
Partikler/cm³ [(5)]	858	513	31500	18 000
H_2S	0.5	0.5	0.4	0.4
Cd+Tl	0.00011	0.00010	0.00087	0.0005
Hg	0.0010	0.0001	0.0022	0.001
Sporelementer[6]	0.0019	0.0025	0.0181	0.01
Di+Fu (ng/Nm³)	0.009	0.002	0.026	0.02
NO	109	98	11	50
NO_2	1.90	1.45	0.85	1.2

[5] Representerer submikron-partikler
[6] Sporelementer som inkluderer, men ikke er begrenset til, tungmetaller. Bestående av Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V (+ Sn i nyere kampanjer)

2.3.2 Beskrivelse av CO_2-fangstanlegget

CO_2-fangstanlegget består av følgende hoveddeler:

- For- og etterbehandling av røykgass;
- Absorpsjon og regenerering (aminkretsløp inklusiv stripper);
- CO_2 etterbehandling;
- Intern transport og lagring;
- Eksport til skip;
- Hjelpesystemer.

Med *amin* i teksten nedenfor menes Shells proprietære absorbentløsning; Cansolv DC-103, blandet med 50% vann.

2.3.2.1 For- og etterbehandling av røykgass

Røykgass fra energigjenvinningsanlegget som skal behandles i CO_2-fangstanlegget tas ut fra kanalføringer til skorstein og forbehandles før behandling i absorber. Det vil være et kanalarrangement med spjeld (innløp, utløp og by-pass) som skal kunne sikre inn- og utkobling av CO_2-fangstanlegget samt nødstopp, uten negative konsekvenser for energigjenvinningsanlegget.

Forbehandlingen av røykgass består av en røykgassvifte, gass/gass varmeveksler og en våtvasker for å oppnå riktig renhet og temperatur på røykgass. Varmeveksleren er av regenerativ type som overfører varme fra varm, urenset røykgass til kjøligere, renset røykgass.

I våtvaskeren blir røykgass kjølt ytterligere ved motstrøms direktekontakt med vann. Røykgassen inn på absorberen vil da ha en temperatur på typisk 40 °C og være mettet med fuktighet. Fuktig røykgass er en fordel for å sikre god absorbsjon av CO_2 til aminet samt hindre høy fordamping av vann fra aminløsningen i absorber.

Vann tilført våtvasker vil bli samlet i bunn og sirkulert i en lukket krets via en pumpe og en kjøler. Sirkulert mengde reguleres automatisk for å sikre en fast temperatur på røykgass ut fra våtvasker. [redacted]

Renset røykgass fra absorber behandles i en [redacted] før den sendes til gass/gass varmeveksler og videre til skorstein. [redacted] vil fjerne små partikler og aerosoler av vann og amin.

2.3.2.2 Absorbsjon og regenerering

Absorbsjon og regenerering omfatter aminkretsløpet og består av to hovedkomponenter (absorber og stripper) samt en rekke andre komponenter som pumper, varmevekslere, amin-fordamper, kondenser, amin lagertank, regenerering av amin (TRU), filtre, dampgjenvinning (MVR kompresjon), etc.

Fuktig røykgass tilføres absorber i bunn og renset røykgass tas ut på toppen. Røykgassen møter amin motstrøms i to separate seksjoner med spesialpakning. Denne pakningen er utformet slik at kontaktflaten mellom røykgass og amin er størst mulig, og CO_2-absorbsjon blir mest mulig effektiv. Absorpsjon av CO_2 er en eksoterm reaksjon som er mest effektiv ved lave temperaturer. For å øke effektiviteten av absorbsjonsprosessen er det derfor innført to seksjoner med kjøling av aminet mellom de to seksjonene.

Etter disse to seksjonene utsettes røykgass for et vasketrinn (vann) for å fange eventuelle amindråper, og for å kondensere vann i røykgassen og opprettholde vannbalansen i systemet. Dette er også en seksjon med spesialpakking og temperaturkontroll, dvs. kjøling av vaskevann. Etter dette vasketrinnet strømmer røykgass gjennom en mekanisk dråpefanger før den forlater absorber.

CO_2-holdig amin strømmer fra absorber via en varmeveksler til en stripper hvor CO_2 blir avgitt og aminet regenerert. Aminet tilføres stripper høyt oppe og renner nedover gjennom to seksjoner med pakning. I disse seksjonene møter CO_2-holdig amin varm vanndamp motstrøms. CO_2 frigjøres og strømmer videre oppover i stripper. CO_2-holdig amin strømmer etter disse to seksjonene videre til en avkoker der vann og resterende CO_2 kokes av. Varme tilføres avkoker i form av lavtrykksdamp som kondenseres. CO_2-fritt amin forlater stripper i bunnen. Dette aminet behandles i et dampgjenvinningssystem (MVR) for å bedre energieffektiviteten i CO_2-fangstanlegget før det sendes til aminlagertank.

Vanndamp og CO_2 strømmer ut av stripper på toppen til en kondenser hvor damp og CO_2 blir delvis kondensert. Gass og væske blir deretter separert og væsken (dvs. vann) blir returnert til stripper. CO_2-produktet forlater separatoren via en dråpefanger for å sikre minimalt innhold av vann og amin i produktet.

Stripperen opererer på ca. 1 bar overtrykk [redacted].

Aminet akkumulerer over tid salter og degraderingsprodukter som må fjernes. Dette gjøres i en regenereringsenhet (TRU). [redacted]

[redacted]

2.3.2.3 CO_2 etterbehandling

CO_2 etterbehandling består av kompresjon, fjerning av oksygen, tørking (dvs. fjerning av vann), kjøling, flytendegjøring og lagring. Etterbehandlingen er nødvendig for å sikre at levert CO_2 møter spesifikasjoner for CO_2 som definert for prosjektet.

CO_2-kompresjon opp til ca. 15 barg skjer i en kompresjonsenhet med flere trinn som alle inneholder væskeutskiller, kompressor og etterkjøler. Før kompresjonsenheten er det en væskeutskiller for å sikre væskefri CO_2 før kompresjon. På innløpet til siste kompresjons-trinn tilsettes hydrogen som brukes til å fjerne oksygen i oksygenfjerningsreaktoren.

Etter fjerning av oksygen tørkes komprimert CO_2 i en molekylær sikt og filter. Tørr CO_2 sendes deretter til flytendegjøringsenheten hvor CO_2 kjøles ned og omdannes til flytende form. Flyende CO_2 vil deretter bli sendt til mellomlagring på Klemetsrud før den transporteres med bil ned til lager på Oslo havn.

Kvaliteten på produsert CO_2 vil bli sjekket før lagring, og eventuell produsert CO_2 som ikke møter spesifikasjonene vil bli returnert til absorber for videre prosessering.

2.3.2.4 Transport og lagring

Flytende CO_2 vil bli lagret i horisontale trykktanker med doble vegger (som isolasjon). Hver tank vil ha et lagervolum på 345 m³. Midlertidig lager på Klemetsrud består av fire tanker, som tilsvarer ett døgns produksjon, mens lageret på Oslo havn består av 16 tanker, noe som tilsvarer ca. 4 døgns produksjon.

CO_2 transporteres fra Klemetsrud til Oslo Havn på vei ved bruk av utslippsfrie biler. Det vil være ca. 45 CO_2-transporter i døgnet.

2.3.2.5 Eksport av CO_2

Terminalen på Oslo Havn vil i tillegg til lagertanker bestå av lossestasjoner for bil, lagertanker for CO_2, rørsystemer (både for eksport til skip og mottak av CO_2-gass fra skip), lastearmer, pumper, målestasjon, system for nødavstenging og kraftforsyning. Det vil også være utstyr og rutiner på plass for å dokumentere riktig kvalitet på eksportert CO_2.

2.3.2.6 Hjelpesystemer

CO_2-fangstanlegget inneholder også en del hjelpesystemer som i stor eller liten grad har et grensesnitt mot eksisterende energigjenvinningsanlegg. Slike hjelpesystemer er:

- Kjølesystemer inkl. varmeintegrering med CO_2-fangstanlegg;
- Dampsystemer;
- Ferskvann/drikkevann/demineralisert vann;
- Avløpsvann;
- Trykkluft;
- Kjemikalieinjisering;

- Elektrisk krafttilførsel;
- Prosesskontroll og sikkerhetssystemer.

CO_2-fangstanlegget skal være selvforsynt med kjølekapasitet både sommer og vinter. Siden et større vannreservoar ikke er tilgjengelig på Klemetsrud må all varme kjøles av til luft. Dette gjøres via en lukket og en åpen krets. Kjølesystemet vil ha en forbindelse til energigjenvinningsanlegget slik at eventuell ledig kjølekapasitet skal kunne nyttiggjøres.

Ca. 40 MW varme tilføres CO_2-fangstanlegget som lavtrykksdamp (til stripper avkoker) fra energigjenvinningsanlegget. Små mengder mellomtrykksdamp trengs også i TRU. Dampen returneres som kondensat i en felles ledning.

Ettersom varmen CO_2-fangstanlegget krever er betydelig, har FOV satt krav om at CO_2-fangstanlegget skal kunne levere tilbake opptil 60 MW varme til fjernvarmenettet når dette trengs. Denne varmen hentes ut og løftes i temperatur via en varmepumpe koblet til CO_2-fangstanleggets kjølesystem (lukket krets).

CO_2-fangstanlegget skal i prinsippet være selvforsynt med vann, men det er behov for vann fra energigjenvinningsanlegget og kommunalt nett ved første gangs fylling. Anleggene vil også utformes slik at overproduksjon og ledig kapasitet kan utnyttes begge steder. F.eks. vil CO_2-fangstanlegget levere demineralisert vann til energigjenvinningsanlegget på kontinuerlig basis.

CO_2-fangstanlegg og CO_2 eksportterminal på Oslo Havn skal være selvforsynt med trykkluft og systemer for injisering av kjemikalier. CO_2-fangstanlegget skal også ha et eget fordelingsnett for elektrisk kraft og et eget kontroll- og sikkerhetssystem uavhengig av energigjenvinningsanlegget.

2.3.3 Arealutnyttelse for CO_2-fangstanlegget (Plot Plan)

Arealutnyttelse for CO_2-fangstanlegget på Klemetsrud er vist i figur 5-14 med 3D-illustrasjoner i figur 5-15 og 5-16.

Som del av CO_2-fangstanlegget på Klemetsrud er det også vist arealutnyttelse for mellomlager med fyllestasjon for lastebiler. Dette er vist i figur 5-21 og med 3D-illustrasjon i figur 5-22.

Utskipning av flytende CO_2 vil skje over Oslo Havn og arealutnyttelse for havneterminal er vist i figur 5-27 med 3D-illustrasjon i figur 5-29 og 5-30.

2.3.4 Teknologikvalifisering

2.3.4.1 Beskrivelse av pilotanlegg og testing

I juli 2018 ble det bestemt å bygge et pilotanlegg i skala 1:350 for å dokumentere at valgt fangstteknologi er egnet for å rense CO_2 fra den spesifikke røykgassen fra energigjenvinningsanlegget, samt vise at utslippene av amin er innenfor de kravene som er satt. Kravene til pilottestingen var minimum 2000 timer driftstid med høy kapasitet, samt at aminutslippene skulle være lavere enn 0.4 ppmv i gjennomsnitt over de siste 500 timene av testen. I tillegg til dette skulle det måles og analyseres degradering av amin, amininnhold i vaskevann, fangst-effektivitet for CO_2, kvalitet på fanget CO_2 samt kvalitet på renset røykgass.

Plan for testing ble utviklet av FOV og Shell, men presentert og diskutert med alle involverte parter – dvs. Gassnova, TCM, Universitet i Oslo, DNV GL og Rambøll. Flere fellesmøter har vært avholdt for å sikre erfaringsoverføring og god kvalitet på testarbeidet.

Hovedkomponentene i pilotanlegget er skalert slik at viktige prosessparametere er tilsvarende som for et fullskalaanlegg. Pilotanlegget inneholder alle hovedkomponenter som et fullskalaanlegg bortsett fra amin regenereringsenhet (TRU) og MVR kompressor. Damp ble levert fra en egen dampgenerator i stedet for fra energigjenvinningsanlegget og kjølevann har vært i form av en åpen krets. Pilotanlegget mottar røykgass fra linje K1, K2 og K3 med mulighet for å styre røykgassmengden fra alle tre linjene. Det har vært et mål å gjenskape samme røykgassblanding for pilotanlegget som et fullskalaanlegg vil motta.

Pilotanlegget ble levert av TechnipFMC og deres underleverandør Kanfa. Prosjekteringen startet i august 2018 og anlegget ble levert til Klemetsrud 24. januar 2019. Montasje og systemutprøving pågikk fram til 1. mars da anlegget ble startet opp for første gang. Anlegget har blitt driftet av FOVs egne driftsoperatører, mens måling av utslipp og analyser har vært utført av Universitet i Oslo og Rambøll Finland.

Punkter for gassmåling har vært 1) urenset røykgass ved innløp, 2) renset røykgass ved utløp og 3) CO_2-produkt. Måling har blitt utført online og ved prøvetaking. Punkter for prøvetaking av væske har vært 1) amin før absorber, 2) amin etter absorber, 3) vann ut fra pre-scrubber, 4) vaskevann fra absorber og 5) refluksvæske (utløp stripper).

Pilotanlegget har fungert som forventet og alle tester har blitt utført i henhold til oppsatt plan. 2000 driftstimer ble gjennomført med en oppetid på mer enn 95%, og ble avsluttet i første uke av juni 2019. Testresultatene viste at aminutslippene lå vesentlig lavere enn måltallet på 0.4 ppmv [redacted]. Amin-degradering viste som forventet en stigende trend gjennom hele testen og endte på ca. 2% etter 2000 timer. Fanget CO_2 har vært relativt ren og inneholdt få forurensninger. Fangst-effektivitet for CO_2 har variert med anleggets belastning og har vært mellom 90 og 99%. Detaljerte testresultater finnes i egen rapport [3].

2.3.4.2 Teknologikvalifisering

På oppdrag fra FOV har DNV GL utfør en kvalifisering av Shells Cansolv teknologi for CO_2-fangst, for bruk på FOVs anlegg for avfallsforbrenning på Klemetsrud. Teknologikvalifiseringen har vært utført basert på DNV GL-publikasjonene DNVGL-RP-A203 [17] and DNVGL-RP-J201 [18]. Begrepet «Kvalifisert Teknologi» er definert av DNV GL som «teknologi hvor et sett definerte akseptkriterier for ytelse og bruksområder er definert og hvor oppfyllelse av disse kriteriene er demonstrert».

Kvalifiseringsarbeidet startet i 2018 og ble ferdigstilt i juni 2019. Arbeidet har omfattet flere arbeidsmøter samt en grundig gjennomgang av teknologi og løsninger, planlegging av kvalifiseringsaktiviteter, trussel- og risikoanalyse, vurdering av resultater fra pilot-testing samt rapportering og utstedelse av sertifikat. Kvalifiseringen er dokumentert i en rapport [4]. Hovedkonklusjoner fra kvalifiseringsprosessen er:

- Testbetingelsene, dvs. relevante prosessparametre, i pilotanlegget har vært representative i testperioden;
- Fangstprosessen har bevist at ved planlagt driftstilstand er gjennomsnittlig verdi for aminutslipp lavere enn 0.4 ppmv, som er definert akseptkriterium for utslipp. Ved stabil drift har faktisk målte verdier for aminutslipp vært lavere enn 0.1 ppmv, [redacted];
- [redacted];

- Representativt nivå av degraderingsprodukter [redacted] har blitt målt i pilottesten.

Basert på ovennevnte konklusjoner har DNV GL utstedt et «Statement of Qualified Technology» for Shells Cansolv teknologi, for bruk til CO_2-fangst fra Klemetsrud energigjenvinningsanlegg (Figure 5-12). Dette sertifikatet dokumenterer at valgt teknologi er egnet for formålet.

2.3.5 Bygging og integrasjon

Det er naturlig å dele det totale CO_2-fangstanlegget inn i to deler: Selve CO_2-fangstanlegget med mellomlager på Klemetsrud og anlegget i Oslo havn for mellomlager og utskipning.

CO_2-fangstanlegget skal etableres i tilknytning til eksisterende energigjenvinningsanlegg. Det er begrenset areal og det må utføres omfattende sprengnings- og grunnarbeider før selve CO_2-fangstanlegget kan oppføres. Nærliggende transformatorstasjon må oppgraderes for å sikre tilstrekkelig kapasitet til CO_2-fangstanlegget.

Det vil være mange personer involvert på byggeplassen, og god planlegging av rekkefølge på bygge- og montasjearbeider er vesentlig for sikkerhet, fremdrift og kostnader. Tilstrekkelig med områder for rigg og mellomlagring/premontasje etc. er viktig, og her er flere aktuelle områder under vurdering. Transport av store/tunge enheter fra havn til anlegget er undersøkt og de ulike transportruters begrensninger er vurdert i FEED-arbeidet.

I Oslo havn er Kneppeskjær valgt som lokasjon for mellomlager og utskipning. Området er etablert med kaianlegg og generell infrastruktur, men byggearbeider vil kreve rivning av eksisterende lagerskur før bygging av CO_2-lager og lasteanlegg for skip kan begynne. Tilførsel av elektrisk kraft fra Bekkelaget transformatorstasjon må oppgraderes.

Integrering med eksisterende anlegg er planlagt for å sikre fleksibilitet med hensyn til fremdrift, samt å begrense de driftsmessige avhengigheter mellom eksisterende og nytt anlegg. Integrasjonspunkter skal i størst mulig grad forberedes slik at de kan etableres i forbindelse med de planlagte vedlikeholdsstoppene på energigjenvinningsanlegget. Integrasjonspunktene er i hovedsak:

- Røykgass til/fra CO_2-fangstanlegget samt by-pass;
- Damp og kondensat;
- 11 kV el-tilførsel;
- Tilkobling til varmepumper for å utnytte lavtemperatur varme inn i fjernvarmenettet;
- Vann og avløp fra offentlig nett;
- Signalutveksling.

Anleggene skal ha separate styringssystemer og kun et mindre antall signaler skal utveksles.

2.3.6 Drift og vedlikehold

CO_2-fangstanlegget kommer til å ha en høy grad av automasjon og vil blir driftet fra samme kontrollrom som eksisterende energigjenvinningsanlegg. Det er i dag en 24/7 6-skifts ordning med [redacted] operatører på skiftet. For å kunne drifte alle FOV sine varmesentraler fra felles kontrollrom er bemanningen planlagt å være [redacted] personer. I god tid før igangkjøring av CO_2-fangstanlegget vil bemanningen bli utvidet med ytterligere en person som skal være dedikert til CO_2-fangstanlegget. Til tross for at en spesifikk person per skift har hovedansvaret for CO_2-fangstanlegget og tilhørende utstyr, skal samtlige operatører læres opp i driften av CO_2-fangstanlegget for å sikre god robusthet. Opplæring skal gjennomføres teoretisk og praktisk som en del av igangkjøring av det nye CO_2-fangstanlegget.

Håndtering av lasting av CO_2 på Klemetsrud og lossing til mellomlager i Oslo Havn skal utføres av tankbilsjåførene.

Mottak av skip og lasting av CO_2 i Oslo havn vil være med bemanning av FOV sitt personell samt overvåket fra kontrollrom på Klemetsrud.

Planlagt vedlikehold skal tilpasses hele verdikjeden og energigjenvinningsanleggets plan for stopp i de ulike linjene. Selv ved den årlige vedlikeholdsstoppen i energigjenvinningsanlegget vil det alltid være en forbrenningslinje i drift, og den planlagte vedlikeholdsstoppen i CO_2-fangstanlegget skal legges slik at tapt CO_2 minimeres.

FOV benytter i stor grad faste samarbeidspartnere, gjennom rammeavtaler, til generelt vedlikehold. Disse vil også bli benyttet ved vedlikehold av CO_2-fangstanlegget med tilhørende utstyr.

2.4 Helse, miljø og sikkerhet

Formålet med HMS-arbeidet i prosjektet er å sikre at risikoen for alle faser av prosjektet er redusert til et minimum gjennom planlegging, organisering og kontrollerende tiltak. Hovedmålet til prosjektet er å unngå skader på mennesker, utstyr eller miljø. HMS-arbeidet vil være et verktøy for den systematiske oppfølgingen av forhold som er relevante for HMS internt, for TechnipFMC eller underleverandører. Hovedlinjene vil være:

- HMS skal være et kriterium ved valg av leverandører;
- Endringer i prosessen, systemer eller organisasjon skal vurderes med tanke på HMS;
- Det skal være fokus på kontinuerlig forbedring med tanke på HMS;
- HMS-funksjonen skal ha rammer og myndighet til å gjennomføre arbeidet;
- HMS er et linjeansvar, og dette betyr at alle har et individuelt og kollektivt ansvar for å identifisere risiko i forbindelse med aktiviteter. Hovedansvaret for HMS ligger hos Prosjektleder.

Gjennom FEED-fasen har prosjektet utviklet følgende HMS-mål for den neste fasen:

- Ulykker: 0;
- Antall tapte arbeidsdager (>1 dag): 0;
- Antall HMS-runder av prosjektledelsen (under uker med konstruksjon på området): 10 hver uke;
- Antall rapporterte nesten-ulykker eller forbedringsforslag: Minimum 300 per 1 000 000 arbeidstimer;
- Antall lekkasjer: 0;
- Antall branner: 0;
- Lydnivået er innenfor de satte nivåer, gitt av tillatelser.

En HMS-plan vil bli utviklet av hovedentreprenør TechnipFMC i begynnelsen av neste fase for deres arbeid. Denne vil bli basert på:

- Fortum Corporate Safety Manual [48];

- SHA-planen utviklet for prosjektet, som er basert på kravene i Byggherreforskriften;
- Sikkerhetsplanen for anleggsområdet.

TechnipFMC vil være Hovedbedrift i byggefasen og derigjennom ha ansvaret for samordning av HMS på byggeplassene.

I FEED-fasen har det vært gjennomført flere HMS-relaterte studier. Et viktig bidrag har vært den kvantitative risikoanalysen. Denne viser at risikoen er akseptabel for 3. person basert på DSB sine foreslåtte akseptkriterier, som er benyttet i prosjektet.

2.5 Kvalitet og risikostyring

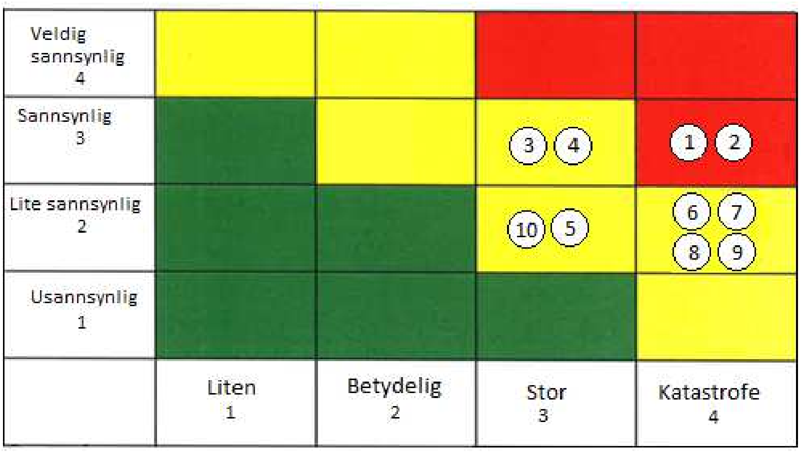
FOV er sertifisert i henhold til ISO 9001:2015 og ISO 14001:2015 og prosjektet har utviklet og fulgt et system basert på FOVs prosedyrer og metodikker samt prinsippene i disse standardene. Kvalitetsarbeidets hensikt er å sikre at prosjektets aktiviteter er i henhold til gjeldende koder, standarder, spesifikasjoner og god industristandard. Følgende kvalitetsmål vil gjelde for neste fase:

- Sikre at risikoregisteret er kontinuerlig oppdatert, og at en grundig gjennomgang er gjennomført månedlig;
- Sikre at to kvalitetsrevisjoner er gjennomført på hovedkontraktør årlig;
- Sikre at fremdriften i prosjektet følger den planlagte fremdriftsplanen;
- Sikre at CO_2-fangstanlegget blir bygget og driftet uten kvalitetsavvik.

Det er blitt gjennomført flere kvalitetsrevisjoner, både av og for prosjektet. Dette er dokumentert og fulgt opp gjennom flere ulike rapporter.

Risikostyring har vært, og vil fortsette å være et integrert og viktig styringsverktøy i prosjektet. Formålet med styringssystemet er å systematisk og periodisk identifisere, klassifisere og behandle risikoer og muligheter som kan øke eller redusere muligheten for å oppnå prosjektmålene.

Gjennom FEED-fasen, har det blitt opprettet og oppdatert et risikoregister som har blitt rapportert månedlig til Gassnova. På slutten av FEED-fasen ble det gjennomført en risikoanalyse der fokuset var på neste fase. Dette risikoregisteret vil bli videreført inn i neste fase.



Figur 2-1: Risikomatrise

Topp 10 risiko for neste fase er presentert i Tabell 2-4:

Tabell 2-4: Topp 10 risiko i utførelse fase.

ID	Kategori	Beskrivelse	Risikoreduserende tiltak
1	Finans og økonomi	Valutarisiko. Det er negativt for prosjektet hvis den norske kronen er svak*	Sikring (hedging) av valuta. Ulike deler av kontrakten er i ulike valutaer.
2	Fremdrift/ Plan	Forsinket ferdigstillelses periode. Definerte tester må være gjennomført før oppstart og drift.	God planlegging, og aktiv involvering av operatører
3	Finans og økonomi	En lang venteperiode er en risiko, fordi kostnader kan øke i perioden, på grunn av markedsituasjonen, valuta og inflasjon	Prosjektet har ingen påvirkning på hvor lang venteperioden blir. Risikoen blir større jo lengre venteperioden er, fordi det er større muligheter til å kontrollere dette når prosjektet har startet, og kontraktene er underskrevet.
4	Fremdrift/ plan	Forsinkelser i grunnarbeider	Gode forundersøkelser og planlegging av arbeidet. Risikoanalyse og oppfølging av risikoreduserende tiltak. Tett oppfølging av entreprenør. Å planlegge arbeidet slik at deler av området blir gjort tilgjengelig så tidlig som mulig for entreprenør for CO_2-fangstanlegget.
5	Tekniske tiltak	Forurenset grunn som oppdages etter at prosjektet har startet	Foreløpig miljøundersøkelse gjennomført i FEED-fasen viser ingen forurensinger eller usikre grunnforhold. Videre miljøundersøkelse av grunn gjennomføres før oppstart av grunnarbeider
6	Finans og økonomi	Konkurs eller finansielle problemer, inkludert sammenslåinger for hovedkontraktør og/eller underleverandører	Dette håndteres gjennom bestemmelser i kontrakten, men risikoen kan aldri bli helt borte
7	Finans og økonomi	Ikke mange nok tilbydere til å oppnå en god pris. CAPEX kan øke på grunn av markedssvinger	Incentiver i kontrakten til å redusere kostnaden, så mye som mulig. Tilrettelegge for konkurranse der det er mulig.
8	HMS	Storulykke med omkommende på området.	Høyt fokus på HMS gjennom planlegging, sikkerhetsrunder, inspeksjoner, forbedringsforslag. Mange HMS-inspektører gjennom byggingen. Bruk av Fortum prosedyrer og rutiner
9	Finans og økonomi	Overskridelse av CAPEX	God planlegging, nøye oppfølging av leverandører og underleverandører, samt kontrakter som begrenser risikoen for overskridelser.
10	Drift	Lavere tilgjengelighet til anlegget enn planlagt under driftsfasen av CO_2-fangstanlegget. Dette kan føre til lavere CO_2 fangst.	Vedlikehold: planlagt revisjonstans ved CO_2-fangstanlegget vil bli koordinert med planlagt vedlikehold på energigjenvinningsanlegget for å redusere nedetid. Standardisering og reservedelsstrategi vil bli utviklet for å for å minimere nedetid. Drift: trent personell er nødvendig for å ha høy oppetid og god ytelse.

*: Endelig valutaeksponering er en del av pågående kontraktsforhandlinger med OED.

2.6 Myndighetskrav og godkjenninger

For å etablere et CO_2-fangstanlegg er det en rekke formelle krav og forhold som må være avklart. Dette er primært knyttet til krav i Plan- og bygningsloven med underliggende forskrifter, krav i Forurensningsloven med underliggende forskrifter og krav knyttet til Brann- og eksplosjonsvernloven.

2.6.1 Plan- og bygningsloven

Et grunnleggende krav er at området må være regulert til et formål som muliggjør etablering av CO_2-fangstanlegg og mellomlager for den fangede CO_2. Ønsket utbygging på Klemetsrud er vurdert i henhold til kravene i Plan- og bygningsloven §12-10 første ledd, j. §§ 4-1 og 4-2 med tilhørende forskrift. Dette tilsa at det var behov for ny reguleringsplan og innebar også et krav om konsekvensutredning. Forskriften om konsekvensutredning regulerer denne prosessen og et planprogram for arbeidet er utarbeidet. Etter en høringsrunde og en justering av planprogrammet er det utarbeidet en reguleringsplan med konsekvensutredning for utvikling av området. Konsekvensutredningen beskriver alle forhold som de planlagte aktiviteter vil kunne få for miljø og samfunn. Dette omfatter forhold som utslipp til luft og vann, støy, trafikkforhold, fjernvirkning, naturmangfold, friluftsliv og en risiko- og sårbarhetsanalyse. Dokumentene har vært på høring, og høringsuttalelser er svart ut og innarbeidet i nødvendig grad i de reviderte dokumentene. Planmyndighetene har oversendt dokumentene til politisk behandling 30.8.2019. Reguleringsplan med konsekvensutredning vil bli godkjent av byrådet i Oslo Kommune innen 1. november 2019.

En godkjent reguleringsplan er en forutsetning for å kunne få behandlet en byggesøknad. Det vil også være behov for noe mer detaljplanlegging knyttet til CO_2-fangstanlegget før byggesøknaden kan bli sendt. I henhold til planlagt framdrift er det derfor stipulert oversendelse av søknaden innen 28.02.2020 og 6 måneders saksbehandlingstid for denne.

Byggteknisk forskrift regulerer de byggtekniske krav til bygninger og dokumentasjon mens byggesaksforskriften bl.a. regulerer selve byggesaksprosessen, og er derfor sentrale i det videre arbeidet.

2.6.2 Forurensningsloven

Formålet med loven er å beskytte miljøet mot forurensning som skyldes kjemikalier og/eller avfall som er skadelig for helse og miljø. Loven regulerer all aktivitet som kan medføre forurensning. Det generelle prinsippet er at ingen forurensning er tillatt med mindre det er gitt en spesifikk tillatelse til dette. Ettersom et CO_2-fangstanlegg vil innebære en slik risiko, må det søkes om utslippstillatelse. Miljødirektoratet er forurensningsmyndighet for dagens avfallsforbrenningsanlegg og vil også være det for CO_2-fangstanlegget.

Dette innebærer at det må utarbeides en søknad i tråd med kravene i forurensningsforskriften §36. Det ble sendt en utslippssøknad i november i 2018 og det er avholdt to møter med direktoratet vedrørende søknaden. En liste over mangler i søknaden er mottatt, og arbeidet med å fremskaffe de påpekte mangler pågår. Dette innebærer bl.a. å utarbeide nye spredningsberegninger som dokumenterer at utslippene fra virksomheten ikke overskrider myndighetenes krav til utslipp av aminer til luft, eller overskridelser knyttet til avsetningsbidrag til vann. Forurensningsmyndigheten vil imidlertid ikke ferdigbehandle søknaden før de reguleringsmessige forholdene er avklart. I planen for videre framdrift er det derfor satt en frist for oversendelse av komplett utslippssøknad til 20.12.2019 og en avklaring på denne innen utgangen av 2020.

2.6.3 Brann- og eksplosjonsvernloven

Formålet med loven er å beskytte liv, helse, miljø og materialer mot brann og eksplosjon, mot ulykker med farlig stoff og farlig gods og andre akutte ulykker, samt uønskede tilsiktede hendelser. Det har vært en dialog med Direktoratet for samfunnssikkerhet og beredskap (DSB) om hvorvidt CO_2-fangstanlegget må ha et samtykke fra dem. Konklusjonen er at CO_2-fangstanlegget er samtykkepliktig i henhold til DSBs regelverk, og søknad er under utarbeidelse. Et viktig grunnlag for søknaden er en risikovurdering av den etablering som planlegges. Det vil primært være risikoen knyttet til mellomlageret som kan innebære en risiko for liv og helse, da store mengder CO_2 oppbevares under trykk og dermed kan utgjøre en viss fare ved en større lekkasje. I henhold til planlagt framdrift vil søknaden til DSB bli oversendt innen 20.12.2019 og en avklaring antas innen utgangen av mars 2020.

2.7 Prosjektplan og Prosjektgjennomføring

2.7.1 Prosjektplan

Prosjektplanen er etablert basert på en investeringsbeslutning i 4. kvartal 2020 og med prosjektoppstart januar 2021. Prosjektplanen er etablert og dokumentert med basis i krav fra AACE RP 38R-06 «Documenting the Schedule Basis».

Prosjektplanen for prosjektering og byggefasen er utviklet på basis av informasjon fra leverandører sammen med nødvendig informasjon fra prosjektteamet. TechnipFMC er den desidert største og viktigste leverandøren, og deres prosjektplan er benyttet for de fleste av aktivitetene i prosjektplanen.

Prosjektplan for prosjektering og byggefasen er visst i figur 10-1.

Både leverandør for grunnarbeider og hovedleverandør TechnipFMC vil starte sitt arbeid kort tid etter prosjektoppstart. Grunnarbeider inklusive sprenging og bortkjøring av masser er en relativt tidkrevende prosess, og starter derfor tidlig. Grunnarbeider for de første arealene vil være klare for start av installasjonsarbeider 1. kvartal 2022.

Prosjekteringsaktiviteter vil også starte kort tid etter prosjektstart og vil ha en varighet på 15 måneder. Selve byggeaktiviteten vil ha en varighet på ca. 24 måneder på Klemetsrud og 12-18 måneder på Oslo Havn.

Stripperkolonnen er den største enkeltkomponenten som skal fraktes til byggeplassen, og den er planlagt levert på Klemetsrud i slutten av desember 2022.

Mekanisk ferdigstillelse og idriftsettelse er planlagt over en periode på 8 måneder, og CO_2-fangstanlegget vil være klart for oppstart i juli 2024. Det vil da gjennomføres en 8 ukers testperiode etterfulgt av en ytelses-test. Når denne er akseptert er CO_2-fangstanlegget klart for normal drift (planlagt til september 2024).

2.7.1.1 Risikovurdering av prosjektplan

Det er gjort en foreløpig risikovurdering av prosjektplanen for prosjektering og byggefasen. I planen er det lagt in buffer for eventuelle forsinkelser der det er mulig.

Forsinkelser av aktiviteter er den største risikoen for en forsinkelse av hele prosjektplanen, og det er identifisert følgende viktigste risikoer for forsinkelser:

1. Forsinkelse av aktiviteter i prosjektgjennomføring som gir forsinkelse av idriftsettelse og oppstart av produksjonsfasen;

2. Prosjektmobilisering: kort tid fra kontrakt til prosjektteamet skal være mobilisert er krevende og kan føre til forsinkelse;
3. Forsinket byggetillatelse for oppstart;
4. Sprenging og fundamentering kan føre til forsinket oppstart av montasjearbeider.

Dette er risikoelementer som vil bli regelmessig vurdert og skadebegrensende tiltak vil identifiseres og iverksettes.

2.7.1.2 Milepælsplan

Det er etablert en milepælsplan med viktige milepæler for prosjektet. Følgende hovedmilepæler er identifisert:

Tabell 2-5: Hovedmilepæler

Milepæl	Planlagt dato
Signert kontrakt med OED	04.01.2021
Kontrakt for grunnarbeider signert	18.01.2021
Kontrakt med TechnipFMC signert	18.01.2021
Destillasjonskolonne (stripper) levert Klemetsrud	[redacted]
Mekanisk ferdigstillelse	29.02.2024
Idriftsettelse ferdigstilt	[redacted]
CO_2-fangstanlegg klart for normal drift	[redacted]
Ytelsestest ferdigstilt	[redacted]
Leveranseprotokoll signert	27.10.2024

2.7.2 Prosjektgjennomføring – bygging og drift

Prosjektet vil bli gjennomført basert på Fortums prosjektgjennomførings-modell, inklusive relevante prosjektprosedyrer og definerte beslutningspunkter.

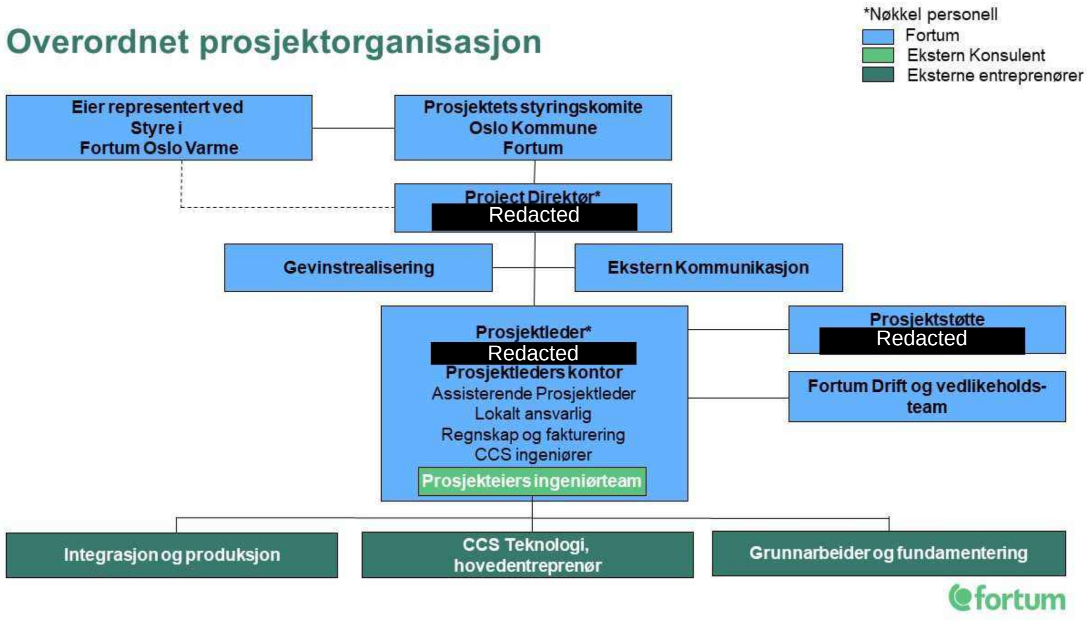
TechnipFMC som hovedleverandør vil ha sin egen prosjektorganisasjon og vil rapportere til Fortums prosjektleder og Fortums prosjektkontor/-organisasjon.

Både Fortum og TechnipFMC har bred erfaring med gjennomføring av store og komplekse industriprosjekter, og innehar den kunnskap som vil være nødvendig for gjennomføring av prosjektet.

Shell er valgt som leverandør av selve fangst-teknologien, med spesifikk kompetanse fra CO_2-fangstanlegg på kullkraftverket til SaskPower Boundary Dam i Saskatchewan, Canada.

2.7.2.1 Organisasjon i Prosjektering og byggefase

I prosjektering og byggefasen er den overordnede organisasjonen i prosjektet som angitt i Figur 2-2.



Figur 2-2: Overordnet prosjektorganisasjon.

Fortum Oslo Varme AS, ved sitt styre, er eier av prosjektet og har det overordnede ansvaret for at prosjektet når sine målsettinger, og at det legges til rette for prosjektgjennomføringen.

Medlemmer av styringskomiteen utnevnes av Eier, og prosjektdirektør rapporterer til Styringskomiteen.

Prosjektdirektøren har i tillegg det overordnede ansvaret for kommunikasjon med Olje- og energidepartementet, samt annen ekstern kommunikasjon og koordinering av gevinstrealiseringsarbeidet.

Ansvarlig for prosjektstøtte sikrer at relevante rutiner og prosedyrer i Fortums prosjektgjennomføringsmodell blir anvendt, og vil være direkte rådgiver til prosjektleder og hans gruppe.

Prosjektleder har det overordnede ansvaret for driften av prosjektet inkludert oppfølging av kostnader, fremdrift, risikostyring og helse, miljø og sikkerhet.

Prosjektleders kontor vil bestå av byggherres prosjektteam, som igjen vil bestå av Fortum-personell og innleid personell. Dette teamet vil være ansvarlig for drift og oppfølging av prosjektet samt for oppfølging av alle kontrakter og entreprenører som er engasjert i prosjektet. Prosjekt teamet vil ha følgende hovedoppgaver i prosjektet:

- Generell prosjektoppfølging og gjennomføring;
- Prosjektering og dokumentoppfølging/ledelse;
- Kvalitetsledelse;
- Grensenittansvarlig;
- Innkjøp og oppfølging av leveranser utenfor TechnipFMCs arbeidsomfang;
- Oppfølging på byggeplass med SHA/HMS- oppfølging, myndighetskontakt og generell oppfølging av arbeider på byggeplass.

2.7.2.2 TechnipFMC organisasjon

TechnipFMC vil etablere sin egen organisasjon for gjennomføring av prosjektet. Prosjektet vil ledes ut fra deres kontor i Lyon. [redacted] er nominert som TechnipFMC prosjektleder og vil ha det overordnede ansvaret for leveransen av prosjektet. TechnipFMC prosjektleder rapporterer direkte til Fortums prosjektlederkontor. TechnipFMC prosjektorganisasjon er gitt i figur 11-5.

Når TechnipFMC starter arbeider på byggeplass vil en byggeplassorganisasjon etableres. Byggeplassleder vill rapportere direkte til TechnipFMC prosjektleder. TechnipFMC byggeplassorganisasjon er gitt i figur 11-6.

2.7.2.3 Organisasjon i driftsfasen

Driftspersonell for CO_2-fangstanlegget vil rekrutteres i god tid før igangkjøringsfasen starter. Personell for drift og vedlikehold av CO_2-fangstanlegget vil inngå i FOVs normale drift og vedlikeholdsorganisasjon og man vil kunne trekke på ressurser i denne organisasjonen ved behov.

Det er antatt at det vil være behov for en ekstra operatør på kontinuerlig skiftordning for å drifte CO_2-fangstanlegget. Organisasjon i driftsfasen er gitt i figur 11-7.

2.7.2.4 Underleverandører

Underleverandører er blitt identifisert og prekvalifisert i forprosjektfasen. TechnipFMC har sine nominerte underleverandører som er identifisert i deres dokumentasjon. Øvrige underleverandører er primært innenfor følgende områder:

- Grunnarbeider og fundamentering;
- Transport av CO_2 fra Klemetsrud til Oslo Havn;
- Integrasjonsarbeider inkludert E&I, rørmontasje, mekanisk montasje og stålarbeider;
- Ingeniørassistanse;
- Juridisk assistanse;
- Kommersiell assistanse.

2.7.2.5 Grensesnittbehandling

Koordinator for grensesnittbehandling vi være ansvarlig for å sikre at grensesnitt mellom de ulike aktørene i prosjektet ivaretas. En grensesnittansvarlig vil bli nominert fra alle aktører, og kommunikasjon angående grensesnitt vil skje mellom prosjektets grensesnittansvarlige og disse.

2.7.3 Prosjektgjennomføringsmodell

Fortum prosjektgjennomføringsmodell vil bli implementert i neste fase av prosjektet. Denne er beskrevet i mer detalj i Project Execution Method [5]. Følgende prosjektfaser er identifisert i gjennomføringsmodellen for bygging:

- Prosjektetablering;
- Prosjektoppstart;

- Prosjektgjennomføring;
- Verifikasjon av at CO_2-fangstanlegget er klar for idriftsettelse;
- Idriftsettelse og overtagelse;
- Prosjektferdigstillelse.

Etter prosjektets ferdigstillelse vil prosjektet gå over i en driftsfase.

Fortums prosjektledelseskontor vil bestå av Fortum-personell i samarbeid med et innleid konsulentteam som beskrevet 2.7.2.1.

2.8 Gevinstrealisering

Hvert år produseres det mer enn 2 milliarder tonn avfall i verden, og håndteringen av dette avfallet forårsaker store globale utslipp av klimagasser. Husholdningsavfall alene (Municipal Solid Waste, MSW) står for hele 5% av de globale klimagassutslippene.

Anslagsvis 1.6 milliarder tonn CO_2-ekvivalenter ble generert fra MSW alene i 2016, og er forventet å stige til 2.6 milliarder tonn CO_2-ekvivalenter i 2050. Overgangen fra deponier til sortering, gjenvinning og energigjenvinning av restavfall reduserer både klimagassutslipp og generell miljøpåvirkning betydelig. Forbedring av avfallshåndteringen er derfor et av de viktigste tiltakene for å nå målene i Parisavtalen fra 2017.

Energigjenvinningsanleggenes viktigste rolle er å brenne avfall som ikke kan forhindres eller resirkuleres, og generere energi fra varmen etter forbrenningen i form av damp, strøm eller varme/kjøling. Energigjenvinning er den mest bærekraftige løsningen i dag for restavfall som ikke kan eller ikke bør gjenvinnes, og er en viktig del av et kretsløpsbasert avfallssystem. Energigjenvinning er ikke en motsetning til sortering og gjenvinning, men en nødvendig del av sirkulærøkonomien som fjerner uønskede, giftige komponenter fra materialkretsløpet og gjør det mulig å ta vare på ressursene i det øvrige avfallet.

Koblingen mellom karbonfangst, energigjenvinning og fjernvarme er viktig ut fra et ressursperspektiv. Den tilgjengelige overskuddsvarmen fra fangstprosessen kan brukes i eksisterende fjernvarmeanlegg eller til og med bidra til å utløse etableringen av nye fjernvarmenett.

Avfallsforbrenning med energigjenvinning vil i seg selv bidra til mer enn 75% reduksjon av klimagasser sammenlignet med deponering av det samme avfallet. Overgangen fra deponier til sortering, resirkulering og energigjenvinning av restavfall gjør det også mulig å fjerne de fortsatt betydelige punktutslippene av CO_2 fra avfallsforbrenningen, og danner grunnlaget for utviklingen av karbonfangst og lagring i avfallsindustrien.

Forbrenning med energigjenvinning er den beste måten å behandle plast som ikke er mulig å resirkulere, eller som har blitt resirkulert flere ganger og ikke lenger kan materialgjenvinnes. Mengden plast i verden vokser og forventes å bli tredoblet i løpet av de neste 30 årene. Dette gir store utfordringer både på kort og lang sikt, selv med omfattende forskning og utvikling av sorteringssystemer, resirkuleringsteknologi og utvikling av mer gjenvinnbare emballasjeløsninger. Ved å etablere CO_2-fangst på energigjenvinning, og dermed fra forbrenning av plast som ikke lenger kan gjenvinnes, kan denne utfordringen håndteres på en bærekraftig måte.

Energigjenvinning med CO_2-fangst kan bidra betydelig til å oppnå negative utslipp. Omtrent 50% av det avfallet som forbrennes er av ikke-fossil (biogen) opprinnelse (blant annet matavfall, tekstiler, tre og papir/papp), noe som betyr at halvparten av CO_2-utslippene fra energigjenvinning vil være en del av det naturlige CO_2-kretsløpet. Dermed vil CO_2-fangst på energigjenvinning i praksis fjerne CO_2 fra atmosfæren. Dette blir ofte referert til som ”negative utslipp”, dvs. utslippsreduksjoner som gir en større effekt enn å redusere utslipp fra forbrenning av fossilt brensel. Avfall er en av få etablerte, globale verdikjeder som produserer energi fra biomasse, noe som gir et betydelig BIO-CCS (BECCS)-potensial i energigjenvinningsindustrien. Negative CO_2-utslipp vil også bidra til å nøytralisere andre utslipp som er mye vanskeligere å redusere eller fjerne i et kort til mellomlangt perspektiv.

CO_2-fangst på energigjenvinning er det naturlige neste skrittet mot en bærekraftig og sirkulær avfallsbehandling. FOVs CO_2-fangstprosjekt demonstrerer hvordan byer kan kutte store utslipp, utnytte lokale ressurser og redusere klimaendringene fra avfallshåndtering som en del av bærekraftige byløsninger. CO_2-fangst fra energigjenvinning kan være en viktig del av byers utslippsreduksjon, ettersom energigjenvinningsanlegg i mange byer er det største punktutslippet av CO_2.

Det er en økende etterspørsel etter energigjenvinningskapasitet i Europa i takt med at EU beveger seg bort fra deponier og mot økt sortering og gjenvinning. 142 millioner tonn restbehandlingskapasitet vil være nødvendig i EU innen 2035 for å oppfylle EUs mål for materialgjenvinning (65% materialgjenvinning og en reduksjon til 10% deponi). Med dagens kapasitet på 100 millioner tonn for energigjenvinning må det etableres rundt 40 millioner tonn ny energigjenvinningskapasitet med mulighet for etablering av CO_2-fangst i EU. Disse anleggene kan i fremtiden bygges med CO_2-fangst som en integrert del av røykgassrensingen.

Fortum verdsetter det unike potensialet som FOVs CO_2-fangstprosjekt representerer for Norge. Oslo og Fortum har sammen en sterk interesse av å utvikle teknologien i retning av kostnadseffektive, sikre og kvalifiserte løsninger for dekarbonisering av avfalls- og energisektoren. Fortum og FOV ønsker å være ledende innenfor utvikling og kommersialisering av CCS-teknologien, og å utvikle både industrien, teknologien og nye, grønne arbeidsplasser.

FOVs CO_2-fangstprosjekt vil generere stor internasjonal lærings- og overføringsverdi. FOV arbeider derfor aktivt for å identifisere potensielle nye fangstprosjekter i den europeiske energigjenvinningssektoren, som kan akselereres med utgangspunkt i realiseringen av FOVs CO_2-fangstprosjekt. Dette gjelder både internt i Fortumgruppen, innenfor nasjonal industri og internasjonalt. I FEED-fasen er det gjort betydelige fremskritt i arbeidet med å få interesse og støtte for CCS-teknologien som en viktig løsning for energigjenvinningsanlegg i hele Europa.

Internt i Fortum-konsernet er det identifisert mulige nye prosjekter for karbonfangst og lagring, og følgende er under utredning:

- Stockholm Exergi gjør studier og pilottesting på sitt anlegg;
- Forstudier ved forbrenningsanleggene i Klaipeda i Litauen og Zabrze i Polen;
- Fortum har også etablert en markedsplass for sertifikater for CO_2-fjerning fra atmosfæren; PURO, som vil være i full drift som en uavhengig plattform i 2020.

FOV samarbeider med eksterne aktører som Borg CO_2 (tidl. Øra CCS Kluster) og det er signert en Memorandum of Understanding mellom Fortum og Equinor på vegne av Northern Lights for samarbeid utover FOVs CO_2-fangstprosjekt. FOV har også en aktiv dialog med akademia, og deltar i flere forskningsprosjekter for å bidra til teknologiutvikling og læringsoverføring i et europeisk perspektiv.

FOV har en utstrakt dialog med andre nasjonale og internasjonale aktører innenfor avfallsforbrenning og energiproduksjon. Gjennomføringen av forprosjektfasen for FOVs CO_2-fangstprosjekt, inklusiv pilottesting, har gitt betydelig oppmerksomhet og interesse i avfallsindustrien. Dette er spesielt tydelig i Nord-Europa; mer spesifikt i Sverige, Danmark, Tyskland, Sveits og ikke minst Nederland, der flere fangstprosjekter (CCU) allerede er besluttet, men det er også en økende interesse fra andre deler av Europa og resten av verden. Det er dessuten en tydelig trend at byene både i Norge og Europa går foran og setter klare mål for utslippsreduksjoner, og karbonfangst på energigjenvinningsanleggene blir et essensielt og svært effektivt tiltak for at byene skal klare å nå disse målene.

Like viktig er dialogen med europeiske beslutningstakere og organisasjoner, og i løpet av FEED-fasen har interessen for og oppslutningen om CCS som en viktig klimaløsning økt merkbart. FOV deltar aktivt i flere kommunikasjonsnettverk og møter politiske beslutningstakere både i bilaterale fora, seminarer og workshops; bl.a. ledelsen i EU's Innovation Fund, representanter fra EUs DG Energy (Directorate-General for Energy), politiske representanter fra de enkelte EU-land og europeiske ambassadører i Norge.

Det er betydelig økende interesse og støtte fra den europeiske organisasjonen for energigjenvinningsbedrifter (CEWEP) og internasjonale organisasjoner for avfallsbehandling (ISWA), samt fra uavhengige organisasjoner som Bellona/Zero etc.

Det arbeidet som allerede er gjennomført i konsept- og FEED-fasen har lagt et meget godt grunnlag for videre arbeid med gevinstrealisering. FOV har lagt klare planer for det videre arbeidet både i interimfasen, prosjekterings- og gjennomføringsfasen, og vil arbeide aktivt for å bidra til realiseringen av nye, europeiske CO_2-fangstanlegg i energigjenvinningsbransjen.

2.8.1 Erfaringsoverføring (Lessons Learned)

Det er utarbeidet en rapport for å identifisere erfaringer som er viktige å ta med inn i neste fase av prosjektet. Erfaringsoverføring er identifisert i tabeller 12-1 til 12-7 og fordelt på følgende hovedområder:

- Tekniske løsninger og ytelser;
- Driftsfase;
- Kostnader;
- Miljøpåvirkning;
- Sikkerhet, helse og arbeidsmiljø;
- Forretningsmodell;
- Prosjektgjennomføring.

Innenfor hvert område er det identifisert underkategorier, med dokumentasjon av erfaringer fra forprosjektfasen og hva som kan forventes i gjennomføringsfasen.

2.8.2 Teknologiutvikling

Den valgte fangstteknologien lisensiert av Shell er kommersielt utprøvd i fullskala på kullfyrte kraftverk. Det har også blitt gjennomført pilottesting på røykgass på Klemetsrud i løpet av forprosjektperioden. Resultatene fra piloten har vært svært gode og har dokumentert teknologiens modenhet.

FOVs CO_2-fangstprosjekt vil også kunne vise til teknologiutvikling med hensyn på integrasjon og varmebalanse mellom energigjenvinningsanlegget og CO_2-fangstanlegget på Klemetsrud. Transportløsninger for nedkjølt og flytende CO_2 vil også demonstreres og være nyttig for anlegg som ligger med avstand til eksisterende havner.

Det er en målsetting å se på standardiserte og modulariserte løsninger for CO_2-fangstanlegget, samt å bidra til utvikling for å integrere CO_2-fangst som en del av røykgassrensingen på fremtidige energigjenvinningsanlegg.

2.9 Patenter og immaterielle rettigheter

Shells CO_2-fangstteknologi for bruk på Klemetsrud er lisensiert, beskyttet av patenter og omfatter konfidensiell informasjon.

Følgende informasjon er konfidensiell:

- Absorbent;
- Klassifisert informasjon om absorbenten: Sammensetning og egenskaper;
- Kritisk utstyr: Utstyr for gjenvinning av amin;
- Lisensiert prosess: CANSOLV CO_2 fangstprosess.

Følgende patenter gjelder i Norge:

Tittel	Patent nummer	Dato
RECOVERY OF CO_2 FROM GAS STREAMS	20055902 / 335887	June 8, 2004
PROCESS FOR THE RECOVERY OF CARBON DIOXIDE FROM A GAS STREAM	20092701 / -	December 14, 2008
PROCESS FOR THE RECOVERY OF CARBON DIOXIDE AND SULPHUR DIOXIDE FROM A GAS STREAM	20140030 / 336005	June 8, 2004

3 INTRODUCTION

The Norwegian Government announced in 2013 that it would support the development of a cost effective technology for capture and storage of CO_2 as part of the Sundvolden policy declaration.

The Government's Carbon Capture and Storage (CCS) strategy was presented by the Ministry of Petroleum and Energy in its Proposition 1 S (2014-2015) to the Norwegian Parliament (Stortinget). The strategy has since then been funded and supported in the National Budget.

While 2015 was the year of pre-feasibility studies on capture, 2016-2017 were the years of concept studies. The 2017 National Budget also focused on supporting concept studies for CO_2 storage. The National Budget of 2018 funded the pre-project phase for the whole CCS value chain (capture as well as transport and storage).

This project, a combined concept and Front-End Engineering and Design (FEED) phase, has been financed by the last National Budgets.

Fortum Oslo Varme (FOV) Klemetsrud Waste-to-Energy (WtE) plant has been first selected in 2015 as one of the potential CO_2 capture sites. This report presents the results of the combined concept and FEED phase, where FOV has been completing the pre-project of a full-scale plant for capture of CO_2 from the flue gas of its Klemetsrud WtE plant.

The aim of this report is to provide input to Gassnova; their report will form the basis for the State's quality assurance and decision processes for a Final Investment Decision (Decision Gate 3), expected in the last quarter of 2020. The FOV CO_2 Capture Project is subject to external quality assurance under the Norwegian state's quality assurance process for large public investments (the "KS scheme").

The scope for FOV includes all the works for integration of the carbon capture plant (CC Plant) to the existing plant. The scope also includes Intermediate storage at Klemetsrud, transport to the Oslo harbour with truck loading/unloading facilities and harbour storage at Port of Oslo.

The Klemetsrud WtE plant, located at Klemetsrud (Oslo, Norway), converts municipal and industrial residual waste produced both nationally and internationally to heat and power. The WtE plant was taken into operation in 1985 and expanded in 2011 with a new independent incineration line (line 3). The plant consists of three separate waste incineration lines and two steam turbines for electricity production. In addition to electricity, the plant also provides district heating to the Oslo district heating networks.

The conversion results in emission of flue gases, which are cleaned to meet the stringent requirements set for waste incineration based on EU directives. The amount of the emitted CO_2 in the flue gases remains unaffected.

The target for the plant future operation is to capture 95% of the CO_2, while minimizing the impact on the existing plant operation (production of electricity and district heating - DH).

3.1 The purpose of the project

The purpose of the project is to:

- Develop a robust and integrated technical solution ready for construction – clarifying technical requirements in the chain;
- Provide basis for investment decision in the next phase (both technical and commercial);

- Prepare for construction.

The FOV CO_2 Capture Project is part of the Norwegian full-scale CCS Project supported by the Ministry of Petroleum and Energy (MPE). This includes two capture sites, ship transportation and permanent storage of CO_2.

The FOV CO_2 Capture Project will contribute to reduce barriers and costs for the next CCS project. The FOV CO_2 Capture Project will also contribute significantly to the City of Oslo's ambitious goals for reducing the city's CO_2 emissions. The results from FOV CO_2 Capture Project will be made available to the Waste-to-Energy industry, and will support the achievement of long-term climate targets in Norway, Europe and world-wide.

In alignment with these principles, the impact goals for a CCS project are established as following:

- The project shall produce knowledge that shows it is safe and possible to conduct full-scale CCS;
- The project shall provide productivity benefits for upcoming projects through learning and scale effects;
- The project shall provide research for regulation and incentives for CCS activities;
- The project shall establish market players, further develop contractors and yield economic development.

3.2 Structure of this report

This report is structured around the Table of Content provided by Gassnova. The structure of this report is harmonised on a few simple principles:

- The DG3 report is, as far as practical, an update of the Concept study report [6], presenting the main activities performed in the FEED phase.
- Contractual requirements with regards to the Study Agreement are delivered throughout the project and latest in the DG3 report. With respect to the delivery requirements (leveransekrav) listed in Appendix 1-1 of the Study Agreement, there might be an existing exhaustive document already approved by the Gassnova. In such case a summary of such document is implemented in the DG3 report itself.
    - If a "supporting document" is existing, information is extracted, organised and presented in the DG3 report.
    - Executive summary and the Expanded Norwegian summary chapters are to be self-supported and can be read autonomously.
- The various sections/chapters of the DG3 report are self-supported and can be read without the need to access supporting documents/appendixes.
- The DG3 report will focus on project features that are considered the largest contribution in value created for the Gassnova.

Table 3-1 presents an overview of the cross-references between the Study Agreement and the chapters of this report.

Table 3-1: Cross-references in between the Study Agreement and the DG3 report.

Section of this report	Requirement in the Study Agreement	Section of this report	Requirement in the Study Agreement
1	Appendix 4 Section 6	6.4	Appendix 1-1 3d
2	Appendix 4 Section 6	6.5	Appendix 1, 2.2 (EO 03 K)
3	(introductory section)	7	(introductory section)
3.1	(introductory section)	7.1	Appendix 1-1 4a 4b
3.2	(introductory section)	7.2	Appendix 1-1 4c 4d
3.3	(introductory section)	7.3	Appendix 1, 5.1 (EO 03 K)
3.4	(introductory section)	7.4	Appendix 1-1 2u
4	(introductory section)	7.5	Appendix 1-1 2m
4.1	Appendix 1-1 1a	8	(introductory section)
4.2	Appendix 1-1 1i (EO 03K)	8.1	Appendix 1-1 8a
4.3	Appendix 1-1 1b	8.2	Appendix 1-1 8c
4.4	Appendix 1-1 1c	9	(introductory section)
4.5	Appendix 1-1 2p	9.1	Appendix 1-1 5a
4.6	Appendix 1-1 1d	9.2	Appendix 1-1 5a
4.7	Appendix 1-1 1e	9.3	Appendix 1-1 5a
4.8	Gassnova comment to draft report	9.4	Appendix 1-1 5a
4.9	Appendix 1-1 1f	9.5	(summary)
4.10	Appendix 1-1 1h	10	(introductory section)
4.11	Appendix 1-1 1h	10.1	Appendix 1-1 6c
4.12	Appendix 1-1 1g	10.2	
4.13	Gassnova comment to draft report	10.3	Appendix 1-1 6d
5	(introductory section)	10.4	Appendix 1-1 6b
5.1	Appendix 1-1 2a	11	(introductory section)
5.2	Appendix 1-1 2b 2c	11.1	Appendix 1-1 7a
5.3	Appendix 1-1 2e	11.2	Appendix 1-1 7b
5.4	Appendix 1-1 2k	11.3	Appendix 1-1 7c
5.5	Appendix 1-1 2i	11.4	Appendix 1-1 7d
5.6	Appendix 1-1 2d	11.5	Appendix 1-1 7e 7f 7h
5.7	Appendix 1-1 2f 2g 2h, EO 03 K	11.6	Appendix 1-1 7g
5.8	Appendix 1-1 2j	11.7	Appendix 1, 5.3 (EO 03 K)
5.9	Appendix 1-1 2l	12	(introductory section)
5.10	Appendix 1-1 2o 2q 2r 2s	12.1	Appendix 1-1 9a
5.11	Appendix 1-1 2t	12.2	Appendix 1-1 9b
5.12	Appendix 1-1 2n	12.3	Appendix 1-1 10a 10b
5.13	Appendix 1-1 2v	12.4	Appendix 1-1 10c
6	(introductory section)	13	Appendix 1-1 11a
6.1	Appendix 1-1 3a	13.1	Appendix 1-1 11a
6.2	Appendix 1-1 3b	13.2	Appendix 1-1 11a
6.3	Appendix 1-1 3c		

3.3 Abbreviations and definitions

3.3.1 Abbreviations

(DCC)	Direct Contact Cooler (Pre-scrubber)
ARC	Amager Resource Center
ATEX	Appareils destinés à être utilisés en ATmosphères EXplosives (referes to EU directives)
BAT	Best Available Technique
[redacted]	[redacted]
BECCS	BIO-CCS

CAPEX	Capital Expenditure
CBS	Cost Breakdown Structure
CC	Carbon Capture
CCR	Central Control Room
CCS	Carbon Capture and Storage
CCTV	Closed-circuit television
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Utilisation and Storage
CEWEP	Confederation of European Waste-to-Energy Plants
CFD	Fluid Dynamic Models (Computational Fluid Dynamics)
CHP	Combined Heat and Power
CW	Cooling Water
DG	Decision Gate
DH	District Heating
DSB	The Norwegian Directorate for Civil Protection (Direktoratet for samfunnssikkerhet og beredskap)
EGE	Agency for household trash management, City of Oslo (Energigjenvinningsetaten)
EHS	Environment, Health, and Safety
EIA	Environmental Impact Assessment
ENVID	Environmental Impact Identification
ESP	Electrostatic precipitator
ETS	Emissions Trading System
EU	European Union
FEED	Front-End Engineering Design
FG	Flue gas
FGS	Fire & Gas System
FOV	Fortum Oslo Varme
GHG	Greenhouse Gas
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HCl	Hydrochloric Acid
HF	Hydrofluoric Acid
HMI	Human Machine Interface
HMS	Helse, miljø og sikkerhet (Health, Safety and Environment)
HOK	Activated Carbon
HP	High Pressure
HSE	Health, Safety and Environment
HSEQ	Health, Safety, Environment, and Quality
ICSS	Integrated Control and Safety System
K1, K2, K3	Incineration Line 1 (K1), 2, 3 at Klemetsrud plant
LCMS	Liquid Chromatography Mass Spectrometry
LLI	Long Lead Items
LP	Low Pressure
MP	Medium Pressure
MPE	Ministry of Petroleum and Energy (Olje- og energidepartementet)
MSW	Municipal Solid Waste
MVR	Mechanical Vapour Recompression

MWe	Megawatt (electric)
MWth	Megawatt (thermal)
NILU	The Norwegian Institute for Air Research (Norsk institutt for luftforskning)
NIPH	Norwegian Institute of Public Health
Nm^3	Normal m3 defined at 0 ˚C / 1.01325 bara
OED	Ministry of Petroleum and Energy (Olje- og energidepartementet)
O&M	Operation & Maintenance
OPEX	Operating Expenditure
P&ID	Piping & Instrumentation Diagram
PAS	Process Automation System
PFD	Process Flow Diagram
PLC	Programmable Logic Controller
ppmv	Parts per million (volume)
PRDS	Pressure Reducing and Desuperheating Station
PTR-TOF-MS	Proton Transfer Reaction Time-of-Flight Mass Spectrometry
RAM	Reliability, Availability and Maintainability
SE	Stockholm Exergi
SHA	Sikkerhet, helse og arbeidsmiljø
TOC	Total Organic Carbon
TRU	Thermal Reclaimer Unit
VAC	Volts AC power
VAV	Agency for Water and Sewage Works, City of Oslo (Vann- og avløpsetaten)
VIP	Value Improvement Practices
VOC	Volatile Organic Compound
WEHRA	Working Environment Risk Assessment
WtE	Waste-to-Energy
WWT	Waste Water Treatment
WWTP	Waste Water Treatment Plant

3.3.2 Definitions

Availability	Fraction of the time a system is operational, assuming that the required external resources are provided. External resources are e.g. production of cement or incineration of waste, and supply of electricity from grid.
Battery Limit	Defined boundary between two areas of responsibility, which may be physical (e.g. a flange on a pipe); or represented by a map coordinate; or some other means (for example a point in time).
CC Plant	Future CO_2 capture plant at Klemetsrud including CO_2 conditioning and liquefaction.
Civil Contractor	To be confirmed, contractor responsible for the total delivery of the civil work
Commissioning	The process carried out by TechnipFMC to ensure the plant is operable and Ready for Start-up.
Fortum	Fortum Corporation, the industrial enterprise with operating responsibility for Fortum Oslo Varme.
FOV	Fortum Oslo Varme AS, owned 50/50 by the City of Oslo and Fortum Corporation.

	FOV is the project owner.
FOV CO_2 Capture Project	Indicates the FOV project ongoing at Klemetsrud, in all of its phases. Also referred to as Project CCS Carbon Capture Oslo.
Gassnova	Gassnova SF, financial backer (*støttegiver*) of the Study Agreement.
Harbour facilities	All CO_2 handling facilities at Port of Oslo, including all the facilities necessary for the export (mooring, truck unloading, ship loading, etc).
Harbour storage	CO_2 storage tank farm providing buffer volumes for CO_2 at Port of Oslo.
Intermediate storage at Klemetsrud	CO_2 storage tank farm providing buffer volumes for CO_2 at Klemetsrud.
Klemetsrud WtE plant	FOV's Klemetsrud Waste-to-Energy (WtE) plant at Klemetsrud, Oslo.
Licensor	Shell Catalysts and Technologies, part of Shell Global Solutions International B.V.
Northern Lights	Northern Lights is a CCS project initiated by Equinor with partners Shell and Total. Northern Lights is responsible for transportation and storage of CO_2.
Norwegian full-scale CCS Project	Project supported by the Ministry of Petroleum and Energy (MPE), including two capture sites (FOV and Norcem), ship transportation and permanent storage of CO_2 (Northern Lights). Also referred as Norwegian CCS Demonstration Project.
Owner's Engineer	Used to define the consulting company providing technical supervision services. The Owner's Engineer is employed by the Owner to have in the project team the necessary competences needed to supervise TechnipFMC and all the other Contractors, and support in project management.
Port of Oslo	Oslo port authority, Oslo Havn KF.
Pre-commissioning	Activities undertaken before Mechanical Completion which include non-operating adjustments, conformity checks, cleaning, and no energy/low energy testing of component and systems.
Site	The sites where the CC Plant and the harbour facilities at Port of Oslo will be built.
Solvent	CO_2 capture solvent (amine based liquid solution) used to absorb CO_2 in the Absorber. Also known as (CO_2 capture) absorbent. The use of (CO_2 capture) solvent and absorbent are interchangeable.
Study Agreement	Study agreement dated 02.05.2017 in between Gassnova and FOV [7].
TechnipFMC	TechnipFMC, the contractor responsible for the engineering, procurement, construction (including installation and commissioning) of the CC Plant including the intermediate storage at Klemetsrud and the harbour facilities at Port of Oslo. Concept and FEED phase work is performed by TechnipFMC fully owned subsidiary Technip E&C Limited. Construction work is to be performed by TechnipFMC fully owned subsidiary Technip France S.A., based on the FEED work performed by Technip E&C Limited.
Transport Contractor	To be confirmed, contractor responsible for the total delivery of the transport scope.

3.4 References

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[4] FOV, NC03-KEA-P-RA-0018 rev.02 - Technology Qualification Report.

[5] FOV, NC03-KEA-A-FD-0002 rev.02 - Project execution method.

[6] FOV, NC02-KEA-A-RA-0002 rev.02 - Concept Study Report.

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[15] FOV, NC03-KEA-A-RA-0023 rev.03 - Scope of work.

[16] FOV, NC03-KEA-P-FD-0009 rev.04 - Design Basis (ref. Appendix 1) - KI 17-64 Appendix 1 - Company's Description of the Assignment.

[17] FOV, NC02-KEA-B-RA-0002 rev.01 - Cost Estimate Report.

[18] FOV, NC02-KEA-A-RA-0010 rev.03 - Endringer fra konsept til oppstart forprosjekt.

[19] FOV, NC03-KEA-B-RA-0002 rev.02 - Cost Estimate risk assessment report (Cost Risk Analaysis).

[20] AACE International, AACE International - Recommended Practice No. 18R-97 - Cost Estimate Classification System.

[21] FOV, NC03-KEA-A-KA-0003 rev.04 - Process description for identifying and assessing cross-subsidization.

[22] FOV, NC03-KEA-P-FD-0001 rev.03 - Design basis.

[23] TechnipFMC, NC03-TEC-A-TA-0001 rev.02 - Project Execution Plan.

[24] Gassnova SF, 16/267-1 rev.5.2 (12.03.2019) - Norwegian CCS Demonstration Project Design Basis for the CCS Chain.

[25] TechnipFMC, NC03-TEC-M-RA-0009 rev.02 - Preliminary RAM Study Report.

[26] FOV, NC03-KEA-Q-RA-0001 rev.01 - RAM analysis.

[27] TechnipFMC, NC03-TEC-P-FD-0001 rev.02 - Process Basis of Design.

[28] TechnipFMC, NC03-TEC-S-RA-0006 rev.02 - Emission Inventory.

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4 COMMERCIAL

The following sections present an overview of how Gassnova's commercial requirements stated in the Study Agreement are met.

4.1 Head of terms and commercial prerequisites (1a)

FOV and the Norwegian Ministry of Petroleum and Energy will enter into a support agreement regarding establishment, operation and decommissioning of the CC Plant. The agreement presupposes that FOV will cover a certain part of the incurred cost and is based on a cost sharing principle.

FOV will be given the opportunity to regain their investments by delivering CO_2 to the CCS chain.

The agreement's basic principles are in place, even though some details remain to be settled.

4.1.1 Cost sharing establishment of the plant

The cost sharing principles for establishment of the CC Plant is as follows:

- FOV may cover the investment costs up to investment level 0.
- MPE will cover the investment costs between level 0 and level 1.
- The parties are to share the costs above level 1 according to the following formula: MPE [redacted]% and FOV [redacted]%.

The amounts for level 0 and 1 have not yet been settled.

The parties are negotiating a possible financial cap. The level of the cap and the mechanism to be applied if the cap is reached have not yet been agreed.

4.1.2 Cost sharing in the operation phase

FOV will receive a fixed and a variable financial support to cover operational cost. MPE will cover [redacted]% of the operational costs up to a defined level 1. The level 1 amount will be identified in FOV's offer to the State.

The parties share the costs above level 1 according to the following formula: MPE [redacted]% and FOV [redacted]%.

4.1.3 Income and cost savings

FOV will receive compensation for the captured CO_2 [redacted]. [redacted], the compensation will either be direct from the State on the whole amount or as a combination of direct compensation and cost saving. [redacted]

Currently FOV is not liable to pay CO_2 tax nor is the emitted CO_2 part of the EU ETS system. The income described above, or possible future cost savings will give FOV the opportunity to regain their investment costs from the establishment and operation of the CC Plant, and obtain a limited profit opportunity on FOV's investment.

A possible future CO_2 cost on emissions from waste incineration is expected to only apply to the fossil part of the CO_2 emissions. [redacted]

FOV will carry the risks and opportunities regarding the delivered quantity of CO_2 as well as changes in the ETS price level.

4.1.4 Continued operation or decommissioning

FOV is obliged to continue capturing and delivering CO_2 after the operation period of 10 years if:

- Transportation and storage services of CO_2 is available on commercially acceptable terms;
- The cost for continued operation makes it economically viable to keep operating the plant (the exact conditions for this have not been agreed).

[redacted]

4.2 Procurement strategy (1i)

4.2.1 Scope of work division

The procurement strategy is described in the Procurement Strategy document [8]. The scope for both the construction phase and the operation phase is presented:

Table 4-1: Procurement - Scope of the construction phase.

Scope	Description
Process with CCS technology	One contractor is responsible for the complete capture process. The contractor will be responsible for engineering, procurement, construction, commissioning and start-up of the plant. The scope of work comprises all relevant disciplines up to the defined interfaces. FOV has already selected TechnipFMC as contractor for this contract, with Shell as Licensor.
Civil works	One contractor responsible for Civil works comprising Site preparation work, underground work and foundations.
Integration	There will be several subcontracts for piping, electro installation, fire detection, CCTV, power supply, etc.
Owner's Engineer Services	One external technical consultant company team of experts, who supplement FOV project team and whose role is to supervise technical and commercial due diligence of the works performed by all project contractors.

Table 4-2: Procurement - Scope of the operation phase.

Scope	Description
Truck Transport	One service provider for transport.
Maintenance & Operation	FOV personnel.
Solvent Cansolv DC-103	One supplier of proprietary Amine – Shell Catalysts & Technologies Limited.

4.2.2 Procurement laws and regulations

FOV has carried out an external legal review to identify the applicable procurement laws and regulations. [redacted]

4.2.3 Procurement package criticality

FOV has assessed the procurement packages criticality based on lead time, expected contract value, complexity and "other risk elements" (HSE, dependencies etc). The top 5 are presented in Table 4-3.

Table 4-3: Top 5 critical procurement packages.

Description	Reason
Process with CCS technology	[redacted]
Civil works	[redacted]
Owner's Engineer Services	[redacted]
Solvent Cansolv DC-103	[redacted]
Truck transport	[redacted]

FOV has also identified the Long Lead Items, defined as item which have a longer lead time than 12 months (from order placement to delivery at Site). They are presented in the Long Lead Item list [9].

FOV will develop a specific follow-up and expediting plan for each procurement package during project start-up. The level of follow up/expediting will be based on the package's criticality. Special attention will however be given to the Process with CCS technology package.

4.2.4 Compensation format

FOV will use various compensation models depending on the nature of each contract.

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]

[redacted]

4.3 Business case for the beneficiary (1f)

4.3.1 Identified opportunities and business possibilities for Fortum

The Fortum Group is the world's fourth largest heat supplier and has a number of combined heat and power (CHP) plants as well as biomass plants for energy recovery and district heating. Circular use of resources, recycling, district heating and sustainable waste management are key features of the Fortum Group's business. With the vision "for a cleaner world" Fortum aims to be at the forefront of developing both the industry, the technology and new green jobs.

The decarbonization of waste management and energy production is one of four pillars in the Fortum Group's strategic roadmap for future utilities:

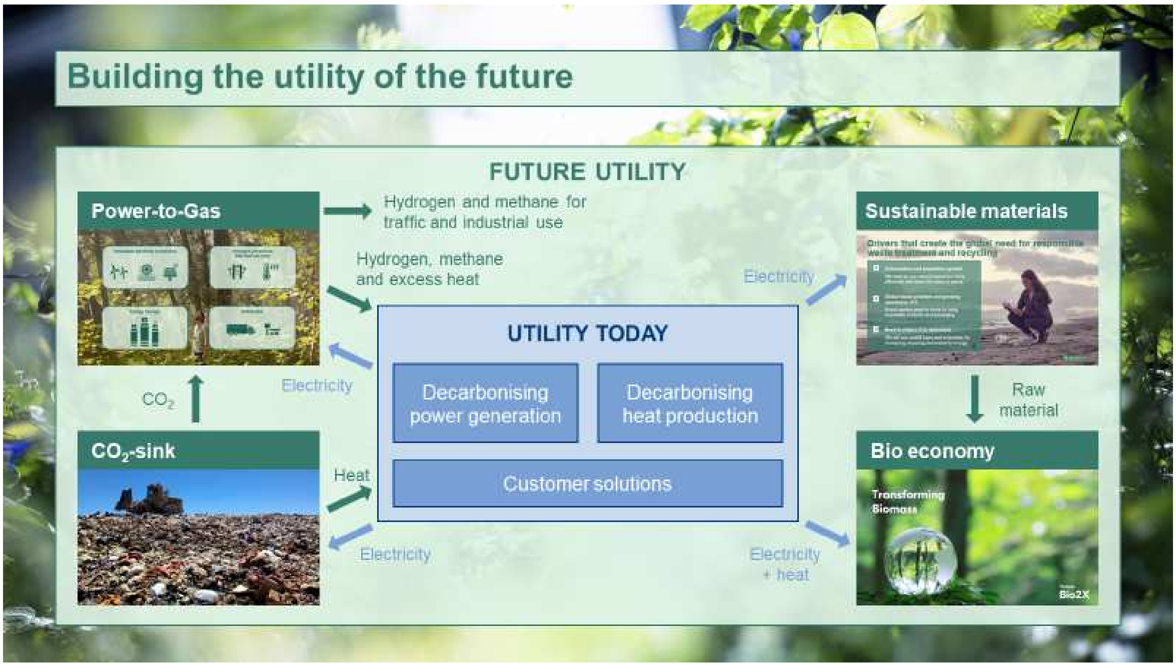

Figure 4-1: Fortum Group's strategic roadmap for future utilities.

Fortum is actively working to develop solutions for capture, utilization, transport and storage of CO_2 to achieve such decarbonization as described in chapter 12.

For the Fortum Group, the FOV CO_2 Capture Project at the Klemetsrud WtE plant and the establishment of Fortum's CCS Centre of Excellence hence represent a unique opportunity for learning and transfer of experience to the rest of the group.

With its large portfolio of facilities, shown in Figure 4-2, Fortum has a strong interest in developing the technology in the direction of cost-effective, safe and qualified solutions for decarbonization.

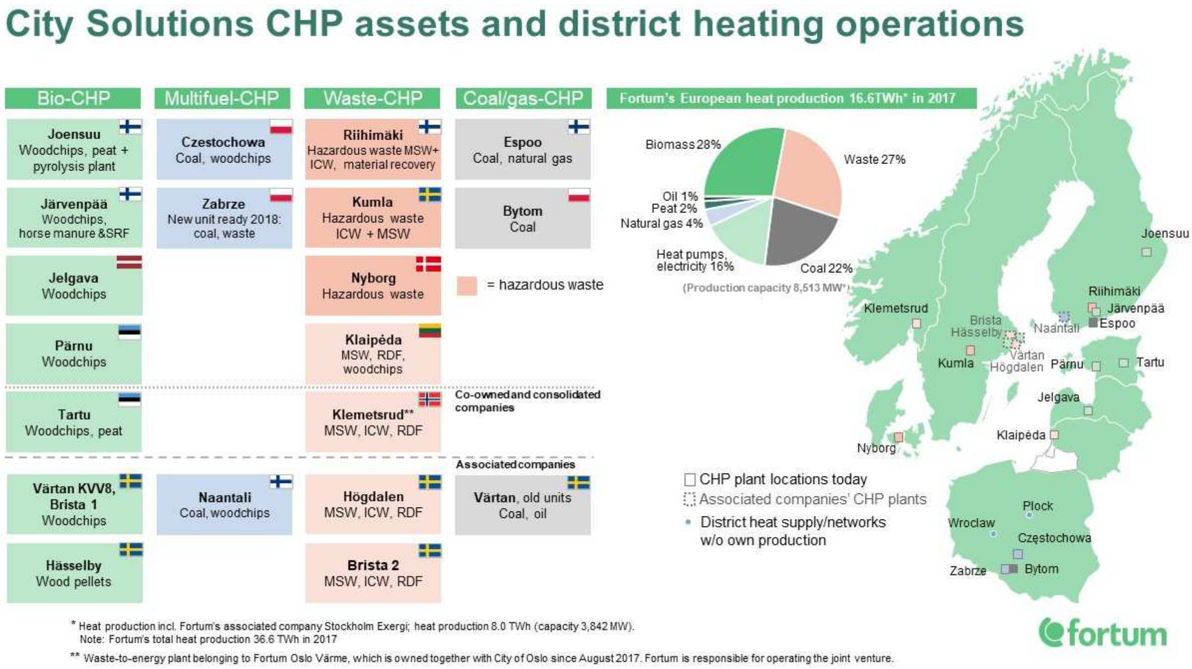

Figure 4-2: Fortum's plants in Europe.

Such a development will lay the foundation for future commercial activities and help maintain and develop its market position as a contributor to the green shift and a supplier of sustainable waste and energy solutions.

4.3.2 Potential of negative emissions for Fortum and cities around the world

The significance of the FOV CO_2 Capture Project at Klemetsrud has increased greatly with the UN Climate Panel pointing at the importance of carbon-negative solutions in order to reach the 1.5 degree target [10]. The FOV CO_2 Capture Project has an added climate value because approximately 50% of the emissions from waste incineration – and 100% of the emissions from biomass plants – are biogenic and a part of the natural CO_2 cycle. The WtE industry thus can contribute to extracting large amounts of CO_2 from the atmosphere, based on the technology development and shared learning from the FOV CO_2 Capture Project in Oslo. By establishing carbon capture on energy recovery of residual waste the emissions from incineration of plastics that can no longer be recycled can also be dealt with, and at the same time carbon negativity is achieved from the biomass fraction of the waste. This can provide a future business potential through the sale of negative emissions [11].

Urban infrastructure and circular solutions are essential measures for cities to reach their climate goals. Waste is one of the few worldwide established large-scale value chains that produces energy from biomass and is closely linked to urban infrastructure and a circular economy. Negative CO_2 emissions from CCS on WtE will help neutralizing other emissions that are much harder to reduce or remove in a short term perspective and can be essential for cities to reach their climate goals in the years to come. By developing the FOV CO_2 Capture Project at Klemetsrud, the City of Oslo will be a pioneer for big cities all over the world, to show how cities can achieve net negative emissions.

Oslo has both established and is participating in a number of city cooperation arenas for the purpose of shared learning and experience, such as the C40-network and the Carbon Neutral City alliance etc. Oslo was also awarded European Green Capital of 2019 and is working hard to implement climate measures in all sectors to reduce emissions.

4.3.3 Future opportunities and business possibilities for Fortum Oslo Varme

The FOV CO_2 Capture Project at Klemetsrud may contribute to a strengthened reputation for FOV as a company with a clear environmental and social commitment, and thus provide a better future market position in the waste market. The First mover advantage will be valuable in order to achieve this position. Removing the CO_2 footprint with CCS may contribute to increased social acceptance for future district heating and cooling, power generation and waste incineration activities, and lay the foundations for building new plants in the future.

Today FOV's Waste-to-Energy plants are not included in the EU Emissions Trading System (ETS). However, specific and ambitious goals for Norwegian emissions cuts have been set in the non-quota sector, the FOV CO_2 Capture Project can demonstrate how emissions can be reduced effectively outside the ETS, in cooperation with the industry and European cities. This will be important to reach both Norwegian and European targets outside ETS.

The link between carbon capture and district heating is also very important from a resource perspective, because it enables the utilization of waste heat from the capture process. The waste heat can be utilized in existing district heating systems.

Energy recovery with CCS provides a comprehensive solution for sustainable waste treatment in a cycle. In practice, this means that contaminated plastics and residual plastic products, after sorting and several rounds of recycling of the plastics, can also be handled in an effective and environmentally sound way.

The project implementation can also in itself contribute to the transfer of experience and learning for other facilities both internally in the Fortum group and towards the rest of the WtE industry. This includes competence areas such as technology qualification, infrastructure, integration into existing plants, assessments of energy efficiency etc.

4.3.4 CO_2 capture cost for a household delivering waste to FOV

Several calculations have been done to measure the added cost of CO_2 capture to the waste management fee for household waste; a regulative instrument on state and municipal level.

A Multiconsult report [12] shows how the additional costs of CO_2 capture will affect a household if the entire cost is added to the waste management fee. The average waste management fee in Norway is NOK 2 750 annually per household, and a gate fee for delivery of waste to a waste-to-Energy plant is estimated at NOK 500 per ton. According to the Multiconsult report [12], the cost of CO_2 capture plants will increase the gate fee with NOK 1 000 per ton.

By 2030, a reduction on investment and operation costs of CO_2 capture plants is expected, which will reduce the additional gate fee (caused by CO_2 capture) to about NOK 700 per ton waste.

Although the gate fee at the Waste-to-Energy plants increases significantly, the waste management fee will not increase by more than 20-30% and the total municipal fees only by 6-8% (this estimation only includes the cost of CO_2 capture, not the transport and storage). These calculations are supported by a similar study performed by the NGO ZERO [13], which concluded with an average increase of about 20% in the waste management fee to establish CO_2 capture and achieve emissions-free and carbon-negative handling of household waste. This calculation does not reflect commercial waste, but the cost of commercial waste incineration will increase by approximately NOK 1 000 per ton.

4.3.5 FOV as Fortum's CCUS Centre of Excellence

FOV has been identified as the Fortum Group's Centre of Excellence for CCS, and knowledge centre for other Fortum facilities. If the FOV CO_2 Capture Project is realized this will lead to a unique experience and competence building in FOV as well as in Fortum. In addition to the FOV CO_2 Capture Project in Oslo, Fortum is also working on several initiatives on Carbon Capture and Utilization (CCU).

From a climate perspective, storage is the main goal because it is more efficient and removes large volumes. Nevertheless, the development of CCU will be important both to increase the focus on carbon capture in general, increase the quantities of CO_2 that must be handled, stimulate technology and market development and to open the dialogue towards the EU and Europe. CCU can also be important for plants with smaller emissions or a location that makes it challenging to establish transport infrastructure for permanent storage. The CCU and CCS competence environments in Fortum are closely coordinated and are working together to promote and develop CCUS solutions both in Fortum, the EU and globally. In this respect, Fortum's CCUS Centre of Excellence is one of the key drivers in the European CCUS agenda together with Fortum Public Affairs.

4.3.6 Creating the future instead of adjusting to it

Both FOV and Fortum are active players in the waste and energy markets and want to be a part of creating the future, rather than having to adapt to new demands and regulations. This includes opportunities to develop the supplier and advisory market both nationally and internationally. It is natural to envision that future waste-to-energy facilities will be built with *integrated CO_2 capture* as part of the flue gas cleaning process, in order to reduce costs of capture and thus increase the potential for future returns in new projects. The potential for cost cuts can be developed in various areas such as material usage, integration, energy and operational optimization and reduction of total investment in flue gas cleaning including carbon capture. Cost cuts will also be realized through volume in production, simplification and standardization and global dissemination of technology.

It will also be important to develop market cooperation and agreements with suppliers to develop modularized capture solutions in a market with increasing competition and a potential for rapid technology development. An important part of this market cooperation will be participation in CCS industrial clusters to develop technology and new solutions, with increased digitization in areas such as user support, training and optimization.

If the FOV CO_2 Capture Project at Klemetsrud is realized, Fortum and FOV will explore the possibilities of offering other plants a package solution for carbon capture on flue gas (build-own-operate), on available land and infrastructure. The opportunity for licensing and construction of greenfield facilities, where Fortum offers operations and maintenance, is also a possible future business opportunity. Implicitly this means creating new jobs, both nationally and globally, and to actively participate in the work to create future European business models for CCU and CCS.

4.4 Basis of estimate (1c)

The Basis of Estimate [14] describes the approach and methods adopted in the preparation of the estimate of the new CC Plant with an overall target accuracy of ±20%. The Basis of Estimate describes the following main topics:

- Project cost and main components, including a preliminary breakdown structure;
- Methodology;
- Assumption for the estimation;
- Cost Basis, including allowance, used for the evaluation; description of the main source of information;
- Assumptions for the estimate.

4.5 Outline of scope of work document for state support agreement (2p)

FOV and the Norwegian Ministry of Petroleum and Energy will enter into a support agreement regarding establishment, operation and decommissioning the CC Plant.

The agreement will include an Attachment A – "Beskrivelse av fangstanlegget og arbeidet", which includes functional requirements and basic high-level descriptions. The Attachment A – "Beskrivelse av fangstanlegget og arbeidet" – will have several appendixes, with hierarchy as follows:

1. Gassnova Design Basis;
2. Beneficiary's Scope of Work Document;
3. Beneficiary's DG3 FEED report.

The Scope of Work [15] document has a higher rank than other parts of the DG3 FEED Report (this report). The document describes the full scope of work for the FOV CO_2 Capture Project.

In conjunction with negotiations for support agreement, MPE and Gassnova will review and might comment the Scope of Work document produced by the project during the FEED phase. Updates might be necessary after the project milestone M10 (delivery of the finalised DG3 report) is reached.

As per instructions received from Gassnova, it is sufficient to refer to the Scope of Work [15] document and include the document as an Attachment to this report.

4.6 Estimated CAPEX (1d)

4.6.1 CAPEX Cost Breakdown Structure

Figure 4-3 presents a visual representation of the CAPEX Cost Breakdown Structure.

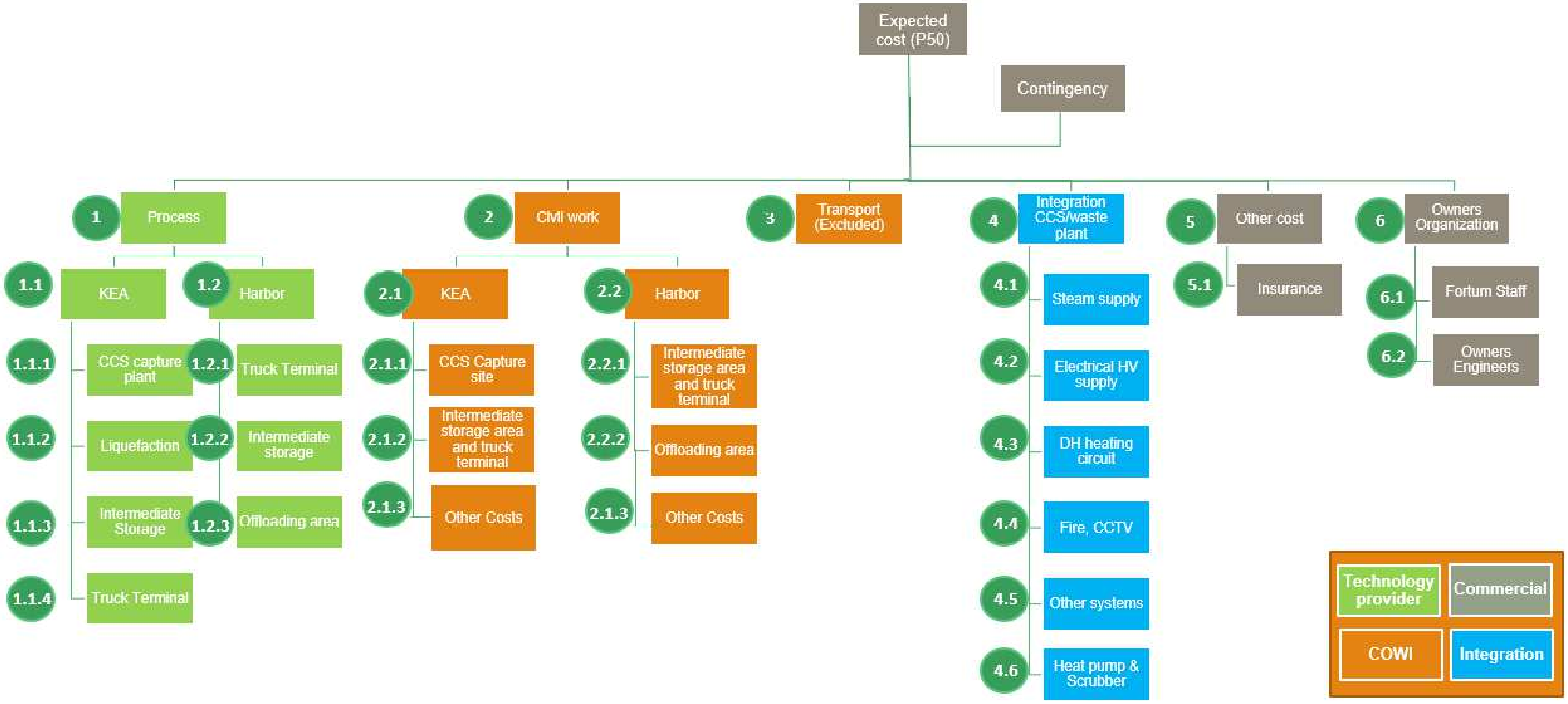

Figure 4-3: CAPEX Cost Breakdown Structure.

The P50 estimate is defined as the median value or expected cost and consists of the base estimate including allowance, and the estimated contingency. The P50 estimate is based on 2019 values and defined exchanges rates set by Gassnova, presented in Table 4-4.

Table 4-4: Exchange rates for cost estimate, as defined by Gassnova.

Currency	Exchange rate
EUR	EUR-NOK: 10
USD	USD-NOK: 9
GBP	GBP-NOK: 11
SEK	SEK-NOK: 0.95
JPY	JPY-NOK: 8.5
DKK	DKK-NOK: 1.30

4.6.2 Summary

Table 4-5: CAPEX summary for Base cost.

		MNOK
1. Process (Process with CCS technology procurement package)		[redacted]
2. Civil Work		[redacted]
3. Transport		-
4. Integration		[redacted]
5. Other cost		[redacted]
6. Owners Organization cost		[redacted]
Total Base cost		[redacted]
Contingency	[redacted] %	[redacted]
CAPEX P50		[redacted]
Management reserve	[redacted] %	[redacted]
CAPEX P85		[redacted]

The CAPEX estimate includes all costs from final investment decision until completion/commencement of the operation period.

The estimated weighting in different currencies for CAPEX are presented in Table 4-6.

Table 4-6: Currency distribution, CAPEX.

Currency	Value (MNOK)	% CAPEX estimate
EUR	[redacted]	[redacted]%
USD	[redacted]	[redacted]%
NOK	[redacted]	[redacted]%

4.6.2.1 Project main quantities

To support the CAPEX estimate, and to facilitate Gassnova's understanding of the estimate, a summary of the main quantities is included.

Table 4-7: Main quantities.

Category	Quantity	Source
Manhours for management, engineering and construction management	[redacted]	TechnipFMC, excluding project management
Direct and indirect construction manhours	[redacted]	TechnipFMC
Soil removed (m³)	[redacted]	FOV
Rock blasted	[redacted]	FOV
Concrete to be poured	[redacted]	FOV
Tons of primary and secondary steel	[redacted]	TechnipFMC
	[redacted]	FOV
Number of mechanical equipment item	[redacted]	TechnipFMC
	[redacted]	FOV, integration excluding electrical equipment
Dead weight mechanical equipment	[redacted]	TechnipFMC
	[redacted]	FOV, excluding electrical equipment
Meter of pipes (linear meters)	[redacted]	TechnipFMC
	[redacted]	FOV
Pipe weight tons	[redacted]	TechnipFMC
	[redacted]	FOV
Meter of cables, electrical	[redacted]	TechnipFMC
	[redacted]	FOV
Meter of cables, instrumentation & signal	[redacted]	TechnipFMC
	[redacted]	FOV
Number of i/o to DCS / ESD	[redacted]	TechnipFMC
	[redacted]	FOV, [redacted]

4.6.3 Process

Table 4-8 presents the estimation from TechnipFMC. TechnipFMC scope of work is detailed in [16].

Table 4-8: CAPEX for Process.

CBS	Description	MNOK
	KEA (Klemetsrud site)	
1.1.1	Capture plant	[redacted]
1.1.2	Liquefaction	[redacted]
1.1.3	Intermediate Storage	[redacted]
1.1.4	Truck Terminal	[redacted]
	Harbour	
1.2.1	Truck Terminal	[redacted]
1.2.2	Intermediate storage	[redacted]
1.2.3	Offloading area	[redacted]
1	**Total cost**	[redacted]

4.6.4 Civil Work

The need for Civil work has been estimated and aligned with the need for area provided by TechnipFMC. For the selected solution, the Civil work is estimated as follows for the CC Plant and harbour facilities.

Table 4-9: CAPEX for Civil Work.

CBS	Description	MNOK
2.1	Klemetsrud	[redacted]
2.2	Harbour	[redacted]
2	**Total cost**	[redacted]

4.6.5 Transport

For transport between the capture site and the harbour facilities, truck transport is the selected solution (the updated concept selection is presented in section 5.11.3). Truck transport cost is included in the OPEX estimates.

4.6.6 Integration to Klemetsrud WtE plant

The need for integration towards the existing plant is estimated and aligned with the necessary interfaces between Klemetsrud WtE plant and the CC Plant.

Table 4-10: CAPEX for Integration to Klemetsrud WtE plant.

CBS	Unit	MNOK
4.1	Steam supply	[redacted]
4.2	Electrical HV Supply	[redacted]
4.2	El HV Supply OPTIONS	[redacted]
4.3	DH heating	[redacted]
4.4	Fire, CCTV, access control	[redacted]
4.5	Other System	[redacted]
4.6	Scrubber line 1 and 2, and related Heat Pump	[redacted]
4	**Total cost**	[redacted]

4.6.7 Other cost

The estimate cost for insurance covers the contractual requirements given by the Norwegian Total Contract NTK15, article 31. The insurance type is Builders Construction "All Risks" (CAR), and covers insurance for CAR property, start-up delay, transportation and accident/financial liabilities.

Table 4-11: CAPEX for other cost.

CBS	Other cost	MNOK
5.1	Insurance	[redacted]
5	**Total cost**	[redacted]

4.6.8 Owners cost

The Owners cost has been estimated based on the assumed length of the project up to the Delivery Acceptance Certificate is signed.

Fortum staff cost will be reassessed based on the agreed compensation with MPE, currently under negotiation.

Table 4-12: CAPEX for Owners cost.

CBS	Owners cost	Cost (MNOK)	Hours
6.1	Fortum staff (internal)	[redacted]	[redacted]
6.2	Owner's Engineers	[redacted]	[redacted]
6	**Total cost**	[redacted]	[redacted]

4.6.9 CBS bridging – Gassnova format

A bridging document in Gassnova's format is presented in the following Table 4-13. The total presented (item 14 of Gassnova CBS) is the P50 estimate. Item 11 of Gassnova CBS, *forventet tillegg*, equals the estimated CAPEX contingency of [redacted]%.

Table 4-13: CBS bridging principles, CAPEX.

Gassnova CBS structure [7]			FOV CBS structure		
Nr.	**Norwegian description**	**English description**	**CBS code**	**Remark**	**MNOK**
1	Tilknytning til pipe	Stack Connection / modification	4.5	Only the pipe connection	[redacted]
2	Forbehandling av røykgass	Flue Gas Conditioning / pre-treatment	1.1.1		[redacted]
3	CO_2 absorbsjon	CO_2 Absorption	1.1.1		
4	Solvent regenerering	Solvent Regeneration	1.1.1		
5	Kompresjon, flytendegjøring og kondisjonering	CO_2 Compression/Liquefaction and Conditioning	1.1.2		[redacted]
6	Transport på land til mellomlager, hvis relevant	Onshore transport to Interim Storage, if any	1.1.4, 1.2.1 (3)	Truck is selected, hence no CAPEX cost except for the terminals	[redacted]
7	Mellomlager	Interim storage	1.1.3, 1.2.2	Intermediate storage at Klemetsrud and harbour storage	[redacted]
8	Kai, og elementer fra mellomlager til lasting på skip	Quay, and Items from Interim Storage to Loading of Ship	1.2.3		[redacted]
9	Prosess spesifikk del-sum (1-8 over)	Process specific part-sum (1-8 above)			[redacted]
10	Hjelpesystemer, hvis ikke inkludert og spesifisert over (trenger å spesifisere utover det som er dekket over) bl. A. damp, strøm, m.m. samt tilknytninger utover de til pipe: eksempelvis tomt, bygg og anlegg, kjølevann, endringer av eksisterende prosess i eget anlegg (CO_2 kilde) m.m.	Utilities, if not already included and specified in elements above (need to specify beyond above) e.g. steam, power, etc. Further, Tie-Ins with existing plant beyond Stack, Site Civil Works, Cooling water system, modification of existing process (CO_2 source) etc.	2, 4	4.5 excluded for the portion included in item 1 "Stack connection / modification"	[redacted]
11	Forventet tillegg for fysiske elementer hvis ikke inkludert i elementer over	Contingency for Physical Elements, if not included and specified in elements above		Estimated CAPEX contingency of [redacted]%.	[redacted]
12	Delsum	Part sum			[redacted]
13	Støttemottakers eierkostnader (trenger å spesifiseres f.eks. eier, stab/management, tjenester under bygning, forventet tillegg m.m.	Owners (Støttemottakers) Costs (need to be specified, e.g.: Owners engineering/management Services during construction, Contingency, etc.)	5, 6		[redacted]
14	Totalsum	Total sum		Expected cost – P50	[redacted]

4.7 Estimated OPEX (1e)

4.7.1 OPEX Cost Breakdown Structure

Figure 4-4 presents a visual representation of the CAPEX Cost Breakdown Structure.

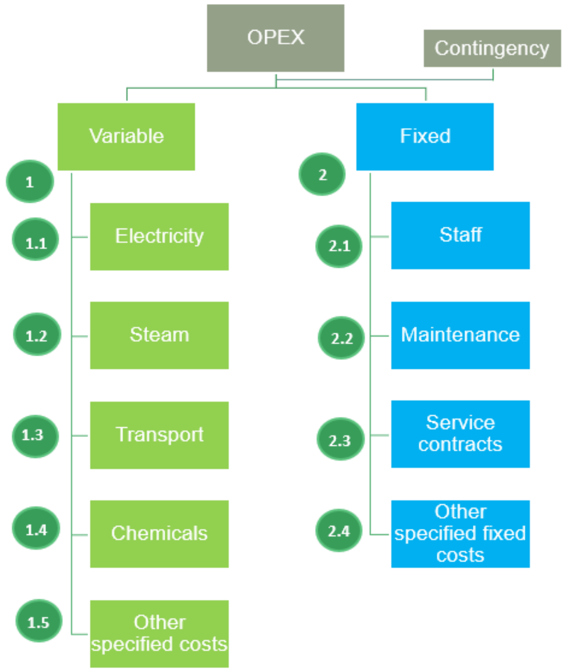

Figure 4-4: OPEX Breakdown Structure.

4.7.2 Summary

The OPEX costs have been estimated to be the following, on annual basis.

Table 4-14: Annual OPEX summary for Base cost.

		MNOK
Variable Costs		[redacted]
Fixed Maintenance costs		[redacted]
Fixed operational costs		[redacted]
Fixed operational costs – project team		[redacted]
Total Base cost		[redacted]
Contingency	[redacted] %	[redacted]
OPEX P50		[redacted]
Management reserve	[redacted] %	[redacted]
OPEX P85		[redacted]

Table 4-15: OPEX summary, CBS split.

		MNOK	%
1.1	Electricity	[redacted]	[redacted]
1.2	Steam	[redacted]	[redacted]
1.3	Transport	[redacted]	[redacted]
1.4	Chemicals	[redacted]	[redacted]
1.5	Other Specified Costs	[redacted]	[redacted]
2.1	Staff	[redacted]	[redacted]
2.2	Maintenance	[redacted]	[redacted]
2.3	Service contracts	[redacted]	[redacted]
2.4	Other Specified Costs	[redacted]	[redacted]
	Total Base Cost	[redacted]	[redacted]

The estimated weighting in different currencies for OPEX are presented in Table 4-16.

Table 4-16: Currency distribution, OPEX.

Currency	Value (MNOK)	% OPEX estimate
EUR	[redacted]	[redacted]%
USD	[redacted]	[redacted]%
NOK	[redacted]	[redacted]%

4.7.3 Variable cost

Variable costs are defined as the variable cost elements associated with the capture and delivery of CO_2.

Table 4-17: OPEX – Variable cost.

CBS	Description	Annual cost (MNOK)
1.4	Solvent Cansolv DC-103	[redacted]
1.4	Solvent, transport sea and road	[redacted]
1.4	Solvent (TRU) waste handling	[redacted]
1.5	Sludge from WWT	[redacted]
1.4	Caustic Soda Solution (low chloride)	[redacted]
1.4	Hydrochloric Acid	[redacted]
1.4	Sodium Chloride	[redacted]
1.4	Hydrogen	[redacted]
1.4	Oxygen Removal Reactor	[redacted]
1.4	Oxygen Removal Reactor	[redacted]
1.4	CO_2 Dehydration Molecular Sieves	[redacted]
1.1	Electricity (of CC Plant, exclusive district heating heat pump)	[redacted]
1.1*	Steam (3-7 bar), including usage (39 bar)	[redacted]
1.1**	Lost electricity production	[redacted]
1.5	Water consumption	[redacted]

CBS	Description	Annual cost (MNOK)
1.5	Waste water	[redacted]
1.5	Reused waste water	[redacted]
1.5	Waste handling, combustion	[redacted]
1.3	Cost of goods (Port of Oslo)	[redacted]
1.3	Arrival of vessel	[redacted]
1.3	Truck Transport of CO_2 to harbor	[redacted]
1.5	Demin water to WtE plant	[redacted]
	Total cost	[redacted]

[redacted]

4.7.4 Cost for maintenance of the CC Plant

Based on experience, FOV has estimated the maintenance cost based on a split of manning and "spares and consumables". Manning includes both permanent daytime personnel and on-call personnel for emergencies. The yearly maintenance stop will be followed up by a cross functional team performing a variety of upgrades. Spares and consumables are based on the information provided by TechnipFMC in their mechanical equipment list and packages with rotating /moving parts.

Table 4-18: OPEX – Maintenance cost.

CBS	Description	Annual cost (MNOK)
2.2	Manhours for maintenance	[redacted]
2.2	Spares and Consumables	[redacted]
	Total cost	[redacted]

4.7.5 Operating costs

Fixed operating costs have been estimated based on experience and scope of work.

Table 4-19: OPEX – Fixed operational cost.

CBS	Description	Annual cost (MNOK)
2.1	Shift personnel - CC Plant	[redacted]
2.1	Other personnel	[redacted]
2.4	Insurance	[redacted]
2.3	Service center / storage area incl. storage labour	[redacted]
2.4	Office space (ca. 10 m² - 25 m²)	[redacted]
2.4	Internal fire response group / area security / HSEQ	[redacted]
2.4	Rental costs area (Oslo harbour)	[redacted]
2.4	Rental costs area (Klemetsrud)	[redacted]
2.4	Property tax*	[redacted]
2.3	Cost of measurement during operation (equipment)	[redacted]
2.1	Cost of measurement during operation (manpower)	[redacted]
	Total cost	[redacted]

*: municipal property tax in Oslo will be reduced to 3 ‰ of the property value.

4.7.6 Operating cost of project team

The operating costs are based on the understanding of the project requirements and FOV's experience for operating similar type of plants.

Table 4-20: OPEX – Fixed operational cost – project team.

CBS	Description	Annual cost (MNOK)
2.1	CCS Director	[redacted]
2.1	CCS Engineer	[redacted]
2.1	HSEQ Manager (sharing with existing)	[redacted]
2.1	ICT and support (incl. HR, procurement, accounting and audit)	[redacted]
2.1	Personnel: other fixed costs	[redacted]
	Total cost	[redacted]

4.7.7 CBS bridging –Gassnova format

A bridging document in Gassnova's format is presented in the following Table 4-21. The total presented is the P50 estimate. A new item (not existing in Gassnova CBS), *forventet tillegg*, equals the estimated OPEX contingency of [redacted]%.

Table 4-21: CBS bridging principles, OPEX.

Gassnova CBS structure [7]			FOV CBS structure		
Nr.	**Norwegian description**	**English description**	**CBS code**	**Remarks**	**MNOK**
1	Variable driftskostnader (inkl. 1. Strøm, 2. Damp, 3. Andre spesifiserte variable kostnader som forbruk av solvent)	Variable costs 1. Electricity, 2. Steam, 3. Other specified variable costs such as solvent usage	1.1		[redacted]
2			1.2		[redacted]
3			1.4, 1.5		[redacted]
N/A			1.3	Truck transport	[redacted]
4	Faste driftskostnader (4. Bemanning, 5. Vedlikehold, 6. Servicekontrakter, 7. Andre spesifiserte faste kostnader).	Fixed costs 4. Staff, 5. Maintenance, 6. Service contracts, 7. Other specified fixed costs.	2.1		[redacted]
5			2.2		[redacted]
6			2.3		[redacted]
7			2.4		[redacted]
N/A	*Forventet tillegg ikke inkludert I elementer over*	*Contingency for operational costs, not included and specified in elements above*		*OPEX contingency of [redacted]%.*	[redacted]
	Totalsum	Total sum		Expected cost – P50	[redacted]

4.8 Cost development from Concept to end of FEED

An evaluation of the cost development for both CAPEX and OPEX from delivery of the concept report until the delivery of the FEED report is given in the following.

The costs have been updated in two steps from delivery of the Concept Cost Estimate Report [17] (October 2017):

- First revision of the cost was included in FOV tender to MPE (dated 1st December 2017)
- Second revision of the cost has been documented in the documented *Endringer fra konsept til oppstart forprosjekt* [18] (rev.03, dated May 2018).

An additional intermediate step from December 2017 is not included separately

The presentation is based on the P50 estimates.

4.8.1 CAPEX cost development

The CAPEX cost estimate was reduced during the intermediate phase following the delivery of the concept phase Cost Estimate report [17].

The development is shown in Figure 4-5.

[redacted]

Figure 4-5: CAPEX cost development from Concept to Start FEED.

The changes in CAPEX can be summarised as follows:

- [redacted]

  [redacted]

  [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

The development of the CAPEX cost estimates from start FEED until end of FEED is presented in Figure 4-6.

[redacted]

Figure 4-6: CAPEX cost development from Start FEED to End FEED.

The changes in CAPEX can be summarised as follows:

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

4.8.2 OPEX cost development

The OPEX cost estimate was reduced during the intermediate phase following the delivery of the concept phase Cost Estimate report [17].

The development is shown in Figure 4-7.

[redacted]

Figure 4-7: OPEX cost development from Concept to Start FEED.

The changes in OPEX cost can be summarized as follows:

- [redacted]
- [redacted]
- [redacted]
- [redacted]

The development of the OPEX cost estimates from start FEED until end of FEED is presented in Figure 4-8.

[redacted]

Figure 4-8: OPEX cost development from Start FEED to End FEED.

The changes in OPEX cost can be summarized as follows:

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

4.9 Cost contribution from beneficiary (1f)

The support agreement between FOV and the State is still under negotiation. This agreement will be the basis for estimating FOV's share of CAPEX and OPEX above investment level 1, with reference to the principles in the support model described in section 4.1.

FOV's offer will be approved by the owners by 2nd December 2019.

4.10 Maturity analysis (1h)

A self-assessment of the project's maturity and estimate-class has been performed; the project maturity level is defined according to AACE-RP 18R-97 [20] class 2 estimate. AACE-RP 18R-97 uses the following definitions:

Table 4-22: Definitions according to AACE-RP 18R-97.

Class 2 definitions	General Project Data	• **Defined:** Project definition is advanced and reviews have been conducted. Development may be near completion with the exception of final approvals.
	Engineering Deliverables	• **Complete (C):** The deliverable has been reviewed and approved as appropriate. • **Preliminary (P):** Work on the deliverable is advanced. Interim, cross-functional reviews have usually been conducted. Development may be near completion except for final reviews and approvals.
Remaining classes definitions	General Project Data	• **Not Required (NR):** May not be required for all estimates of the specified class, but specific project estimates may require at least preliminary development. • **Preliminary:** Project definition has begun, and progressed to at least an intermediate level of completion. Review and approvals for its current status has occurred.
	Engineering Deliverables	• **Not Required (NR):** Deliverable may not be required for all estimates of the specified class, but specific project estimates may require at least preliminary development. • **Started (S):** Work on the deliverable has begun. Development is typically limited to sketches, rough outlines, or similar levels of early completion.

4.10.1 Cost estimate classification form

The project engineering deliverables within the corresponding class are presented in the table below.

All deliverables concerning General Project Data and Engineering Deliverables have been evaluated by the technical project team, and the combined evaluation confirms approval of Class 2 maturity.

And overview of the main project documents used in the evaluation process is attached to the report (see section 14).

Table 4-23: Cost estimate classification form.

		Cost Based Structure				
	Class 2 Estimate Classifications	**Process***	**Civil**	**Transport**	**Other Cost**	**Owners Org.**
General project data:						
Project Scope Description	Defined	Defined	Defined	Defined	Defined	Defined
Plant Production/ Facility Capacity	Defined	Defined	Defined	Defined	Defined	Defined
Plant Location	Defined	Defined	Defined	Defined	Defined	Defined
Soils & Hydrology	Defined	Not applicable to Scope of Contract	Defined	Defined	Defined	Defined
Integrated Project Plan	Defined	Defined	Defined	Defined	Defined	Defined
Project Master Schedule	Defined	Defined	Defined	Defined	Defined	Defined
Escalation Strategy	Defined	Defined	Defined	Defined	Defined	Defined
Work Breakdown Structure	Defined	Defined	Defined	Defined	Defined	Defined
Project Code of Accounts	Defined	Defined	Defined	Defined	Defined	Defined
Contracting Strategy	Defined					
Engineering Deliverables:						
Block Flow Diagrams	C	C	C	C	C	C
Plot Plans	C	C**	C	C	C	C
Process Flow Diagrams (PFDs)	C	C	C	C	C	C
Utility Flow Diagrams (UFDs)	C	C	C	C	C	C
Piping & Instrument Diagrams (P&IDs)	C	C	C	C	C	C
Heat & Material Balances	C	C	C	C	C	C
Process Equipment List	C	C	C	C	C	C
Utility Equipment List	C	C	C	C	C	C
Electrical One-line drawings	C	C	C	C	C	C
Design Specifications & datasheets	C	C	C	C	C	C
General Equipment Arrangement Drawings	C	C	C	C	C	C
Spare Parts Listings	P	P	P	P	P	P
Mechanical Discipline Drawings	P/C	P/C	P/C	P/C	P/C	P/C
Electrical Discipline Drawings	P/C	P/C	P/C	P/C	P/C	P/C

		Cost Based Structure				
	Class 2 Estimate Classifications	Process*	Civil	Transport	Other Cost	Owners Org.
Instrumentation / Control System Discipline Drawings	P/C	P/C	P/C	P/C	P/C	P/C
Civil/Structural/Site Discipline Drawings	P/C	P/C	P/C	P/C	P/C	P/C

*: Process packages defined in this report as "to be finalized during project execution" will be delivered as complete supplier packages where the detailed design will be the responsibility of the supplier. TechnipFMC has prepared package specifications for these packages to ensure that the interfaces and process conditions are defined and, hence, the connecting process systems can be designed to achieve the required maturity level. These package specifications will be included in the future purchase orders. FOV consideration is that this TechnipFMC strategy is sufficient to obtain the class 2 maturity level and that the internal package configuration/design not covered by the package specification is not essential for obtaining the required maturity level.

**: Adjustment will need to be made to accommodate the footprints of selected subsuppliers packages in the next phase.

4.11 Cost risk analysis (1h)

An independent Cost Risk Analysis (CRA) has been performed by Holte Consulting (HC) [19].

The objective of the Cost Risk Analysis is to establish the appropriate level of contingencies and management reserve, resulting in P50 and P85 estimates for the project. The basis for the cost risk analysis is the cost and is calculated by key resources in the project and by TechnipFMC.

Two analyses were run; one for CAPEX and one for OPEX.

The main risk contributors identified in the Cost Risk Analysis has been evaluated in relation to the top risks mapped in the Risk Matrix for constructional and operational phases (section 8.2). They are considered consistent.

4.11.1 CAPEX

The S-curve on cost risk calculated by the Project Management Team and Holte Consulting is shown in the figure below.

[redacted]

Figure 4-9: S-curve for CAPEX without currency fluctuations [19].

The recommended cost framework is presented in Figure 4-10.

[redacted]

Figure 4-10: Cost structure for CAPEX without currency fluctuations [19].

The Tornado diagram in Figure 4-11 indicates how much each of the top ten uncertainties contribute positively and negatively to the cost uncertainty in the project.

[redacted]

Figure 4-11: Tornado diagram for CAPEX without currency fluctuations [19].

The top uncertainties factor identified by Holte Consulting are as following:

SUPPLIER/CONTRACTOR CAPABILITIES

[redacted]

PROJECT ORGANISATION

[redacted]

MARKET

The market evaluated for this factor comprises Engineering, Equipment and Construction Work, both internationally and locally in Oslo area. [redacted]

[redacted]

MECHANICAL

[redacted]

AMINE

[redacted]

4.11.2 OPEX

The S-curve on cost risk calculated by the Project Management team and Holte Consulting is shown in the figure below.

[redacted]

Figure 4-12: S-curve for OPEX without currency fluctuations [19].

The recommended cost framework is presented in Figure 4-13.

[redacted]

Figure 4-13: Cost structure for OPEX without currency fluctuations [19].

The Tornado diagram in Figure 4-14 indicates how much each of the top uncertainties contribute positively and negatively to the cost uncertainty in the project.

[redacted]

Figure 4-14: Tornado diagram for OPEX without currency fluctuations [19].

The top uncertainties factor identified by Holte Consulting are as following:

ELECTRICITY, WATER AND WASTE

The highest risk element is represented by the uncertainty factor Electricity, water and waste. [redacted]

FIXED MAINTENANCE COSTS

The estimate uncertainty Fixed maintenance cost represents a high source of cost risk. [redacted]

ORGANISATION

[redacted]

AUTHORITIES AND REGULATIONS

This uncertainty factor represents the cost consequence authorities and regulations may have on the project. There is no upside to this cost risk in best or probable case. In Worst Case the project's cost may increase due to new and different health, environment, and safety standards and labour market regulation.

STAKEHOLDERS

This uncertainty factor represents the influence and consequence stakeholders may have on the project's cost due to handling and adjusting to their requirements or requests. [redacted]

4.12 Cash flow analysis (1g)

Table 4-24 presents the cost plan for the construction phase. The costs are periodized per quarter during the total project duration, until plant ready for operation. Total duration is 46 months. The estimated contingency is included in the cash flow, hence total value is the expected cost, P50.

Table 4-24: Cost plan for the construction phase. All costs are in MNOK.

Date	%	Sum	1 Process	2 Civil work	4 Integration	5 Other Cost	6 Owners Org
Q1 2021	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q2		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q3		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q4		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q1 2022	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q2		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q3		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q4		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q1 2023	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q2		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q3		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q4		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q1 2024	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q2		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q3		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Q4		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Sum	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

4.13 Potential cross subsidization

The process for identification and assessment of potential cross subsidization areas is stated in the cross-subsidization identification procedure [21]. The procedure covers method for identifying, assessing and allocating cost in accordance with the prerequisites for the grant during each phase of the project (FEED, establishment and operation of the CC Plant).

FOV will carry out workshops throughout the establishment and operation of the CC Plant to identify areas of cross-subsidization. At the end of FEED phase, FOV has carried out three workshops and have identified the following potential areas related to the CC Plant at Klemetsrud:

1. Heat pumps;
2. Increased capacity of demineralised water;
3. Increased cooling capacity during summer operation;
4. Common storage / spare parts;
5. Operational personnel;

6. Maintenance personnel;
7. Land area rental;
8. Potential available area.

5 PROJECT DESCRIPTION

This chapter presents a technical description of the FOV CO_2 Capture Project starting with the existing WtE plant at Klemetsrud (section 5.1) and the flue gas produced (section 5.2). An extensive technical description of the new CC Plant and its reliability is presented from section 5.3. Section 5.7 presents the technology qualification process and the pilot plant at Klemetsrud. After a description of the use of the plot plan at Klemetsrud and at the Port of Oslo (section 5.8), this chapter closes with a description of the Construction, Integration, Commissioning, Operation and Maintenance philosophies (sections 5.9, 5.10 and 5.12).

5.1 Functional description of existing plant (2a)

This section provides an overall functional description of the existing Klemetsrud WtE plant that will be integrated with the CC Plant.

The Klemetsrud WtE plant was taken into operation in 1985 with two lines, line 1 (K1) and line 2 (K2). In 2011 the plant was expanded with a new independent WtE line 3 (K3) and today the plant consists of three separate waste incineration lines and two steam turbines for electricity production. All three lines consist of individual grate fired boilers.

In addition to electricity production, the plant also provides district heating to the Sentrum (Oslo city centre), Holmlia and Bjørndalen district heating networks. The Sentrum network is connected to line 3, whereas Holmlia and Bjørndalen networks are connected to line 1 and 2.

5.1.1 Waste incineration lines 1 and 2

Incoming waste is received and temporarily stored in a bunker. The waste is fed by crane to a feed hopper in each individual incineration line. The combustion of the waste takes place on a moving grate. Primary (through the grate) and secondary (from other locations) air is provided and controlled to ensure an excess of oxygen for complete combustion and good control of the emissions. The temperature in the furnace is typically between 850 and 1100 °C and most of the heat is recovered by the steam system via water and steam filled tubes in contact with the hot flue gases. An illustration of the waste incineration process at line 1 and 2 is shown in Figure 5-1.

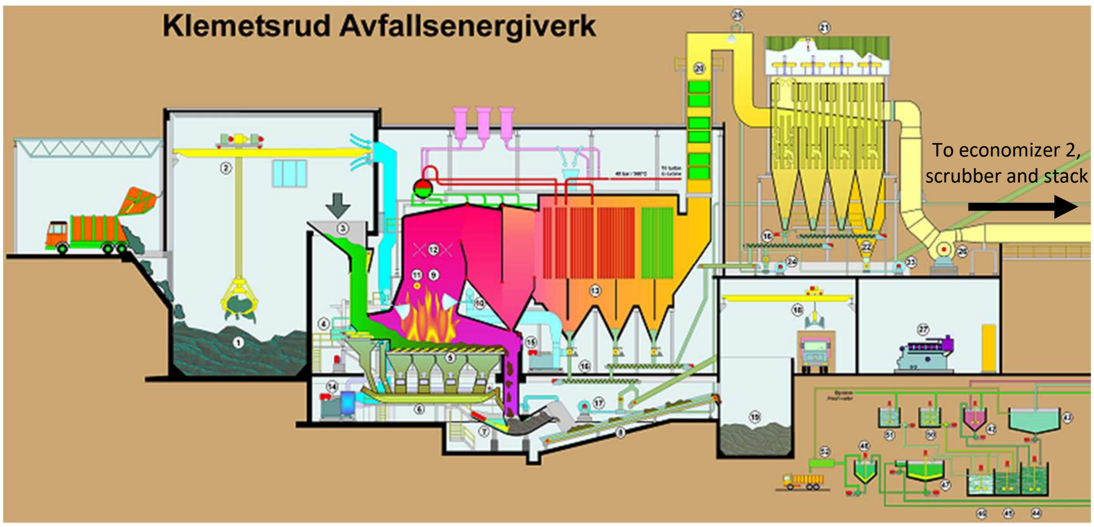

Figure 5-1: Incineration process at line 1 and 2.

After the primary heat recovery has taken place and the flue gases have passed through the boiler, the temperature of the flue is around 200°C. The temperature is further reduced by heat exchangers/economizers providing heat to the DH network.

Downstream of the two flue gas heat exchangers (RGK Nedre and RGK Øvre in Figure 5-2), the flue gas is treated with calcium hydroxide ($Ca(OH)_2$) in powdered form and activated carbon (HOK) in order to remove acidic- and other harmful components. The nitrogen oxide emissions are reduced already in the boiler using a method called selective non-catalytic reduction (SNCR) by carbamine (urea) injection. The final flue gas cleaning step for lines 1 and 2 takes place in the bag filters. The bag filters remove dust and calcium hydroxide that has reacted with sulphur dioxide (SO_2) and hydrogen chloride (HCl) as well as the HOK having reacted with trace elements including heavy metals, dioxins/furans and other components. After the bag filter the flue gas is directed through a final heat exchanger RGK 2.

The base case design for FEED study is based on the upgrading of the flue gas cleaning system for line 1 and 2 with the installation of a scrubber after RGK2. A schematic flow diagram with indicative temperatures is shown in Figure 5-2.

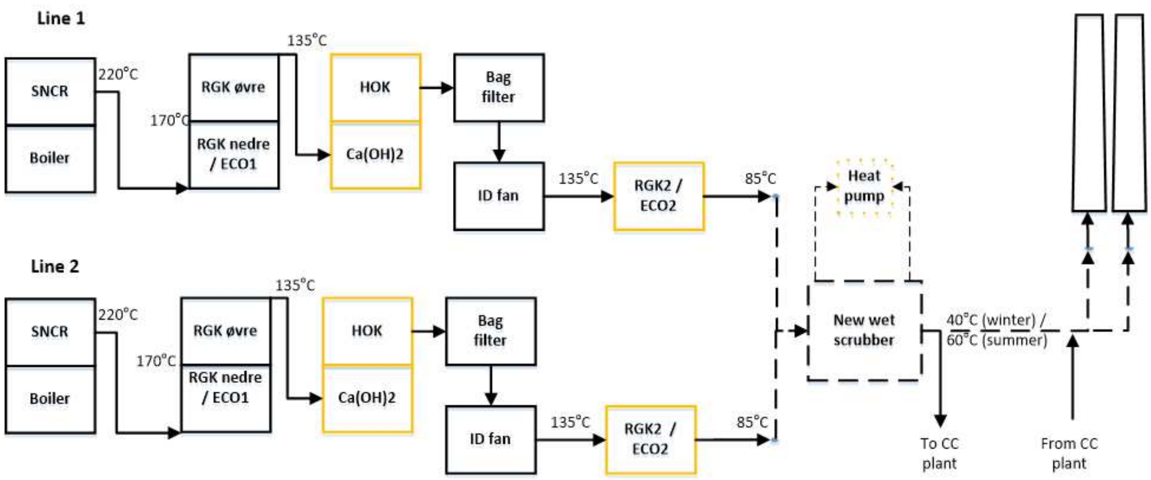

Figure 5-2: Schematic flow diagram of the base case design including a common wet scrubber(updated version of the schematic presented in [16]).

5.1.2 Waste incineration line 3

While the basic setup (incineration, heat recovery and disposal through stack) of the waste incineration line 3 is similar to that of line 1 and 2, the flue gas treatment consists of slightly different elements and arrangements. The first part of the flue gas treatment consists of an electrostatic precipitator for particle removal (ESP), then the flue gas is passed through a 4-stage wet scrubber and finally it is treated in the selective catalytic reduction (SCR) reactor, using aqueous ammonia.

A schematic flow diagram of the flue gas system for line 3 with indicative temperatures, is shown in Figure 5-3.

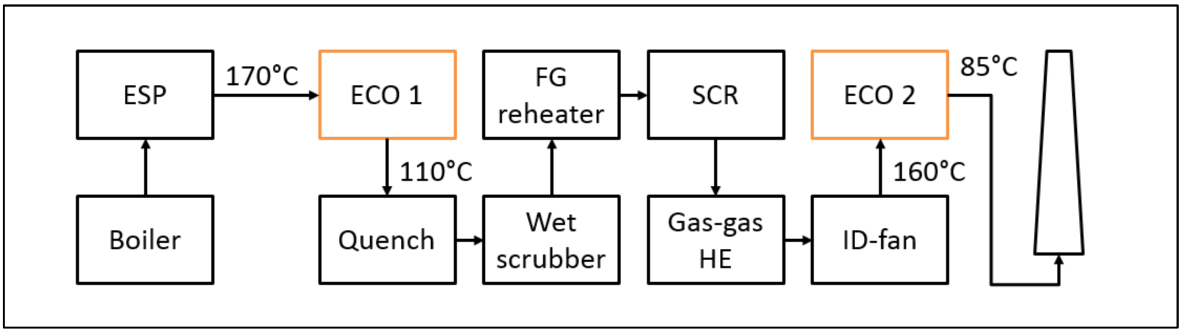

Figure 5-3: Schematic flow diagram of the flue gas system for line 3 [16].

A heat pump is installed and connected to the wet scrubber. The heat pump uses condensation heat from flue gas to deliver outgoing water temperature up to 80 ˚C.

The use of heat pump lowers the outlet temperature of the scrubber from approximately 60 °C to 35-40 °C thus removing roughly 12 tons/h of water from the flue gas. The Line 3 scrubber heat pump is normally in operation only during the winter season when there is high district heating demand.

5.1.3 Steam and condensate cycles

Lines 1 and 2 are similar and provide steam to a common steam and condensate cycle, including a common steam turbine. Line 3, on the other hand, is completely independent and generates electricity in a separate steam turbine. A simplified illustration of the three lines is shown in Figure 5-4.

Line 3 includes an auxiliary dump condenser which uses the excess high-pressure steam that is not used in line 3.

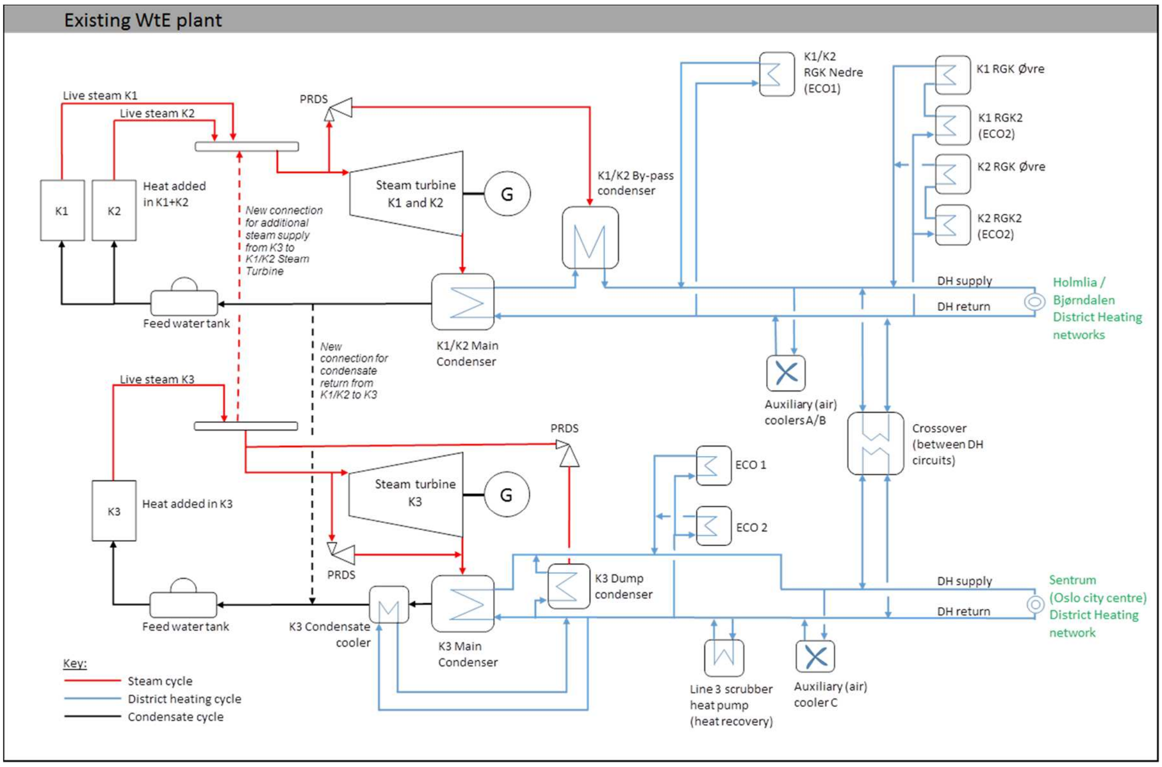

Figure 5-4: Simplified illustration of the steam and condensate cycles.

5.1.4 Electrical power supply

The power to the Klemetsrud WtE plant is supplied by the Klemetsrud transformer station (operated by Hafslund Nett). The supply is via two 11 kV cable connections: one for line 3 and one for the common systems (K0), line 1 and line 2.

A redundant connection exists for K0, K1 and K2; one connection to a switchgear for the gas engine driven generators. There are totally six 11 kV switchgears.

Dry type transformers, fed from the 11 kV switchgears, supply low voltage power to the plant consumers. For the older part of the plant (line 1, line 2 and their common equipment) the voltages are 690 V IT and 230 V IT. The supply for new line 3 is 400 V TNS.

Fixed speed motors are used for Direct On Line (DOL) operation, while Variable Speed Drive operation are carried by motors with power/flow regulation.

The heat pump compressors are powered by two large compressor motors (1.8 MW), connected directly in the 11 kV system. During start of these motors a capacitor bank is also connected.

Uninterruptible Power Supply (UPS) power is arranged as 230 VAC with batteries for energy storage. Design capacity is 60 minutes.

Automation systems and other critical consumers are normally supplied from two sources, 230 V regular supply and 230 V from Uninterruptible Power Supply (UPS) system.

5.1.5 Process control system

5.1.5.1 Data centres

The Klemetsrud WtE plant is arranged with two data centres – one for common system plus line 1 and 2 and one for line 3. These two datacentres are isolated from each other and from an external network as this is a closed production environment. The datacentres are dedicated for the automation systems.

The server infrastructure has a redundant design, so if one physical server fails, the other will run all the virtual machines.

Thin clients are installed in the control room and on engineering workplace. Future operator stations will be based on Wonderware System Platform.

5.1.5.2 Automation System

The Automation system consist of PLCs (Programmable Logic Controller) and HMI system (Human Machine interface).

The PLC is a digital computer that control and manage the WtE energy process. All components such as pumps, valves, motors etc. are connected to the PLC. Redundant PLCs are arranged as "hot standby".

The HMI system is the visualization of the process. It is used for monitoring and control of the process. The data from PLC are sent to the HMI system and application servers. These data are used for operational optimization.

The PLC, the HMI system and the network have redundant design; one single failure will not stop the system from operating.

For line 3 the PLC communicate with remote IO's via a redundant ControlNet bus system. Transmitters are connected to Foundation Fieldbus ring communication which are linked to the remote IO stations.

Line 1, line 2 and the related common systems have local IO units connected to the PLCs via a Device Level Ring which is a redundant ethernet communication installation. Transmitters use 4-20 mA. In some cases, HART signals are implemented.

Redundant servers/switches are connected to the PLCs and to the operator stations.

5.2 Description of the flue gas (2b, 2c)

This chapter describes the flue gas composition and the compositional range of the flue gas to which the CC Plant design is based on.

5.2.1 Source of the flue gas

The flue gas to be treated at the CC Plant is the result of waste incineration at Klemetsrud WtE plant. The source of the waste incinerated at the Klemetsrud WtE plant, in turn, has different origins, but due to effective (largely automated) waste handling systems, the quality (composition, humidity and dry heating value) of the incinerated waste remains fairly homogenous throughout the year.

The waste received at Klemetsrud WtE plant consists of municipal and industrial waste from Norway and abroad. The household waste from Oslo is treated so that plastics, food, paper, glass and metal waste are sorted out from the waste stream by source separation for treatment elsewhere. The remaining fraction is incinerated at the plant. The plant also receives hospital waste (approximately 610 tons in 2018). This waste represents only a small fraction (less than 0.2%) of the total amount incinerated.

5.2.2 Flue gas volume flow, composition and operational parameters

The data in Table 5-1 presents design values.

The WtE is undergoing an upgrade programme. The changes include capacity increase and optimization of the incineration process in all the three lines, meaning a reduction of the oxygen (O_2) content of the flue gas. For the purpose of design, waste incineration lines 1 and 2 are considered equal.

Table 5-1: Klemetsrud WtE plant design data [16][1].

Description	Sum K1 & K2	K3	Total
CO_2 amount	201 900 ton/year	258 300 ton/year	460 200 ton/year
FG amount[2]	157 600 Nm³/h	199 200 Nm³/h	356 800 Nm³/h
FG amount (target O_2, dry)	112 200 Nm³/h	132 400 Nm³/h	244 600 Nm³/h
FG O_2 target level	7 %-vol (dry)	6 %-vol (dry)	-
FG CO_2 content (11 % O_2)	8.1 %-vol (dry)	8.1 %-vol (dry)	-
FG CO_2 content (target O_2)	11.4 %-vol (dry)	12.2 %-vol (dry)	-
FG H_2O content			-
Winter	Saturated 35-45 °C	Saturated 35-45 °C	-
Summer (avg.)	18.1 %-vol	14.5 %-vol	-
Summer (max)			
With scrubber	Saturated 60 °C	Saturated 60 °C	-
Without K1&K2 scrubber	25.5 %-vol	Saturated 60 °C	
FG temperature (with K1&K2 scrubber)			
Summer	60 °C	85-100 °C	-
Winter	35-45 °C	85-100 °C	-
FG temperature (without K1&K2 scrubber)			
Summer	110 °C	85-100 °C	-
Winter	80-85 °C	85-100 °C	-
FG pressure	0.95 - 1.05 bar(a)	0.95 - 1.05 bar(a)	-
Operational hours per year	[redacted]	[redacted]	-
Organic fraction (of the waste)[3]	50-60 %	50-60 %	50-60 %

[1] All yearly data accounts for operational hours, while hourly data represents momentary values
[2] Nm³/h: dry gas, 0 °C, 101.3 kPa, 11 %-vol O_2. The amount has been recalculated and updated in FEED phase based on feedback from TechnipFMC.
[3] Based on the latest analysis performed in FEED phase.

5.2.3 Flue gas contaminants

Table 5-2 provides information about the limit values in accordance with current emission permits, average mixed (all three lines) flue gas contaminants, and design maximums for unregulated contaminants. For contaminants that are not regulated by the current emission permit, an evaluation of the upper range (design max) has been provided.

Table 5-3 provides information about the concentration of various contaminants separately for all three lines. For an easy comparison, the two last columns in Table 5-3 are the same as in Table 5-2.

The online measured flue gas components are: NO_x, SO_2, NH_3, HCl, H_2O, CO, HF, O_2, and dust for lines 1 and 2. In addition, the total organic content (TOC) emissions are measured for lines 1 and 2, while VOC emissions are measured for line 3.

Measurement of contaminants that are currently not continuously (online) monitored are presented as campaign data.

Table 5-2: Design FG composition (avg. of all lines), (design/permit) limit values and design maximums at Klemetsrud WtE plant (at 11 % O_2 and mg/Nm³ unless otherwise indicated).

Component	Limit values (mg/Nm^3)			Combined FG (mg/Nm^3) [7]	
	24 h	A- 100% [1,3]	B- 97 % [2]		
Online measured data				**Average**	**For info 99 %ile**
Dust	10	30	10	2.0	13.9
TOC/VOC	10	20	10	0.8	2.4
HCl	10	60	10	0.6	7.3
HF	1	4	2	0.07	1.1
CO	50	100	150 [4]	18.4	58.3
SO_2	50	200	50	6.0	38.5
NOx	200	400	200	57.0	106.9
NH_3	10	-	-	2	N/A
Campaign data[8]				**Average**	**Design max**
Acid mist (SO_3)	-	-	-	4.9	35
Nuclei/cm^3 (5)	-	-	-	18 000	600 000
H_2S	-	-	-	0.4	0.9
Cd+Tl	0.05	-	-	0.0005	-
Hg	0.05	-	-	0.001	-
Trace elements [6]	0.5	-	-	0.01	-
Di+Fu (ng/Nm^3)	0.1	-	-	0.02	-
NO	-	-	-	50	120
NO_2	-	-	-	1.2	12

[1] 100% of all half-hour average values have to be within the value A
[2] 97% of all half-hour average values have to be within the value B
[3] Limit value A can be exceeded for four consecutive hours before the incineration plant must shut down
[4] This CO value (of 150 mg/Nm³) is a ten-minute average value
[5] Representing submicron particles
[6] Trace elements that include, but are not only, heavy metals. Consisting of Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V (+ Sn in more recent campaigns)
[7] Combined data has been calculated based on FG flow provided in Table 5-1.
[8] Additional information regarding campaign data can be found in Attachment 1 of the Project Design Basis [22]

Table 5-3: Current FG composition (K1, K2 and K3 separately) at Klemetsrud WtE plant (at 11 % O_2 and mg/Nm³ unless otherwise indicated).

Component	Concentration (mg/Nm^3)			Combined FG (mg/Nm^3) [7]	
	K1 (Avg.)	K2 (Avg.)	K3 (Avg.)		
Online measured data				**Average**	**For info 99 %ile**
Dust	2.2	5.2	0.7	2.0	13.9
TOC/VOC	1.2	1.3	0.4	0.8	2.4
HCl	1.4	1.2	0.1	0.6	7.3
HF	0.05	0.05	0.08	0.07	1.1
CO	31.9	34.6	7.4	18.4	58.3
SO_2	14.5	8.7	1.9	6.0	38.5
NOx	117.7	111.2	14.4	57.0	106.9
NH_3	1.9	N/A	1.3	2	N/A
Campaign data				**Average**	**Design max**
Acid mist (SO_3)	10.7	8.7	1.3	4.9	35
Nuclei/cm^3 (5)	858	513	31500	18 000	600 000
H_2S	0.5	0.5	0.4	0.4	0.9
Cd+Tl	0.00011	0.00010	0.00087	0.0005	-
Hg	0.0010	0.0001	0.0022	0.001	-
Trace elements [6]	0.0019	0.0025	0.0181	0.01	-
Di+Fu (ng/Nm^3)	0.009	0.002	0.026	0.02	-
NO	109	98	11	50	120
NO_2	1.90	1.45	0.85	1.2	12

[5] Representing submicron particles
[6] Trace elements that include, but are not only, heavy metals. Consisting of Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V (+ Sn in more recent campaigns)
[7] Combined data has been calculated based on FG flow provided in Table 5-1.

5.3 Technical description of the new plant (2e)

This chapter contains both the design basis (section 5.3.1) as well as functional and technical description of the new CC Plant (sections 5.3.2 and 5.3.3) including the Intermediate storage at Klemetsrud (section 5.3.4), truck loading, transport (section 5.3.5) and ship loading facilities.

This section also presents the necessary upgrades to the existing WtE plant as consequence of installation of the new CC Plant at Klemetsrud, including integration scope.

Figure 5-5 below gives a simplified overview / flow diagram of the CC Plant at Klemetsrud, however this chapter benefits from being read in conjunction with the Process Flow Diagrams listed in Table 5-4.

Table 5-4: PFDs of the new CC Plant, from TechnipFMC.

PFD Number	PFD title
NC03-TEC-P-XA-0001	PFD - Legend and Symbols
NC03-TEC-P-XA-0002	PFD - Flue Gas Pre-Treatment
NC03-TEC-P-XA-0003	PFD - CO_2 Absorption
NC03-TEC-P-XA-0004	PFD - Absorbent Handling
NC03-TEC-P-XA-0005	PFD - Absorbent Regeneration
NC03-TEC-P-XA-0006	PFD - Thermal Reclaimer-100
NC03-TEC-P-XA-0007	PFD - Absorbent Drain Tank and Vent Header
NC03-TEC-P-XA-0008	PFD - Chemicals Storage and Unloading
NC03-TEC-P-XA-0010	PFD - MP And LP Steam and Condensate System
NC03-TEC-P-XA-0011	PFD - Waste Water Treatment
NC03-TEC-P-XA-0012	PFD - Instrument Air System
NC03-TEC-P-XA-0013	PFD - Demineralised and Tap Water System
NC03-TEC-P-XA-0014	PFD - Cooling System
NC03-TEC-P-XA-0015	PFD - CO_2 Compression and Conditioning
NC03-TEC-P-XA-0016	PFD - CO_2 Conditioning Dehydration and Regeneration
NC03-TEC-P-XA-0017	PFD - CO_2 Liquefaction Intermediate storage and loading
NC03-TEC-P-XA-0019	PFD - Oslo Harbour CO_2 storage and loading
NC03-TEC-P-XA-0021	PFD - Oslo Harbour Instrument Air System
NC03-TEC-P-XA-0022	PFD – Relief headers – Main site intermediate storage and harbour

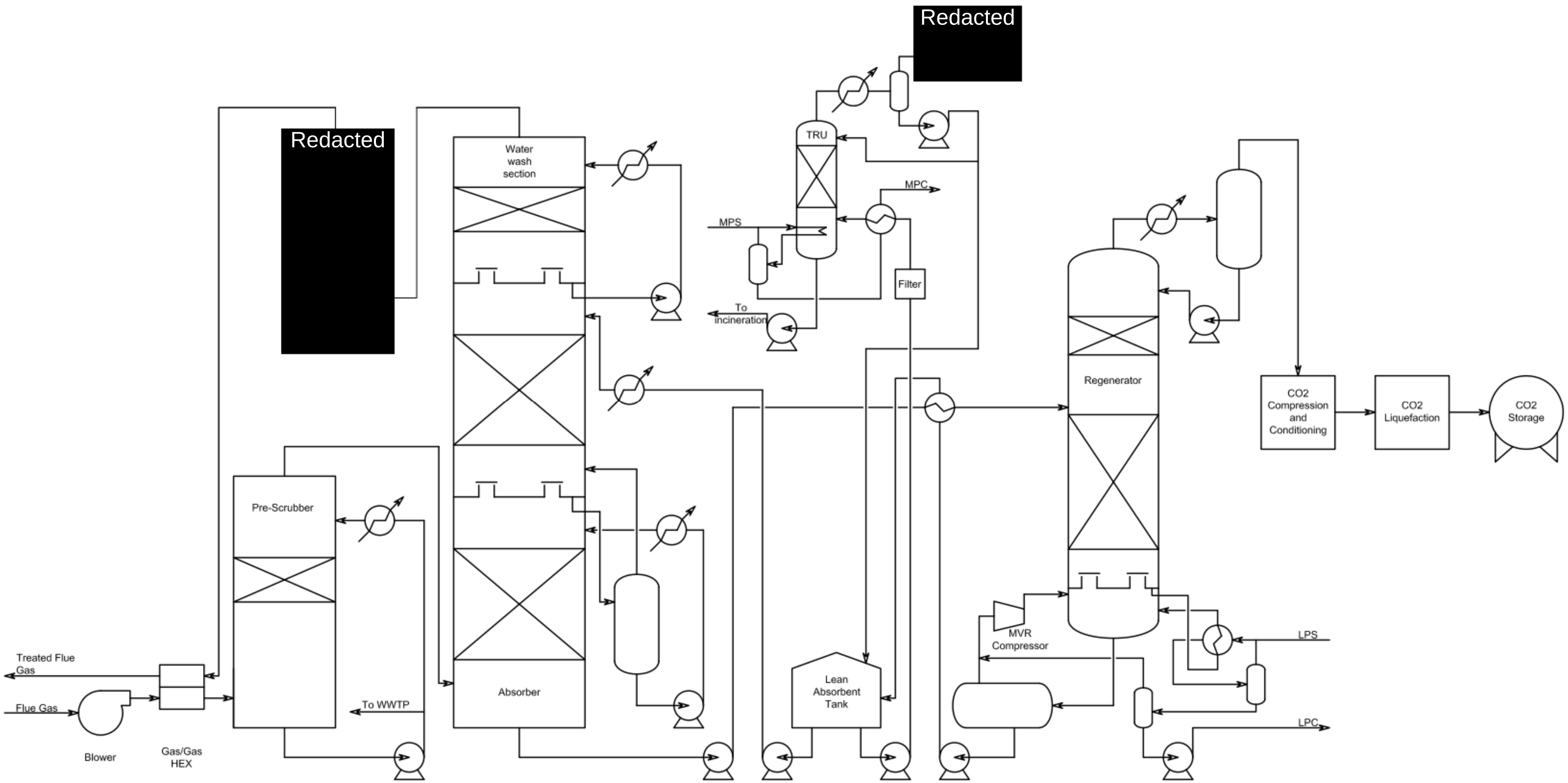

Figure 5-5: Simplified flow diagram of the CC Plant at Klemetsrud [23].

5.3.1 Design Basis

This section provides an overview of the most important design driving elements from a process perspective.

For additional information regarding the design basis, reference is made to the Project Design Basis [22] as well as the scope of work prepared by FOV for TechnipFMC [16]. It should be noted that all details presented here represent the latest input and in case of contradictory information found in named references (representing older submittals), information in this document shall prevail.

5.3.1.1 CC Plant design

- The following two cases are defined as operation design cases:
  - Summer Case – Based on summer operating conditions of the WtE plant. Cooling provided by cooling system only;
  - Winter Case – Based on winter operating conditions of the WtE plant. Cooling provided by heat pump / cooling system.
- The following two cases are defined as rating cases:
  - Turndown Case – Based on lines 1 and 2 in operation during summer conditions and 90% flow rate. Cooling provided by cooling system only. The plant will not be optimised to operate at turndown for long periods of time;
  - Max Contaminants Case – Based on design maximum concentration of impurities in the flue gas. Cooling provided by cooling system only. Cooling is possible up to 45°C. This case will not to be used to optimise the plant to operate for long periods of time, but to estimate the maximum solvent degradation rate.
- Design life is 25 years;
- The CC Plant shall be designed to be self-sufficient, highly automated and capable of handling the entire flue gas amount from all three incineration lines at Klemetsrud;
- The CC Plant shall be integrated with the Klemetsrud WtE plant such that the primary task, incineration of waste and delivery of heat to the district heating network, is not negatively impacted. The operation of the CC Plant is not allowed to reduce the operability, maintainability, Availability nor capacity of any of the incineration lines;
- The CC Plant shall be designed to capture 95% of CO_2 entering the Absorber;
- The CC Plant shall deliver minimum 400 000 tons CO_2 per year at the harbour, based on the design capacity of 460 200 tons CO_2 per year (57 t/hour) received from the WtE plant.
- The Availability of the CC Plant shall be high. Target is 95%.
- The CC Plant shall be able to operate with flue gas from WtE incineration lines 1 and 2 only (e.g. when line 3 is down for maintenance) as well as with flue gas from line 3 only (when line 1 and 2 is down for maintenance);
- The captured CO_2 shall be compressed and liquefied at Klemetsrud;

- The Intermediate storage volume at Klemetsrud shall as minimum account for one day of full production of CO_2. Harbour storage shall as minimum account for 4 days of full production;
- The footprint of the CC Plant (including liquefaction and intermediate storage) should be minimized and fit the designated areas available at Klemetsrud.
- The captured CO_2 shall be delivered from the CC Plant in refrigerated liquid state by truck to the harbour storage at Port of Oslo;
- From the Port of Oslo, the CO_2 shall be loaded onto a ship for transportation to final storage location;
- The CC Plant design target is to be able to handle all flue gas variations; bypassing may in extreme situations be considered for CC Plant protection,
- All new emissions/effluents/discharges are evaluated to meet the existing and future (when known) authority requirements.

5.3.1.2 Flue gas source

The flue gas source (composition, contaminants and emission limits) is described in detail in section 5.2. The CC Plant design is:

- Optimized based on average values (composition and contaminants);
- Capable of handling contaminant concentrations up to the prevailing emission permit limit. In addition, the CC Plant should be able to handle peaks above the permit values:
    - Table 5-2, Limit value A (which represents an average half-hour value) can be exceeded for four hours before the incineration plant must shut down. In other words, if emissions are above these permit values for more than four consecutive hours, the WtE plant is starting the firing down process (stop feeding of waste and after some time start oil burners).
    - If the 24-hour average limit value (Table 5-2) is exceeded, the WtE plant needs to start the firing down process.

5.3.1.3 Unit Margins, Capacity and Turndown

The following flue gas design margins will be applied:

- Flue gas max/min flowrate: [redacted];
- Oxygen concentration in flue gas: [redacted];
- CO_2 concentration in flue gas: [redacted];

For equipment and systems either the margin shown above or in Table 5-5 should be used, whichever is greater. For example, for blower type of equipment design margin is [redacted]. But since the flue gas flowrate design is [redacted], the flue gas blower shall have [redacted] design margin.

Table 5-5: Equipment design margin.

Equipment	Design Margin	Parameter
Booster Fan	[redacted]	flow
Pre-Scrubber tower	[redacted]	gas flow
Absorber	[redacted]	gas flow
	[redacted]	liquid flow (including water wash)
Stripper	[redacted]	gas flow
	[redacted]	liquid flow
CO_2 Capture plant pumps	[redacted]	flow
Compressor	[redacted]	flow
Instrument Air System	[redacted]	maximum flow
Utility Water System	[redacted]	
Steam System	[redacted]	maximum flow/consumption
Waste Water Treatment/ Demineralisation water system	[redacted]	
Plate Heat Exchangers	[redacted]	flow and duty (or manufacturer's margin, whichever is greater);
Shell &Tube Heat Exchangers	[redacted]	flow and duty
Centrifugal pumps	[redacted]	flow
Dosing pumps & reflux pumps	[redacted]	flow

Flue gas max flowrate margin will be included in the rated flowrate. Flue gas min flowrate negative margin will be applied in the Turndown Case. The Oxygen concentration margin will be considered in the Max Contaminants Case. The CO_2 concentration margin will be included in the rated flow. It should be considered also when calculating the solvent degradation rate.

The normal design flowrate will correspond to the Summer or Winter case operation, whichever higher.

[redacted]

The turndown capacity of the plant will be based on the Turndown Case (as specified in section 5.3.1.1).

5.3.1.4 CO_2 product specification

The CO_2 product to be shipped shall meet the specifications provided in Table 5-6. For the latest specification, reference is made Gassnova Basis of Design [24] in its latest revision.

Table 5-6: CO_2 product specification [24].

Component	Concentration ppm (mol)	Remarks / Comments
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 and onshore 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, SO_x	≤ 10	Required to avoid accelerated corrosion in presence of water. Value set conservatively to allow wider range of materials.
Nitric oxide/Nitrogen dioxide, NO_x	≤ 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, Tl	≤ 0.03 (sum)	Toxic to personnel entering vessels, replacing filters, etc. May cause embrittlement of metals.

5.3.1.5 Environmental Impact

All existing regulatory requirements shall be met after the addition of the CC Plant. Health, safety and environmental requirements are detailed in chapter 6.

The main objective with regards to waste handling is to avoid emissions (zero discharge plant) from the entire Klemetsrud site as a total. All effluent streams should primarily be utilized/handled within the Klemetsrud site. In addition:

- Process wastewater from CC Plant shall not be disposed of, instead primarily utilized as process water in the WtE plant, secondarily as cooling water (in wet or hybrid coolers);
- The CC Plant should be designed to not exceed the Norwegian Institute of Public health (NIPH) recommendations for the total amount of nitrosamines and nitrammites in air (0.3 ng/m³) in air and water (4 ng/l);
- The total noise level (including the additional noise from the CC Plant) must not exceed the existing regulations;
- For civil works, all parties shall focus on using secondary materials to the extent practically and financially reasonable to contribute to a circular economy. In addition, the building site shall as far as possible utilize fossil free energy sources.

5.3.2 Pre- and Post- Treatment Units

The Gas Pre-treatment is necessary to cool down the flue gas to the temperature required for CO_2 absorption and to reduce the concentration of contaminants, such as ammonia, present in flue gas. The Pre-Treatment Unit is comprised of:

- Booster fan;
- Pre-Scrubber;
- Gas-Gas Heat Exchanger (cooling).

The Post Treatment is comprised of:

- [redacted];
- Gas-Gas Heat Exchanger (heating).

5.3.2.1 Flue Gas Pre-Treatment

A combined stream of flue gas from the WtE plant is routed to the CC Plant via the Pre-Treatment Unit. A centrifugal type Booster Fan provides sufficient pressure to drive the flue gas through to the Gas-Gas Heat Exchanger, Pre-Scrubber, CO_2 Absorber, [redacted] and back through the Gas-Gas Exchanger to the top of the stacks.

The flue gas from the Booster Fan flows to the Gas-Gas Heat Exchanger where it is cooled, whilst heating the treated flue gas from the Absorber. The Gas-Gas Heat Exchanger is a rotary regenerative heat exchanger, in which a slowly rotating element transfers heat from the hot side to the cold side. Purge and Scavenge Fans are used to maintain a low level of leakage between the two sides.

The flue gas flows into the Pre-Scrubber via two inlet nozzles, where it is cooled by direct contact with recirculating water. It is critical to saturate and cool the flue gas prior to feeding to the Absorber to ensure proper CO_2 absorption and prevent excessive water evaporation from the absorbent solution in the Absorber. The cooled flue gas from the top of the Pre-Scrubber is then sent to the Absorber for CO_2 removal.

The circulating water collected in the bottom of the Pre-Scrubber is pumped by the Pre-Scrubber Pumps and cooled in the Pre-Scrubber Water CW (Cooling Water) Cooler. The cooling extent is regulated by the cooling medium flowrate, controlled by the Pre-Scrubber overhead temperature controller. The cooled circulating water then enters the top of the Pre-Scrubber under flow control. [redacted]

[redacted] Therefore, the Pre-Scrubber effluent water is sent for treatment in the Waste Water Treatment package before it can be reused within the CC Plant and WtE plant or discharged into the municipal sewage system. Some of this water is also used as dilution water for the Thermal Reclaimer Unit (TRU). [redacted]

5.3.2.2 Flue Gas post-treatment

[redacted]

[redacted] flue gas is directed to the Gas-Gas Heat Exchanger where it is warmed up before being released to the atmosphere through the existing stacks.

5.3.3 Carbon Capture Unit

The CO_2 Capture System comprises the following major components (as shown in Figure 5-5):

- Absorption Section;
- Water Wash Section;
- Stripping Section;
- Mechanical Vapour Recompression Section;
- Absorbent Filtration Unit;
- Thermal Reclaiming Unit;
- Absorbent Storage.

5.3.3.1 Absorption Section

The flue gas exits the Flue Gas Pre-treatment Unit and enters the CO_2 Absorber in the bottom [redacted]. CO_2 is removed from the flue gas by counter-current contact with lean absorbent in a vertical multi-level packed-bed CO_2 Absorber tower. The gas entering the absorption section of the tower will have sufficient pressure to overcome the pressure drop in the tower packing, Gas-Gas Heat Exchanger and [redacted] before being released to the atmosphere through the existing stacks.

The Absorber Feed Pump delivers lean absorbent, under flow control, from the Lean Absorbent Tank through the Lean Absorbent CW Cooler, to the top of the CO_2 Absorption section.

CO_2 absorption is an exothermic reaction. The heat generated by absorption must be removed to prevent absorbent temperature increase, which would reduce the absorption capacity. To prevent heat accumulation in the tower, hot absorbent is collected on a chimney tray above the bottom packing section from where it flows by gravity to Intercooler Drum. Liquid from the intercooler drum is routed to the Intercooler Pump and is pumped to the CW Intercooler. The temperature of the cooled absorbent is controlled by the CW supply and is returned to the Absorber to resume CO_2 absorption in the bottom packing section.

The treated flue gas leaving the top of the CO_2 absorption section passes through a Water Wash section within the same column before being released to the atmosphere through two existing stacks.

5.3.3.2 Water Wash Section

The Water Wash Section is installed above the absorption section in order to capture entrained absorbent droplets and to condense water from the flue gas to maintain the water balance in the system. Wash water is circulated counter-currently to the flue gas through a packed bed in this section. Wash water is drawn from a chimney tray at the base of the Water Wash Section and is re-circulated to the top of the packed bed via the Water Wash CW Cooler, by the Water Wash Pump. The Wash Water Cooler reduces the temperature of the circulating wash water, which minimises water loss and enhances capture efficiency. Temperature control is achieved by the CW supply to Water Wash Cooler. Water condensed from the flue gas into the wash water section overflows from the chimney tray down into the absorption section. The treated flue gas leaving the Water Wash Section flows upwards through a Demister, then through the [redacted] and Gas-Gas Heat Exchanger and finally to be discharged to atmosphere via two existing stacks.

Demineralised water is used primarily upon start-up to fill this system and could also be used to control the water inventory in the loop.

5.3.3.3 Stripping section

The CO_2 rich absorbent collected in the sump of the CO_2 Absorber is pumped by the Rich Absorbent Pump, under level control, and heated in the Lean/Rich Exchanger by recovering heat from the hot lean absorbent discharged from the CO_2 Stripper. Rich absorbent exiting the Lean/Rich Exchanger is directed to the CO_2 Stripper for absorbent regeneration and CO_2 recovery.

The rich absorbent enters the CO_2 Stripper Column under the rectification section via a "schoepentoeter", allowing for disengagement of vapour from the rich absorbent before flowing down to the two stripping packing sections. Above each stripping section there is a vane collector for a better liquid cross-mixing and a liquid distributor. The CO_2 bound to the rich absorbent is liberated by the addition of heat, provided by LP steam in the CO_2 Stripper Reboiler, which also regenerates the lean absorbent required for the absorption process in the CO_2 Absorber. The LP steam is added under flow control with input primarily from the rich absorbent feed rate, if the overhead temperature is low then this temperature will override the steam to absorbent ratio control and will increase the flow of steam to re- establish the Stripper overhead temperature.

Lean absorbent flowing from the bottom packing section of the CO_2 Stripper is collected on a chimney tray and gravity fed to the Reboiler. A two-phase mixture of water vapour and lean absorbent flows from the Reboiler back to the Stripper sump, underneath the chimney tray. Water vapour flows upwards through the chimney tray while the lean absorbent collects in the bottom sump.

LP steam condensate from the Reboiler is collected in the Steam Condensate Pot and directed to the Steam Condensate Flash Pot on a level-to-flow cascade control where the condensate is flashed. The resulting flash steam is directed to the Lean Absorbent Flash Vessel to further remove liquid droplets before being sent to the bottom of the Stripper through the MVR (Mechanical Vapor Recompression) compression section. Using the LP steam condensate flash as a stripping medium minimizes steam and energy required. The condensate from the bottom of the flash pot is directed to condensate return system under a level-to-flow cascade control via Steam Condensate Pumps.

Lean absorbent flows from the CO_2 Stripper sump through a level control valve to the Lean Absorbent Flash Vessel, where it flashes and releases vapour for reuse in the CO_2 Stripper through the MVR compression system. During start-up the bypass line from the Lean Absorbent Flash Vessel to the Stripper Column is used to equalise the pressure before bringing the MVR Compressor online. The Lean Absorbent Pump delivers the lean absorbent, under level control, from the Lean Absorbent Flash Vessel to the Lean Absorbent Tank after being cooled in the Lean/Rich Absorbent Heat Exchangers.

Water vapour in the Stripper, carrying the stripped CO_2, flows up the Stripper Column into the rectification packing section in the top of the column, where a portion of the vapour is condensed by counter-current contact with recycled reflux stream to enrich the overhead CO_2 gas stream.

The CO_2 Stripper overhead vapour is partially condensed in the CO_2 Stripper Overhead CW Condenser by CW. The partially condensed two-phase mixture flows to the Reflux Accumulator where the two phases separate. The reflux water is collected and returned on level-to-flow cascade control via the Stripper Reflux Pump to the CO_2 Stripper rectification section. The purge stream is taken from this location as there is minimal absorbent and CO_2 present in the CO_2 Stripper reflux, leading to lower absorbent losses and less corrosive purge stream. The CO_2 product gas passes through a Demister and exits from reflux accumulator to the compression and conditioning.

[redacted]

5.3.3.4 Mechanical Vapour Recompression

The Lean Absorbent Flash Vessel receives the lean absorbent from the CO_2 Stripper sump. The level control valve reduces the pressure of the CO_2 lean absorbent, which causes water vapour and some CO_2 to flash from the absorbent. The CO_2 containing water vapour, along with flashed condensate (vapour) from the Steam Condensate Flash Pot is directed to compressor via MVR Compressor Suction Knock Out Drum. Any liquid knocked out is pumped back to the lean absorbent flash vessel using MVR Compressor Suction Knock Out Drum Pumps. The liquid free vapour is then recompressed by the MVR Compressor, to increase its pressure up to the operating pressure of the CO_2 Stripper, before being reintroduced beneath the CO_2 Stripper bottom chimney tray. The stream is desuperheated using the Stripper reflux before entering the column.

5.3.3.5 Absorbent Filtration Unit

The lean absorbent may pick up dust or other insoluble contaminants as it flows through the various unit operations of the CO_2 Capture System. Such contaminants could, in the long run, accumulate in the system and foul the heat exchanger surfaces.

For this reason, an Absorbent Filtration Unit is required to maintain the dust concentration in the circulating absorbent at a steady concentration. The Absorbent Filtration Unit design will be finalised during project execution. The recommended configuration, based on the dust concentration provided in the design basis, is a non-regenerable filtration unit, which consists of a cartridge type mechanical pre-filter for mechanical impurities, the main activated carbon filter and a cartridge type mechanical after-filter to capture activated carbon particles.

5.3.3.6 Thermal Reclaiming Unit

The absorbent accumulates both heat stable salts and non-ionic absorbent degradation products over time which must be removed from the solvent by the Thermal Reclaimer Unit (TRU). [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

5.3.3.7 Absorbent Storage

The Absorbent Transfer Pump delivers fresh absorbent from an ISO container or tanker truck to the Lean Absorbent Tank. The Lean Absorbent Tank feeds the CO_2 Absorber with lean absorbent, which is delivered by the Absorber Feed Pump under flow control. TRU Feed Pump will be used to provide absorbent to the TRU via Absorbent Filtration Unit. The Lean Absorbent Tank is also designed to have a sufficient volume to contain the entire absorbent inventory (lean and rich) for the whole CC Plant.

5.3.4 Conditioning, liquefaction, storage and loading

The following processes are described in this section:

- CO_2 Conditioning (compression, oxygen removal and dehydration);
- Liquefaction and Intermediate storage at Klemetsrud;
- Harbour storage at Port of Oslo.

5.3.4.1 CO_2 Conditioning (compression, oxygen removal and dehydration)

The captured and stripped CO_2 stream is routed from the Stripper Reflux Accumulator to the 1st Compression Stage Suction Knockout Drum. From the drum the separated liquid is removed by a Process Condensate Return Pump and sent to the Waste Water Treatment (WWT) package under flow control, which can be overridden by knockout drum level control. The liquid free CO_2 gas enters a CO_2 Compressor Package. The configuration of the package is to be finalised during project execution. It is expected that the compressor train will consist of a number of stages, each having a compressor, aftercooler and interstage knockout drum. After the compression, the temperature of the stream is reduced by an aftercooler and the two- phase stream is directed to a knockout drum to remove any further water out of the gas stream. The water removed is sent to the previous stage knockout drum under level control, so that all process condensate is collected in the 1st stage knockout drum and sent to the WWT package. The liquid-free CO_2 is fed to the next compression stage.

At the suction of the final stage of compression, hydrogen is injected and the stream is not cooled at the discharge, passing straight to an Oxygen Removal Reactor. Hydrogen injected into the process reacts with oxygen to form water, reducing the concentration of oxygen to the required level. Excess hydrogen is used to ensure that any side reactions do not starve the desired reaction of oxygen.

After oxygen removal, the stream is cooled in a Reactor Outlet Cooler using cooling water before being sent for a dehydration.

The dehydration starts in a CO_2 Dehydration Filter Coalescer, which removes any liquid droplets from the stream. The condensate removed is sent to the last stage suction drum of the compression package under level control. The CO_2 stream from the coalescer is then sent to CO_2 Dehydration Molecular Sieves. This is a dual vessel dryer system which involves one bed being online whilst the other is being regenerated. Dry CO_2 gas is used for the regeneration.

The gas treatment is completed by a CO_2 Dehydration Basket Filter, which removes any potential particles of the molecular sieves from the dry and conditioned CO_2 stream.

The dry CO_2 gas is used for the molecular sieve bed regeneration. The slip stream of the CO_2 leaving the dehydration basket filter is heated in a Regeneration Gas Electric Heater to reach the temperature necessary for regeneration before being sent to the molecular sieve bed. Used wet CO_2 is then flows through a Regeneration Gas Discharge Filter to remove any molecular sieve particles and cooled down in a Regeneration Gas Discharge Cooler. After the cooling, condensed water is removed in a Regeneration Gas Discharge Separator and the liquid free CO_2 is compressed in a Regeneration Gas Compressor before being reintroduced into the wet CO_2 stream, downstream of the Oxygen Removal Reactor, going for dehydration.

After regeneration the bed can be cooled by the same slip stream of the dry CO_2, bypassing the electric heater. The same scheme is utilised for the Oxygen Removal Reactor bed regeneration, which is required periodically.

5.3.4.2 Liquefaction and Intermediate storage at Klemetsrud

The liquefaction package is installed on-site, along with the associated intermediate storage. Upon removal of the oxygen and water, the CO_2 vapour stream is directed to a CO_2 Liquefaction Package. The configuration of the package will be finalised during project execution. The liquefied CO_2 is then sent to intermediate storage. The quality of the CO_2 product is monitored by an online analyser, which can initiate alarm and divert CO_2 stream back to the Absorber to prevent off-spec product being sent to the storage.

The Liquefied CO_2 Intermediate Storage Bullets are four horizontal bullet type vessels to provide enough storage capacity for one day's production of liquefied CO_2. The preliminary selection for the intermediate CO_2 storage at Klemetsrud is due to cost optimization and standardization reasons. During the EPC phase, the option of vertical storage vessels at Klemetsrud will be investigated and the most cost optimal solution will be selected.

The Liquefied Transfer Pump is used to load the road trucks. The metering package measures the amount of gas sent from the CC Plant. A re-liquefaction facility is installed at the Port of Oslo to manage any boil-off gas from the storage or handling.

5.3.4.3 Harbour facilities and ship loading

The harbour storage at Port of Oslo consists of 16 horizontal Bullet type vessels, arranged in two rows one above the other. From the harbour storage the CO_2 will be pumped by the Liquid CO_2 Pumps and, following fiscal metering, transferred to CO_2 transport ship via loading arms. The vapour return from the ship will be directed to the re-liquefaction package via the Vapour Return Arm. Boil off gas from the CO_2 Harbour Storage Bullets will be also directed for the re-liquefaction. The horizontal orientation of the storage tanks is due to a restriction in building height at the Port of Oslo.

The Harbour facilities export will comply with all relevant SIGTTO recommendations and OCIMF guidelines as communicated to Northern Lights through their interface register (PIMS) and in interface meetings during the FEED phase of the project.

Fiscal metering is installed before the ship loading facilities. The need for fiscal metering for truck loading lines and on the vapour return arm will be considered in the next phase of the project.

5.3.5 Transport from Intermediate storage at Klemetsrud to Port of Oslo

Refrigerated and liquefied CO_2 is transported by road trucks from the intermediate storage at Klemetsrud to the harbour storage.

The logistics system is designed with 3 parallel loading stations at Klemetsrud, and 3 unloading stations at the harbour facilities at the Port of Oslo.

It is currently estimated a need for 6 trailer trucks running close to a 24/7-operation, where a reduction in transport during weekends may be possible.

The daily number of loading and unloading operations is expected to be in the area of 38-45 depending on final trailer payload.

Road trucks to be used will be of non-CO_2 emitting type. Several alternative fuels and drivelines have been investigated and currently the most viable fuel to be used is biodiesel (based on a 400 hp minimum requirement for a 50-ton semi-trailer).

Manufacturers are currently testing electrical trucks with external charging of batteries as well as trucks with internal charging of batteries through fuel cells. The majority of the tested trucks are smaller, with a total weight of up to 25 tons limiting their usefulness in this project. However, as technology is rapidly developing, electric tractors capable of a total freight weight of 50 tons is expected to be available by the time the CC Plant is up and running. Electric drive seems like the desired alternative with an advantageous option of installing charging capabilities at both the loading and the unloading facility.

The fuel and driveline alternatives should be in constant review throughout the project life span.

5.3.6 Utilities

This section contains a brief description of the CC Plant utility systems and the flow rates of utilities exchanged between the WtE Plant and the CC Plant. The main utilities are:

- Cooling System;
- Steam, LP and MP, and condensate return (to/from WtE plant)
- Tap water (from WtE plant);
- Waste water/process water (to/from WtE plant);

- Demineralised water (CC Plant supplied, to WtE plant);
- Instrument Air (CC Plant internal system);
- Chemical Injection (CC Plant internal system);
- Electrical Power Supply (from WtE plant);
- Process Control and Shutdown System (CC plant internal system).

5.3.6.1 Cooling System

The Cooling system for CC Plant consists of the two loops, a closed loop and an open loop. The closed loop provides cooling to the plant users, while the open loop cools the closed loop. The heat exchange between the loops takes place in a Cooling System Package. The design of the package is to be finalised during project execution. Essentially this is an air cooler, where the closed loop warm fluid flowing through the tube bundle is cooled by the air fans, and the open loop water is sprayed over the tube bundle for additional cooling effect.

The open loop spray water needs to be replenished. Make-up is available as treated water from the Waste Water Treatment package, as waste water from the WtE plant and as tap water.

The cold cooling water from the package is pumped by the Closed Loop Circulation Pumps to the users. The Closed Loop Circulation Filter located on the slip stream from the discharge line removes any particulate accumulating in the system. The Closed Loop Chemical Dosing Package on the suction line provides injection of the corrosion inhibitor, microbial and pH control. The expansion Vessel connected to the process air and to the atmosphere facilitates thermal expansion of the closed liquid system. From time to time the inventory of the closed loop can be replenished with the demineralised water with propylene glycol.

5.3.6.2 LP and MP Steam

MP steam is continuously provided from the WtE plant and is used in the TRU.

Desuperheated MP steam from the WtE is supplied to the TRU Reboiler by flow control (set point is TRU Column bottom temperature). The condensate stream from the Reboiler is collected in the Desuperheating Pot which has a balancing line with the steam supply. The bottom liquid stream is sent to the TRU Feed Preheater under level-to-flow cascade control with a set point from the Desuperheating Pot level controller. The subcooled LP condensate is then sent to the Steam Condensate Flash Pot, along with the LP condensate from the Absorbent regeneration section, before being returned to the WtE plant via a common LP Condensate Return Header mixed with LP condensate.

The consumption of MP steam is as shown in the Table 5-7. During normal operation only one of two TRU lines is in use. At maximum level of contaminants in the flue gas, both units operate.

Table 5-7: MP steam consumption in the CC Plant.

Equipment	Operating pressure (barg)	Operating temperature (ºC)	Flow rate – normal (kg/h)	Flow rate – max contaminant (kg/h)
TRU Reboiler, line 1	21	217	[redacted]	[redacted]
TRU Reboiler, line 2	21	217	[redacted]	[redacted]
Total			[redacted]	[redacted]

LP steam is provided from the WtE plant. After being desuperheated, the steam is used in the CO_2 Stripper Reboiler and in the TRU for sparging.

LP steam condensate from the Stripper Reboiler is collected in the Steam Condensate Pot and directed to the Steam Condensate Flash Pot on level control where the condensate is flashed. The resulting flash steam is directed to the bottom of the Stripper through the MVR Compressor. The liquid phase is returned to the condensate system through the Steam Condensate Pump under level control. The slip stream from the pump discharge is sent for LP steam desuperheating under temperature control.

The consumption of LP steam is as shown in the Table 5-8.

Table 5-8: LP steam consumption in the CC Plant.

Equipment	Operating pressure (barg)	Operating temperature (ºC)	Flow rate – summer (kg/h)	Flow rate – winter (kg/h)
Stripper Reboiler	6	165	[redacted]	[redacted]
Sparging in TRU*	6	165	[redacted]	[redacted]
Total			[redacted]	[redacted]
*: the maximum contaminant case is shown. During normal operation, the consumption is [redacted]				

LP Condensate (in quantities according Table 5-9) to is returned to the WtE plant. The difference between steam consumed by the CC Plant and condensate returned to the WtE is reintegrated as demineralised water.

Table 5-9. LP condensate returned to the WtE.

Stream	Operating temperature (ºC)	Flow rate – summer (kg/h)	Flow rate – winter (kg/h)
Condensate	101	[redacted]	[redacted]

5.3.6.3 Tap water

Tap Water will be used for the initial fill of wash water in the Pre-Scrubber and Waste Water Treatment package. It is also used to replenish spray water in the Cooling System Package. There is a Tap Water Break Tank to prevent back flow to the tap water system and Tap Water Pump for transfer to the users.

Tap water consumption is as shown in Table 5-10. The total demineralised water required for initial fill of the Waste Water Treatment package is shown in Table 5-10, assuming 70% WWT Package recovery rate.

Table 5-10. Tap water consumption.

Equipment	Initial supply (tons)	Intermittent flow (tons/h)
Pre-Scrubber	[redacted]	[redacted]
Waste water treatment package	[redacted]	[redacted]
Safety showers	[redacted]	[redacted]
Utility stations	[redacted]	[redacted]
Total	[redacted]	[redacted]

5.3.6.4 Waste water/process water and Demineralised water

The Waste Water Treatment package treats all waste water from the CC Plant.

The main source of the waste water is the effluent from the Pre-Scrubber. This stream has a low mineral content but contains contaminants from the flue gas. This stream can potentially be reused in the plant for TRU waste dilution and sent to the WtE plant where it can replace tap water in various uses. Other sources of waste water are condensate from compression and dehydration package and some intermittent sources, such as wash water purge from the Absorber, closed loop cooling system spray water blowdown and absorbent drains.

It is expected that the WWT plant will consist of an ion exchange system and ammonia Stripper (design to be finalised during project execution). Air from the ammonia stripping is sent to the treated flue gas line going to the stacks.

Part of the waste water is to be upgraded to the demineralised water quality and the balance is to be treated to meet the specification of the local sewage system to be safely disposed of. This stream is also used to replenish spray water in the Cooling System Package.

Produced demineralised water will be sent to the CC Plant for distribution and to the WtE plant to compensate for the loss of the LP steam condensate used in TRU and any additional amount if required.

During start-up when the Pre-Scrubber effluent is not available, demineralised water can be produced from the tap water. Any waste generated by WWT Package will be disposed of by vacuum truck.

The demineralised water consumption levels are reported in Table 5-11. In addition to what is reported, the absorbent drain tank may have additional intermittent consumption.

Table 5-11: CC Plant and WtE plant demineralised water consumption.

Equipment	Initial supply (tons)	Flow rate – summer (kg/h)	Flow rate – winter (kg/h)
TRU Vacuum system	[redacted]	[redacted]	[redacted]
Caustic dilution	[redacted]	[redacted]	[redacted]
Absorbent drain tank	[redacted]	[redacted]	[redacted]
Lean Absorbent Tank (first fill)	[redacted]	[redacted]	[redacted]
Lean Absorbent Tank (make-up)	[redacted]	[redacted]	[redacted]
Water Wash Absorber	[redacted]	[redacted]	[redacted]
To WtE plant (steam compensation)	[redacted]	[redacted]	[redacted]
To WtE plant (FOV requirement)	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]

5.3.6.5 Caustic Soda Solution

A concentrated caustic soda solution of low chloride grade is delivered to the Caustic Storage Tank by a road tanker. The Caustic Transfer Pump delivers caustic to the Pre-Scrubber circulating water, TRU feed and WWT Unit. Before being sent to the users, caustic soda is diluted with demineralised water under ratio control to produce a less concentrated caustic soda solution.

5.3.6.6 Instrument Air

Plant and Instrument Air required for CC Plant facilities is supplied by a new Instrument Air System.

Within an Instrument Air Compressor Package atmospheric air is filtered before being compressed by an instrument air compressor. Wet compressed air is cooled to 40°C using a CW cooler, after which condensed water is collected in a vessel. Plant/tool air is taken from this stage. Instrument air is dried in the Instrument Air Drier Package to achieve a water dew point of -40°C (at atmospheric pressure) at the drier outlet. Dry instrument air is taken for use through the Instrument Air Buffer Vessel which provides 10 minutes hold-up. Interconnection with the existing Instrument Air System is provided upstream of the buffer vessel. A minimum pressure controller is provided on the plant air header to CC Plant to stop supply to plant air users if pressure falls below a minimum value.

A nearly identical system comprising of an Instrument Air Compressor Package, Instrument Air Drier Package and Instrument Air Buffer Vessel is provided at the Port of Oslo to provide Plant and Instrument Air for liquefaction, harbour storage and ship loading facilities at the Port of Oslo. Unlike the CC Plant Instrument Air Compressor System, CW is not provided the Harbour Instrument Air System, and coolers are air cooled.

The predicted air consumption is shown in Table 5-12.

Table 5-12: CC Plant air consumption.

	Instrument air		Plant air
Area	**Consumption – max (Nm³/h)**	**Consumption – normal (Nm³/h)**	**Consumption – intermittent (Nm³/h)**
CC Plant - Klemetsrud	[redacted]	[redacted]	[redacted]
Port of Oslo	[redacted]	[redacted]	[redacted]

5.3.6.7 Chemical injection

Chemicals and catalysts will be added/injected for various purposes. Table 5-13 gives information about of the most important chemicals and catalysts used in the CC Plant.

Table 5-13: Overview of the main chemicals and catalysts used in the CC Plant.

Area/Service	**Chemical**	**Injection point**	**Average dosing rate (kg/day)**
CO_2 capture	Amine absorbent (Cansolv DC-103)	Lean Absorbent Tank	[redacted]
TRU	Caustic Soda (20%). Caustic soda is diluted with demineralised water under ratio control to produce a less concentrated caustic soda solution.	TRU Feed Pump	[redacted]
Pre-Scrubber		Circulation water line	[redacted]
WWT		Within package	[redacted]
WWT	Hydrochloric acid	Within package	[redacted]
WWT	Sodium chloride	Within package	[redacted]
Heat Pump	Refrigerant	Within package	[redacted]
Absorber/Stripper	Anti-foam	Various locations	[redacted]
Oxygen removal	Hydrogen	4th stage CO_2 compressor suction	[redacted]
Cooling system	Propylene glycol	CW Pump Package	[redacted]
Cooling system	Corrosion inhibitor	CW Pump Package	[redacted]
Cooling system	Biocide	CW Pump Package	[redacted]
Oxygen removal	Catalyst to be decided	Within package	[redacted]
CO_2 dehydration molecular sieves	Catalyst to be decided	Within package	[redacted]
[redacted]			

5.3.6.8 Electrical Power Supply

Klemetsrud

The CC Plant will have its own 11 kV switchgear that will be supplied from the new Klemetsrud substation. The 11 kV supply is described in section 5.10.5.1.

Motors rated above 400 kW will be fed from the 11 kV switchgear, while low voltage motors will be supplied from 690 V MCCs. Other low voltage consumers (not motors) will be fed from 400 V distribution boards.

Both the 690 V MCCs and 400 V distribution boards will be supplied via redundant transformers fed from A- and B-side of the 11 kV switchgear. All boards will have two supply sources.

Two capacitor banks will be connected to the 11 kV switchgear and this will improve the overall power factor of the CC Plant.

The largest electrical power consumers are shown in Table 5-14. For spared equipment, the presented loads are applicable per unit of equipment.

Table 5-14: Largest electrical power consumers of the CC Plant.

Equipment	Voltage	Load – summer (kW)	Load – winter (kW)
Rich Absorbent Pumps [redacted]	11 kV	[redacted]	[redacted]
Absorber Intercooler Pumps [redacted]	690 V	[redacted]	[redacted]
Pre-Scrubber Pumps [redacted]	690 V	[redacted]	[redacted]
Absorber Feed Pumps [redacted]	690 V	[redacted]	[redacted]
Lean Absorbent Pumps [redacted]	690 V	[redacted]	[redacted]
Liquid CO_2 Pumps [redacted]	690 V	[redacted]	[redacted]
Closed Loop CW Pumps [redacted]	11 kV	[redacted]	[redacted]
Booster fan [redacted]	11 kV	[redacted]	[redacted]
MVR Compressor [redacted]	11 kV	[redacted]	[redacted]
Damper Seal Air Fans [redacted]	11 kV	[redacted]	[redacted]
Purge and Scavenge fans [redacted]	690 V	[redacted]	[redacted]
Heat Pump package	11 kV / 690 V	[redacted]	[redacted]
CO_2 Compressor package	11 kV	[redacted]	[redacted]
CO_2 Liquefaction package	11 kV / 690 V	[redacted]	[redacted]
Regeneration Gas Electric Heater	11 kV	[redacted]	[redacted]
Total (including all loads)		[redacted]	[redacted]

Port of Oslo

The 11 kV supply to the harbour facilities is described in section 5.10.5.1.

Shore to ship power (690 V) will be fed from the 11 kV switchgear. All motors are low voltage and will be fed from 400 V MCCs / distribution boards. The 400V MCCs / distribution boards will be supplied via redundant transformers fed from A- and B-side of the 11 kV switchgear. All boards will have two supply sources.

Two capacitor banks will be connected to the 11 kV switchgear and this will improve the overall power factor of the harbour facilities.

The total power consumption at harbour facilities at Port of Oslo is, for all consumers including shore to ship power, not yet finalised.

5.3.6.9 Process Control and Shutdown System

The CC Plant will be controlled from the CCR, located in the WtE plant control building, which will be the centre of operations. A new Local Equipment Room (LER) will house the CC Plant ICSS cabinets. The LER will also house the Package Equipment Systems and the Machinery Monitoring Systems.

A new local equipment room will be provided the harbour facility with a new operator station to allow monitoring and control of the road tanker, harbour storage and ship loading activities.

The CC Plant will be controlled and protected by an Integrated Control and Safety System (ICSS), which will control the entire operations in the plant from the flue gas pre-treatment plant through to the ship loading at the harbour. The ICSS consists of:

- Process Automation System (PAS)
- Emergency Shut Down System (ESD)
- Fire and Gas Detection System (FGS)

PAS, ESD & FGS are functionally independent at control level and fully integrated at information level. In other words, each system will perform the functions for which it is designed, without relying on any other part of the ICSS, but the PAS will form the primary HMI for all systems that are part of the ICSS.

Packaged equipment control systems will also interface with the ICSS to extend the common HMI to all plant control equipment.

The WtE plant control and protection system is based on Allen Bradley controllogix hardware. The CC Plant control systems will be separate from the WtE plant systems, except for the FGS, which will be integrated into the existing Honeywell fire detection and display system.

A provision for connections between the CC Plant and the WtE plant control systems will be made by data transfer over a redundant FO link with hard-wired links for alarm & trip signals. It is intended that there will only be limited interface signals required.

The communications between the main CC Plant ICSS and the harbour PAS will be via redundant communications implemented using fibre optic connections. The fibre optic network is an existing facility.

Where safety related signals are required between the CCR and the harbour, these will be implemented over independent fibre optic communications links using a suitably certified safety communications protocol.

Operators working out in the plant areas will communicate with the CCR via UHF portable radios (existing radio system).

Local panels and gauges will be provided, as necessary, to assist in plant operations.

5.3.7 Interfaces between the CC Plant and the Klemetsrud WtE plant

This section describes the system interfaces between the CC Plant and the WtE plant. Integration of the interfaces is described in section 5.10.

This section benefits from being read in conjunction with the Process Flow Diagrams listed in Table 5-15.

Table 5-15: PFDs of the new CC Plant.

PFD Number	PFD title
NC03-KEA-P-XA-0001	PFD - Main flow diagram
NC03-KEA-P-XA-0002	PFD - KEA DH System Overview
NC03-KEA-P-XA-0004	PFD - KEA DH Network K3
NC03-KEA-P-XA-0007	PFD - Line K3 flue gas Tie in to/from CC plant
NC03-KEA-P-XA-0008	PFD - Steam and condensate system
NC03-KEA-P-XA-0009	PFD - Utility supply to/from CC plant
NC03-KEA-P-XA-0010	PFD - Amine reclaimer waste handling
NC03-KEA-P-XA-0011	PFD - Facilities at harbour export terminal
NC03-KEA-P-XA-0014	PFD – Lines K1/K2 flue gas tie in to/from CC plant

5.3.7.1 Flue gas system

The purpose of the new flue gas duct tie-ins is to supply CO_2 rich flue gas from the WtE plant to the CC Plant for CO_2 capture and return CO_2 lean flue gas from the CC Plant back to the existing stacks.

The interface connections with the CC Plant supplier will be located downstream the new scrubber (design base case, see Figure 5-2). On the line 3 flue gas system, flue gas will be supplied to the CC Plant downstream the existing ECO 2.

The flue gas lines to and from the CC Plant will be equipped with on/off dampers. Additionally, an on/off bypass damper will be installed at the interface point allowing flue gases to bypass the CC Plant when required. The bypass damper will be fail-open type ensuring that the existing incineration lines are not influenced by a possible damper malfunction.

5.3.7.2 Degraded Absorbent/Solvent

The disposal of amine waste can be done either at the WtE plant by incineration or by transporting it to a treatment facility located outside the WtE plant. The amine waste coming from the CC Plant is in the form of slurry and contains approximately 50%wt dilution water.

In case of disposal at the WtE plant, two options exist:

1. The amine waste will be temporarily stored and supplied for incineration or an alternative treatment in transportable containers e.g. similar as used today for hospital waste. The degraded absorbent tank at the CC Plant will have such a buffer capacity that the transportable container can be filled e.g. once per day or even less often.
2. The amine waste will be temporarily stored in a tank and supplied for incineration by new pumps to be installed after the tank. This option requires a pipeline from the amine waste storage tank (to be located at the CC Plant) to the incinerators and new penetrations for amine waste piping through the membrane wall of the furnaces. Additionally, control valves are to be installed to the piping to control the amine waste flow to the existing incinerators.

Option 1 is considered as primary solution at the end of FEED.

5.3.7.3 District Heating CC Plant Heat Pump System

The new Heat Pump transfers the heat from the CC Plant to supply the District Heating system. The heat pump operation is therefore dependent on the DH network demand. Typically, the heat pump will be in operation during winter season but during summer, the heat pump will not be in operation due to low DH demand.

Heat is recovered from the CC Plant by pumping DH water from the existing line 3 DH through the condenser of the CC Plant heat pump and back to the existing line 3 DH network. In the condenser, heat from the CC Plant heat pump circulation will be transferred to DH water. New DH circulation pumps will be installed to regulate DH water flow through the CC Plant heat pump. The DH water temperature back to the existing DH network is controlled by the CC Plant heat pump system.

Design parameters for heat pump are:

- Total maximum capacity out of heat pump: 60 MWth;
- Maximum DH water circulation rate: 2300 m^3/h;
- Temperature of DH water supply (to heat pump): 55 – 70 °C;
- Temperature of DH water return (from heat pump): ≤ 90 °C.

The Heat Pump may operate with any refrigerant with ozone depletion potential = 0 and global warming potential <5.

The Heat Pump Package is to be finalised during project execution. The system is a closed refrigeration cycle consisting of a number of parallel compressors, separator, condenser, sub-cooler and evaporators. The working fluid is evaporated using low grade heat rejected by the CW return streams from the various CW users within the plant.

The new DH CC Plant heat pump system will be in operation when the existing DH systems are not sufficient to fulfil the heat demand of the Sentrum, Holmlia and Bjørndalen DH networks. It should be noted that the line 3 scrubber heat pump system should be started before the CC Plant heat pump system is started.

5.3.7.4 Tap water System

The tap water system supplies fresh water from the existing municipal town water grid to the CC Plant. Tap water is used for demineralised water production and to cover evaporation and blowdown losses in the cooling tower circulation at the CC Plant.

The tap water system consists of two valves and underground piping. The tap water system is equipped with a check valve to prevent back-flow from the CC Plant to the municipal town water grid. Tap water consumption is measured with a flow meter at the CC Plant.

5.3.7.5 Waste Water System

The purpose of the waste water tie-in is to deliver waste water from the CC Plant to the existing municipal sewer.

The Waste Water System consists primarily of underground piping; the waste water amount to the sewer is measured with a flow meter at the CC Plant.

5.3.7.6 Process water System

The purpose of the process water tie-ins is to supply water (waste water quality) from the WtE plant to the CC Plant. This water is to be used in various processes to reduce the utilization of fresh water (tap water).

Waste water is either pumped to the CC Plant as make-up water in the CC Plant's processes or pumped to the sewer (or to the acidic water hold tank).

For the new system, an on/off valve will be installed in pipe upstream the CC Plant interface point.

The existing waste water treatment plant has sand filters and carbon filters. They are back-flushed every 72 hours. Back-flushing operations take less than 1 hour, and in this period waste water cannot be supplied to the CC Plant.

5.3.7.7 Demineralised water System

As part of the project, the existing demineralised water production units at the WtE plant will be replaced by the CC Plant demineralised water supply. The CC Plant will therefore provide all demineralised water for the WtE plant and for the CC Plant. Demineralised water is needed at the WtE plant to compensate water losses due to steam losses in both the WtE plant's own processes and in the CC Plant's processes.

During normal operation, the control system of the CC Plant ensures that demineralised water is supplied to the WtE plant at required quantity and quality.

In the WtE plant line 1+2 system, the water level in the tanks will be controlled with a new on/off valve. The on/off valve will be controlled by existing level transmitters in the tanks.

In the line 3 system, water level in the tanks is controlled with the existing on/off valves. The on/off valves will be controlled by the existing level transmitters in the tanks.

5.3.7.8 Service (Instrument) Air System

The service air system at the CC Plant is designed for the CC Plant's own consumption and the system has no reserve capacity for the WtE plant. The existing compressed air system at the WtE plant is designed with the same principle. Therefore, the Compressed Air Crossover either to or from the CC Plant is to be utilized only for a short period if necessary.

5.3.7.9 Steam and Condensate Systems

Steam System

The purpose of the steam system is to supply heat in terms of MP and LP steam to the CC Plant consumers.

HP steam is supplied from the existing K1, K2 and K3 boilers to the new HP steam header. From the new HP steam header, HP steam (at about 40 barg) is supplied to the K1/K2 steam turbine and to the two Pressure Reducing and Desuperheating Stations (PRDS).

The LP steam (at about 6barg) is supplied to the CO_2 Stripper Reboiler, directly from the K1/K2 steam turbine, while one of the PRDS continuously supply MP steam (at about 21 barg) required for the TRU. The other PRDS will supply LP steam when the steam turbine is bypassed.

For the planned new K1/K2 steam turbine, the following two options are under evaluations by FOV operations:

- Option 1: condensing steam turbine;
- Option 2: back-pressure steam turbine.

The final decision regarding the selection of new K1/K2 steam turbine type is part of FOV's own scope and was not studied as part of the project.

During winter, situations may occur where DH networks demand cannot be fulfilled. Then the LP steam supply to the CC Plant will be reduced and more steam will instead be directed to the existing DH condensers. This will temporarily reduce the CO_2 capture efficiency of the CC Plant reducing also the heat output from the CC Plant heat pump.

The CO_2 capture efficiency as a function of steam supply (to the CO_2 stripper reboiler) is shown in Figure 5-6.

[redacted]

Figure 5-6: CO_2 capture efficiency as a function of the steam flow (TechnipFMC, indicative).

Condensate system

The purpose of the condensate system is to return condensate from the CC Plant to the existing condensate system(s) at the WtE plant. The LP steam and MP steam supplied to the CC Plant will be returned as combined condensate stream to the WtE plant.

TechnipFMC is responsible for the design and construction of the condensate piping until the interface point and is responsible for the design and construction of the condensate piping from the interface point to the existing system(s).

5.3.7.10 Electrical Power Supply

The CC Plant electrical power supply will be from a new substation at the Klemetsrud WtE plant. The supply capacity will be as determined by TechnipFMC; there will be two redundant connections each rated 3150 A. Due to the high current, the connections will be realized as bus ducts. The new substation at the Klemetsrud WtE plant will be located close to CC Plant station.

5.3.7.11 Process Control and Shutdown System

The CC Plant process control and shut down system will be a self-sufficient system and not integrated into existing WtE plant controls. Dedicated operator stations, alarm annunciators, process screens etc. will be installed in the CCR.

The CC Plant will have Fire detection system with a new unit, connected to existing installation at the WtE plant subcentral.

5.3.8 Modification to the Klemetsrud WtE Plant and the existing infrastructure

5.3.8.1 Scrubber K1 and K2

The base case design for FEED study is based on the upgrading of the flue gas cleaning system for line 1 and 2 with the installation of a scrubber after RGK2.

The new scrubber installation will be executed as a separate project. The scrubber will be installed and in operation prior to erection of CC Plant.

5.3.8.2 11 kV supply and infrastructure

Due to the CC Plant requirement for electrical power, the existing supply system must be modified to be able to supply sufficient power to both CC Plant and existing WtE plant. The modifications will include the following areas:

Klemetsrud transformer station:

- New and upgraded transformers;
- New and upgraded switchgear for 47 and 11 kV.

11 kV supply from transformer station with underground cables to new Klemetsrud WtE plant substation:

- All existing cables will be cut and redirected to new WtE plant substation to utilize capacity as the capacity of existing cables are not utilized sufficiently;
- Additional cable set may be installed to increase capacity / redundancy.

New substation at Klemetsrud WtE plant:

- Supply will be via existing cables from the Klemetsrud transformer station;
- All existing and new consumers will be fed from the new WtE plant substation;
- Switchgear will be with double bus bar to provide operational flexibility;
- Existing steam turbine generators may be connected directly to the switchgear for commercial reasons;
- New switchgear may lead to general upgrade of the existing WtE plant 11 kV station control system.

5.3.8.3 Low voltage supplies

Process interface will include some motor drives (pumps and actuators) related to process interface. The motor drives will be supplied from the existing spare units in the MCC's, and the installation will be similar to motors regarding both operation and local service-/safety switches.

Supply to lighting and sockets in process area/buildings will be done by extending existing installations.

5.3.8.4 Process Control and Shutdown System

The WtE plant process control and shut down system will be modified/extended to cover process interface. Major modifications may be realized with new PLC installations, while the smaller modifications will be done with extension of local IO. Any modification will follow the existing systems regarding redundancy of PLC, power supply and communication. Minor modifications will utilize existing spare IO available in existing cabinets.

Process modification will include new programming of PLC's and HMI, but will not include any hardware installations as servers, switches or operator stations/clients.

5.3.8.5 CCTV and Access Control

Both Access control and CCTV installations will be realized as extension of existing systems.

5.4 Reliability analysis for CO_2 production (2k)

To investigate the potential reliability of the CC Plant, two RAM (Reliability, Availability, Maintainability) analyses have been performed during FEED phase of the project. One is performed by TechnipFMC [25] and one by FOV [26]. Both analyses cover the entire CO_2 chain, from flue gas until the CO_2 is loaded to the ship.

An Availability between 90 and 96% for CO_2 capture is calculated in the analyses, depending on the assumptions made. The results of the two analyses are seen as consistent, with both analyses using "critical failures" from OREDA 2015 as the main source for failure data. The difference in calculated Availability is also affected by the methods used.

This report presents the findings from TechnipFMC assessment, with the scope of work of the RAM shown in Figure 5-7.

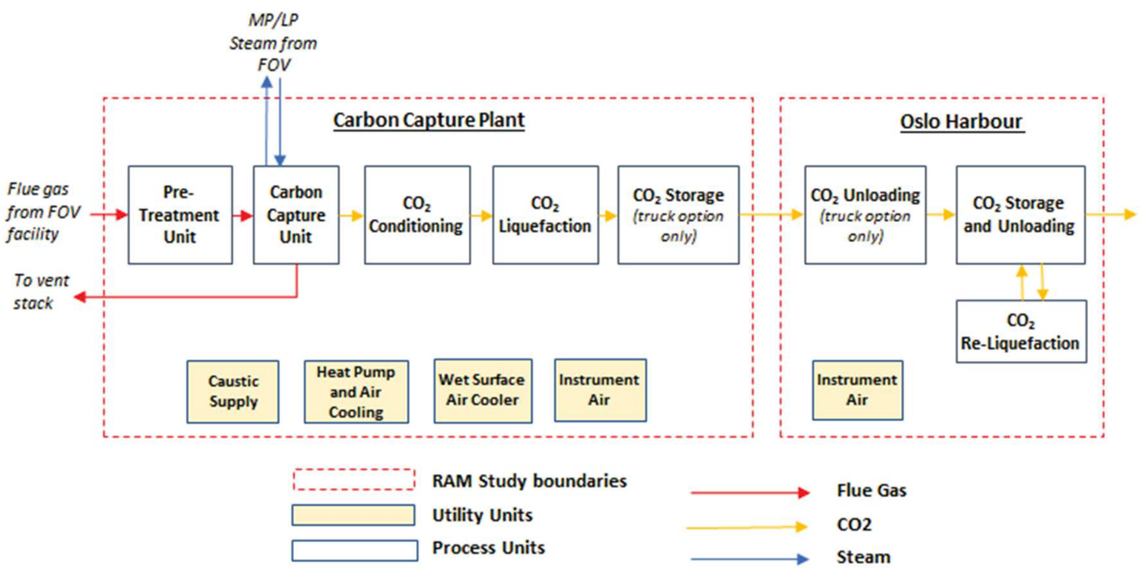

Figure 5-7: Scope of Work for the RAM analysis, TechnipFMC [25].

RAM analysis will be further developed during the next project phase, when more detailed information on the equipment is available.

The overall downtime is governed by lack of redundant process equipment and process modules that are mainly in series.

Table 5-16 presents the breakdown in terms of downtime contribution per system from the TechnipFMC study [25].

Table 5-16: RAM analyses – downtime per system [25].

Rank	Description	Contribution (%)
1	CO_2 Liquefaction	[redacted]
2	Planned Maintenance	[redacted]
3	CO_2 Conditioning	[redacted]
4	Gas Inlet	[redacted]
5	CO_2 Re-liquefaction	[redacted]
6	CO_2 Compression	[redacted]
7	Instrument Air System – harbour	[redacted]
8	Instrument Air System – CC Plant	[redacted]
9	Stripping Section	[redacted]
10	CO_2 Absorption	[redacted]
11	Pre-Scrubber	[redacted]
12	Mechanical Vapour Recompression	[redacted]
13	Water Wash System	[redacted]
14	Wet Surface Air Cooler Package	[redacted]
15	Gas-Gas Exchanger	[redacted]
16	Absorbent Storage	[redacted]
	Total downtime contribution	[redacted]

[redacted]

To enhance the Availability, three main mitigating actions are identified:

1. **Technical reliability:** currently reliability data and planned maintenance data have been taken from OREDA or an inhouse TechnipFMC database. When this data is available from vendor, it can be included in an updated RAM modelling for more accurate modelling. The key equipment items are the compressors, electric motors, pumps and reactor. The key packages are the Liquefaction and Conditioning packages.

   The potential Availability improvement are listed in Table 5-17.

2. **Maintenance:** The planned shutdown of CC plant will take place during the WtE plant maintenance stop to minimise production loss. This has not been considered in the RAM modelling. Standardization and spare part strategy will be also be developed to minimise downtime.

3. **Operations:** Skilled personnel is required to obtain high uptime and plant performance. Operating staff will participate in exhaustive training to familiarize

them with all relevant procedures, manuals and instructions. Refresher courses will be conducted to reinforce awareness about procedures and operational knowledge. This will ensure that the plant will be operated according to the intentions, i.e. smoothly with caution and within the actual design limits.

Table 5-17: Potential Availability improvement, per system [25].

Rank	Description	Contribution (%)
1	Liquefaction Package	[redacted]
2	Booster Fan	[redacted]
3	Regeneration Gas Electric Heater	[redacted]
4	Re-liquefaction Package Compressor	[redacted]
5	Instrument Air Compressor – CC Plant	[redacted]
6	Instrument Air Compressor - Harbour	[redacted]
7	Regeneration Gas Discharge Cooler	[redacted]
8	Reactor Outlet Cooler	[redacted]

With the potential mitigating actions, it is possible to reach the target Availability of 95%.

5.5 Reliability analysis for delivery of CO_2 (2i)

The reliability for delivery of CO_2 depends on the amount of CO_2 in the flue gas, the capture efficiency and the Availability of the CC Plant. To calculate the amount of delivered CO_2 per year, several factors have been considered.

The primary input is the Availability of the CC Plant. The value used is 95%, based on the target in the CC Plant Design Basis [16]. The value is substantiated by the recommendations in the RAM analysis (see section 5.4) and FOV planned work in the interim phase.

The required CO_2 capture efficiency in the Absorber is [redacted] [16], [27].

It is estimated that there will be approximately [redacted] loss in the internal processing of the CO_2. This figure includes losses during transport, loading, unloading etc. and is documented in the TechnipFMC Process Basis of Design [27] and Emission Inventory report [28].

The total CO_2 ready for delivery to the ship with the plant in normal operation is therefore [redacted] of all the CO_2 from the WtE plant flue gas.

Table 5-18: Basis for calculation for delivery of CO_2.

Factor	Value	Reference/ Comment
CO_2 produced by the WtE plant	460 200 ton/year	CC Plant process Design Basis [16]. Variations and uncertainty are taken into account, as described in the CC Plant process Design Basis [16].
Capture efficiency, Absorber	[redacted]	CC Plant process Design Basis [16]
Loss in process	[redacted]	Assumption made together with TechnipFMC, documented in TechnipFMC Process Basis of Design [27]
Availability	[redacted]	CC Plant Design Basis [16], TechnipFMC RAM analysis [25]

Based on the figures in Table 5-18, the CO_2 delivered to ship will be [redacted] tons of CO_2 per year (including seasonal variations).

[redacted]

5.6 The prospective of the emission source (2d)

Fortum and the City of Oslo own 50% each of Fortum Oslo Varme. The Fortum Group is the world's fourth largest heat supplier and has a number of combined heat and power plants (CHP) for energy recovery and district heating, focusing on sustainable urban development and a circular economy.

Circular use of resources, recycling, district heating and sustainable waste management is a key part of the Fortum Group's present business and strategy. Fortum made a strategic choice by investing in a collaboration with the City of Oslo to develop the district heating business and utilize the city's resources in the best possible way. Recovered heat from waste incineration is the primary heat source (50-60%) in the district heating system in Oslo.

Fortum and FOV have for several years sold waste treatment services to Europe and have a solid foundation for securing a broad portfolio with further long term operations and growth. By implementing this strategy, Fortum contributes to reducing European emissions from landfills.

5.6.1 Fortum Oslo Varme's future prospects

FOV has long-term plans for growth and development, in collaboration with City of Oslo. The Klemetsrud WtE plant processes around 350 000 tons of waste per year, with concrete plans to increase future capacity.

Line 1 and 2 started operations in 1985, and have since then been rehabilitated several times. The Klemetsrud plant also reinvested around 500 million NOK in the period 2012-2017 and achieved increased capacity and extended life on existing incineration lines. The latest major reconstruction and rehabilitation was in 2015, where the cleaning technology was rebuilt and changed from liquid cleaning with scrubber technology to a semi-dry cleaning technology. The life expectancy of line 1 and 2 is approximately 20 years from 2015 (2035), and the incineration capacity at Klemetsrud is expected to be at the same level as or higher than today's capacity also after 2035.

As part of FOV's future development plans at Klemetsrud, a concept study for an additional WtE incinerator ("Line 4") at Klemetsrud is being performed. Potential effects on the CC Plant will be further investigated when after the FOV Line 4 concept study has concluded in December 2019.

The waste heat from the incineration is utilized to produce electricity and supply district heating and cooling delivered to the buildings in Oslo. The plant at Klemetsrud has long-term predictability because FOV's operations are inextricably linked to the city's district heating system, and therefore cannot be relocated. The plant has been in operation since the mid-1980s and FOV is now planning an expansion of the district heating business through expansion of the district heating network itself, development of district cooling and plans for increased capacity at Klemetsrud with a new incineration line (Line 4).

Oslo is experiencing strong growth and has come a long way in phasing out heating with fossil fuels in the city's buildings. The Norwegian Government has introduced a national ban on oil heating for individual heating, effective from 2020. This further increases the need for renewable district heating in Oslo.

The City of Oslo has another WtE plant at Haraldrud in Oslo. At Haraldrud site, FOV has thermal production from two energy recovery plants, respectively industrial waste and biopellets. All the plants at Haraldrud site deliver heat to the district heating network of the City of Oslo, and the two owners share their dedication to realizing the FOV CO_2 Capture Project. Thus, close cooperation on operations, maintenance, investment and carbon capture at all these facilities will be natural, regardless of future ownership.

5.6.2 Prospects and opportunities towards Europe

There is a growing demand for energy recovery capacity in Europe to handle waste that cannot be reused or recycled, as EU moves away from landfills and towards increased sorting and recycling. 142 million tons of residual waste treatment capacity will be needed in Europe by 2035 in order to fulfil the currently set EU targets on municipal solid waste (MSW). This assumes that the ambitious recycling targets (65% material recycling and a reduction to 10% landfilling) will be achieved. Current Waste-to-Energy capacity is 90 million tons and the capacity for co-incineration is around 11 million tons. This leaves a gap of around 40 million tons; new capacity that must be established in Europe [29].

Waste is a commodity regardless of national boundaries. In principle, there is a deficit on waste incineration capacity in Norway, and excess capacity on incineration in Sweden. More than one million tons of Norwegian waste is exported to Sweden due to market competition. In addition, plants in Norway and Sweden are receiving large quantities of Municipal Solid Waste (MSW) from the UK, as part of the country's efforts to reduce landfill waste. The plants in Scandinavia have efficient cleaning of the flue gas and very low emissions, with cold winters giving good utilization of the heat for district heating and electricity production. This means that such cross-border waste trading results in significant savings in greenhouse gas emissions [30]. It is therefore good climate and social economy that the capacity of Scandinavian facilities is fully utilized also in the future. In addition, heat from energy recovery is competitive heat because waste can be utilized as cost effective fuel in district heating systems due to the large investments in already existing and planned incinerators.

5.6.3 Solving the plastic challenge

Today, a lot of plastics cannot be recycled, nor can plastics be recycled an unlimited number of times [31].

The best climate and social solution for these waste fractions is incineration with energy recovery. At the same time, it is a fact that the amount of plastics in the world is growing. Globally, we are approaching production of 350 million tons of plastic every year, and this is expected to triple over the next 30 years [32]. If today's consumption patterns and waste management are not improved, by 2050 there will be around 12 billion tons of plastic waste on the world's landfills and in the environment [33] .

This presents major challenges in both a short and long term perspective, even with extensive research and development of sorting systems, recycling technology and the development of more recyclable packaging solutions. Manufacturers of goods that need solid packaging must also develop better packaging products that can be recycled. With the decommissioning of polluting landfills and increased plastic quantities and types, new fractions must be energy recovered in the future to ensure that pollutants are removed from the cycle (sewage sludge, dirty and contaminated plastics, mixed products etc.).

5.6.4 Prospects in negative emissions

The FOV CO_2 Capture Project has an added climate value because about 50% of the emissions from waste incineration – and 100% of the emissions from biomass plants - are biogenic and a part of the natural, short-term CO_2 cycle. Capturing the biogenic CO_2 is in effect removing CO_2 from the atmosphere. A full-scale CO_2 capture plant on FOV will therefore remove up to 200 000 tons yearly from the atmosphere. With the implementation of CCS in the WtE industry, the industry as a whole can contribute to extracting large amounts of CO_2 from the atmosphere, starting with learning and technology development at Klemetsrud.

By establishing carbon capture on energy recovery of residual waste the emissions from the incineration of plastics that can no longer be recycled, can be dealt with, at the same time achieving carbon negativity by capturing emissions from biomass. This can in itself provide increased prospects for the emission source through future prospects regarding sales of negative emissions [11].

5.7 Technical maturity and technology qualification (2f, 2g, 2h)

5.7.1 Description of the pilot plant

In July 2018 it was decided to build a pilot plant to test and qualify the selected CO_2 capture technology against the specific flue gas from Klemetsrud WtE plant. The pilot plant was ordered from TechnipFMC, and Table 5-19 presents an overview of the participants involved in the project:

Table 5-19: List of participants to the pilot plant project.

Participant	Role
FOV	Project owner. Integration with the existing WtE plant
TechnipFMC	Pilot plant supplier
Kanfa Ingenium Process AS	Subsupplier to TechnipFMC. Engineering, fabrication and supply of the pilot plant
Slåttland Mek. Industri AS	Pilot plant fabricator
Shell	Technology Licensor
University of Oslo	Flue gas analysis contractor
Ramboll Finland Oy	Analysis contractor
Eurofins Environment Testing Finland Oy	Offsite analysis laboratory

Participant	Role
Airborne Labs International, Inc.	Offsite analysis laboratory
TCM (Technology Center Mongstad)	Advisory services
DNV GL	Technology qualification, advisory services

The period from project start to start of operation and completion of the test has been tight. An overview of the key milestones and dates is presented in Table 5-20.

Table 5-20: Key milestones for pilot plant delivery.

Milestone	Planned date	Actual date
Project start	21.08.2018	21.08.2018
Engineering complete	01.10.2018	12.11.2018
Start container assembly	22.11.2018	04.12.2018
Delivery to Site	01.02.2019	24.01.2019
Ready for testing	19.02.2019	01.03.2019

The pilot plant has been designed to meet the objectives as stated in section 5.7.2 and to be able to operate continuously on all possible variations of incoming flue gas composition within the limits of the WtE plant emission permit. A process flow diagram (PFD) for the pilot plant can be found in the Figure 5-8.

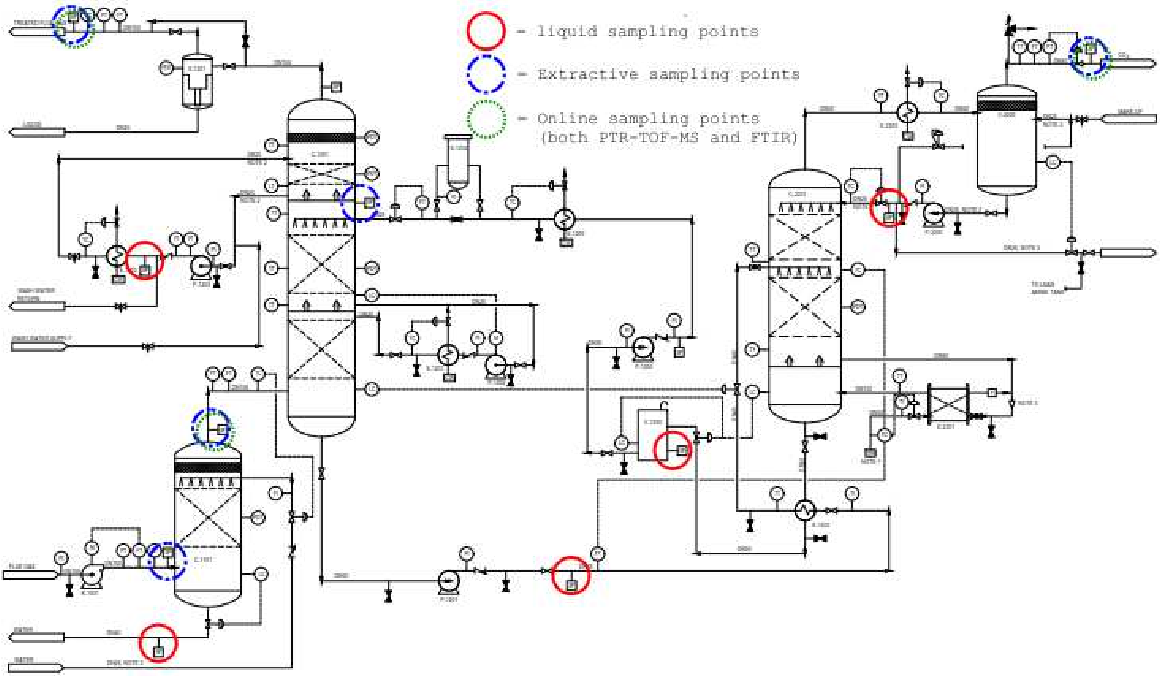

Figure 5-8: PFD of the pilot plant with measurement and sampling points indicated [34].

The main parts were located inside a 40 ft (12.2 m) container. Columns (Absorber and Stripper) were erected on the container roof and supported by backstays. The container and all equipment including storage containers/tanks were designed to capture and contain any leakage of chemicals to prevent spills to soil/ground.

A second 20 ft (6.1 m) container in the close proximity of the pilot plant was provided for sensitive measurement and analysis equipment. In addition, a suitable space was allotted for an onsite laboratory (a field laboratory) for some of the liquid sample analysis.

The pilot plant has been equipped with provisions to enable online measurements as well as prepared for the necessary sampling for external analysis.

The pilot plant can be divided into three parts with the following main equipment (similar to the full-scale plant described in section 5.3):

- Pre-Treatment: DCC/Pre-Scrubber
- Capture Unit: Absorber, Regenerator (Stripper), Water Wash and Demister
- Post treatment: [redacted]

The below figure gives an overview of the equipment inside the container. However, it should be noted that all three columns (Pre-Scrubber, Absorber and Stripper) penetrate the container roof [redacted].

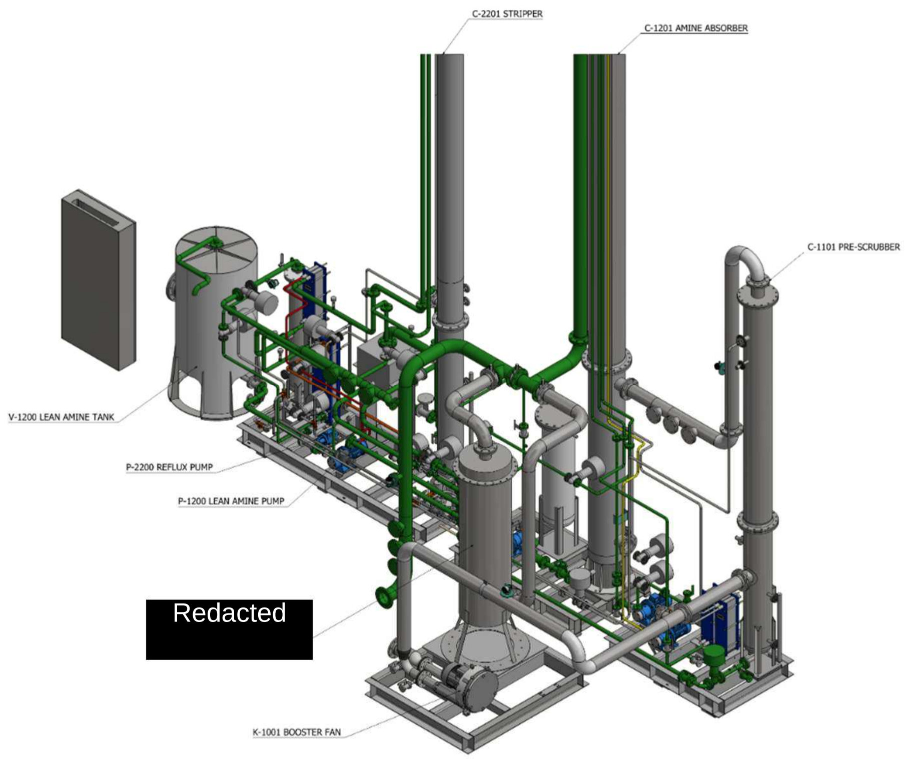

Figure 5-9. Simplified 3D view of the pilot plant (without the container). Note that the Water Wash Section and Demister are located on top of the Absorber Column and therefore not shown in the figure [34].

Due to cost and complexity reasons, it was agreed by FOV and Gassnova to develop the pilot plant with the following exemptions or modifications compared to a full-scale plant:

- No Thermal Reclaimer Unit (TRU) installed;
- No Mechanical Vapour Recompression (MVR) compression system installed;
- Steam supply from a separate steam generator instead of from the WtE plant;
- Pass-through cooling systems, i.e. no closed loops in the cooling system.

To have the pilot plant representing the full-scale plant in the best possible way, equipment has been sized in accordance with Table 5-21 below.

Table 5-21: Full-scale plant vs. pilot plant equipment - sizing.

Equipment	Parameter	Full-scale plant	Pilot plant	Discussion of differences between pilot and full-scale plant
General	**Flue gas flow**	**356.800 Nm³/h (dry, 11% O_2)**	**700 Nm³/h (dry)**	
Absorber	Gas velocity at packing base	[redacted]	[redacted]	[redacted]
Absorber	No of sections and height of packing	[redacted]	[redacted]	[redacted]
Absorber	Diameter	[redacted]	[redacted]	[redacted]
Absorber	Height	[redacted]	[redacted]	[redacted]
DCC/Pre-Scrubber	Gas velocity at packing base	[redacted]	[redacted]	[redacted]
DCC/Pre-Scrubber	Packing Height	[redacted]	[redacted]	[redacted]
CO_2 Stripper	Diameter	[redacted]	[redacted]	[redacted]
CO_2 Stripper	Height	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Other equipment	-	-	-	Will be designed based on the heat and mass balances required to ensure required Absorber performance.

During the test period, some smaller modifications were carried out to improve the operability and the Availability of the plant.

Flue gas tie-ins points for the pilot plant are located for all lines in the same position as for the full-scale plant. The flue gas composition to the pilot plant has therefore been representative of the one that will enter the full-scale plant.

The most common (~80% of the time) mixture of flue gases entering the full-scale CC Plant would be 23%vol from line 1, 23%vol from line 2, and 54%vol from line 3. This mix was the target flue gas mix for the pilot plant and was achieved by manual throttling valves on the flue gas tie-in lines.

5.7.2 Pilot Plant Test Campaign and Results

The operations of the pilot plant can be divided into three campaigns, the first of which is described extensively below and called the 2000-hour test campaign. Following this test campaign, two more campaigns have been planned for 2019, the first of which was completed by end of August 2019. This is briefly described under section 5.7.2.5. The third campaign is not discussed in this report and planned executed between September and December 2019.

The planning of the first 2000-hour test campaign has involved all participants (Table 5-19). All the parties have reviewed and commented the Pilot Plant Test Program [34] and other documents as well as participated in three coordination and planning meetings at Klemetsrud.

5.7.2.1 Objectives

The following acceptance criteria set for the pilot plant were:

- 2000 cumulative hours of successful pilot plant operation;
- Below 0.4 ppmv total amine emissions (on average) to air at conditions representative of the full-scale plant. Both PTR-TOF-MS and extractive gas sampling measurements of the total amine emissions shall be below the set requirement on average during the last 500 hours of the required 2000 hours period.

In parallel to the pilot plant acceptance criteria defined above, the pilot plant should also measure and provide information about (in no particular order):

- The degradation rate of the solvent;
- [redacted]
- The ability to maintain low amine content in wash water;
- The CO_2 capture efficiency of the Absorber;
- The efficiency of the Pre-Scrubber;
- That expected CO_2 quality after the CC Plant (before further treatment) is met.

These secondary objectives were pursued and monitored in parallel to the primary objectives.

The target and limit operational parameters, representing the conditions required for successful pilot plant operation, were defined.

5.7.2.2 Pilot Plant operation

The pilot plant has been operated by a separate FOV operations team with supervision by the Licensor. The manning was 24/7 during the first 5 weeks and daytime manning for the remaining period as the pilot plant operation stabilized.

The plant has been operated in a steady state mode as close as possible to the target parameters defined in the Pilot Plant Test Program [34]. Target values for other parameters have been defined by the Licensor. The plant has operated in automatic mode with manual interventions required when upsets from the WtE plant occurred. Occasional operation outside the target and limit operational parameters have occurred without having negative impact on the testing. These situations have been reported in the weekly status reports and in the final test report of the 2000-hour test campaign.

5.7.2.3 Testing, sampling and analysis scope

Sampling, measuring and analysing activities for both gas and liquid samples are presented below:

- University of Oslo (UiO): online analysis (PTR-TOF-MS and NO_x) of treated (CO_2 lean) flue gas. Possibility to switch instrument between different locations;
- Ramboll Finland Oy (Ramboll):
  - Online analysis (FTIR, CO_2, O_2 and SO_2) of flue gas around Absorber. Possibility to switch instruments between different locations;
  - All extractive gas sampling;
  - Operation of the field analysis laboratory of lean solvent samples (amine concentration, CO_2 loading, foaming);
- Eurofins Environment Testing Finland Oy (Eurofins): offsite analysis of liquid samples (LCMS, ICP-MS, IC);
- Airborne Labs International, Inc. (Airborne): offsite analysis of CO_2 product bag samples;
- Shell (Licensor): verifications / quality control.

All gas measurements (online and extractive sampling) have been done isokinetically to ensure representative samples (with the exception of the CO_2 product outlet). The pilot plant has a number of 4" (DN100) connections for setting up isokinetic sample lines between the sample location and online analysis instruments. The sample lines have been heated to avoid condensation and other possible reactions inside the lines.

During the test period, the following measurements and samplings have been carried out:

Online measurements

The two primary online gas analysers consisted of PTR-TOF-MS and FTIR. In addition, O_2, SO_2, CO_2 and NO_x (mainly NO_2) have been measured using separate instruments ("The Rack"). These three process gas streams have been monitored with on-line analysers:

1. Inlet flue gas - after Pre-Scrubber (Absorber inlet);
2. Treated flue gas outlet;
3. CO_2 product - after condenser.

In addition, all process parameters (pressures, temperatures, flow rates and levels) have been measured through the process control system for the pilot plant.

Extractive gas sampling

In addition to particle matter (dust) and ELPI+ measurements (aerosols and sub-microns sized particles), extractive gas sampling was performed to verify the amine concentration at two locations:

1. Treated flue gas outlet [redacted];
2. CO_2 product - after condenser.

Liquid sampling

The sampling points for liquid sampling were provided with Dopak sampling systems for easy and representative sample collection.

Liquid samplings have been done from the following streams/locations:

1. Lean solvent entering the Absorber;
2. Rich solvent exiting the Absorber;
3. Pre-Scrubber effluent (mainly water);
4. Water wash circulation fluid (mainly water);
5. Reflux circulation fluid (mainly water).

5.7.2.4 Results and Conclusions

The pilot plant tests have been successful and showed that the selected Licensor CO_2 capture technology is able to meet the targets and requirements when utilised at Klemetsrud WtE plant.

The Pilot Plant Final Test Report [3] for the 2000-hour campaign presents detailed test results.

Operational hours

During the 2000-hour test campaign, the pilot plant has had an uptime of approximately 96%. The main causes for downtime have been steam generator failures and upsets from the WtE plant. The recorded operational hours are shown in Figure 5-10.

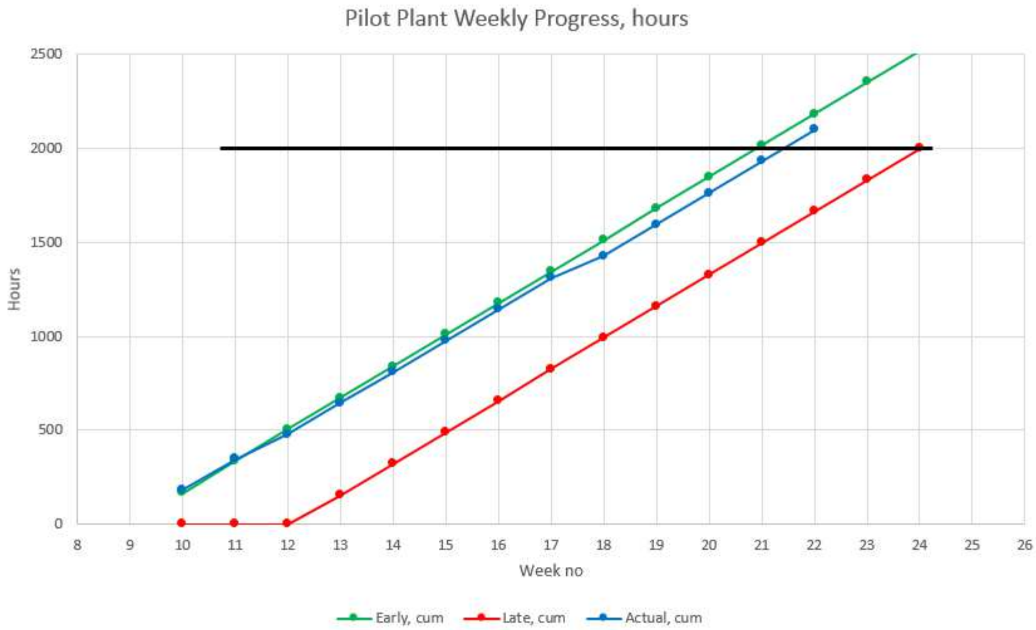

Figure 5-10: Recorded operational hours of the pilot plant.

The targeted 2000 hours including the last 500 hours were reached 3rd June 2019.

Status of the pilot plant testing were reported weekly to all the involved stakeholders through weekly reports.

Amine Emissions

The main objective was to demonstrate amine emissions below a target of 0.4 ppmv, which constitutes the lower limit of the confidence interval established by the Norwegian Institute for Air Research (NILU) and the University of Oslo. This 0.4 ppmv target level represents the maximum concentration of amines in the emissions from Klemetsrud that will not lead to exceedance of the recommended guidelines for nitros- and nitramines in air and fresh water [35].

Solvent (absorbent) degradation was also monitored, as well as other performance parameters, with emphasis on the CO_2 product purity.

During the 500-hour test, the amine emissions were on average 159 ppbv (0.159 ppmv). Only occasionally the value exceeded the target of 400 ppbv (0.4 ppmv), such as during a malfunction of the WtE plant particle filter (ESP). [redacted]

Table 5-22 below summarize the average emissions over the stable operation period starting 5th April and the 500-hour test period.

Table 5-22: Amine emissions over the stable operation period.

Amine emission	Value (ppbv)
Target	< 400
Stable operation period (1)	203
500h test period	159
500h test period excluding ESP malfunction	43

[redacted]

Amine Degradation

The pilot plant is not equipped with a TRU and started with virgin Cansolv DC-103 solvent/absorbent. Degradation products steadily increased over time, and it was expected that at the start of the 500h test period the degradation level would be close to that maintained in the full-scale plant.

The total degradation rate was evaluated based on the evolution of relative concentrations of undegraded amines and degradation products. The total degradation rate is calculated to be [redacted] kg/tCO_2 (captured).

The graph in Figure 5-11 shows that the 500h test was run at degradation products concentration within the typical design window. Based on the latest results, it is clear that the analysis performed at the end of the 500h test is an outlier / erroneous.

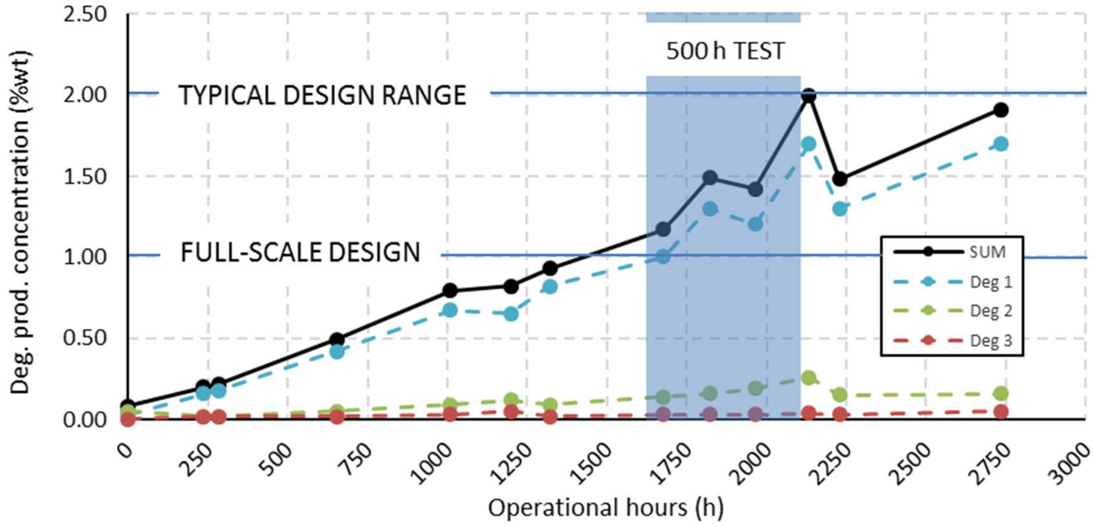

Figure 5-11: Degradation products concentration (including Licensor confidential degradation product DEG 1, 2 and 3) are shown. The total degradation product is at or above the full-scale design value [redacted] for the final 500h test, which is within the typical design window.

CO_2 product purity

Contaminants have been either detected at very low levels or have been found to be below detection limits.

CO_2 capture efficiency

During operation of the pilot plant, the gas flowrate was maintained as much as possible at the design value to ensure operating conditions representative of a commercial plant. The CO_2 capture efficiency was in the range 90–99%.

Depending on the relative split of the inlet gas from the three flue gas lines, the inlet CO_2 concentration fluctuated, and frequently exceeded the maximum design concentration of the unit. With the unit operating at design gas flowrate, this means that the unit was operating above the maximum design CO_2 load.

It should be noted that operation of the unit was not optimized; the lean solvent loading was kept within the initial target range, while lower lean loading [redacted] could have helped increase capture efficiency in periods of high inlet CO_2 concentration.

Steam Consumption

Although the steam consumption observed on a pilot plant is typically not representative of a full-scale unit (due to higher heat losses and to uncertainty on steam flow measurement), it has been compared to values predicted by the tools used to design the full-scale plant.

The observed steam consumption was [redacted] GJ/t CO_2 (captured), while the predicted value is [redacted] GJ/t. It is important to note that:

- The consumption values for the pilot plant (observed and predicted) are significantly higher than those used for the design of the full-scale unit as the pilot plant is not equipped with an MVR heat recovery system.
- The pilot unit operating conditions have not been optimized to minimize energy requirements, in particular for target lean loading. They have been maintained within the window of operation representative of the full-scale plant, which are expected to be optimal in terms of energy requirements. However, it is expected that a full-scale plant will achieve lower steam consumption once its operating conditions are optimized.
- The reported energy requirement is dependent on the steam flow measurement, the reliability of which has not been thoroughly assessed as this was not one of the primary objectives of the pilot campaign.

5.7.2.5 Extended pilot plant testing

Following a successful 2000-hour test campaign completed in early June 2019, the pilot plant operations have been extended to continue tracking solvent degradation rate and its impact on key process parameters as well as to gain more knowledge about the CO_2 capture technology. This section presents the results from the extended testing up until September 1st, 2019.

The degradation rate has, as expected, been fairly linear during the extended pilot plant testing and is as of 27th August, [redacted]. In addition to tracking the degradation of the solvent, multiple tests have been performed to evaluate what effect varying process- and seasonal parameters have on amine emissions and CO_2 capture efficiency. [redacted]

However, due to a long period of revisions on the WtE plant and potentially too short test durations, many of the performed tests need to be revisited during the next test campaign (September to December 2019). Very low levels (less than 0.1 ppmv on average for the period) of amine emissions have been observed indicating that the process is very robust with regards to amine emissions when not being stressed to its limits. Accumulated operating hours as of end of 26th August is 3560 hours.

5.7.3 Qualification of the CO_2 Capture Technology

Licensor's CO_2 capture technology intended for use at the Klemetsrud WtE plant has been subject to a Technology Qualification process carried out by DNV GL. The assessment has been done in accordance with DNVGL-RP-A203 [36] and DNVGL-RP-J201 [37].

The term "Qualified Technology" have been defined by DNV GL as *technology for which an adequate set of acceptance criteria for the delivery and limits for use have been defined to assure defined technical performance of solutions.*

Preliminary qualification work in 2018 resulted in a "Statement of Feasibility" from DNV GL. Further qualification activities to achieve the final qualification status and "Statement of Qualified Technology" required further evidence regarding amine emissions, solvent degradation and energy efficiency for operating conditions similar to the Klemetsrud WtE plant conditions. To provide such additional evidence, a custom made pilot plant has been designed and installed at Klemetsrud to test the Licensor's CO_2 capture technology on the Klemetsrud WtE plant flue gas.

DNV GL have produced the Qualification Report included in the Project's Qualification Report [4], as a documentation of the Technology Qualification process and results/conclusions.

The main conclusions from the qualification process are:

- Test conditions have been representative for most of the test period, in particular from week 17/2019 onwards, regarding process parameters, flue gas quality pollutants and solvent degradation levels.
- The capture process has demonstrated, at design conditions, weekly average amine emission values below 0.4 ppmv.
- At stable conditions values of amine emission below 0.1 ppmv have been achieved, [redacted], demonstrating the effectiveness of the amine emission control technology proposed for the full-scale plant. During the last 500 hours of operation, the average emission level was 0.18 ppmv, significantly below the acceptance criteria of 0.4 ppmv.
- The amine emission peaks above 0.4 ppmv seem to be related to events occurring outside the pilot plant control, which caused unexpected deviation from design conditions. The peaks in emission are not therefore due to malfunctioning in the process. The cause-effect mechanism is yet not fully completely understood and will be further investigated.
- The representative level of degradation product of 1%wt in solvent has been observed during the pilot plant testing (from week 17/2019 onwards).
- Total degradation rate measured during the pilot test is below the value expected for full-scale operation.
- The energy performance of the pilot plant, in combination with estimation calculated, provide sufficient confidence to expect that the performance of the full-scale installation will be in the range of 2.5-3 GJ/tCO_2 typically reported for state-of-the art carbon capture technologies. It should be noted that this range represent typical values and is, thus, not specifically related to the Shell CO_2 Capture Technology with its energy-saving solutions.
- The design of full-scale plant integration has kept into account, within the limit of practical and cost/effective limitations, optimization of heat integration and minimization of CC Plant's impact on district heating operations.

Based on the conclusion above, DNV GL have issued a Statement of Qualified Technology (Figure 5-12) for application of the Licensor's carbon capture process using the Cansolv DC-103 solvent/absorbent for the flue gasses at the Klemetsrud WtE plant.

This documents that the selected technology is qualified for the intended use.

DNV·GL

STATEMENT OF QUALIFIED TECHNOLOGY

Statement no.: 2019-0303 Valid until: 2023-06-26

This is to state that the technology designated

CANSOLV CO_2 Capture Technology

has been qualified for its designated service with basis in DNV-RP-A203 /1/ and DNV-RP-J201 /2/, as defined in /3/.

End user:	**Fortum Oslo Varme**
Owner	**Shell**
Description and designated service:	The technology is a full-scale solution for capture of CO_2 from the flue gas of the Klemetsrud waste to energy plant. The process uses Shell's CANSOLV CO_2 capture technology for CO_2 removal from flue gases, by chemical absorption/desorption using an amine-based solvent (DC-103), as further detailed in /5/.
Performance:	The carbon capture plant is designed to assure >90% capture rate, resulting in 400 kt of CO_2 captured per year. Pilot testing representative for the full-scale plant has confirmed the following performance: • Emission of amines to air: < 0.4 ppmV on weekly average • Solvent degradation rate below full-scale design rates as specified in /4/ • Energy requirement in the range 2.5-3 MJ/kgCO_2, in line with what is typically reported for state-of-the art carbon capture technologies
Limitations:	The qualification is limited to the current conditions at the Klemetsrud waste to energy plant.
Involvement:	DNV GL has been involved in the qualification process in accordance with /3/ and has facilitated and documented the technology qualification process as explained in /4/.
Conditions:	Information which may affect the technology qualification status shall be brought to the attention of the below signatories immediately.
Reference documents:	/1/ DNV-RP-A203, Technology qualification, June 2017 /2/ DNV-RP-J201, Qualification procedures for carbon dioxide capture technology, July 2017 /3/ DNVGL-SE-0160, Technology qualification management and verification, 2016 /4/ Technology Qualification Report, DNVGL-2019-0303/Rev.0, 2019-06-26 /5/ Qualification Basis, TechnipFMC 072460C001-000-RT-0008-00002, rev. 3, 2018-04-26

DNV GL shall not be held liable for undiscovered failure modes or causes or for missing qualification activities.

Høvik, 2019-06-26
for DNV GL AS

Helle, Kaare Digitally signed by Helle, Kaare Date: 2019.08.14 14:25:54 +02'00'

Kaare Helle
CCS manager

Hanssen, Ketil Firing Digitally signed by Hanssen, Ketil Firing Date: 2019.08.13 14:49:17 +02'00'

Ketil Firing Hanssen
Project Manager

Figure 5-12: Statement of Qualified Technology from DNV GL.

5.7.3.1 Qualification Basis

The carbon capture (CC) technology from Licensor aims to capture CO_2 produced in Klemetsrud WtE plant. The CO_2 will then be transported by Northern Lights offshore for injection to storage. The storing and transport are not part of the scope in this qualification.

The CO_2 capture technology is based on a conventional chemical absorption/desorption cycle that uses a proprietary amine-based solvent (Cansolv DC-103).

5.7.3.2 Technology and Threat Assessment

A combined technology and threat assessment workshop was arranged in May 2018, with participants from DNV GL, FOV, TechnipFMC, Shell and Gassnova. The main outcome of the workshop was to identify the following points requiring further evidence:

- Mitigation of the total amine emission to the levels required. Other operating plants (e.g. Boundary Dam) may be used as reference point. This evaluation should include considerations around the design of the Water Wash, Demister and [redacted].
- Sizing of the TRU, which was sized too small at Boundary Dam while the plant in South Africa was designed correct.
- Concern that the degradation of the solvent at the CC Plant at Klemetsrud will be similar to the level of degradation that has historically been observed at Boundary Dam.

Based on the identified action items, a Qualification Plan was prepared – with all the actions followed up in a close-out report included in the Project's Qualification Report [4]. The final qualification required further evidence regarding amine emissions, solvent degradation and energy efficiency for operating conditions more similar to the Klemetsrud WtE plant conditions. On this basis, it was decided to include the pilot plant test campaign in the qualification process.

5.7.3.3 Qualification activities during pilot plant testing

The following performance parameters have been demonstrated during the pilot plant testing in order for DNV GL to be able to issue a Statement of Qualified Technology:

- Emissions to air;
- Solvent degradation;
- Energy efficiency.

Except for the requirement to maximum total amine emissions, no specific quantitative acceptance criteria have been set to these performance parameters. The performance assessment of the parameters is in section 5.7.3.5.

5.7.3.4 Pilot plant objectives

The primary objectives of the pilot plant testing were to provide sufficient evidence for the remaining qualification activities as well as to measure the total amine emissions to air and verify that the emissions (on average) can be kept below a defined level. The acceptance criteria for the primary objective is stated in section 5.7.2.1.

5.7.3.5 Performance Assessment

Representativeness of pilot plant test conditions

The results of emission and process efficiency were evaluated for periods where the test conditions were stable and representative for full-scale operation. After a first period of unstable operation due to initial troubleshooting and process stabilization, stable operation was achieved starting from week 16/2019. The performance assessment was based on the stable period. The main conclusions were:

- Process parameters have been within acceptable range from week 16 onwards, but more representative from week 18 after achievement of target flue gas flow.
- Flue gas blend has slightly deviated from expectations due to various trips and for maintenance of the lines, however, the concentration of pollutants has been on average within the representative range for full-scale. It is to be noted that time-limited deviations of pollutants have negligible effect on emission. The long-term averaged concentrations of pollutants are more relevant as they have an effect on degradation.
- Based on FOV statement in weekly reports, aerosols measured by extractive sampling in feed flue gas are very low.
- Degradation is considered sufficiently representative for the final period of the test. The full-scale Reclaimer is designed to maintain an equilibrium concentration of degradation products of 1%wt; in this respect the representative level of degradation of 1%wt has been reached and exceeded during the pilot plant testing during the last 500h test.

Considering the above observations, it is concluded that operating conditions from week 17 to week 22, i.e. the final 500 hours, have been sufficiently representative of full-scale operation.

Emission to air

A main performance requirement is the ability to control the amine process related emissions to air from the stack to comply with the expected and assumed regulations for ground level concentrations in air and nearby fresh water concentrations.

A 0.4 ppmv emission limit has been defined as acceptance criteria for the CC Plant. The 0.4 ppmv limit represents the lower limit (i.e. worst case) of an uncertainty range 0.4 to 3.3 ppmv for acceptable emissions.

The main observations and conclusions regarding emission to air were:

- From week 17 onwards 10-min average emission values have been below 0.4 ppmv for most of the time and emission peaks above 0.4 ppmv have been fairly limited in number and duration;
- Temporary emission peaks seem mainly related to unexpected deviations in flue gas blend, which however will not occur in full-scale configuration. Therefore, they do not represent a realistic cause of increased emission in full-scale operation. The cause/effect mechanism for all emission peaks are yet not completely understood and will be further investigated.
- Weekly amine emission average from week 17 to 22 has been well below 0.4 ppmv, except for week 21 where average emission has been equal to 0.4 ppmv.
- The duration of the emission peaks, beyond the duration of the cause, could be due to amine residues in sampling lines leading to PTR-MS-TOF instruments and will be investigated further by FOV and the Licensor during the extended pilot testing.
- [redacted]

It is concluded that the pilot testing has demonstrated ability of the CC Plant to meet, at stable design conditions, average weekly amine emission values below 0.4 ppmv.

Solvent degradation

Solvent degradation is important since it can influence the performance of the plant and potentially have some influence on the emissions.

Degradation was observed by measurements of specific degradation products analysed by LCMS. [redacted]

The commonly used basis to report degradation rate is kg/tCO[redacted]

Since the pilot has been operating representatively regarding flue gas quality and operating parameters, the rate of degradation predicted for full-scale seems to be rather conservative, providing thus enough design safety margin, e.g. for a correct TRU sizing.

Steam requirements

An important parameter when retrofitting carbon capture to an existing process is the energy penalty caused by the additional energy use in the CO_2 capture process. No specific requirements or target values have been set to the overall energy penalty (or energy efficiency) for the CC Plant. However, Gassnova has in their Design Basis for the CCS chain [24] specified that efficient use of energy is a design requirement.

The goal for TechnipFMC is to minimize this penalty which depends on

- the performance of the capture process (i.e. specific energy requirements);
- the way energy supply to the CC Plant is integrated to the power plant.

A capture process requires both electricity and thermal energy. Use of thermal energy in a capture process is far bigger than the use of electric power; minimizing the use of steam is therefore the primary goal to achieve better energy efficiency of the capture process. The main parameter to assess the thermal energy use is the regeneration energy, expressed as the amount of heat required to liberate 1 kg of CO_2 from the solvent in the regenerator (typically expressed as MJ/kgCO_2 or GJ/tCO_2). This parameter depends on the capture process design and on the performance of the solvent.

The regeneration energy of the pilot plant can be evaluated observing the amount of heat supplied as steam to the Reboiler, and the CO_2 captured, for a given time period (e.g. hourly average). A comparison of simulations run with and without lean solvent / condensate MVR contributions allows to calculate their effect to reducing the energy penalty. It should be noted that the MVR system is not included in the pilot configuration.

Based on these simulations and the pilot test results, the steam consumption that could be achieved in full-scale is in the range of 2.5-3 GJ/tCO_2, which is in the range typically reported for state-of-the art carbon capture technologies, therefore it is a value realistically achievable.

5.7.3.6 Residual Risks and Opportunities

The main residual risks and opportunities to be followed up in the next project phase are described in this section. These residual risks (Table 5-23) are considered as minor based on the results from the pilot testing and the threat assessments made during the technology qualification.

Table 5-23: Residual risk after qualification.

Area of concern	Risk	Mitigating Factor
Solvent degradation	Long-term effects and possible non-linearity in degradation rate.	Degradation rate is being investigated further during the extended pilot testing campaign.
Steam consumption	The pilot plant steam consumption is not fully representative of the full-scale plant [redacted]	[redacted]
TRU sizing	Pilot plant does not have a TRU and therefore cannot be tested with the pilot plant	The rate of degradation predicted for the full-scale plant is higher than observed during pilot plant operation, thus providing additional design margin for adequate TRU sizing.

In addition to the residual risks listed above, the pilot plant operation has also introduced some opportunities listed in Table 5-24.

Table 5-24: Residual risk after qualification: opportunities.

Area of concern	Opportunity	Supporting factors
[redacted]	[redacted]	[redacted]
TRU	Reduce the size / number of TRU's from the full-scale design.	The full-scale plant has been designed to handle a high level of flue gas contaminants. Data obtained by flue gas measurements linked to the pilot plant can potentially be used to lover the maximum flue gas contaminant design case.

5.8 Land use and plot plans (2j)

The plot plans and layouts of technical equipment has been a continuous area of development during the FEED phase of the project. In this section the current layouts will be presented along with 3D illustrations and an overview of the works needed to prepare the project sites for their respective installations.

5.8.1 Klemetsrud – CC Plant

The current plot size and placement of the CC Plant is shown in Figure 5-13 below (green outline). Placement of equipment etc. may be subject to changes in the next project phase. The total area covered by the current layout is approx. 11.300 m².

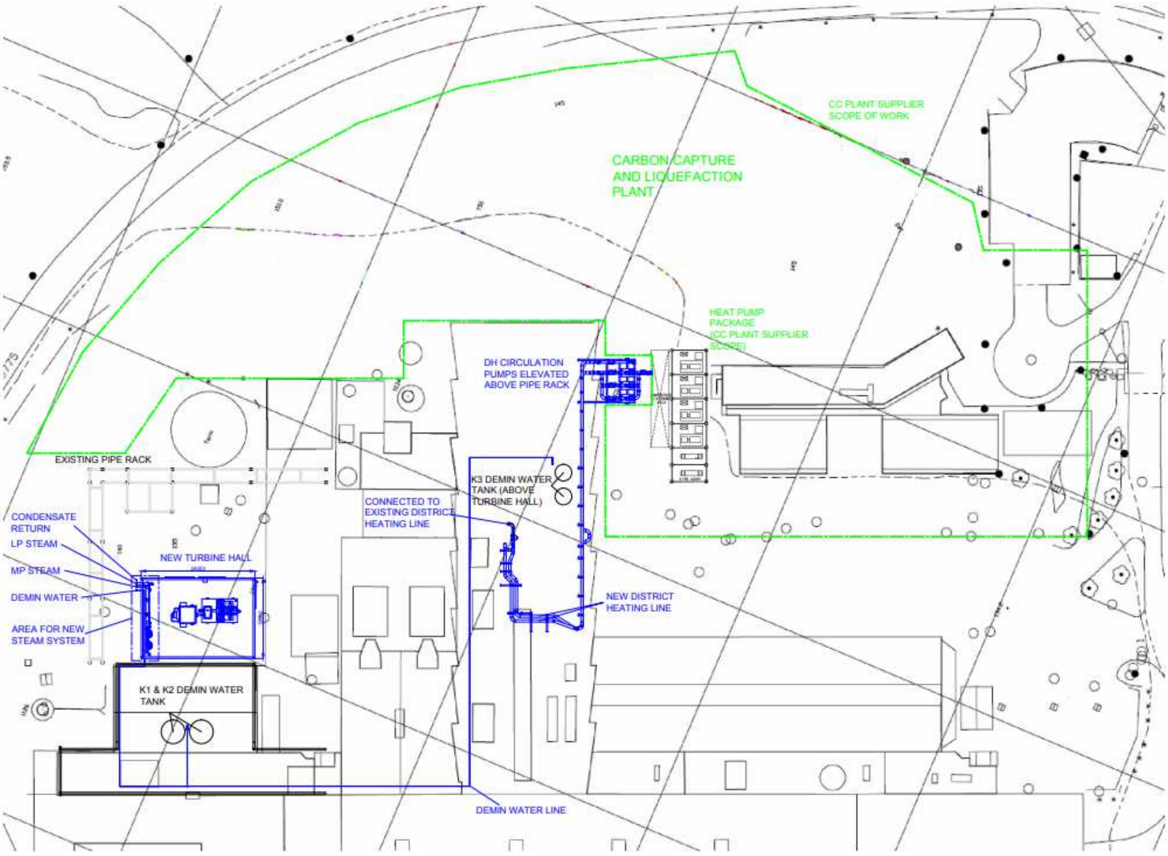

Figure 5-13: Area to be occupied by the CC Plant (green area) [38].

An overview of the preliminary layout prepared by TechnipFMC is presented in Figure 5-14. Figure 5-15 to Figure 5-18 present a 3D visualization of the area.

Figure 5-14: Preliminary Layout of the CC Plant, TechnipFMC [39].

Figure 5-15: 3D illustration of the CC Plant and intermediate storage at Klemetsrud seen from north-east [2].

Figure 5-16: 3D illustration of the CC Plant and intermediate storage at Klemetsrud seen from north-west [2].

Figure 5-17: 3D illustration of the CC Plant and intermediate storage at Klemetsrud seen from south-west [2].

Figure 5-18: 3D illustration of the CC Plant and intermediate storage at Klemetsrud seen from south-east [2].

5.8.1.1 Plot conditions

The CC Plant will be placed next to the existing WtE facility. A large amount of rock needs to be blasted away and the plant will be built on the bedrock. A large amount of work, performed during the concept phase, is described in detail in the concept Geotechnical Evaluation and Blasting Study [40]. The evaluations contained in the concept study has been reviewed and considered adequate for the FEED phase.

The rocks in the area consists of eye gneiss, granite and foliated granite. The rocks in the area is unweathered and is mainly massive with large blocks, and rather jointed in some localities.

The total rock volume that needs to be blasted is estimated to approximately 134.500 m³ (without over blasting), a 3D visualization of the volume is depicted in Figure 5-19.

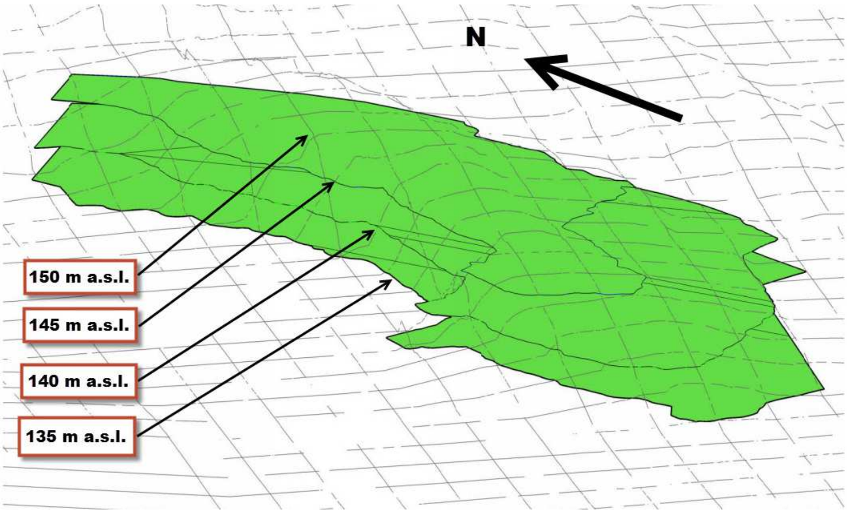

Figure 5-19: 3D representation of the rock volume that has to be blasted before the CC Plant construction [40].

Based on the geological surveys and simulations, a blasting plan with 3 different zones (based on the estimated amount of explosive needed) has been prepared. The zone division is presented in Figure 5-20.

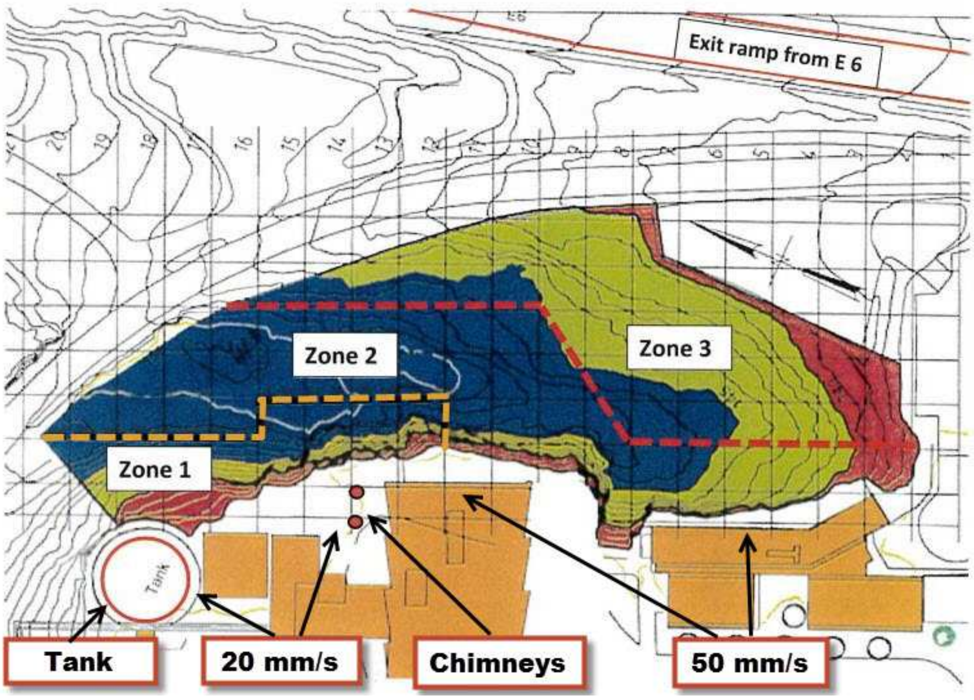

Figure 5-20: Zone division of the area, (red and yellow stippled lines) according to the approximate amount of explosives needed for blasting [40].

- Zone 1: Theoretical 0.15-1.3 kg explosives/interval. This is an expensive blasting round, with small blasting benches. The rock closest to the diesel tank is likely to require mechanically removal by hammering. When blasting will take place in this area it is not necessary to close for the traffic the E6. Requirements to the maximum pallet height: 5 m.

- Zone 2: Theoretical 1.3-9 kg explosives/interval. It might be necessary to close E6 during the blasting. Requirements to the maximum bench height: 5 m.
- Zone 3: Theoretical > 9 kg explosives/interval. This is virtually free blasting in terms of peak particle velocity limits) with exception of the requirement of using heavy rubber mats. In this zone there is no limit for the maximum bench height.

5.8.2 Klemetsrud – Intermediate storage and truck loading facilities

During the project's FEED phase the location of intermediate storage, truck loading facilities and liquefaction plant has been moved. The plan in Figure 5-21 shows new the location including driving patterns. Figure 5-22 and Figure 5-23 present 3D visualization of the area.

The layout may be subject to changes and details are expected to vary depending on further detail design development.

The total area needed including room for manoeuvring the semi-trailers is approximately 8000 m².

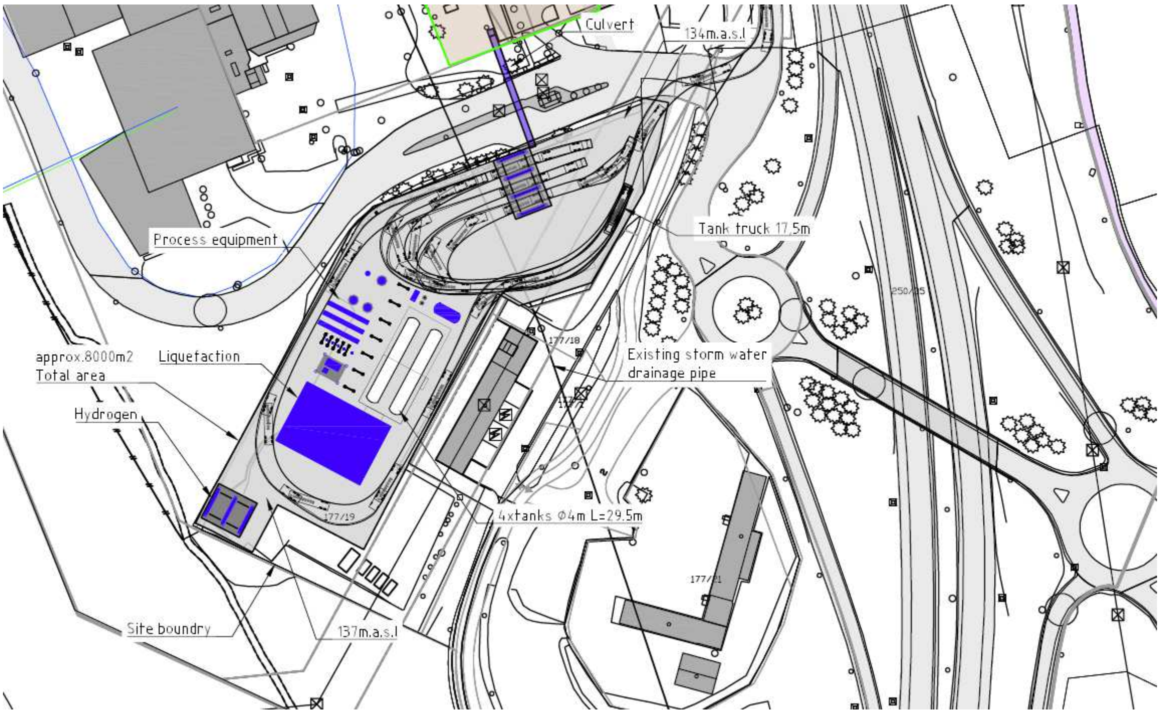

Figure 5-21: Overview of the Intermediate storage and truck loading area at Klemetsrud [41].

Figure 5-22: Intermediate storage and truck loading facilities at Klemetsrud , view from south-west. Picture from the 3D model [2].

Figure 5-23: Intermediate storage and truck loading facilities at Klemetsrud , view from north-east. Picture from the 3D model [2].

5.8.2.1 Plot conditions

The expected ground conditions are some fill material, with underlying beach and ocean deposits, as shown in Figure 5-24.

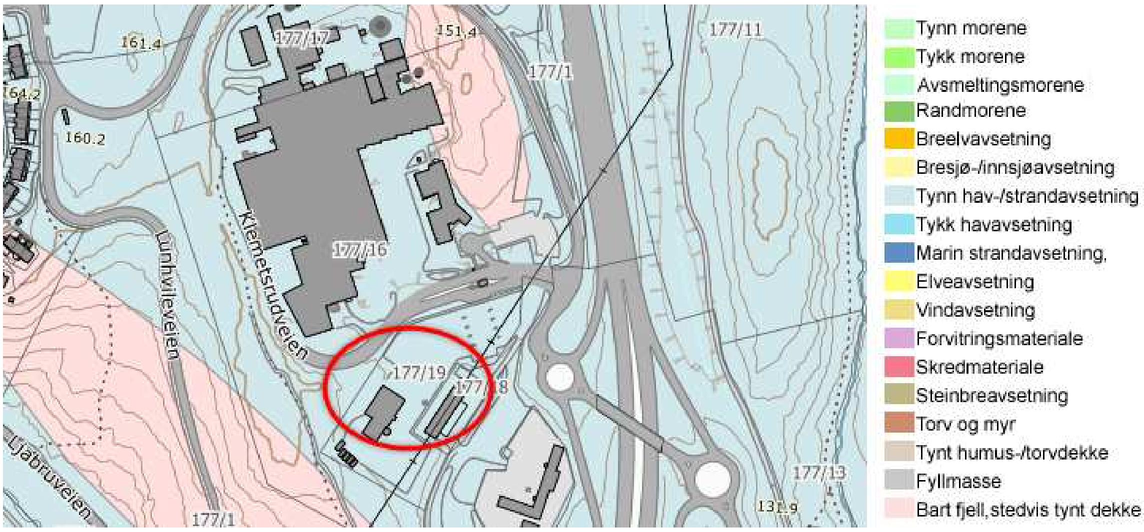

Figure 5-24: Area around the Klemetsrud WtE plant. The red circle shows the area where the intermediate storage tanks will be located, beach and ocean deposits are indicated. Source: NGU [42].

Earlier in the concept phase, in June 2017, COWI performed field investigations at Klemetsrud. During the FEED phase the location for the Intermediate storage and truck loading facilities changed. For this reason, the field investigations data from 2017 does not cover the current plot location. There is little reason to expect large deviations from the investigations from nearby areas, field investigations in the early next phase of the project will be used for confirmation.

5.8.3 Harbour facilities

This section contains a general overview of the harbour facilities, presented extensively in the Port of Oslo Terminal Report [43].

Table 5-25 summarizes the area required for the harbour facilities at Port of Oslo.

Table 5-25: Area requirement at Port of Oslo.

Item	Area (m²)
Liquefaction/process/piping area	[redacted]
Harbour storage are	[redacted]
Truck unloading facilities area	[redacted]
Roads and access	[redacted]
Area for loading arms and utilities at quay	[redacted]
Total area	[redacted]

The following main installations will be part of the terminal:

- Truck unloading terminal with 3 offloading bays;
- Tank farm with storage capacity based on a transport ship arriving every 4 days, with a capacity to load 5400 m³;
- Cooling equipment;
- Re-liquefaction equipment;
- Pump station with a nominal loading rate of 800 t/hour;

- Custody transfer metering station;
- Pipeline from pump station to quay side ship loading facility;
- Quay top-side installations, loading arms;
- Quay for loading transport ship with a dedicated mooring site for ship up to 130 m in length and minimum draft of 8.5 m;
- Vapour return line with facilities;
- Control room and office;
- Services provided to the ship (shoreside electrical power, potable water, etc.);
- Fencing and access control.

5.8.3.1 Location of the harbour facilities

Location of the harbour facilities has been selected based on plot availability, technical suitability and the risk evaluation for a major spill of CO_2 from the harbour storage tank farm.

Port of Oslo initially identified four potential locations for the harbour facilities within their areas at Sydhavna. After reviewing the area requirements in the FEED phase of the project, a location at Sjursøya was identified as the most suitable of the four.

However, due to the larger required plot area (compared to the concept described in 5.11.3, truck transport requires more area), an area slightly south of the preliminary site at Sjursøya called Kneppeskjær was identified and selected. See Figure 5-25 and Figure 5-26 for an overview of harbour facilities location. The area selected is currently occupied by a warehouse (skur 89), the demolition activities of the existing structures are included in the Civil Contractor's scope of work.

Figure 5-25: Location of Kneppeskjær, Port of Oslo.

Figure 5-26: Location of the CO_2 export terminal area at Kneppeskjær, Port of Oslo. The red outline shows approximate location of the truck unloading facilities and harbour storage, while the yellow outline shows the jetty where the ship will berth.

5.8.3.2 Harbour Layout and Arrangement

Figure 5-27 to Figure 5-32present the layout and arrangement of the harbour facilities at Port of Oslo.

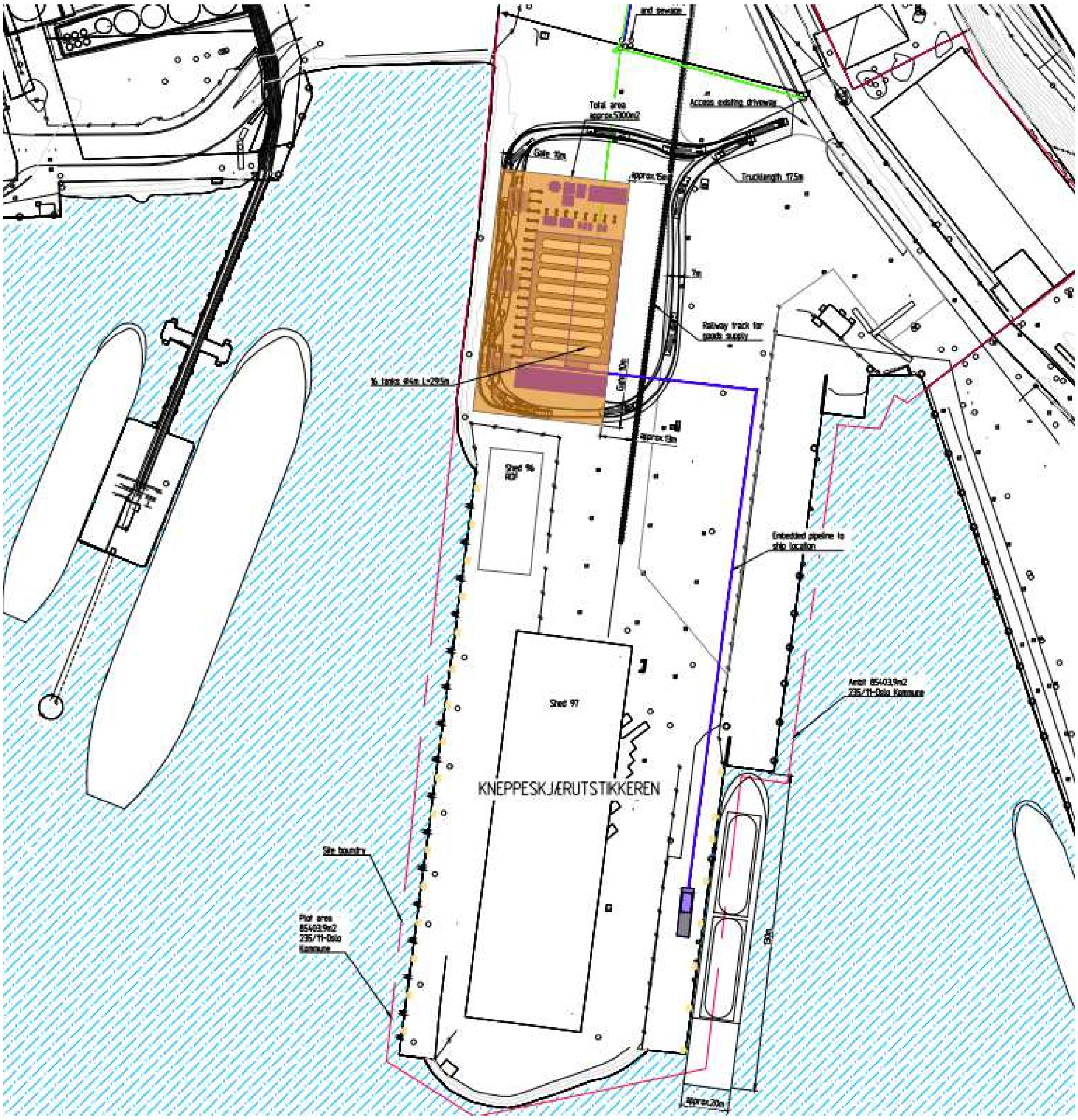

Figure 5-27: Sketch of current general design of harbour facilities at Port of Oslo. Ship will moor on the east side of Kneppeskjær and underground pipeline from the truck unloading facilities to the loading arms will carry CO_2 product for ship loading [44].

Figure 5-28: 3D-illustration of the harbour facilities at the Port of Oslo. View from south east [2].

Figure 5-29: 3D-illustration of the harbour facilities at the Port of Oslo. View from north-east [2].

Figure 5-30: The harbour storage area at Port of Oslo seen from north-west [2].

Figure 5-31: The harbour storage area at Port of Oslo seen from south-west [2].

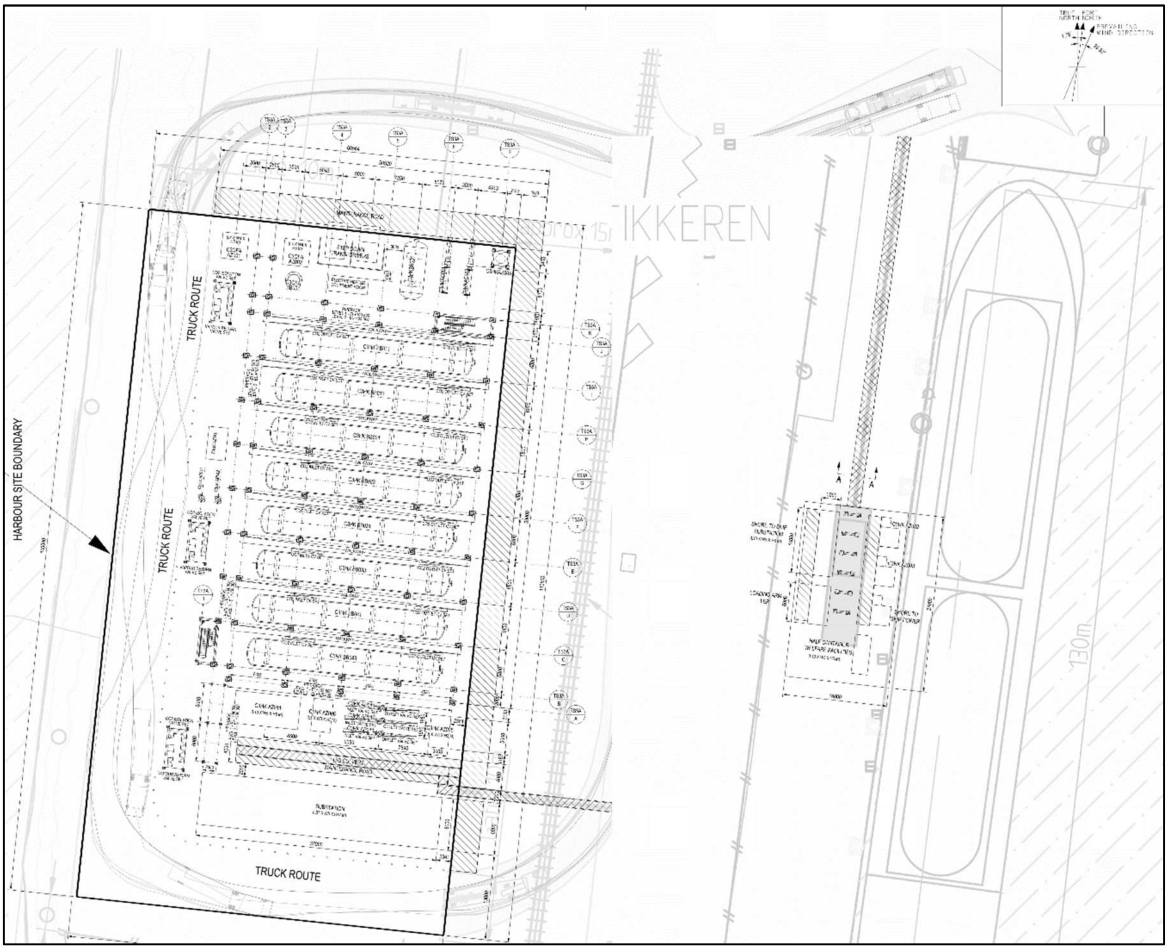

Figure 5-32: Preliminary layout of the truck unloading/harbour storage installations (left) and the ship loading arrangement (right), provided by TechnipFMC [45] [46].

5.8.3.3 Mooring Arrangement

The mooring location will be on the east side of the jetty at Kneppeskjær. The east side is selected due to depth restrictions on west side of quay.

This part of the quay is an ISPS port (International Ship and Port Facility Security Code).

Existing quayside facilities are considered suitable for the CO_2 transport ship due to the suitability of the existing mooring capability. Port of Oslo will provide a mooring plan based on the exiting quayside facilities during the next project phase.

5.8.3.4 Plot conditions

Site preparation at Port of Oslo include deconstruction and disposal of the existing pier structures (skur 89). The scope includes (described in detail in [47]) includes excavation activities, preparation of the foundations for the storage tanks and the process equipment as well as a new road suitable for heavy transport trucks.

Geotechnical considerations [42]

The area in general is well known for its big quay fillings which has been propagating during for a long time. The considerations at this stage are only based on an old bedrock contour report, and some old digging trials. The filling at Kneppeskjær is expected to be moderate, with a distance to bedrock in between 0 and 30-35 meters. The filling of Kneppeskjær is quite old, mainly constructed in the years 1967 to 1972.

Parts of the quay is constructed on a former island (Figure 5-33), and the location of the storage tanks seem to coincide with the island location.

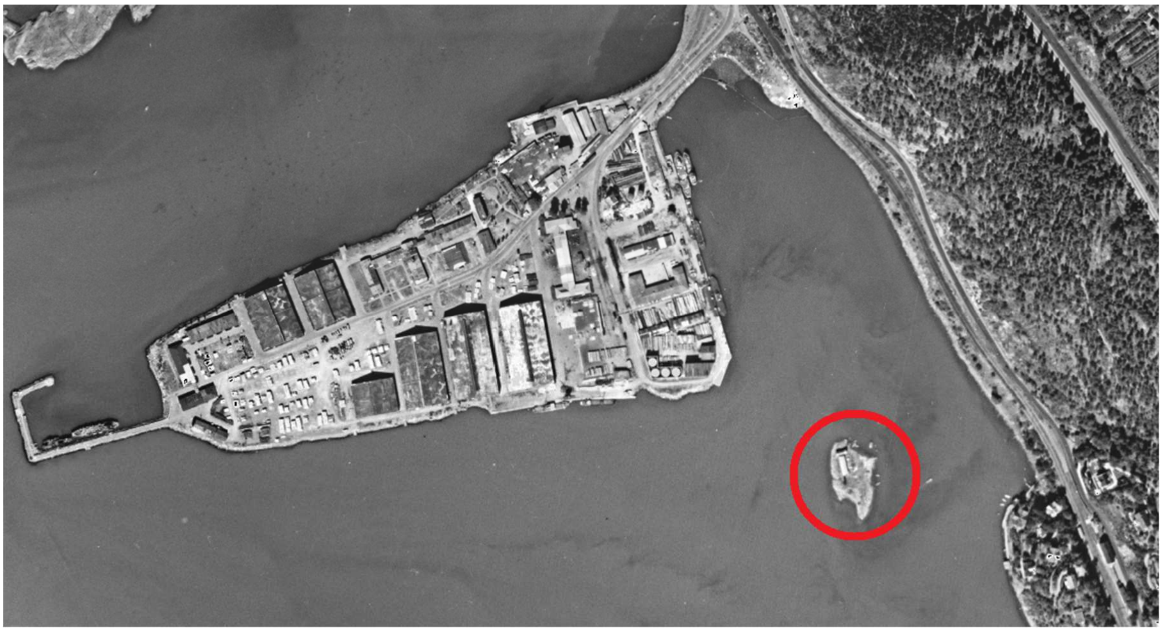

Figure 5-33: The old island of Kneppeskjær, seen in red, on which the pier is constructed , 1947 [42].

Settlements and horizontal movement of the filling is assumed at a very moderate level, and the global stability evaluation for Kneppeskjær will be finalised during the next project phase.

From a geotechnical perspective, the harbour storage tanks are the most critical items due to their weight. However, their location will be away from the quay front, reducing the contribution to the instability of the sea filling. The foundation of the storage tanks is likely to be at least in part on the firm rock of the old Kneppeskjær island. The evaluated filling conditions is expected to have sufficient stability to handle the weight of the storage tanks. Ground condition will be assessed with detailed site investigation and any eventual remaining risk can be mitigated by pile foundations.

5.9 Commissioning philosophy (2I)

This section presents the necessary steps needed for ensuring that the new CC Plant at Klemetsrud is commissioned and made Ready for Start-up.

Subsequent trial runs, performance testing and handover from TechnipFMC to FOV will be detailed in the next project phase.

The activities relating to commissioning are presented below. It should be noted that these activities are in typical order and will be defined further during the next project phase.

- **Construction and Integration:** comprises many activities which include detailed engineering, procurement, pre-fabrication, assembly, construction and integration with the WtE plant. This will mainly be carried out by TechnipFMC.

  The construction and integration philosophy [48] outline the main guidelines for construction and integration that needs to be taken into consideration in the planning and design of the CC Plant and upgrade to the existing WtE plant to integrate the CC Plant.

- **Mechanical Completion:** the plant is ready for commissioning when the plant is mechanically complete, documented with mechanical completion (MC) check list and accepted by FOV. This activity is part of the construction and integration phase.
- **Pre-Commissioning:** involves activities undertaken after mechanical completion which include non-operating adjustments, conformity checks, cleaning and no energy/low energy testing of components and systems. This activity is carried out during both the "construction and integration phase" (part 1) and the "commissioning phase" (part 2).

- **Commissioning:** the process carried out by TechnipFMC to ensure the CC Plant and the new facilities are Ready for Start-up. The commissioning verifies that the new plant is functionally sound and built up in a systematic way from items to systems to complete plant. The following it typically included:
  - Pre-commissioning part 2;
  - Testing of the equipment included in the plant under normal and disturbed conditions;
  - Testing of the plant instrumentation, control, regulation, protection and alarm systems included in the new plant and facilities.

  Commissioning will be split into:
  - Cold Commissioning;
  - Hot Commissioning.
- **Functional Test:** activity performed by TechnipFMC during commissioning phase to ensure that the new plant and facilities operate as intended including control system alarm and trip checks. Typical functional tests comprise:
  - Start-up tests and shut down tests;
  - Load rate change tests;
  - Disturbance tests;
  - Tests required by network operator.
- **Ready for Start-up:** the acceptance that the plant is mechanically complete and commissioned successfully.
- **Trial Runs:** after TechnipFMC has aligned the new plant and facilities and ensured that they are functioning according to requirements and intentions, the Trial Run starts. The Trial Run will show that the plant can operate and perform according the contract.
- **Final acceptance:** the acceptance by FOV of the work carried out by TechnipFMC, after that performance tests, following the issuance of Delivery Acceptance Certificate of the work.

Reference is made to Commissioning Philosophy [49] for further details.

5.9.1 Overall Commissioning Philosophy

TechnipFMC will carry out the commissioning of the new CC Plant including integration with the existing WtE plant as well as commissioning of the harbour facilities. All commissioning activities will be under TechnipFMC responsibility and supervision.

The commissioning period will be used by FOV to train and educate the Operation and Maintenance (O&M) team, e.g. by being actively involved in commissioning activities to familiarise themselves with the new plant.

The WtE plant at Klemetsrud will be in operation (either all lines or just some depending on the WtE situation/yearly maintenance stops) during the whole phase including commissioning and start-up of the new CC Plant.

A separate commissioning team, comprising personnel from FOV O&M team and other relevant personnel will be set up for the new facilities at the Port of Oslo.

5.9.1.1 Methodology

The overall commissioning includes provisional acceptance, pre-commissioning, first start-up, trial runs, performance testing and final acceptance. Careful planning is necessary for commissioning and start-up. Integration of the various systems, particularly the control systems with others, must be seamless. This implies a wide range of verifications, checks and tests under realistic conditions.

Equipment packages will be commissioned to the extent possible by suppliers under supervision of TechnipFMC. Verifications of statuses will be through check lists and reports.

5.9.1.2 Commissioning Organisation

The planned organization for the commissioning team is shown in Figure 5-34. The commissioning is to be led by TechnipFMC in close cooperation with the operation personnel from WtE plant.

The FOV Commissioning Team Leader will work closely with the Commissioning Manager (from TechnipFMC organization), to ensure that commissioning personnel from WtE plant operations are involved with the commissioning activities. The TechnipFMC Commissioning Manager reports to the Site Manager (Figure 11-6).

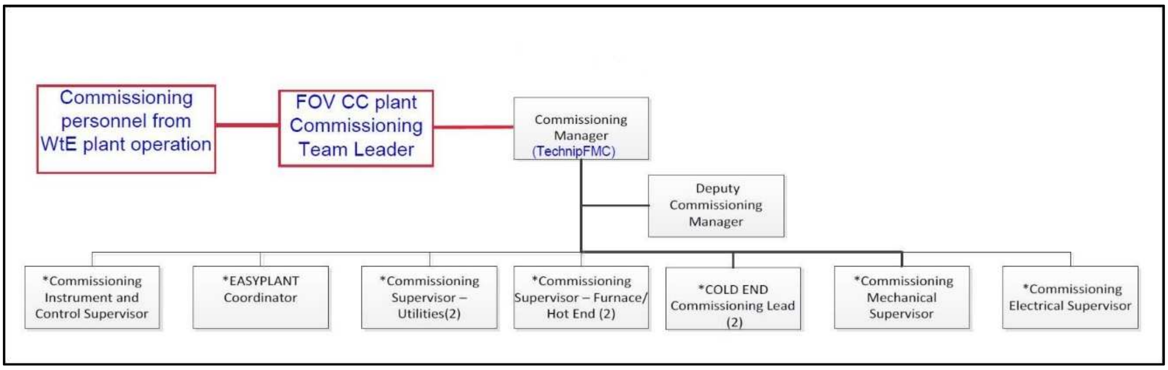

Figure 5-34: Preliminary Commissioning Team functional organisation chart.

The FOV Commissioning Team Leader belongs to the FOV O&M organisation as illustrated in Figure 5-35.

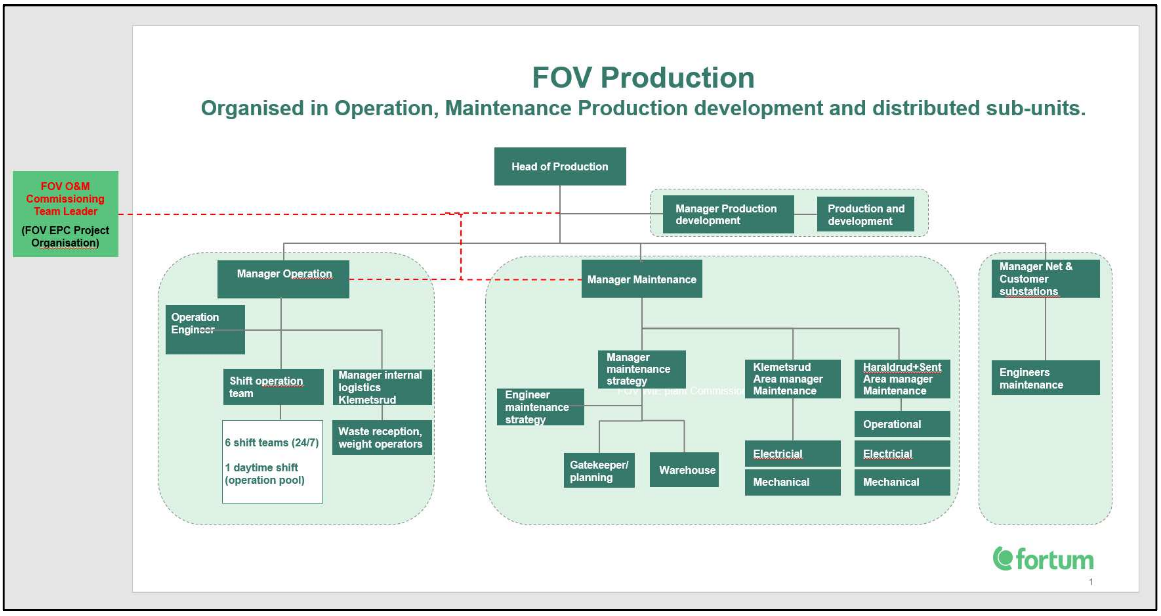

Figure 5-35: FOV Production team organization chart - Klemetsrud WtE plant. The WtE plant organisation might change and will be confirmed during the next project phase.

5.9.1.3 Commissioning procedures

Detailed commissioning procedures will be developed during the next project phase well in advance of commissioning start. The following documents are as a minimum foreseen as necessary:

- Commissioning execution plan including:
  - Plan for pre-commissioning Part 2 (Part 1 is described in section 5.10);
  - Organization chart;
  - Commissioning procedures and records;
  - Follow up and progress report;
  - Method statements.
- Commissioning HSE plan including:
  - HSE responsibilities and tasks;
  - HSE organization and communication plan;
  - HSE information and training;
  - Procedures for safe maintenance/lock out of equipment;
  - Integration into FOV current safety procedures.
- Performance test procedure.

5.9.2 Commissioning of the facilities at Klemetsrud

It is foreseen that all parts, equipment and systems are commissioned as fully stand-alone, i.e. the CC Plant (including CO_2 conditioning and liquefaction), Intermediate storage, truck loading and auxiliaries are tested and commissioned independently of each other.

The TechnipFMC Pre-commissioning, Commissioning and Start-up Plan [50] provides a general definition of the activities, manpower, utilities, and system support required for the Pre-commissioning, Commissioning and start-up of the CC Plant facilities.

The plant will be divided into sections /subsystems for commissioning. Each section will be commissioned separately. Sections will then be grouped in larger systems / areas and tested and verified Ready for Start-up.

Utility systems should be commissioned first as other sections may depend on their availability for commissioning. The commissioning of these system interfaces will be carried out together with the CC Plant commissioning.

The following systems have interfaces to/from the Klemetsrud WtE plant:

- Flue gas system;
- K3 / Sentrum (to Oslo City Centre) DH system tie-in to CC Plant heat pump;
- Steam and condensate systems;
- Water systems (demineralised water, tap water, process water and waste water);
- Back up service air system connection;
- Amine derived waste collection;
- Other system: instrumentation, control, electrical power and civil preparations.

5.9.3 Commissioning of the harbour facilities at Port of Oslo

The commissioning of the harbour facilities will be carried out by TechnipFMC together with FOV O&M personnel and other relevant personnel.

Commissioning plans and procedure will be established to test the Battery Limits of CO_2 loading system interfaces towards the CO_2 transport ship. Proper routines for analysis and verification of the export cargo (liquid CO_2 product quality) will be established.

These procedures are to be developed in cooperation with Northern Lights and the Contractor responsible for the Ship design during the next project phase.

The commissioning of the truck unloading facilities will be a joint effort between TechnipFMC and the Transport Contractor, with the participation of FOV O&M personnel.

5.10 Construction and Integration (2o, 2q, 2r, 2s)

This section of the report outlines the main guidelines for the CC Plant planning, construction and integration to the Klemetsrud WtE plant.

Further details of the sections presented below are detailed in the Construction and Integration Philosophy [48] and Integration and Modification Works [51]. In addition, relevant information is contained in section 7.3.

The foreseen steps during next project phases, presented in Figure 5-36, are in the following order:

1) Construction and Integration phase, including detailed engineering, procurement and construction;
2) Commissioning phase;
3) Operation and Maintenance phase.

Figure 5-36: Foreseen project activities during next phase.

5.10.1 Detailed engineering

During the detailed engineering phase all new equipment and systems will be designed to minimize the operation costs and optimizing energy efficiency (as defined in the design basis, see section 5.3.1). Additionally, easy access to the new equipment and components will be emphasized in the design.

O&M personnel from FOV will be assigned to the project to ensure that operability and maintenance considerations are addressed in the plant design.

As safety is of top priority in the FOV CO_2 Capture Project, the design of all new systems will ensure that sufficient safeguards are in place for enabling safe operation and maintenance of the new systems.

5.10.2 Procurement of new equipment

During the procurement phase, it is important to consider the delivery time of the new equipment and components. Long lead items [9] and items that need to be installed during WtE plant yearly maintenance stop need to be procured early to avoid any delay for the project.

5.10.3 Construction

5.10.3.1 Construction project team organisation

The FOV project team and TechnipFMC team organization during construction phase will be organized according to the organization described further, in section 11.3.

Peak manpower (FOV project management team, TechnipFMC and Civil workers on Site) is estimated to be around 600 persons, as shown in Figure 5-37.

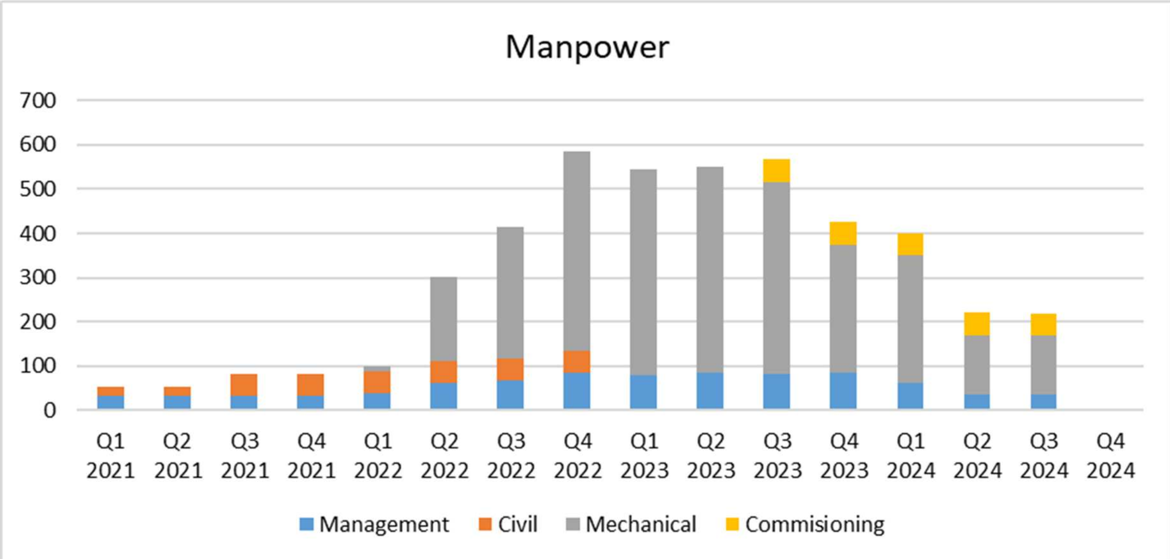

Figure 5-37: Estimated manpower at Klemetsrud during construction.

5.10.3.2 Site preparations and civil works at Klemetsrud

The area dedicated at Klemetsrud for the CC Plant will be levelled by suitable means to enable construction of the CC Plant. This also includes the civil preparatory works for concrete foundations.

The major demolition and site preparatory works include clearing away the area east of the WtE plant, the current parking area and the administration building at Klemetsrud.

Civil preparation works for the integration of the CC Plant both at Klemetsrud and at harbour facilities are described in section 5.8.

5.10.3.3 Temporary storage and rigging area for construction phase

Rigs

Area related to offices, wardrobes and canteen facility has been estimated. All rig units are assumed to be stacked in two heights.

Office rig

Site management from all involved parties will have a need for office spaces during the construction phase. The combined need for office space of FOV, TechnipFMC, Civil contractor, subcontractors and integration team is estimated to a peak of 86 office spaces. The office rig will contain all necessary support rooms such as toilets, meeting rooms (2 with 20+ capacity, and 6 with 5-8 capacity), small kitchen space, stairwells, printer and server rooms etc. The 86 offices are estimated to require a total of 65 barracks units, with each unit (TEK10 approved) having a footprint of 2.9 by 8.4 meters. Estimated footprint is shown in Figure 5-38.

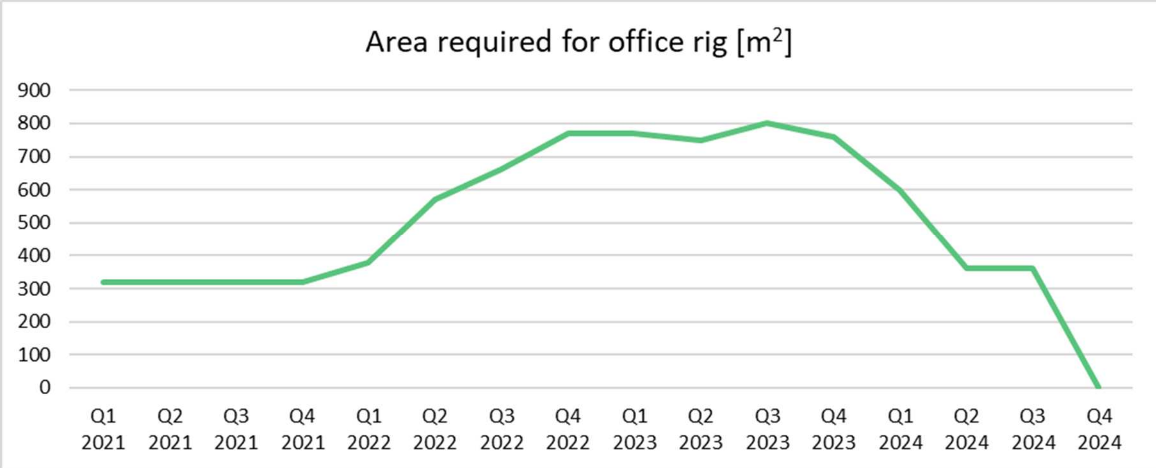

Figure 5-38: Estimated footprint of the office rig.

Wardrobes and sanitary facilities

The manpower related to the construction of the facilities peaks at about 500. These will need wardrobes and sanitary facilities preferably close to the construction site. A wardrobe unit includes toilets and showers required to serve 12 people. At peak the wardrobe rig will need to accommodate about 520 workers. This amounts to a total of 42 wardrobe units.

The total plot space needed is shown in Figure 5-39.

Figure 5-39: Estimated footprint of the wardrobe rig.

Canteen

All on-site workers excluding administration will use the canteen rig. Administration and management are expected to eat in the office rig. It is assumed that eating will be done in 2 sittings so canteen rig will be halved. At peak manpower the number of canteen units needed is estimated to 18. The total plot space needed is shown in Figure 5-40.

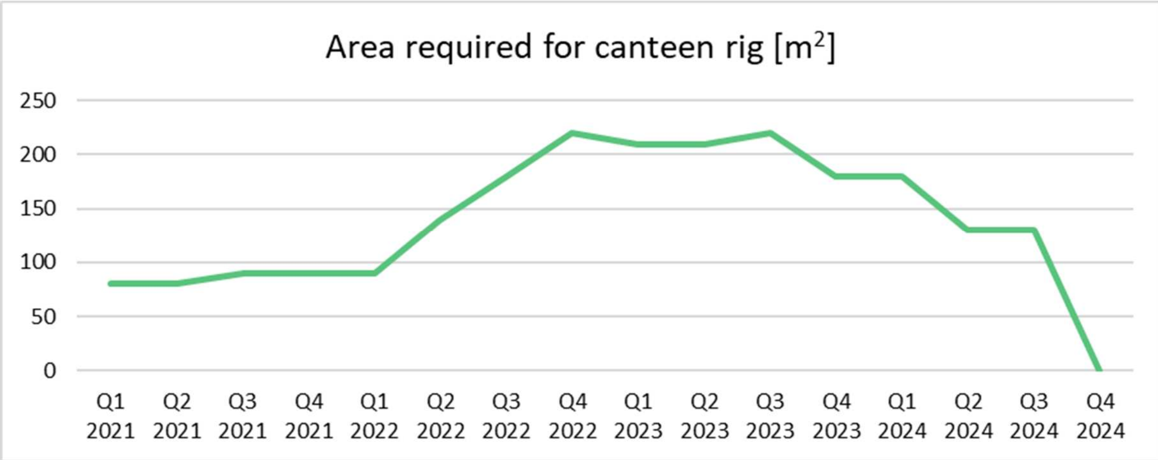

Figure 5-40: Estimated footprint of the canteen rig.

Construction-, storage and parking areas

TechnipFMC estimated peak area requirement is approximately 25 000 m² [52] including construction areas, parking, storage etc. The required area is approximated using the estimates for on-site manpower.

The large area required, showed in Figure 5-41, means that part of the 25 000 m² probably needs to be at a remote location.

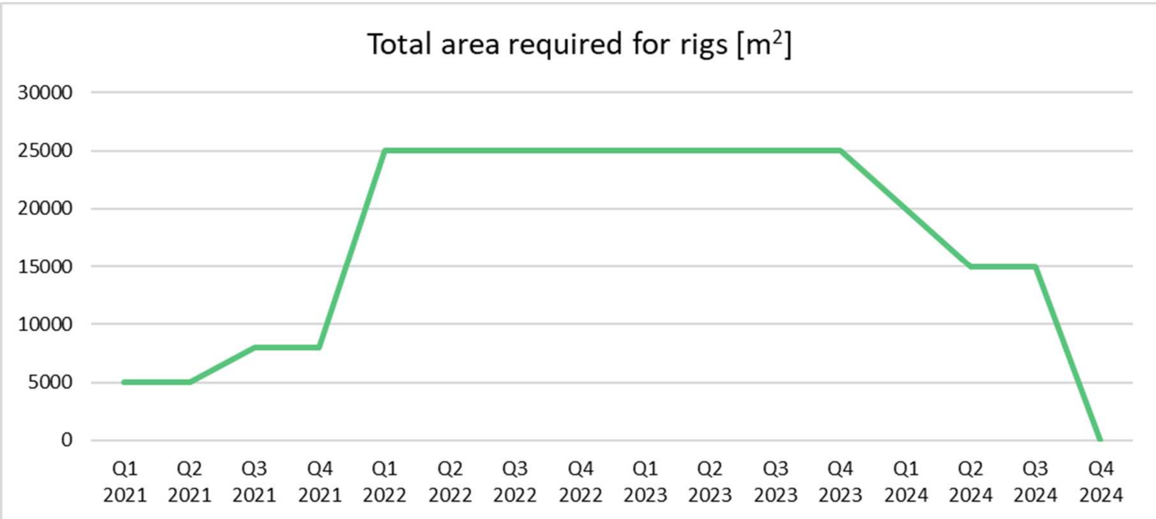

Figure 5-41: Estimated footprint for rigs, parking, storage and construction areas.

5.10.3.4 Area availability

Klemetsrud / Mortensrud (plot 178/183)

An area north of the WtE plant has been identified as a desirable area for construction and rig equipment.

Figure 5-42: Area directly north of CC Plant site

The total area usable without large amounts of ground preparation is estimated to be in the area 10 000 to 12 000 m². The area is owned by the City of Oslo and is regulated in the existing zoning plan for business in combination with sports facilities (as shown in Figure 5-43).

Future plans, with a schedule does not interfere with the construction of the CC Plant, contain an expansion of E6 highway along with a planned road parallel to the highway.

A dialogue with the City of Oslo Agency for Real Estate and Urban Renewal (Eiendoms- og byfornyelsesetaten, EBY) has been initiated to clarify the availability of the area for temporary rig use. The sports arena marked on Figure 5-43 may interfere with the planned rig area, but initial feedback indicate that it will not be an issue. Further clarifications are ongoing.

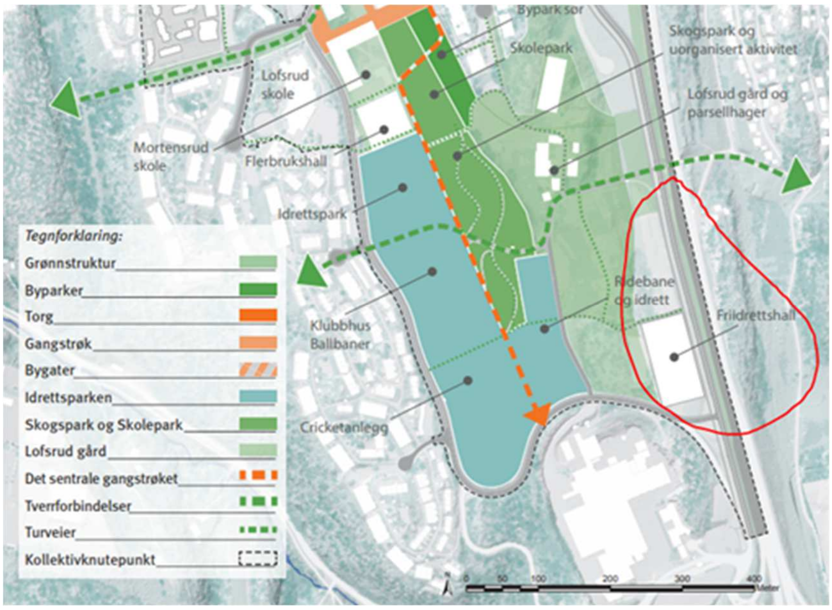

Figure 5-43: *Veiledende plan for offentlig rom* (VPOR) for Mortensrud area showing future public spaces. Red circle marks area with potential sports arena.

Stensrud (plots 173/44 and 173/28)

Parts of the properties 173/44 and 173/28 are considered interesting areas suitable for a remote rig for storage, construction and parking. Distance from construction site is approximately 3 km as shown in Figure 5-44.

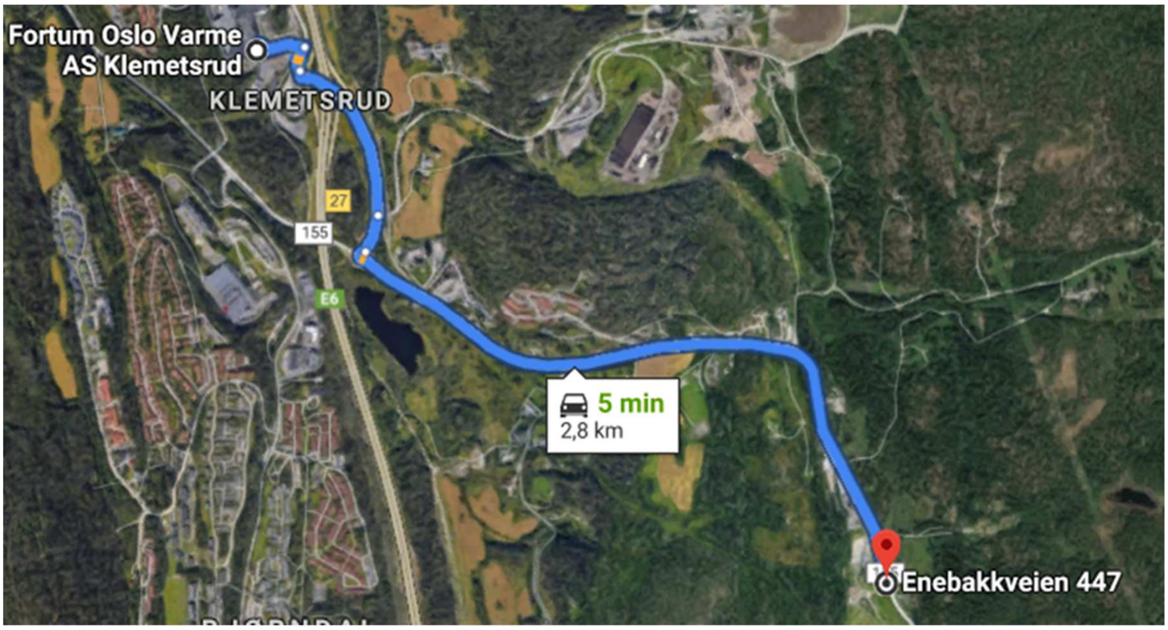

Figure 5-44: Location and distance of the potential remote rig area at Stensrud.

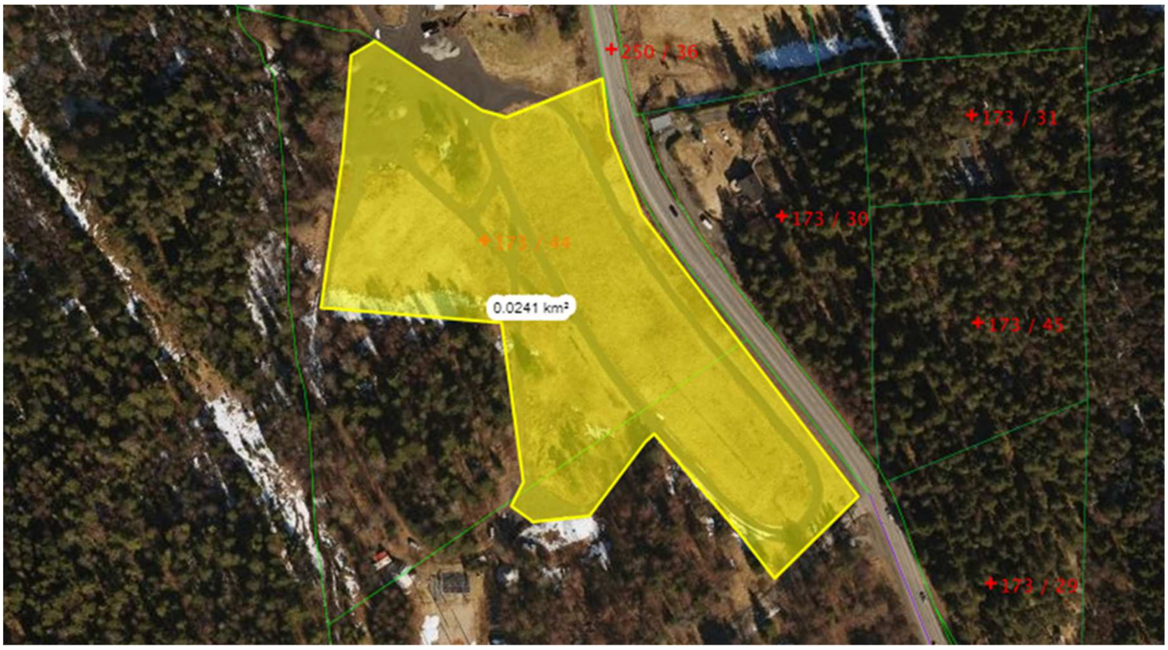

Figure 5-45: Marked area suitable for parking, rig and lay-down areas.

The area marked in yellow in Figure 5-45 (about 24 000 m²) is owned by the City of Oslo and is currently used for agriculture. The existing zoning plan has different purposes including residential, business and service.

Feedback from the City of Oslo Agency for Real Estate and Urban Renewal (Eiendoms- og byfornyelsesetaten, EBY) indicates that any plan begin before 2025; the areas should be available during the construction phase of the project. A formal request to use the location during the construction phase has been issued.

Additional areas

Additional areas are also being considered with ongoing dialogues with interested parties.

Areas at and around the WtE plant at Klemetsrud will be considered for placing the offices, wardrobes and canteen rigs.

5.10.3.5 Control room

FOV is currently establishing a new CCR to include more services, including sufficient space for two operator stations for the CC Plant.

5.10.3.6 Construction of CC Plant

The CC Plant will be constructed independently in order not to disturb the operation of the WtE plant.

The construction works will be carried out with maximum caution and planning as well as minimize the downtime needed to install the necessary interconnections for the CC Plant. Planned yearly maintenance stops for the WtE lines will be utilized to install the necessary interconnections for the CC Plant.

5.10.3.7 Construction of Intermediate storage, truck loading facilities at Klemetsrud

The intermediate storage tanks will be cylindrical prefabricated bullet tanks with sufficient storage volume for approximately one day's production of liquid CO_2.

Tanks will be installed on preinstalled foundations. The truck loading facilities will be located near the intermediate storage tanks.

5.10.3.8 Construction of the harbour facilities at Port of Oslo

As the harbour facilities will be built in an existing harbour area in the Port of Oslo, care has to be taken to coordinate activities and logistics to avoid interfering with the ongoing activities at the Port. The harbour facilities will comprise of truck unloading facilities, liquid CO_2 storage, re-liquefaction plant, power supply to ship and ship loading facilities, which are all in the scope of TechnipFMC.

The Port of Oslo will be responsible for modification of mooring facilities and water supply to CO_2 transport ship.

5.10.3.9 Harbour storage and truck unloading facilities at Port of Oslo

The harbour storage tanks will be cylindrical prefabricated bullet type tanks with sufficient storage volume for approximately 4 day's production of liquid CO_2. The tanks are designed with focus on safety with regards to minimizing dispersion in case of an incident, reduced installation time and cost.

The truck unloading facilities will be installed near to the storage tank area. Three unloading bays with required road access and turning circles for heavy transport will be prepared.

5.10.3.10 Ship loading facilities

The terminal will be equipped with a loading arms package to deliver the liquid CO_2 product to the ship and bring vapour return from the ship back to the storage tanks. The re-liquefaction package will ensure any excess vapour is liquefied and stored.

5.10.3.11 Personnel facilities at harbour

A housing (either fixed or portable) containing wardrobe, a small rest room and toilets for the use of O&M crews will be installed on predefined foundation and with facilities to hook-up to existing electricity, water and sewage systems at Port of Oslo.

5.10.4 Mechanical integration

New equipment will be installed in dedicated areas with as little impact on existing facilities as possible. Care will be taken to minimize the impact on existing systems, when existing equipment/component needs to be replaced to enhance or ensure operation or when the new systems are connected to the existing systems. Integration works requiring downtime in WtE lines will be scheduled to match the yearly downtime of the WtE plant. Further details of these works are presented in this section.

All incineration lines are stopped for yearly maintenance during the summer season, typically June - August. Line 1 and 2 are shut down for maintenance for three plus three weeks. Typically, there is an overlap in between the last week of the first line shutdown and the first week of the second line shutdown.

Line 3 is scheduled for the annual maintenance stop not to collide with the other lines; at least one incineration line is in operation at all time.

The following sections provide an overview of the main integration points. A full overview of the integration points is provided in the Master Interface Register [53].

5.10.4.1 Flue gas inlet, bypass, conditioning and outlet

The flue gas from the three waste incineration lines is supplied to the CC Plant from the interface points at the incineration plant. The interface points (supply and return) for flue gas from the lines 1 and 2 are after the new scrubber (base case, see Figure 5-2). For line 3, the interface points are in the existing flue gas duct before the existing continuous emission monitoring systems (CEMS) unit. All ducting works related to the interface points (duct connections for supply and return lines including all dampers) will be done during the annual maintenance stop of the WtE plant. All connection works are in the scope of TechnipFMC.

5.10.4.2 Steam and condensate

A continuous LP and MP steam supply is required for the CO_2 capture. The steam interface points will be made so that LP and MP steam are available in sufficient amounts to maintain the carbon capture process regardless of which incineration lines are running and whether or not the steam turbines at the incineration plant are in operation.

Piping for steam supply from the HP-steam header to the Pressure Reduction and Desuperheater Station (PRDS) can be installed during normal operation of the WtE plant as there is proper isolation between the steam lines on FOV side of Battery Limits and the new steam supply lines to PRDS.

5.10.4.3 District heating heat recovery system

The CC Plant will be requiring a large portion of the thermal energy presently used for heating of DH water. As the CO_2 absorption process generates heat (exothermal process), and heat pumps are used to recover that energy to the DH circuit. Heat is recovered from the CC Plant by pumping DH water from the existing line 3 district heating network through the condenser of the CC Plant heat pump and back to the existing line 3 DH network.

The integration of the heat pumps is foreseen to only cause minor modifications to the mechanical piping system; modification to the control system will be moderate.

5.10.4.4 Water systems

Tap water

An underground piping connection with a root valve at the interface point to CC Plant will be performed as part of the civil work scope.

Process water

The old automatic on/off valve will be re-installed after the modification of the system. The valve will be installed on the existing pipe before the interface point with TechnipFMC. Integration will be done during the annual maintenance stop of line 3. Installation of valve is within TechnipFMC scope.

Demineralised water

Piping connections to the existing line1/line2 and line 3 demineralised water systems, including the installation of root valves, will be done during the annual maintenance stop of the lines.

Waste water

The works belongs in the civil scope of work. Connection to the existing municipal sewer can be done anytime.

5.10.4.5 Other Systems

Service air

The interface connection is only for back-up purpose and will be used only as required.

Piping connection to the existing line 3 service air system with a root valve will be done during the annual maintenance stop of the line 3.

Amine waste

Section 5.3.7.2 describes the options for amine derived waste handling and disposal; a decision on which option will be executed will finalised in the next project phase.

5.10.5 Electrical & Instrument integration

This section describes the electrical and instrumentation integration of the Klemetsrud WtE plant to the CC Plant in the existing control & monitoring system.

Modifications of the electrical system and the 11 kV network are detailed described in two documents ([54] and [55]).

5.10.5.1 Electrical power supply

Klemetsrud

The maximum load demand for CC Plant may be [redacted]. For this reason, the 11 kV supply will be modified.

The WtE plant is supplied from Hafslund Nett transformer station where voltage is transformed from 47 to 11 kV. The modification at the transformer station will include a new transformer, upgrade of two other transformers and modification / additions to the existing 47 and 11 kV switchgears.

FOV will install a new 11 kV substation at the Klemetsrud WtE plant, and both the existing consumers and the new CC Plant will be supplied from this substation.

The new substation will be fed from both Klemetsrud transformer station (Hafslund Nett) and steam turbine generators at WtE plant. Existing 11 kV cables between transformer station and WtE 11 kV switchgears will be modified to utilize the existing transmission capacity.

The 11 kV supply from new substation to CC Plant switchgear will be with two fully redundant connections.

Harbour

The power supply to storage and ship loading facilities will be taken from a substation owned and operated by Hafslund Nett. The 11 kV substation is located at the Bekkelaget transformer station.

The 11 kV supply from Bekkelaget transformer station will be with two fully redundant connections.

Shore to ship power (690V) will be fed from the 11 kV switchgear. All motors within the harbour facilities included in TechnipFMC scope are low voltage and will be fed from 400 V MCCs / distribution boards.

5.10.5.2 Storage and export terminal at Port of Oslo

The electrical equipment is included in TechnipFMC scope.

5.10.5.3 Control System Integration

Existing control system at the WtE plant will be extended to cover the process integration scope. In most areas the modification will be low or moderate and the existing PLC/IO will have sufficient capacity. Modification at steam generation and DH control systems may require additional IO or PLC capacity. The modifications will follow the existing structure of control system.

5.10.6 Pre-commissioning and Mechanical Completion

The construction and integration phase include mechanical completion and pre-commissioning activities before the project then moves into the commissioning phase.

Pre-commissioning and mechanical completion are described in section 5.9.

A plan on how to handle the transition from mechanical complete to commissioning and from commissioning to start-up will be developed during the next project phase.

5.11 Concept evaluations and selection (2t)

The FEED phase was built on the concept selected during the Concept phase.

During Concept phase, FOV considered the following design elements as concepts that were explored in the Concept phase and their conclusion:

- CC Plant and Integration with the Klemetsrud WtE plant;
- Selection of the EPC Contractor for FEED phase;
- CO_2 transportation;
- Location and plot space.

5.11.1 Integration with WtE plant

The new plant is described in section 5.3, while the overall integration philosophy as matured during FEED phase is described in section 5.10.

The following modification to the concept took place at the beginning of the FEED phase:

- Base case is that amine waste from CC Plant is to be treated outside the Klemetsrud WtE plant – further work with the emission permit is needed for handling within the WtE plant;
- CC Plant – defined technical principles and requirements:
    - The CC Plant has two TRU. Even though the emission permit allows for higher emissions than what is experienced on average at the WtE plant, it was decided to have two TRU to not restrict future WtE plant operation.

      The CC plant solvent reclaimers (TRUs) are designed to receive and emit flue gas with component concentrations up to the emission permit limits. This has been considered as worst case design requirement and is the reason for the increased TRU capacity. However, it is acknowledged that the actual flue gas composition for most components (NOx/NO_2, CO, HCl, SO_2, TOC/VOC) are far below the worst case. Two TRUs were specified where one will be on duty in normal operation and the other will be in stand-by and put on duty when needed (i.e. at high solvent degradation rate). Relating to TRU capacity, FOV will in the interim period investigate possible TRU options, for instance to remove the stand-by TRU based on cost-benefit considerations;
    - 60 MW heat pumps have been optimised and the connection to the existing DH infrastructure has been simplified, with an overall reduced complexity;
- The new demineralised water plant for the CC Plant is to supply demineralised water to the WtE plant as well.

5.11.1.1 Heat Integration concept evaluation

Heat integration options have been evaluated during the FEED phase of the project [56].

As a result of the pre-FEED evaluations the heat integration solution identified as "solution 3b" (as described in [6]) was selected as the most feasible solution and selected for further evaluation during the FEED phase. In heat integration *solution 3b*, the steam needed for the CC Plant is fed from the steam cycle of incineration line 1 and 2. A simplified illustration this heat integration solution is presented in Figure 5-46.

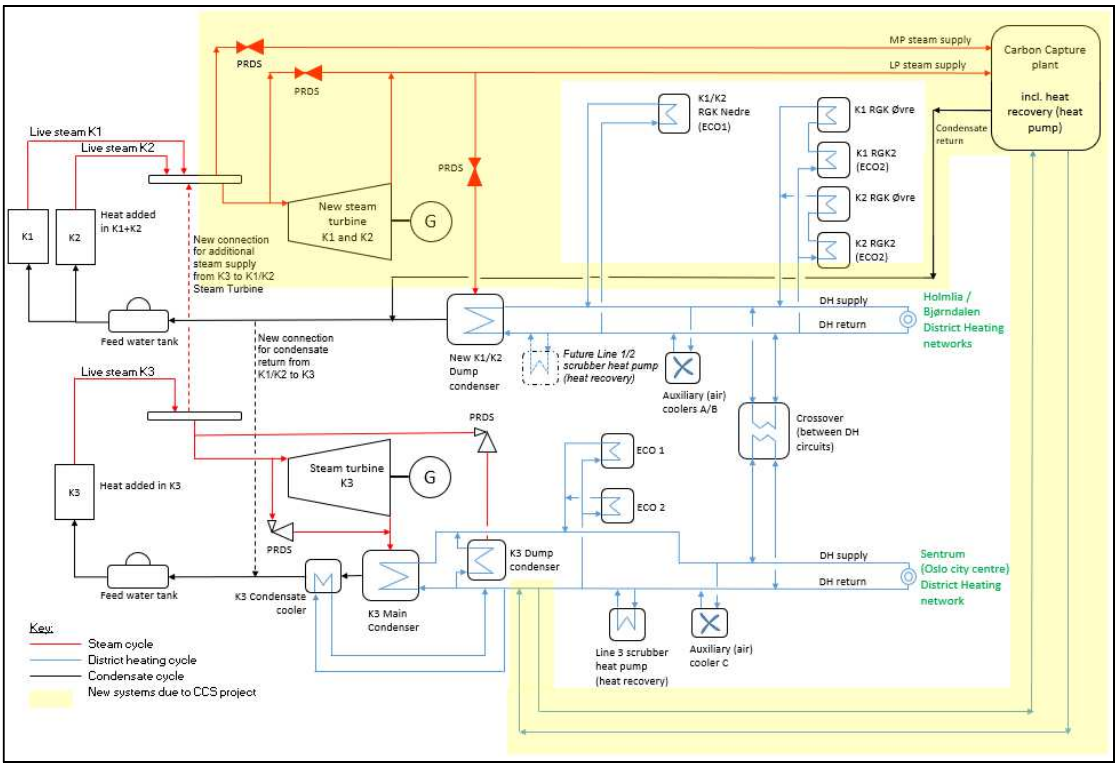

Figure 5-46: Heat integration solution 3b - Illustration of upgraded WtE plant.

The solution is can be summarised as following:

- The medium pressure (MP) steam for the CC Plant is fed directly from the HP steam header through a Pressure Reduction and Desuperheating Station (PRDS);
- The LP steam for the CC Plant is fed from a new steam turbine on lines 1 and 2 or directly from the HP header through a Pressure Reduction and Desuperheating Station (PRDS) should the turbine be bypassed (The system will also have opportunity to use steam from line 3);
- The return condensate from the carbon capture plant is consequently in turn fed back to the condensate cycle on lines 1 and 2;
- To maintain the district heating output of the WtE plant, a heat pump solution is installed to recover waste heat from the CC Plant.

The solution has been evaluated based on simulations based on the input data received from TechnipFMC. The first phase screened a subset of four cases that were taken in to the second phase of the simulations.

The project, together with FOV's heat-operations team has selected the *solution 3b* as it is considered leaner to implement and more beneficial from a commercial point of view.

The new scrubber on lines 1/2 would add some surplus heat to the Holmlia/Bjørndalen DH network, which would in the coldest ambient conditions increase the overall DH production. The new scrubber installation will be executed as a separate project. The scrubber will be installed and in operation prior to erection of CC Plant.

The steam turbine is outside the project scope and not studied as part of the FEED phase. The selection of steam turbine will not impact the current requirements of heat integration.

5.11.1.2 Overall energy balance

The overall heat, mass and energy balances associated with the integration of the CC Plant with Klemetsrud WtE plant is presented by simplified energy balance block diagrams in Figure 5-47 (winter operation) and Figure 5-48 (summer operation).

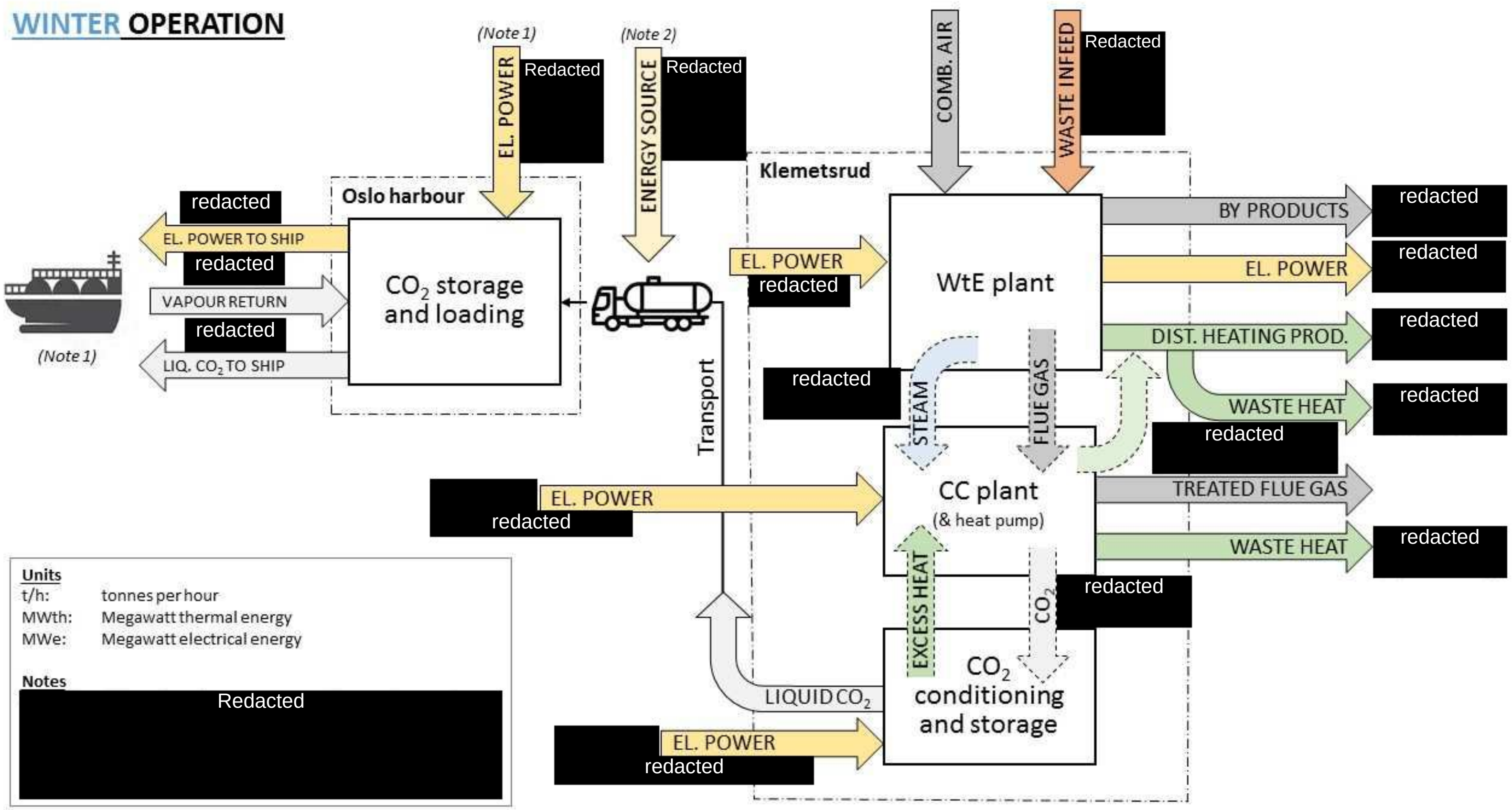

Figure 5-47: Simplified energy balance diagram, winter operation [57].

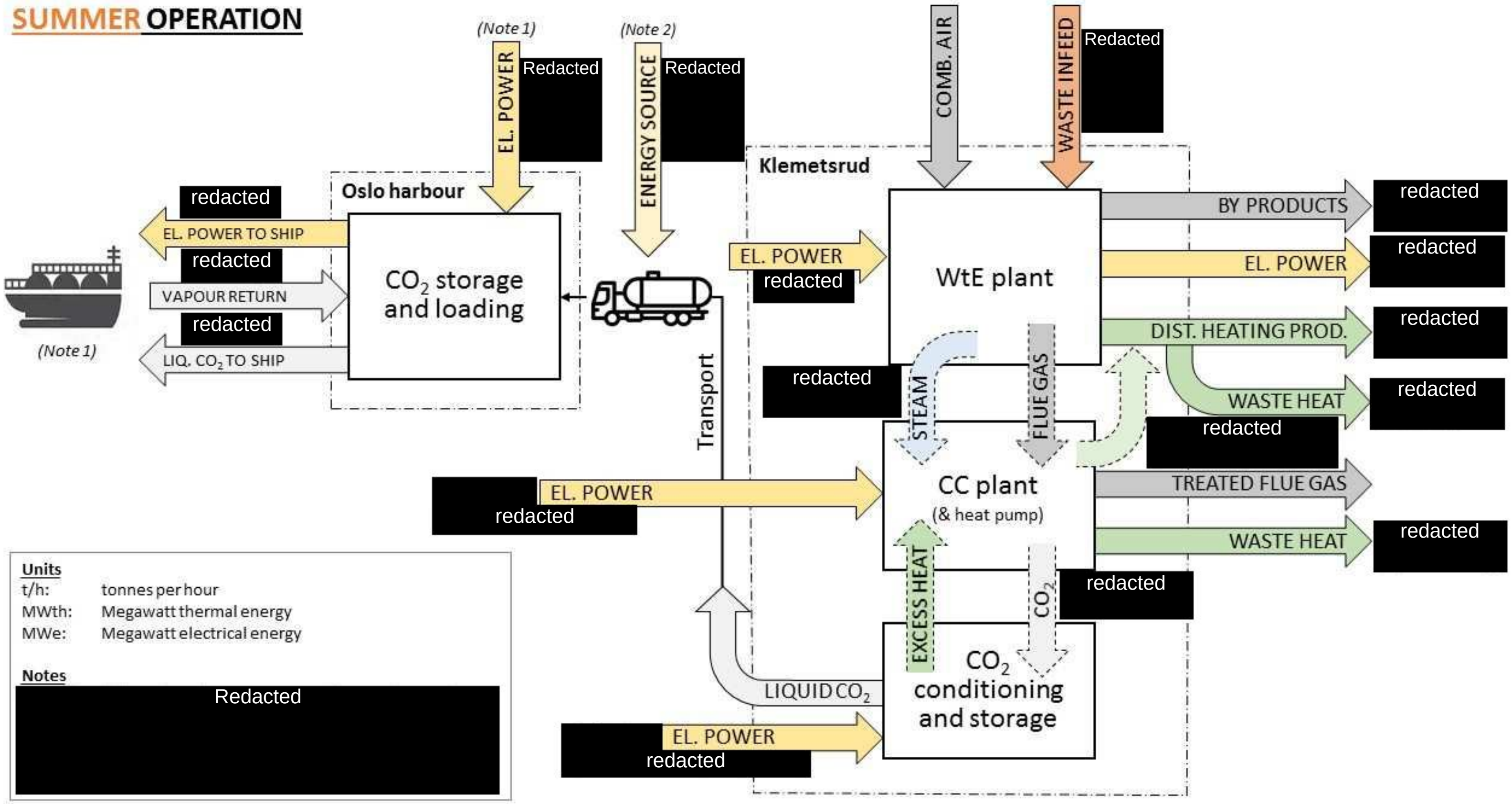

Figure 5-48: Simplified energy balance diagram, summer operation [57].

5.11.2 Selection of Contractor for FEED phase

TechnipFMC (Technip E&C Limited) is the Contractor selected for FEED phase, with Shell as Licensor.

The selection was made at end of Concept phase and is documented in the Concept phase Cost Estimate Report [17].

5.11.3 CO_2 transportation by Pipeline Option or Truck Option

The concept selected for the transportation of CO_2 from Klemetsrud to the Port of Oslo has been revised.

In the pre-FEED phase the concept defined for transportation was using a pipeline as base case with fallback to truck transport.

The concept was revised during FEED phase, and truck transport (including liquefaction) is now the selected as base concept. The use of truck transport presents a significant reduction in investment cost and schedule risk for the project.

5.11.4 Location and plot space

During pre-FEED, the Klemetsrud location has been evaluated with respect to compatibility with the plot space need of the CC Plant and the intermediate storage. In addition, sites for harbour storage at Port of Oslo have been evaluated.

With regards to CC Plant and Intermediate storage at Klemetsrud, the concept selected at pre-FEED has been updated following the update of the concept with truck transport:

- CC Plant is placed east of the current incineration area, with 11 500 m² allotted;
- Liquefaction and Intermediate storage at Klemetsrud are placed in a plot area currently occupied by a bus parking belonging to the City of Oslo. Final approval of the transaction of the area will be given in City council meeting 8th November. A written statement of availability will be issued to Fortum Oslo Varme AS the week starting 11th November 2019. The land plot is closer to the CC Plant and capture location and will lead to a more compact facility.

A visual representation is provided in section 5.8.

With regards to harbour facilities at Port of Oslo, the concept has been updated with the selection of a new location at Kneppeskjær (from Kongshavn) during FEED phase. The new location is also shown in section 5.8. Port of Oslo does not have a fixed quay in the previous selected area while the new location has one – this is more suitable for the new export terminal location.

5.12 Operations and maintenance philosophy (2n)

This section is to summarize the operations and maintenance philosophy for the new CC Plant and for the harbour facilities at Port of Oslo. More details are available in the project documentation ([58] [59] [60]).

5.12.1 Operation philosophy

Operation of the new CC Plant will be done in a way which does not disturb to the operation of the WtE plant. The main safeguarding philosophy is that the WtE plant and the CC Plant are independent and have independent safety systems.

To ensure that operability and maintainability considerations are addressed in the plant design, both FOV and TechnipFMC operation & maintenance personnel have been and will continue to be included in the project. They will review the plant layout from the maintenance perspective and provide input to engineering regarding accessibility, valving, maintainability, etc. They will also participate in design reviews (P&ID reviews, hazard reviews, 3D-model reviews, etc.).

5.12.1.1 Operation and maintenance organization

The organization for the FOV O&M team is shown in Figure 5-35. The same team will be responsible for the operation and maintenance of the new CC Plant and the new systems at the WtE plant.

5.12.1.2 Manning

All daily operations will be managed from the CCR together with dedicated field operators. Field operators will carry out inspection rounds at the WtE plant and harbour facilities sites on regular basis in accordance with guidelines.

The CC Plant is designed for low/minimum manning with a high degree of automated process control and sequences.

The truck loading and unloading at the Klemetsrud and at Port of Oslo will be operated by the specially trained truck drivers after thorough training, in accordance with similar process for truck loading of Liquefied Petroleum Gas (LPG).

The harbour facilities will be included in routine inspections and checks by the field operators. The harbour facilities will be manned by a field operator during the arrival of the ship and during loading of CO_2 to the ship. FOV will be responsible to keep the harbour facilities in the required condition and high standard required for safe loading of CO_2.

5.12.1.3 Start-up

The start-up of the CC Plant will primarily be done from the CCR when the existing boilers and all auxiliary systems have reached stable operation. Start-up procedures will be accomplished in accordance with O&M manuals. Start-up sequences will be developed to ensure a smooth re-direction of the flue gas path to the CC Plant without disturbing the WtE plant ID fans and boilers.

5.12.1.4 Normal operation

CC Plant

During normal operation, the automation system of the WtE plant will control the existing systems. New process control system will control the operation of the CC Plant. All systems will be monitored and controlled from the existing WtE plant CCR.

Harbour

The operation of the harbour storage at Port of Oslo will be fully automatic. All systems will be monitored and controlled from the CCR at Klemetsrud.

- Unloading of CO_2 from trucks will be done via mechanical hoses handled manually by specially trained truck driver. The automatic sequence selection, part of process control system, will route liquid CO_2 to the relevant storage bullet. The boil off gas from bullets will be routed back to the truck tank via a vapour return connection. Each truck unloading is foreseen to be 20 to 30 minutes in duration.
- Loading of CO_2 to the transport ship will be done via loading arms. The ship loading process involves preparatory measures including cool down of pumps, pipelines and loading systems as well as establishing communication with ship loading team and the control system at harbour. The vapour return from the ship will be routed to storage bullets via a vapour return loading arm. Each ship loading is foreseen to be 9 to 11 hours in duration.

5.12.1.5 Shutdown

Planned shutdown

Shutdown procedure will be initiated from the CCR and the automation system will include sequences to ensure safe shutdown of all the systems.

Emergency shutdown

There may be circumstances related to the plant emergency when the CC Plant or harbour facilities must be shut down immediately. This generally requires simultaneous shutdown of major equipment without any priority.

There will be different levels of emergency shutdown which will be detailed in the next project phase; If shutdown sequence is required to safely shutdown a system, then procedures in that sequence will be followed.

5.12.2 Maintenance philosophy

Yearly maintenance of the CC plant at Klemetsrud and related equipment will be coordinated with the yearly scheduled shutdown of the WtE lines.

Maintenance of the CO_2 transport trucks will be under the responsibility of Transport Contractor.

The CO_2 loading equipment for the ship will only be in intermittent operation allowing for maintenance between the loadings. Maintenance will be coordinated with Northern Lights and carried out mostly during the scheduled shut down of incineration lines, when CO_2 production is also reduced.

5.13 Technical standards (2v)

A detailed list of regulations and technical standards that should be applied in the project has been developed throughout the FEED phase.

In addition to the information presented in this chapter, requirements and standards for FOV and TechnipFMC will be included in the contract for the CC plant. FOV requirements will be formalized through separate specifications included as appendix to the contract. TechnipFMC requirements will be included through the FEED document package, which will be included in the contact.

5.13.1 Norwegian Authorities

The most relevant Norwegian authorities are shown in Table 5-26:

Table 5-26: Most relevant Norwegian authorities.

Norwegian name	Official English translation of the authority name
Direktoratet for samfunnssikkerhet og beredskap (DSB)	The Norwegian Directorate for Civil Protection
Miljødirektoratet	Norwegian Environment Agency
Plan- og bygningsetaten i Oslo Kommune	Agency for Planning and Building Services, City of Oslo.
Fylkesmannen i Oslo og Viken	County Governor of Oslo and Viken
Arbeidstilsynet	The Norwegian Labour Inspection Authority
Norges vassdrags- og energidirektorat (NVE)	The Norwegian Water resources and Energy directorate

5.13.2 Norwegian Acts and Regulations

Table 5-27 contains a list of the most relevant Norwegian regulations:

Table 5-27: Norwegian Acts and Regulations.

Norwegian name	English name	Note
Plan- og bygningsloven	Planning and Building Act	This regulation applies for area planning and construction works;
Forskrift om konsekvensutredninger	EIA regulations	Regulations for environmental impact assessment (EIA) have the main purpose to ensure that impact on environment and society is taken into consideration during area planning and project planning
Forurensningsloven	Pollution Control Act	The pollution control act is the general legislation for preventing and controlling pollution
Brann- og eksplosjonsvernloven	Fire and Explosion Prevention Act	The object of this regulation is to protect life, health, environment and material against fire and explosion. The most relevant regulations "Regulations related to handling of flammable, hazardous and pressurized materials as well as equipment and facilities used in handling of these", "Regulations related to equipment under pressure" and "Regulations for transport of dangerous goods on land".

5.13.3 EU Directives

The most relevant EU Standards to be applied are:

- EU 2006/42/EC Machinery Directive (Maskinforskriften);
- EU 2014/30EU Electromagnetic compatibility;
- EU 2014/68/EU Pressure Equipment Directive (PED);
- EU 2014/29/EU Simple pressure vessels;
- ATEX 2014/34/RU Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations;
- EU 93/68/EEC CE Marking.

It Should be noted that these EU directives are all ratified as Norwegian legislation.

5.13.4 Applicable Standardisation organisations

Table 5-28 presents an overview of Standards from different standardization bodies, including applicability

Table 5-28: Standardization bodies.

Standardization body	May applies to
British Standards Institute (BSI)	Safety of machinery and miscellaneous
Engineering Equipment and Materials Users Association (EEMUA)	Process control systems and control room
International Standards Organization (ISO)	Design of Cryogenic vessels, CO_2 storage and Quality Management.
American Society of Mechanical Engineers (ASME)	Boilers, pressure vessels, piping, valves, pumps, heat exchangers
Tubular Exchanger Manufacturers Association	Heat exchangers
American National Standards Institute (ANSI)	Piping and valves
National Association of Corrosion Engineers (NACE)	Materials and surface protection
American Standards for Testing and Materials (ASTM)	Materials and surface protection
American Petroleum Institute (API)	Tanks, pumps, compressors, heat exchangers, machinery protective, couplings, fans, amine units, installations and Inspections.
International Electrotechnical Commission (IEC)	Electrical systems, EX-classification and Safety Instrumented Functions.
National Fire Protection Association (NFPA)	Piping, ducts and fire protection systems
DNV GL	Miscellaneous Recommended Practices, Qualification process
Electrical standards from • Norsk Elektroteknisk Komite (NEK) • Direktoratet for samfunnssikkerhet og beredskap (DSB)	Although the Norwegian standards to a large extent is based on IEC, the protection installations must be according to main Norwegian standards (NEK 400 for low voltage

Standardization body	May applies to
	installations and FEF 2006 for High voltage installations)
Institute of Electrical and Electronic Engineers (IEEE)	Miscellaneous
International Society of Automation (ISA)	
Norwegian Standards (NS)	Miscellaneous
European Standards (EN)	Miscellaneous

6 HEALTH, SAFETY AND ENVIRONMENT

FOV is committed to maintain and achieve a high standard towards health, safety and environment in all phases of the FOV CO_2 Capture Project in line with Fortum corporate policies and guidelines. This includes assessing risks encountered by the project and ensuring that all risk acceptance criteria set by Norwegian Directorate for Civil Protection (DSB) and other applicable parties are met. Risk mitigation measures should be identified and implemented for all risks. To achieve this, HSE have a high priority in planning and execution of work in all phases of the FOV CO_2 Capture Project.

The project has as far as possible adopted FOV's existing work processes, systems and procedures related to HSE. FOV has a quality management system which contributes to ensure that the project is managed and controlled by defined goals, adopted values and strategies. Further, the project has implemented a risk management system where HSE risks are systematically identified, assessed, and mitigated.

During the FEED phase, the Project Manager had the overall responsibility for HSE and quality in the project. The HSEQ/Risk Manager has been responsible for identifying and managing the HSEQ risks in the project, as well as preparing related plans and mitigating measures. The HSEQ/Risk Manager also had an active role against the authorities and other parties in the project.

Roles and responsibilities for the next project phase are described in section 11.3.

Key guidelines regarding HSE in FEED phase are defined below:

- HSE shall be a criterion in choice of suppliers;
- Changes in processes, systems and organization shall be evaluated with regards to risk to personnel, health and environment;
- Focus on continuous improvement with regards to HSE aspects;
- The HSE function shall be given frames and authority to perform HSE work;
- HSE is a line responsibility and implies that all project members have individual and collective responsibility to identify risks in relation to activities. The main HSE responsibility in the project lies at the Project Manager;

These items will be followed up in the next project phase.

6.1 HSE goals, processes and results at DG3 (3a)

6.1.1 HSE goals and results in FEED phase

The HSE goals of the project follows FOV's established objectives and are as follows:

- Accidents: 0;
- Number of lost working days (>1 day): 0;
- Number of leaks: 0;
- Number of fires: 0;
- Noise levels are within limits set in the permits.

The CC Plant has been designed in FEED with a focus on the following requirements, that will be further followed up in the next project phase:

- Inherent safe solutions. This shall be the preferred safety strategy, and Safety Instrumented Functions (SIFs) shall only be used where it is required to meet acceptable risk;
- Third party personnel shall be affected as little as possible by the project. Risk contours shall be within acceptable limits, as proposed by DSB in its guidance "Sikkerheten rundt anlegg som håndterer brannfarlig reaksjonsfarlige, trykksatte og eksplosjonsfarlige stoffer, Kriterier for akseptabel risiko»;
- Work planning that minimise the need of lifting;
- All areas requiring a frequent presence of personnel shall have easy access;
- Reduce the work in height. If work in height is necessary, proper protection against falling and dropped objects shall be used;
- During detail engineering focusing on safe operation and maintenance of the plant;
- All chemicals have a safe and easy handling method and safe storage.

Through the FEED phase of the project, number of incidents, injuries, near misses and safety walks have been reported monthly for pilot plant construction and operation. Status as per end of FEED is:

- Number of accidents: 0;
- Number of lost working days: 0;
- Number of safety walks: 23;
- Number of incidents: 2;
- Number of leaks/fires: 1 (steam leak minor incident).

The two recorded minor incidents were one near miss and one steam leak (no injuries or lost manhours).

6.1.2 HSE goals and reporting for the next project phase

The project team has worked with the HSE goals of and objectives for the next phase. These are:

- Accidents: 0;
- Number of lost working days (>1 day): 0;
- Number of management safety walks (during weeks with construction work at Site): 10 per week;
- Number of reported near misses, or improvements suggestions: Minimum 300 per 1 000 000 Site man-hours;
- Number of leaks: 0;
- Number of fires: 0;
- Noise levels are within limits set in the permits.

FOV's sustainability policy [61] is to ensure that the project's activities will not lead to excess emissions and acute emissions, as well as to minimize negative environmental impact. The following environmental goals will apply in the project:

- Compliance with emission requirements to air, water and ground;

- Compliance with all standards, rules and regulations that are applicable for the project;
- Strive to reduce the negative environmental impact for the neighbouring area;
- Continuous improvement to reduce environmental impacts;
- Ensuring good communication with local interest groups.

The following will be reported monthly:

- Number of manhours;
- LWIF - Lost Workday Injury Frequency (number of injuries per one million working hours) separated by own and contractor personnel;
- MTC – Medical Treatment Cases (number of medical treatment cases for own and contractor personnel;
- TRIF – Total Recordable Incident Frequency (reflecting number of lost workday injuries and medical treatment cases)
- Number of serious accidents;
- Number of serious near misses;
- Number of employees at Site.

All serious near misses, accidents, environmental incidents and fires where external fire brigade is involved are to be reported in FRIDA – Fortum reporting system – and investigated. Improvement actions recognised in investigations are reported in FRIDA and implemented; reports are distributed to Fortum top management and will be used for knowledge sharing and learning in the rest of FOV and Fortum organization.

Further details regarding the HSE in the next project phase are described in the Project Execution Method [5] document.

6.1.2.1 Fortum HSE guidelines and manuals

Fortum HSE guidelines and manuals are to be used during execution phase:

- Fortum Sustainability Policy [62] gives a foundation on how HSE topics is to be handled in the FOV CO_2 Capture Project. Fortum wants to excel in sustainability and believes that balanced management of economic, environmental and social responsibility brings the company to a competitive advantage, is beneficial to the stakeholders and is necessary for the development of future societies;
- Fortum Safety and Security Handbook [1] will be used as basis for all the HSE work in the FOV CO_2 Capture Project and gives some overall guidance and perspective;
- The Project Safety Manual [63] will be used as basis for the more detailed safety work in the project. This document describes objectives and principles, roles and responsibilities, implementation and reporting;
- FOV's "General EHS requirements for contractors" [64] will be included as appendix to all contacts and used as basis for the development of the requirements at site. This document highlights the requirements related contractor's responsibility to subcontractors, competence and qualifications, training, safety procedures on site, tools, machinery and equipment, environmental housekeeping, reporting and incident handling. It also includes contractor's

performance, follow-up and disciplinary actions. FOV has adapted the general Fortum document, to comply with Norwegian rules and regulations.

6.2 HSE program (3b)

6.2.1 HSE program in FEED phase

An HSE Program [65] was developed and maintained throughout FEED phase. The intention of the HSE program is to ensure that risk in all phases of the FOV CO_2 Capture Project is reduced to a minimum through planning, organization, and control. The program works also as a tool for the systematic follow-up of subjects and issues that are relevant for HSE, both internally in the project, and for the contractors. The HSE program describes the Goals, Philosophy, Management, and deliverables of HSE. It also describes the Emergency Preparedness and how to handle deviations and unwanted events.

Furthermore, the Fortum Corporate Safety Manual [63] gives guidance on checklists and issues that should be followed up in different phases of the project. Figure 6-1 presents the main topics for "Project execution and take over" and "Warranty period" phases.

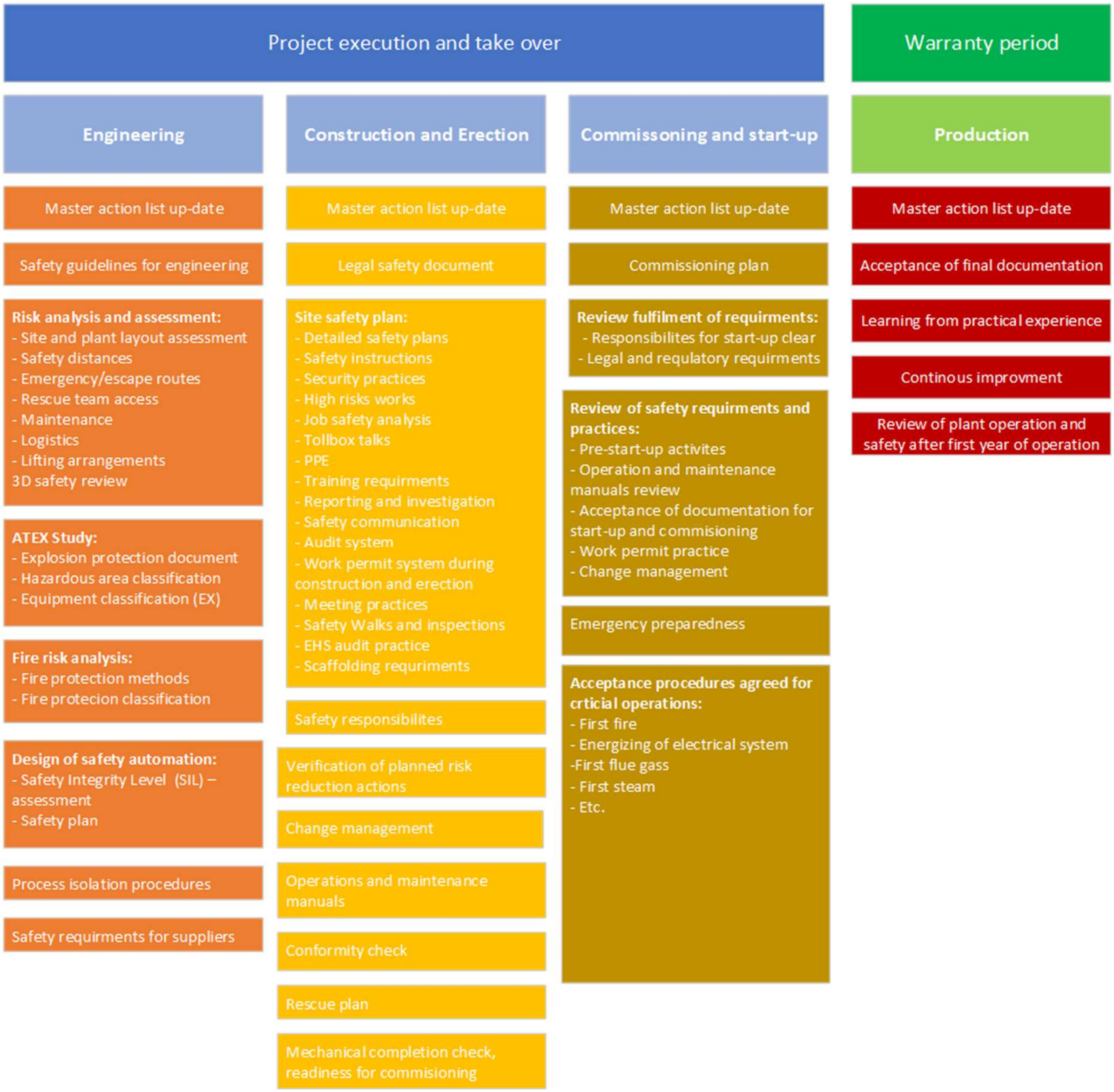

Figure 6-1: Main topics of the Safety Manual.

The topics described under the *Engineering* phase are mainly covered during FEED phase. The *Construction and Erection* topics will mainly be the responsibility of TechnipFMC, while the *Commissioning and start-up* will involve FOV more directly even though the activities will be mainly responsibility of TechnipFMC.

With regards to the model presented in the safety manual, Figure 6-1, some analysis and tasks have been performed during FEED, while other are planned to be performed in the next phase. This is described in the list below:

- The safety guidelines for engineering have been communicated to TechnipFMC, and the risk assessment has been performed by the project in cooperation with TechnipFMC. A full ATEX study has not been performed in the FEED phase, but TechnipFMC has performed Area Classification [66] and identified specific equipment. A constructability review [52] has also been performed.
- The 3D safety review was performed and documented as part of the WEHRA [67]. The fire risk analysis was covered by the Quantitative Risk Analysis [68] and the HAZAN report [69].

- The Design of the safety automation has been started in FEED and will be finalised in the next project phase. A Layer of Protection Analysis [70] has been performed to identify and classify the relevant Safety Instrumented Functions.
- FOV's "General EHS requirements for contractors" [64] will be used for all contractors.
- The Legal Safety Document will include a list of the relevant rules and regulations that apply for the project. The Site Safety Plan will be developed by TechnipFMC in cooperation Project Management Offices during start-up the next project phase.
- The change management system developed during FEED will further mature in next phase. TechnipFMC must inform FOV about major changes; changes must be checked, documented and approved.
- Operations and maintenance manuals are TechnipFMC responsibility and must be developed prior to commissioning. TechnipFMC is also responsible for Certificates etc. that will be part of the conformity check.
- A rescue/emergency response plan will be developed by TechnipFMC, as part of the Site safety plan.

6.2.2 HSE program for the next project phase

An HSE plan will be developed by TechnipFMC ("Hovedbedrift" during the whole project period), during start-up of execution phase. This will be based on the requirements from:

- The Fortum Corporate Safety Manual [63];
- Requirements included in the FOV Safety, health and working environment plan (SHA plan, as described in the Construction Client Regulation);
- Site safety Plan.

6.3 HSE study results (3c)

Several HSE studies have been performed through the FEED phase. The following section describes the studies. The main conclusions of the studies are found in section 6.3.2. The presentation of HSE studies contains reference to the observations and activities identified, as well as their status at the end of the FEED phase. Actions to be follow up in the next phase are documented in the project action follow up register [71].

6.3.1 HSE studies – description

6.3.1.1 HAZOP

A major HAZard and OPerability (HAZOP) analysis of the entire CC Plant, including storage and harbour facilities was performed by TechnipFMC in January 2019 on the TechnipFMC own scope of work. A total of 265 recommendations were identified.

- TechnipFMC has closed 161 items and transferred 84 items to the next project phase;
- 2 items were transferred to Equinor / Shell for further follow up;
- 2 items were closed during the HAZOP session, while 16 items have been followed up and closed by FOV after the HAZOP.

This is documented in a HAZOP report [72], and HAZOP Close-out report [73].

6.3.1.2 Integration HAZOP

The objective of the HAZOP was to systematically review the integration scope design for the new CC Plant at Klemetsrud. The HAZOP, facilitated by ORS Consulting AS, was managed, facilitated and recorded based on directions given by IEC 61882. The HAZOP identified a total of 25 recommendations, that has been followed up [74]. Of the 25 recommendations, 23 were assigned to FOV. 5 of them are closed during the FEED phase, 18 are transferred to the next project phase. The remaining recommendations (2) were assigned to TechnipFMC and transferred to the next project phase.

6.3.1.3 HAZAN

The scope of the HAZAN report was to analyse and report the credible major accident scenarios and their consequences for the FOV CO_2 Capture Project. The analysis was performed by TechnipFMC in March 2019, and the methodology is shown in Figure 6-2.

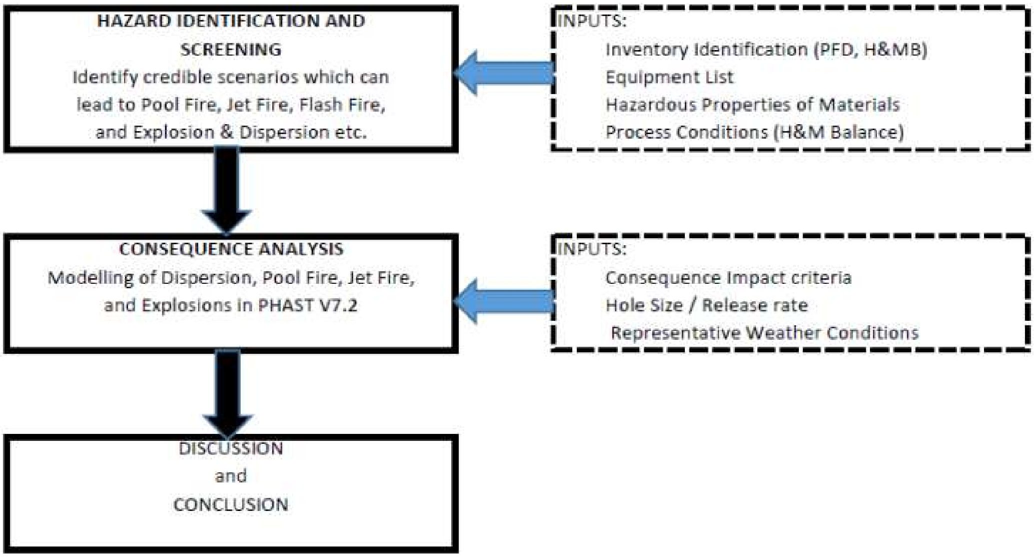

Figure 6-2: HAZAN methodology.

The report [69] is based on worst case scenarios without already implement risk reducing measures. The report is then used as input to implement adequate passive fire protection, fire and gas detectors and separation distances, to reduce the risk to an acceptable level.

6.3.1.4 HAZID

A HAZard IDentification (HAZID) analysis of the total CC Plant, including storage and harbour facilities was performed by Lilleaker Consulting AS in January 2019, and documented as a separate study [75]. The scope of the HAZID is to identify safety hazards at the plant. The main hazards that could affect third party are associated with temporary storage and truck/ship loading.

The HAZID was also the starting point for the continuous work with the Quantitative Risk Analysis (QRA) [68].

A total of 42 HAZIDs where identified, resulting in 15 recommendations. Ten of these are transferred to the EPC phase, while 5 were closed during FEED [71].

6.3.1.5 Environmental Issues and ENVID

During concept phase, several environmental issues where identified. The major findings and how they are followed-up is described below:

- Flue gas containing amines, degraded amines and nitrosamines: this topic is addressed in several sections of this report;
- Solvents (amines dissolved in water) and hazardous substance: the release to sewage is possible, following the requirements of the existing WtE plant [76];
- Incineration of Hazardous waste / reclaimer waste: the current solution handling outside the WtE plant. Other solutions may be selected in the next project phase.
- Previous discussions regarding use of a Variable Speed Drive (VSD) for a common fan for the WtE and the CC Plant are not yet concluded; this item is not directly linked to environmental issues.

As part of the FEED study, an ENVironmental IDentification (ENVID) analysis of the total CC Plant, including storage and harbour facilities was performed, facilitated by Lilleaker Consulting AS in January 2019, and documented as a separate study [77]. No actions were identified, the six comments given are followed up in the ENVID report.

Scenarios with potential impact to environment were identified and described. Released chemicals is the main concern, including the following scenarios:

- Flue gas containing amines, degraded amines and nitrosamines;
- Solvents (amines dissolved in water);
- Degraded solvent (sludge from TRU).

6.3.1.6 LOPA

A Layer Of Protection Analysis (LOPA) was performed by ORS Consulting AS in February 2019 and documented as a separate study [70]. The LOPA was conducted in accordance with IEC 61511. The hazard scenarios, relevant for the LOPA were identified based on the HAZOP. The total number of hazardous scenarios generated during this screening were 62. During the LOPA workshop, some of the scenarios were excluded from LOPA assessment due to low severity, others were merged, and some new scenarios were generated. This yielded in 38 LOPA scenarios. 23 of the 38 scenarios include Safety Instrumented Functions (SIFs). Most of the actions were incorporated into design during the FEED, while 10 actions are transferred to the next project phase for further follow up [71].

6.3.1.7 3D Review and WEHRA

A 3D Review and a Working Environment Health Risk Assessment (WEHRA) was performed by ORS Consulting AS in February 2019 and documented as a separate study [67]. This review and risk assessment took the form of a multidiscipline workshop and was completed at Klemetsrud.

The planned CC Plant including intermediate storage and harbour facilities were evaluated in five sections:

- Capturing plant and liquefaction;
- Intermediate storage at Klemetsrud;
- Transportation;

- Harbour storage at Port of Oslo;
- Transfer-to-Ship.

The workshop was structured using a guided view of the latest 3D model. The model elements and scope of planned engineering activities was explained. Participants were asked to systematically consider the operations and maintenance tasks associated with each node. Hazard categories and guidewords were applied to ensure a thorough analysis, and on this basis, exposures to health hazards for Site personnel were identified. Credible risks were then assessed using an assessment matrix, and mitigations proposed where the risk did not meet As Low As Reasonably Practicable criteria. 35 recommendations were identified. Two were closed during the FEED phase and 33 are transferred to the next project phase [71].

6.3.1.8 Quantitative risk assessment (QRA) and consequence simulations

Based on the HAZID, a full QRA and consequence simulations using Computational Fluid Dynamics (CFD) of the CC Plant has been carried out [68]. The QRA identified several potential scenarios that could affect the surroundings of the plant, with accidental release of large quantities of CO_2 being the main driver.

The overall risk was found acceptable, with respect to the general acceptance criteria from Norwegian Directorate for Civil Protection (DSB):

- Individual risk shall be less than 10^{-5} per year for personnel outside the facility;
- For third party persons in residential areas, individual risk shall be less than 10^{-6} per year;
- For particularly vulnerable persons in the residential areas, individual risk shall be less than 10^{-7} per year;
- Identified accident scenarios with a frequency of 10^{-8} per year or less are considered broadly acceptable.

Figure 6-3 and Figure 6-4 show the ISO-risk curves for Klemetsrud and Port of Oslo. These describes the hazard distances with a given frequency and are measurable against the risk acceptance criteria for individual risk.

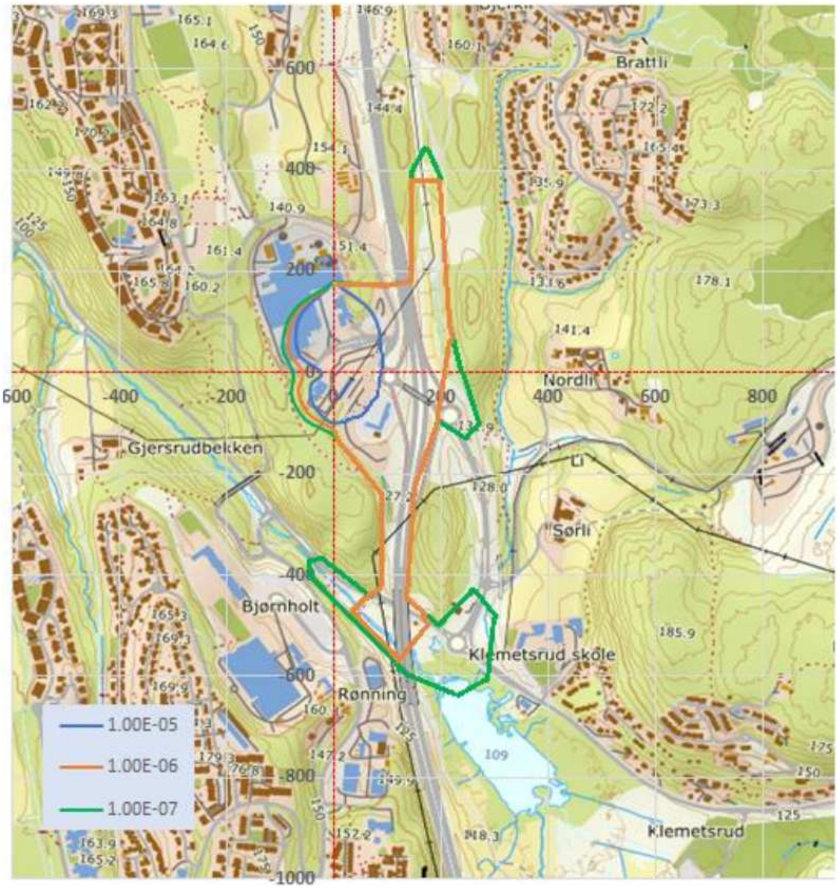

Figure 6-3: Risk contour at Klemetsrud [68].

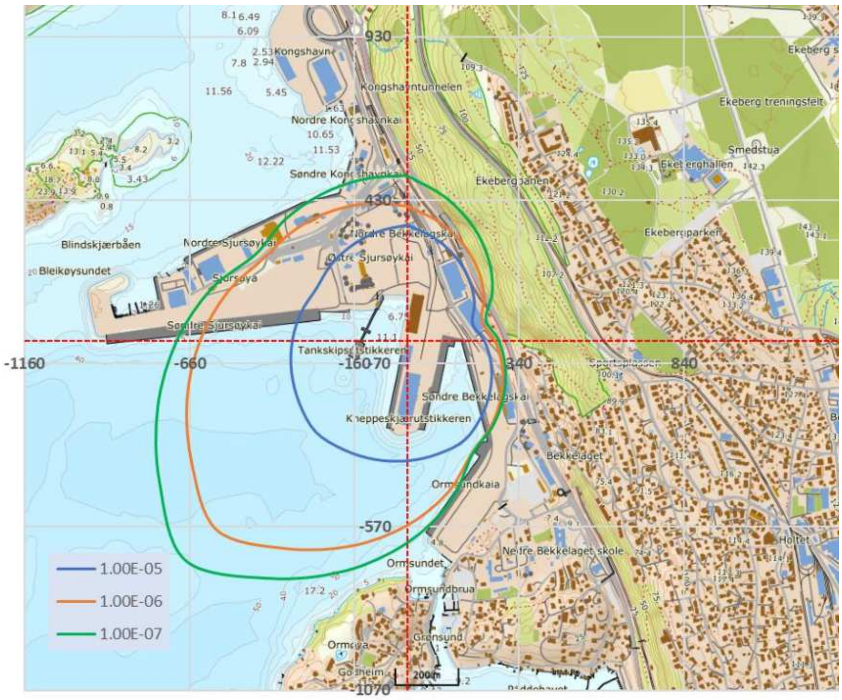

Figure 6-4: Risk contours for Port of Oslo/Sjursøya including existing risk picture and harbour facilities [68].

6.3.1.9 Flue Gas Dispersion analysis

During the concept phase, the Norwegian Institute for Air Research (NILU) performed calculations of flue gas dispersion in the atmosphere and transformation of amine emissions from the planned CC. These concluded with an amine emission limit value of 0.4 ppmv out of the stack. The stated uncertainty in the calculations have been taken into account in the emission limit conclusion.

During the FEED, new atmospheric flue gas dispersion calculations have been carried out by Norsk Energi to investigate the amine dispersion differences for "cold" and "hot" flue gas [78]. However, it was decided to run a similar case as for NILU and compare the results to validate the consistency of the calculations.

Comparison of the NILU model and Norsk Energi calculations:

Norsk Energi has used a different model than the one used by NILU. In order to validate the consistency of the results, a set of calculations have been performed by setting the amine concentration at the emission point to 0.4 ppmv. All other relevant parameters have been the same as for the NILU calculations.

The Norsk Energi calculations [47] show another topological emission picture, with a maximum amine concentration level occurring substantially closer to the CC Plant.

The reasons behind these differences have not yet been concluded but will be investigated in the next phase. The differences between the calculations need to be better understood to ensure the required results quality.

Norsk Energi calculation results:

The new amine dispersion calculations have been done for a case with and without reheat of the flue gas. The amine concentration in the emission point is set to 0.2 ppmv, based on results from the pilot plant. The flue gas outlet temperature is set to 65 ºC and 44 ºC for the cases with and without reheat. The calculations show minor differences in atmospheric amine dispersion for these two cases. In neither of the cases the NO_x air quality criteria are exceeded

6.3.1.10 External noise study

Noise studies have been performed during the FEED phase of the project. This work allows for a good understanding of the actual noise situation and for the requirements that are to be in place during and after the construction of the CC Plant. An overview of the mitigation activities that will need to be performed has also been prepared, with noise reduction installation choice to be finalised in the next project phase based on the requirements to be met and the overall cost-benefit.

The work performed by the project team has been focused on the Environmental Impact Assessment connected to the new zoning plan [79]. In this respect, a study of the level of noise in residential and recreational area surrounding the Klemetsrud WtE plant has been performed. Figure 6-5 shows calculated Day Evening Night Sound Level (L_{den}) from the existing WtE plant calculated at 4m height. The discharge permit limits are met at all points in the surrounding areas, with the noise limit for Sundays/holidays as the most critical. Dwellings west of the WtE plant (Blakkens vei), almost reach the limit value, corresponding to light yellow coloured contoured area in the noise contour shown in Figure 6-5. Dwellings situated east and northeast of the WtE plant have noise levels well beneath the limits.

Further action during the construction of the CC Plant must be taken to ensure that the noise requirements are met. Noise sources at the existing WtE plant are mapped, with air coolers connected to the landfill gas motors as largest noise contributor. These motors and the coolers are planned to be phased out in the near future.

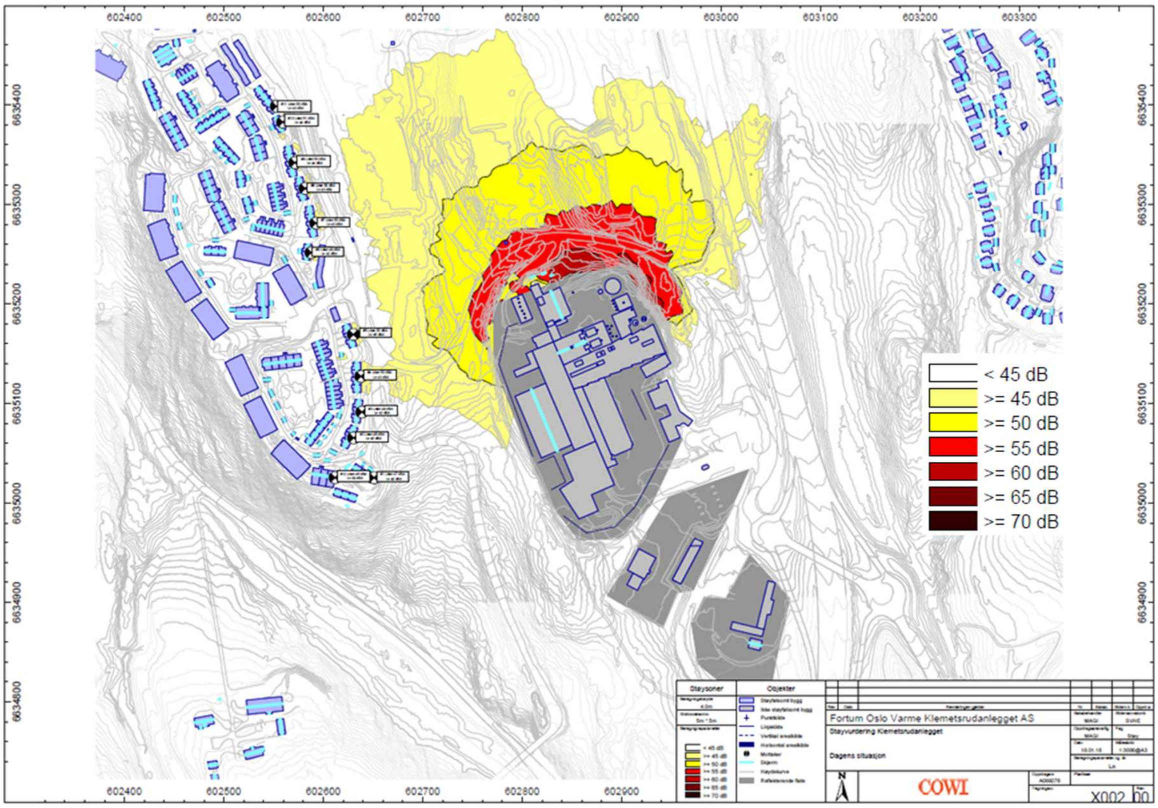

Figure 6-5: Existing situation (noise zone map) at night [79].

The study from TechnipFMC [80] covers noise evaluation from mechanical equipment of the CC Plant with focus on the environment noise. The mechanical equipment is included in a noise prediction model that computes propagation.

The study report contains a situation map with simulated noise level and a list of recommendation with follow up activities including noise reduction installations for both sites (CC Plant at Klemetsrud and harbour facilities).

Table 6-1 contains a list of recommendations for noise sources in the CC Plant. High focus on low-noise design is necessary to achieve the recommended sound power levels, with relevant actions include one or several of the following:

- Low-noise equipment;
- Enclosures/buildings;
- Silencers;
- Variable frequency drives (low rpm);
- Pipe insulation/cladding.

Table 6-1: Recommendations for the noise sources for the CC Plant [80].

Description	Estimated sound power - L_{WA} (dB)	Recommended sound power - L_{WA} (dB)
Small pumps	[redacted]	82
Large pumps	[redacted]	87
Instrument air compressor package	[redacted]	82
Booster fan	[redacted]	95
CO_2 compressor package	[redacted]	92
Regeneration gas compressor	[redacted]	92
Heat pump package	[redacted]	89
Cooling system air cooler package	[redacted]	89

Furthermore, an overall reduction of 2 dBs from the existing WtE plant has been recommended. Phasing out gas engines and their coolers might have a large contribution to the overall noise reduction.

Figure 6-6 presents calculated Evening Night Sound Level (L_{den}) for the combined WtE plant and CC Plant, with the recommendations described above implemented. Calculation height 4 m.

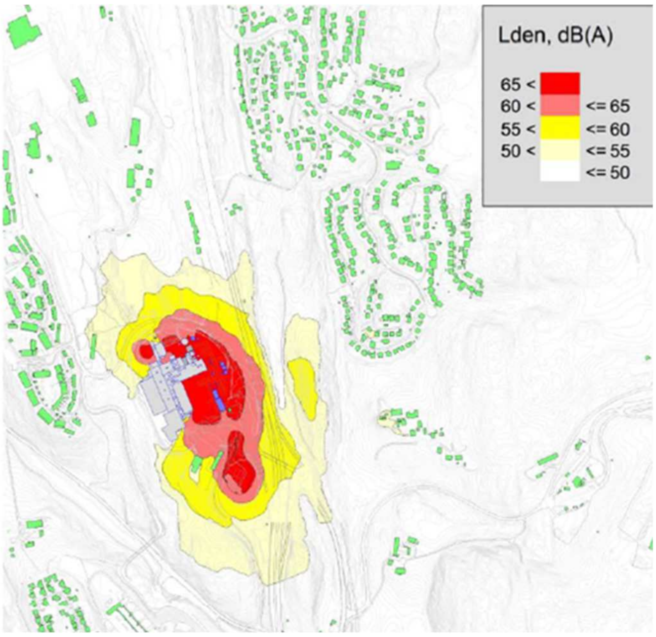

Figure 6-6: Calculated Day Evening Night Sound Level (L_{den}) for the combined WtE plant at Klemetsrud and CC Plant with the recommended set of actions implemented [80].

With regards to noise connected to the cooling facilities explored during the concept phase, the possibility for water cooling to replace air cooling has not been further developed due to other technical challenges.

6.3.2 HSE studies – main conclusions

Table 6-2 presents the main findings from the HSE studies performed in the FEED phase.

Table 6-2: Main findings from the HSE studies.

Study	Facilitator / Performed by	Document number	Main findings
FEED HAZOP CC Plant	TechnipFMC	NC03-TEC-S-RA-0008	No deviations that could threaten the progress of the project were identified.
HAZAN Report	TechnipFMC	NC03-TEC-S-RA-0009	There are several possible scenarios that could occur at the CC Plant that should be handled with technical barriers and other risk reducing measures. These include release of flue gas, handling of amine, low- and high-pressure CO_2, liquid CO_2 and H_2.
Integration HAZOP	ORS Consulting	NC03-KEA-S-RA-0005	No deviations that could threaten the progress of the project were identified.
HAZID	Lilleaker Consulting	NC03-KEA-S-RA-0003	Potential accidental releases of solids, liquids and gases, fire, explosion and vehicle impact risks were identified. With respect to third party risk exposure, release of CO_2 from intermediate storage facilities is the main concern. The risk is found acceptable.
ENVID	Lilleaker Consulting	NC03-KEA-S-RA-0006	The environment studies have not identified any critical environmental risk not possible to be controlled.
LOPA	ORS Consulting	NC03-KEA-S-RA-0004	A SIL identification process using the LOPA methodology was performed. This resulted in a total of 23 Safety Instrumented Functions (SIFs), that should be followed up further.
3D Review and WEHRA	ORS Consulting	NC03-KEA-S-RA-0007	A 3D review and WEHRA was performed. The main recommendations where linked to: • New perimeter road on the CC Plant – dimensions, signage and barriers; • Access routes; • Outdoor tasks and exposure to cold weather conditions, including falling ice hazards.
Quantitative risk assessment (QRA)	Lilleaker Consulting	NC03-KEA-S-RA-0001	The overall risk is found acceptable, with respect to the general acceptance criteria from Norwegian Directorate for Civil Protection (DSB).
Flue Gas Dispersion analysis	Norsk Energi	NC03-KEA-S-RA-0008 (HOLD)	New analyses have been carried out and the new model gives deviant results compared to the NILU model. The reasons for this must be followed up in the next phase.
External noise study	Project TechnipFMC	NC03-KEA-K-RA-0001 NC03-TEC-Z-RA-0004	Actual noise situation is evaluated, noise requirements are analysed. An overview of the mitigation activities that will need to be performed has been prepared.

6.4 HSE regulations overview (3d)

The HSEQ/Risk Manager has been responsible for the implementation of applicable HSE regulations during the FEED study phase. Furthermore, it has been a focus in the project, that participants from FOV involved with HSE at different operational levels were present in relevant meetings and workshops.

The HSE requirements are fulfilled throughout several HSE studies, as describe in section 6.3. The minimum requirement is that the work is to be executed according to the applicable Norwegian laws and regulations.

FOV has established, as part of its governing system, an overview of regulations and legal requirements that are applicable for HSE. These are summarized in the table below.

Requirement Group	Requirement Document	Relevant paragraph / chapter
Work Environment	Arbeidsmiljøloven	§2-1, 2-3 3-2, 3-3, 4-1, 4-4, 4-5, 4-6
Work Environment	Arbeidsplassforskriften	§5-19, 2-1, 2-14, 7-1, 7-2, 7-3, 7-4, 8-1, 8-2, Chapter. 2
Work Environment	Forskrift om administrative ordninger	§8-7, 11-1
Work Environment	Forskrift om maskiner	§11, Appendix 1, point 1.2.4.3, Appendix 1, point 1.7.3, Appendix 1, point 1.7.4
Work Environment	Forskrift om organisering, ledelse og medvirkning	§ 10-1, 10-2, 10-3, 11-1, 14-4, 14-6, 15-1, 15-3, 2-1, 7-1, 7-2, 8-1, 9-1 Chapter 15, Chapter 8
Work Environment	Forskrift om systematisk helse-, miljø- og sikkerhetsarbeid i virksomheter	All
Work Environment	Forskrift om tiltak- og grenseverdier	Chapter 1 to 7
Work Environment	Forskrift om utførelse av arbeid	§ 3-1, 3-11, 31-1, 3-13, 3-16, 3-17, 3-2, 3-20, 3-25, 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 5-1, 5-2, 5-5, 5-6, 5-7, 5-8, 6-1, 6-12, 6-2, 6-4, 6-5, 6-7, 6-9, 10-1, 10-13, 10-2, 10-20, 10-22, 10-9, 11-1, 12-2, 12-3, 12-4, 12-8, 13-1, 13-2, 13-3,14-2, 14-5, 17-21, 17-22, 17-21, 18-4, 18-5, 18-6, 18-7, 18-8, 23-1, 23-2, 23-3, 29-1 Chapter 2,4, 5, 7, 17 and 19
Fire and Explosion	Brann- og eksplosjonsvernloven	§ 5, 6, 8
Fire and Explosion	Forskrift om brannforebygging	Chapter 1 to 6
Fire and Explosion	Forskrift om enkle trykkbeholdere	Chapter 1 to 6

Requirement Group	Requirement Document	Relevant paragraph / chapter
Fire and Explosion	Forskrift om landtransport av farlig gods	Chapter 1 to 7
Fire and Explosion	Forskrift om sivil håndtering av eksplosjonsfarlige stoffer	All
Fire and Explosion	Forskrift om trykkpåkjent utstyr	Chapter 1 to 6
Fire and Explosion	Internkontrollforskriften	§ 5
El-safety	Forskrift om utstyr og sikkerhetssystem til bruk i eksplosjonsfarlig område	All
El-safety	Forskrift om elektrisk utstyr	All
El-safety	Forskrift om elektriske forsyningsanlegg	Chapter 2
El-safety	Forskrift om elektriske lavspenningsanlegg	§ 12, 16, 20, 33, Chapter V
El-safety	Forskrift om elektroforetak og kvalifikasjonskrav for arbeid knyttet til elektriske anlegg og elektrisk utstyr	All
El-safety	Forskrift om helse og sikkerhet i eksplosjonsfarlige atmosfærer	§ 9, 15, 16
El-safety	Lov om tilsyn med elektriske anlegg og elektrisk utstyr	All
Pollution	Avfallsforskriften	Chapter 10, 11 and 13
Pollution	Forskrift om farlig gods	
Pollution	Forskrift om smittefarlig avfall fra helsetjeneste og dyrehelsetjeneste mv.	
Pollution	Forskrift om varsling av akutt forurensning eller fare for akutt forurensning	
Pollution	Forurensningsforskriften	§ 15 A-4 Chapter 1, 2, 5, 8, 27 and 36
Pollution	Forurensningsloven	§ 7, 8, 11, 28, 32, 39
Pollution	Klimakvoteforskriften	Chapter 1
Pollution	Klimakvoteloven	Chapter 1-6
Pollution	Miljøinformasjonsloven	§ 9, 16
Pollution	Produktforskriften	§ 2-1, 3, 3a, 10
Pollution	Forskrift om registrering, vurdering, godkjenning og	All

Requirement Group	Requirement Document	Relevant paragraph / chapter
	begrensning av kjemikalier (REACH)	
Pollution	Forskrift om innkjøpsregler i forsyningssektorene (forsyningsforskriften)	All
Environment and Health	Forskrift om miljørettet helsevern	All
Project	Forskrift om sikkerhet, helse og arbeidsmiljø på bygge- eller anleggsplasser	§ 3-17, 19
Project	Plan- og bygningsloven	All
Safety and Emergency Preparedness	Beredskapsforskriften	Chapter 1 to 8
Safety and Emergency Preparedness	Forskrift om industrivern	§ 5, 6, 7, 8, 9, 10, 12, 14, 15, 16, 17, 18
Safety and Emergency Preparedness	Sivilbeskyttelsesloven	§ 21
Safety and Emergency Preparedness	Storulykkeforskriften	§ 1 to 13

The main HSE regulations that are applied in the project are the Norwegian Working Environment Act (Arbeidsmiljøloven) and the Construction Client Regulations (Byggherreforskriften).

The purpose of the Norwegian Working Environment Act is to secure a working environment that provides a basis for a healthy and meaningful working situation, that affords full safety from harmful physical and mental influences and that always has a standard of welfare consistent with the level of technological and social development of society. The employer shall ensure that the provisions laid down in and according to the Working Environment Act are complied with. This shall be done in close cooperation with the employees and other stakeholders.

The Construction Client Regulations (Byggherreforskriften) purpose is to ensure that all workers are protected against hazards, and that the HSE and work environment is considered during planning, engineering and construction of all construction work. The regulation is valid for all construction sites in Norway. The Construction Client is responsible for complying with the regulation, no matter which type of contract that is used. Prior to start-up, the Construction Client must ensure that a Safety, Health and Working Environment plan is developed.

In general, the project will follow the Fortum safety manual [63]. The safety manual is based on the applicable European legislation and refers further to European directives and other standards.

6.5 Climate Footprint

With regards to calculations regarding the project's carbon footprint, FOV scope of work has been limited to data collection [81], while the actual calculations are part of Gassnova scope. DNVGL has, on behalf of Gassnova, developed a model for collecting data in a uniform manner to calculate what greenhouse gas emissions will entail from the establishment, operation and decommissioning of a carbon capture plant. The model includes also CO_2 factors.

In the spreadsheet [81] data is collected regarding emission connected to consumption of materials, required energy and chemicals, preparation of the Site, establishment, operation and the decommissioning of the CC Plant. The spreadsheet has been used for collecting data for carbon footprint over the entire life cycle of the CC Plant.

With the current information available, Gassnova will have a basis for calculating the total greenhouse gas emissions that the plant will generate and will be able to understand which phase of the life cycle of the CC Plant contributes most to the carbon footprint.

The following sections present some information regarding the origin of the data capture.

6.5.1 Construction phase – Site clearing

Information regarding the amounts of rock and soil to be excavated are from the projects reports on traffic [79] and foundation [82] [83] [84].

6.5.2 Construction phase - Building materials

Information on amounts of concrete for the foundations are from the concrete foundation drawing [82] [83] [84].

TechnipFMC has provided information on types and quantities for all types of steel structures, piping, steel components, etc. Smaller steel components and structures are calculated as a percentage in addition to the larger individual components.

6.5.3 Operational phase – Energy requirement and Chemicals

The amounts of chemicals and energy required in the operational phase are provided by TechnipFMC. The figures are based on the yearly consumption and gives Gassnova a baseline to calculate the total CO_2 emissions related to the energy and chemical requirements.

6.5.4 Operational phase – Transport to docks

The report on Transport logistics [85] is based on used of fossil fuel as a basis to be able to collect and compare prices in today's market (the alternative technology is currently immature). However, it is assumed that electric lorries will be used for transporting of CO_2 to the Port of Oslo.

Electric vehicles are therefore used as basis for calculating CO_2 emissions from transport. The software TEMA 2015 is used for calculating energy required for transportation. This software can only make the calculation for diesel lorries, so it is further assumed, based on approximate tank to wheel efficiency, that an electric vehicle requires half the energy of its diesel counterpart.

6.5.5 Decommissioning phase – Waste disposal

The amounts of building materials to waste disposal is based on material input in the construction phase. Treatment and waste transport are based on assumptions (such as distance to plant and size of trucks).

7 QUALITY ASSURANCE

The FOV CO_2 Capture Project has developed and followed a quality system that is based on FOV procedures, methods and the principles of ISO 9001. This is further described in the sections below.

7.1 Accreditation and Quality Plan (4a, 4b)

FOV is certified according to ISO 9001:2015 and ISO 14001:2015 (the certificates included as an Attachment to the report, section 14), and the quality management in the project has been founded on the principles of these standards. The quality objectives and goals are designed to ensure that the FOV CO_2 Capture Project activities comply with applicable regulations, codes, standards and specifications in accordance with good industry practice.

7.1.1 Quality objectives and goals during FEED phase

The following quality objectives are applicable for the FEED phase:

- Ensure that the risk register is updated, and a major review is performed monthly;
- Ensure that two quality management audits are performed on main contractors yearly;
- Ensure that the project progress is following the planned schedule;
- Ensure that the CC Plant will be constructed and operated without any quality deficiencies.

The following quality goals applies for the FOV CO_2 Capture Project:

- Ensure that in the project is in accordance with the Fortum code of conduct;
- Ensure that individuals have the necessary qualifications, experience, and training to perform their duties in a systematic manner, to minimize errors and deficiencies;
- Ensure early identification of issues and concerns relating to the quality of work or performance and to bring these to the attention of Project Management Office;
- Ensure feedback of project experiences, continuous improvement and incorporation of lessons learned;
- Ensure communication and alignment with requirements between the FOV CO_2 Capture Project and other partners in the Norwegian full-scale CCS Project;
- Provide good communication and ensure that Gassnova requirements and needs are meet, also beyond the Study Agreement;
- Prevention of quality issues through risk management and auditing. Ensure that the planned audits and examinations are performed, and that identified actions are followed-up and closed;
- Ensure that project documentation, including supplier documentation, have the required quality, and that it is developed according to the relevant procedures;
- Ensure that the correct version of documents is always available for, and used by contractors;
- Develop relevant and measurable quality goals for next phase of project (i.e. target number for inspections, risk assessments and review sessions);

7.1.2 Quality Plan

This project activities have been executed during the FEED phase according to the Quality Plan [86].

A detailed Quality Plan will be developed for the next project phase based the principles presented in the following sections and in the Project Execution Method [5] document.

7.1.2.1 Organization

All project personnel is to be qualified, and adequately trained to ensure that the project can be performed in accordance with the requirements. The project organization is further described in section 11.3.

7.1.2.2 Resources and competence

Competences will be evaluated during personnel recruitment. For the Owner's Engineer, and contractors the evaluation will be carried out during negotiation. The contracts will also include clause regarding personnel change and approval of new personnel.

A process for onboarding project personnel will be developed during project start-up.

7.1.2.3 Contractors' responsibilities

All contractors will be responsible to develop their own quality plan dedicated to their scope of work. The plan should in principle covers the following items:

- Identify the responsible persons for quality, and other key personnel in their organization, including their responsibilities and areas of responsibility;
- Procedures for manning of the project, how they are hiring subcontractors, and the applicable routines for changes of key personnel;
- Description of the Non-Conformance Request (NCR) system;
- Description of the document control system, including checklists and internal discipline checks;
- Other quality management systems in the project should be described, like the plan for internal audits and reviews;
- An overview of the system that handles risk and opportunities that affect quality;
- A reference to the progress plans, and description on how they are developed should also be included.

7.1.2.4 Change management

A Management of Change (MoC) procedure [87] has been developed and used in the FEED phase of the project. The procedure will be further developed by the project team in the next project phase.

The change management process ensures that changes to the project (e.g. scope, cost, schedule, resources etc.) are formally defined, evaluated and approved prior to implementation in the project. The procedure describes a process where several steps are completed to ensure that, if implemented, the change will cause minimal impact to the project.

7.1.2.5 Interface management

The project has developed an Interface Management Procedure [88], which was used in the FEED phase. Interface management is further described in section 11.6.

7.1.2.6 Non-conformance control

The project will continue to use FOV's system "Simpli Better" for reporting incidents and for improvement proposals. All non-conformities that are identified are reported into the system.

Major safety incidents are, in addition, reported in Fortum's system "FRIDA".

7.1.2.7 Information management – information review and analysis

The Project Manager is responsible for ensuring that the contract is reviewed by the project team and the requirements are understood.

The purpose of the review is to:

- Identify and become familiar with project requirements;
- Identify statutory and regulatory requirements;
- Identify, address, and resolve any omissions, contradictions, or lack of clarity;
- Check if the identified project requirements can be fulfilled. If not, then this is to be addressed and/or these requirements are to be qualified.

7.1.2.8 Document control and Technical Queries

The project document controller maintains the project document control files and operates the document control system for all documentation in the project.

During FEED phase, the project has used guidelines for management of FOV's documentation [89] and the review procedure for TechnipFMC documentation [90]. The procedure will be further developed by the project team in the next project phase.

7.1.2.9 Training of project personnel

The project Manager Office will have responsibility to train all the project personnel on procedures, methods and tools available to prepare project deliverables according to project requirements.

7.1.2.10 Audits and Examinations

The project will conduct audits and examinations to verify that the projects quality and HSE goals are met and as a risk reduction tool. Contractors and subcontractor's participation in project audit are required in all contracts.

The Quality Manager in the Owner's Engineering prepares the audit program for internal and external audit. Additional audit might be triggered based on performance.

7.2 Performed quality control and assurance (4c, 4d)

Several quality control and assurance activities has been performed during FEED phase.

7.2.1 Internal Audit in project

The objective of internal audits was to assure quality and delivery capability of the project during the FEED phase.

7.2.1.1 Internal project audit

The HSEQ/Risk Manager led a project audit. The scope was limited to the parts of the management system of the project that affects the cost estimation, planning and progress monitoring, cost control, cost coding, Interface Management and Document Control. The audit was focused to the management system and provision of the project scope of works.

A total of 18 findings was identified in the internal audit; the findings and their proposed follow up is documented in the Internal Audit Report (ref. KEA-Q-0007 - Internal Audit Report). All actions are followed up.

7.2.1.2 Internal audit by FOV

FOV performed an audit on the project, to ensure that project has sufficient maturity, relevance and quality of the documentation to pass the Fortum's investment process TG2/G2 decision gate (implement investment and start the project) in the Fortum Board. No deviations to the TG2/G2 requirements where identified in this review, 3 observations were given and are followed up. The report is documented as internal audit 7/19 in the FOV system.

7.2.2 Subcontractor audit

Two subcontractor audits have been performed during the FEED phase.

7.2.2.1 Kanfa Ingenium Process AS Audit

The objective of the audit of Kanfa Ingenium AS was to assure quality and delivery capability of Kanfa concerning the project's Pilot Plant and to enable Kanfa's status as a qualified supplier for FOV. The scope of the audit was limited to management system of Kanfa that affects the Pilot's scope of work, and the audit focused to the management system and provision of the Pilot.

Kanfa's management system affecting Pilot scope was found to be well established, documented, implemented and maintained. [redacted]

The audit report [91] contains findings of the audit.

7.2.2.2 TechnipFMC (Technip E&C Limited) Audit

The objective of the audit was to assure quality and delivery capability of TechnipFMC during the FEED project phase. The scope of the audit was limited to management system that affected the project's scope of work.

The findings of the audit were that the management system affecting the project was found to be well stablished and effectively organized. No nonconformities were found. There were found five improvement proposals. The conclusion is that the management system facilitating the project portfolio of TechnipFMC as well as the Carbon Capture project specific management system was well documented, and the personnel were familiar with the related processes, procedures and requirements.

The audit report [92] documents the audit findings.

7.2.3 Client audit

7.2.3.1 Gassnova audit

Gassnova carried out an audit of the project to examine and review the project's capability and conformance to the requirement of ISO 9001:2015.

Another objective was to provide reasonable assurance that FOV had effective controls to ensure a successful completion of the FEED phase in the project. The audit scope was FOV's quality management system in the project FEED phase.

A total of 11 audit findings were reviewed and discussed in the closing meeting. [redacted] 3 examples of good practice are described. The audit results provide the assurance that FOV top management is fully committed to carry out the FEED project in accordance with the Study Agreement.

The findings are documented in audit report from Gassnova (Audit no. 18/205 – Audit Report – Fortum Oslo Varme AS, closed out in a letter from Gassnova in February 2019).

7.2.3.2 Metier OEC audit

Metier OEC performed a Project Control Function Audit of the project on behalf of Gassnova. The main objective of the audit was to:

- Examine and review FOV's project control functions and routines, with special focus on project schedule, progress reporting and cost control.
- Provide Gassnova with insight that will help run the project up to DG3 more efficiently, as well as advise and / or assist FOV if and where it may benefit FOV and the project.

The audit did not base its findings/observations on deviations from the Study Agreement but rather provide observations on what Metier OEC regards as "Good Practice".

A summary of the findings can be found in the audit report (Metier OEC report – Project Control Function Audit, Fortum Oslo Varme, March 2019, closed out in NC03-KEA-MM-0032).

7.2.4 Action follow-up register

To ensure that all formal actions are closed out, an Action follow-up register [71] has been developed and maintained throughout the project FEED phase.

7.2.5 Pilot Quality Plan and Inspection and Test Plan

A specific Quality Plan that included an Inspection and Test Plan (ITP) [93], was developed by Kanfa for the pilot plant. The ITP included a number of inspections and tests, including the Factory Acceptance Testing. FOV witnessed at the most critical activities.

7.2.6 Document Control

To ensure the correct quality on documents, a dedicated Document responsible has been appointed to the project. The project has used guidelines for management of FOV's own documentation [89] and the review procedure for contractor's documentation [90].

As part of this work, separate document checklist has been used to document the checks and approval. The checklists are archived in the project document management system.

7.3 Constructability review

Obtaining good constructability is the process to ensure the optimal use of construction knowledge and experience in planning, design, and procurement and field operations to achieve the overall project objectives.

A constructability review was performed at the end of the FEED phase. The objective was to benefit from participants previous construction experience to identify as much as possible of the main constructability constraints. The feedback is the used to optimize project cost, schedule, design and procurement and to secure the targets of the project.

Personnel knowledgeable in construction activities and with direct impact on construction tasks from FOV, Fortum and personnel from TechnipFMC participated in the review; the review was prepared and lead by a coordinator of constructability from TechnipFMC.

The basis for the review is a presentation of the project, including the process scheme, the basis of the design and the main design assumption at the basis for the layout.

The main topics discussed during the review were:

- HSE: works condition (including co-activity with plan in operation);
- Temporary site facilities;
- Preliminary transportation & lifting studies;
- Main construction sequence;
- Construction Management: organization and resources;
- Subcontracting strategy.

7.3.1 Findings and actions

All topics and findings reviewed are documented in the Constructability Review [52].

The general challenges raised during the review were mostly regarding:

- Working at height, which is to be minimised;
- Cleanliness levels in the process pipes. TechnipFMC recommended a stringent approach with regards to cleanliness during pipe fabrication activities as well intermediate follow up during pre-commissioning. In this respect, FOV should consider witnessing the operations during fabrication and testing.
- Early availability/planning for underground piping, cable etc. is necessary to guarantee a smooth interface with the Civil Contractor. Changes later in the project will impact severely the schedule.
- In general, the interface between the Civil Contractor and TechnipFMC is a critical area and requires focus. Limitation in engineering details could cause significant delay in the project.
- Lay down area availability;
- Transportation and lifting of the CO_2 Stripper: the heavy (approximately 220 t) and large equipment is to be installed in one piece.

7.4 Value improvement practices and cost reduction assessment (2u)

Value improvement practices have been a continuous activity throughout the Concept and FEED phase to improve the FOV CO_2 Capture Project with regards the State objectives. Focus have been to reduce overall cost in combination with maintaining or improving the safety of the total system.

FOV has documented and investigated a number of value improvement opportunities (referred to as VIPs) with the intention to improve the FOV CO_2 Capture Project. Improving the project usually means reducing the cost (CAPEX and/or OPEX), but it can also mean reducing the risk, improving Availability etc.

The documented VIPs have been tracked throughout the project, and this section presents the status of the VIP activities at the end of FEED.

It should be noted that the VIPs considered in this section include:

- VIPs identified in internal meetings;
- VIPs identified during a dedicated VIP workshop facilitated by DNV GL is September 2018 [94]. This VIP workshop was based on minimum requirements such as:
  - Identify the project's absolute minimum functional requirements;
  - Define the minimum technical solution;
  - Identify step-by-step add-ons that can increase value or reduce uncertainties beyond the minimum technical solution;
  - Identify "lean scope".

  The project's absolute minimum functional requirements were based on the review of the below two information sources:

  - Design information provided in the Concept Study Report [6];
  - Description of the nodes, Appendix II in the VIP workshop report [94].

  Guidewords like *Is this part of the project really necessary? All of it? Immediately?* were used to prompt ideas for value improvement.

VIPs identified during the Cost Cut brainstorming meeting in January 2019 are tracked separately [95] and presented in section 7.4.2.

7.4.1 Value improvement opportunities

Identification and evaluation of VIPs has primarily been based on meetings and workshops where ideas have been shared and documented.

All VIPs were assigned unique identifiers and responsible persons ensuring that the VIPs in question were studied in sufficient detail for further decision making. For a more detailed description reference is made to the VIP assessment report [96].

In total, 64 value improvement opportunities (VIPs) have been raised and documented during the concept and FEED phase of this project. A number (13) of VIPs have been accepted, while one is still under evaluation at the time of writing.

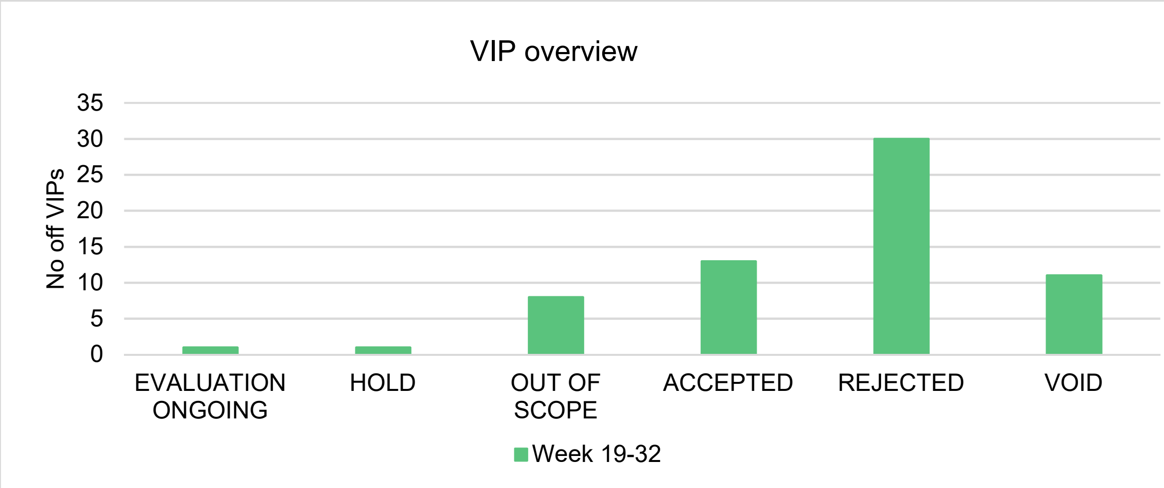

Figure 7-1: VIP status per week 32 2019.

The accepted VIPs are summed up Table 7-1. The VIP assessment report [96] presents a more detailed description of the VIPs.

Table 7-1: Summary of accepted VIPs.

#	Title	Description	End of FEED assessment
1	Turbine	Increase output by installing a condensing turbine	Evaluation completed by project team. Further work with the turbine is outside project scope, but the resulting steam system is part of the project design basis.
2	Wet or hybrid coolers	Wet or hybrid coolers to improve efficiency	FOV is open to all alternatives, available area considered. Hybrid coolers selected by TechnipFMC.
3	Scrubber for line 1&2	Installation of scrubbers for line 1& 2 in combination with heat pump	Scrubber on lines 1 and 2 is current Basis of Design.
4	Additional DH	Utilize the additional heat from the process	Decided on 60 MW @90 °C, i.e. 20 MWth additional heat.

#	Title	Description	End of FEED assessment
5	Water production	CC Plant to produce additional demineralised water for WtE plant	One new package will have lower OPEX than operation of three packages, size of WWTP to accommodate required flow for the existing WtE plant.
6	Sharing of facilities	Potential cost-sharing of warehouse, work shop, office facilities, O&M capacity ++	To be shared
7	Optimizing CO_2 storage	Optimize to reduce size	Optimized based on Gassnova Basis of Design; 4- day ship arrival frequency.
8	Solvent waste incineration	Incineration of solvent waste at WtE plant	TechnipFMC to design a solution to facilitate incineration at Klemetsrud or transport to external treatment.
9	Utilities integration	Utilities and possible interconnection points such as instrument air, plant air, nitrogen, hydrogen, chemicals etc.	Partly integrated (compressed air) based on TechnipFMC Basis of Design. HCl is part of WWTP package and caustic solution will have a separate tank.
10	Automation optimization	High degree of automation, with one man per shift to operate CC Plant. Additional daytime operator (to serve harbour).	Included in the Basis of Design for FEED phase.
11	Coefficient of performance of heat pumps	Evaluate the alternatives to improve the coefficient of performance (COP) for proposed heat pumps	Design shall be 90°C out of HP, coefficient of performance to be optimized by tendering companies in the next project phase.
12	Dedicated filling person to be changed to automatic or driver based	Replacing the dedicated filling person with automatic or driver based filling.	Drivers to carry out the filling operations.
13	Metering method for truck loading/unloading	Metering is proposed to detect possible leaks	Metering method to be detailed in detail engineering, alternatives to be evaluated and optimized solution to be selected.

The one VIP still under evaluation is identical with VIP priority no 1 from the Cut Cost workshop presented in section 7.4.2.

7.4.2 Top five VIPs from Cut Cost workshop

The most recent major VIP activity was the Cut Cost brainstorming workshop held in January 2019 with representatives from Gassnova, Shell, TechnipFMC, CCS Knowledge Centre and FOV.

While a complete list of results from the meeting with status at end FEED and cost consequence (where relevant) is presented in the seminar summary [95], the top five prioritised ideas are presented in Table 7-2.

Table 7-2: Cut Cost - top five priority list.

#	Main Idea	Comment, status
1	Remove Gas-Gas Reheater on FG line	Use Pilot to [redacted], could add reheat at top of Absorber if needed for added dispersion. Nozzle arrangement at Absorber outlet to increase outlet velocity. Status: new dispersion analyses have been carried out, but give no clear answer to the possibility to remove the reheater. To be followed up in the interim phase.
2	Reduce cooling capacity for the warmest days (max 21°C), not design for extreme conditions	Low cost saving, reduced robustness. The design will use 27 °C as outdoor temperature for cooling size. Status: Closed, rejected. Note: a seasonal bias to operation of the facility with less capture due to less incineration – while still meeting the production requirement – will be optimized during operation.
3	Plant arrangement - optimization workshop, 3D - flue gas ducting and flow measurements	Layout is frozen for FEED.
4	Equipment selection/size to have several possible suppliers – competition.	Competition principle is implemented in all sourcing activities; alternative suppliers are included in the possible suppliers list. Status: Implemented.
5	Reduce the CO_2 spec requirements. Challenge Gassnova to re-open this discussion with Equinor.	Cost of cleaning at Northern Lights intermediate storage is higher than total savings for both the capture plants in FEED phase. Status: Closed, rejected.

Items 2, 3, 4 and 5 have already been closed; while investigation on item 1 is ongoing.

7.5 Freedom to operate analysis (2m)

FOV has hired the legal advisor BAHR to conduct an assessment of the risk related to the patent connected with the Licensor's carbon capture technology [97]. BAHR has in turn used the patent attorney Onsagers AS to perform the patent search and technical assessments. A summary of BAHR recommended follow up to FOV is presented below:

BAHR recommendation	FOV planned follow up
[redacted]	[redacted]
[redacted]	

The patent attorney firm Onsagers AS has conducted a technical assessment of:

1) The patent protection of the technology Shell shall make available to the FOV CO_2 Capture Project;
2) The potential risk for patent infringement of third parties patented technology when implementing Shell's CO_2 Capture Technology.

As basis for Onsagers' work, Onsagers has received flow diagrams of the main technical setup of the planned facility at Klemetsrud, together with a list of confidential information and patented technology from Shell. A work-shop meeting with the project and BAHR has also been held to address the basis for the work.

[redacted]

Shell has performed an IP risk assessment for Cansolv DC-103 [redacted]

8 RISK MANAGEMENT

Risk management has been and will be an integrated and important management tool in the FOV CO_2 Capture Project. The following sections describes the risk management process in the project and report the identified risks and opportunities for the next phase.

8.1 Risk management and processes (8a)

Risk management is a key feature and integral part of project management in the FOV CO_2 Capture Project. The objective of the risk management system is to systematically and periodically identify, classify and mitigate risks and opportunities that may reduce or increase the probability of achieving or strengthening the project objective and project goals.

The risk management process used during the FEED phase is documented in a project procedure [98], aligned with Fortum guidelines. The process consists of a series of steps that enable continual improvement in decision making. These can be summarized in the following sub-processes.

- Risks and opportunities identification
- Risk analysis
- Evaluation of risks and opportunities and risk ranking
- Monitoring and mitigating measures and actions

The main steps are also illustrated in Figure 8-1.

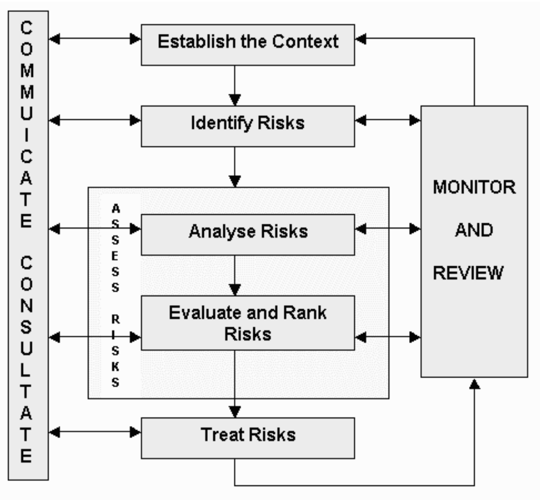

Figure 8-1: Risk Management Process (ISO 31000).

To document this process, a risk register [99] has been established. This includes a description, classification and mitigation actions for the risks and opportunities. The risk register has been continuously updated throughout the FEED phase, and monthly sent to Gassnova for information, as well as discussed as part of the monthly Project meeting.

The FEED risk register was updated from the Concept phase. About mid-way through the FEED phase the methodology for assessing risk was updated. The entire risk register was then revisited with the new categories. The current risk matrix and categories used are presented in Figure 8-2 and Figure 8-3.

Likelihood		Consequences				
		1	2	3	4	5
		Insignificant	Minor	Moderate	Major	Catastrophic
5	Almost certain (>90%)	5	10	15	20	25
4	Likely (50-90%)	4	8	12	16	20
3	Moderate (10-50%)	3	6	9	12	15
2	Unlikely (3-10%)	2	4	6	8	10
1	Rare (0-3%)	1	2	3	4	5

Figure 8-2: Risk Matrix - FEED phase [98].

Risk Acceptance Category	Consequences				
	1	2	3	4	5
	Insignificant	Minor	Moderate	Major	Catastrophic
Personnel	First aid without leave	First aid with medical treatment	Serious injury with sick leave < 10 days	Serious injury with potentially permanent injury	Fatality
Environment	Very small environmental damage. No registration in recipient	Small environmental damage. Registration in recipient, but short recovery time	Considerable environmental damage. Local damage potential	Very serious environmental damage. Local damage potential	Very serious environmental damage. Regional damage potential
EPC CAPEX (Full Scale)	Problem easily handled (< 5M NOK)	Some disruption (5-20M NOK)	Significant time/ resources required (20-50M NOK)	Project severely disrupted (50-300M NOK)	Project survival is at risk (>300M NOK)
EPC OPEX (Full Scale)	Problem easily handled (< 1M NOK /year)	Some disruption (1-5M NOK/ year)	Significant time/ resources required (5-20M NOK/year)	Project severely disrupted (20-50M NOK/year)	Project survival is at risk (>50M NOK/ year)
Project Cost (FEED)/ Schedule	Problem easily handled (< 1M NOK)/ Minor effect on project progress	Some disruption (1-5M NOK)/ Severe effect on project progress	Significant time/ (5-20M NOK)/ Project end date affected by 1 month	Project severely disrupted/ (20-50M NOK)/ Project end date affected by 1-6 month	Project survival is at risk/ (>50 M NOK)/ Project end date affected by > 6 month
Reputation	No interest in mass/ social media	Limited interest in mass/ social media	Local interest in mass/ social media	Regional interest in mass/ social media	National interest in mass/ social media

Figure 8-3: Risk Categories – FEED phase [98].

As part of the monthly meeting and several follow-up meetings, the risk register has acted as important management tool, both for project management and the individuals in the project.

Risks were mitigated throughout the progression of the project: while during autumn 2018 the Pilot plant had many top risks, towards the end of the FEED phase the focus switched towards items with potential impact on the next project phase.

8.2 Risk matrix (8c)

As part of the preparation for the next project phase, a risk analysis focusing on the Construction and Operational phases was performed [100]. This risk analysis followed the same process as described above, and was documented in a separate risk register [100], with a risk matrix and criteria, as described below.

The established risk register will act as the starting point for the new register for next phase. During the next project phase, the risk register will be subject to a monthly general review and a quarterly detailed discussion, with follow-up, reclassification and new mitigation measures discussion (as described in [5]).

This section presents the top 10 risk that was identified at the end of the FEED phase (a total of 50 risks were identified in the process).

The risk matrix that was used in the workshop is presented below in Figure 8-4, while Table 8-1 reports the top 10 identified.

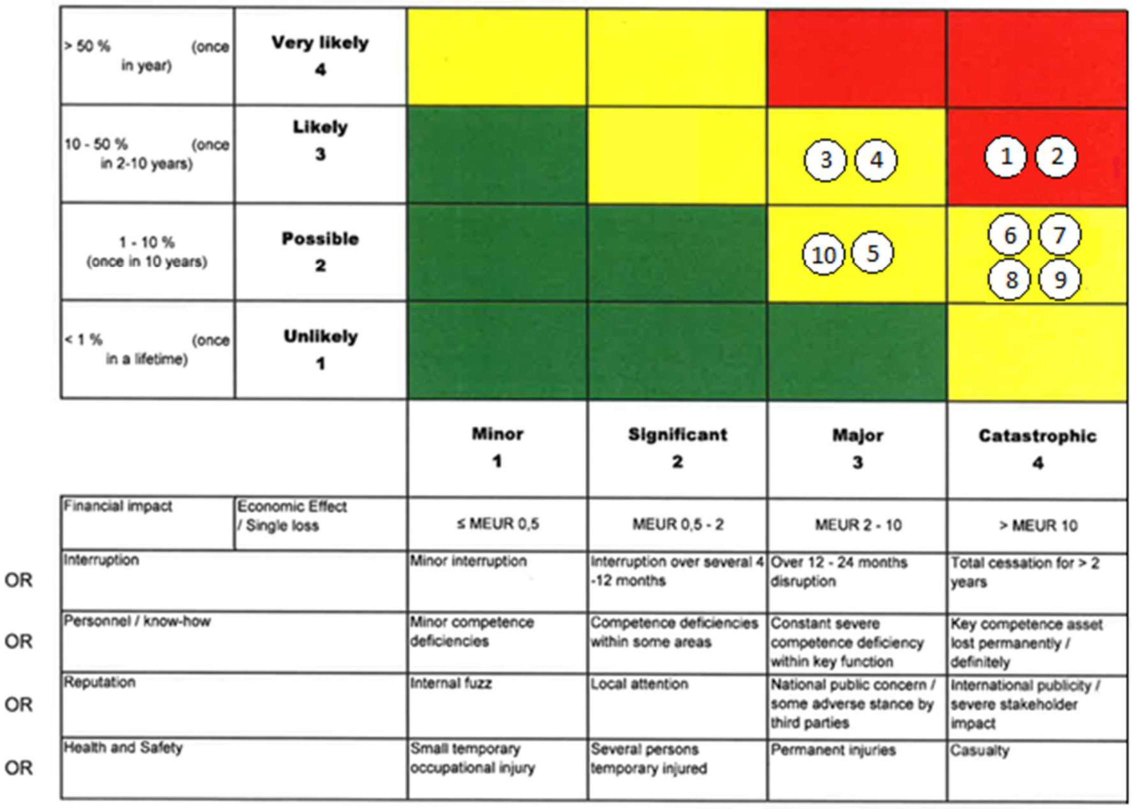

Figure 8-4: Risk Matrix for Construction and Operational phases.

Table 8-1:Top 10 risks for Construction and Operational phases.

Rank	Category	Description	Risk Reducing Measure
1	Financial and economic	Currency risk* – If the Norwegian krone is weak, it can have a negative impact on the cost in the FOV CO_2 Capture Project.	Hedging of the currency, and different parts of the contract is in different currencies.
2	Progress/ Schedule	Delayed commission period. Performance test must be performed, before start-up of operational phase.	Good planning, and active involvement of plant personnel.
3	Financial and economic	A long interim period is a risk due to costs may increase in this period, due to market conditions, currency and inflation.	The FOV CO_2 Capture Project cannot influence the duration of the interim period. The risk is larger during interim period, because when project start, it is mitigated with hedging and firm contracts.
4	Progress/ Schedule	Civil work delayed.	Good preparation and planning of the work. Close follow up of the Civil Contractor. Plan of the work so that the area needed first by TechnipFMC is available first.
5	Technical Issues	Contaminated Soil found during ground works.	Preliminary investigations during FEED phase indicating no contamination. Further investigation prior to start of Civil works.
6	Financial and economic	Bankruptcy or financial problems including merges of the main contractor and/ or subsupplier.	This is mitigated with a good contract, but the risk can never be neglectable.
7	Financial and economic	Insufficient suppliers to get a competitive price – CAPEX will increase due to market conditions.	Incentives in contract, to reduce cost as possible. Increase competition as possible.
8	HSE	Major accident with fatalities at Site.	High focus throughout planning. Safety Walks, inspections, improvement proposals. Many HSE supervisors during construction. Implementation of Fortum good practices from other large construction projects.
9	Financial and economic	Overrun of CAPEX.	Good planning, close follow-up of subcontractors and suppliers, and contract terms limiting risk of overrun.
10	Technical Issues	Lower Availability of the CC Plant than expected during operational phase of the CC Plant. This can result in less CO_2 captured.	Maintenance: The planned shutdown of CC plant will take place during the WtE plant maintenance stop to minimise production loss. Standardization and spare part strategy will be developed to minimise downtime. Operations: Skilled personnel is required to obtain high uptime and plant performance.

*: Currency risk is part of the ongoing contract negotiations with MPE.

9 REGULATORY STRATEGY (5A)

This section presents an overview of the most relevant documents and regulatory requirements which have been identified and implemented during the FEED phase.

The FOV CO_2 Capture Project, including the CC Plant shall comply with all relevant Norwegian legislation. The most relevant authorities are listed below (the list is the same as in Table 5-26):

- The Norwegian Directorate for Civil Protection;
- Norwegian Environment Agency;
- Agency for Planning and Building Services, City of Oslo;
- County Governor of Oslo and Viken;
- The Norwegian Labour Inspection Authority;
- The Norwegian Water resources and Energy directorate.

9.1 Overview of regulations

This section presents a description of relevant legislation for developing a carbon capture plant in Norway, with focus on the regulation that are relevant for the planning phase of the project.

9.1.1 The Planning and Building Act and underlying regulations

The Planning and Building Act applies for area planning and construction works. Main purpose of legislation is to ensure that all area planning, area utilization and building in Norway gives the highest possible benefit for the society and the individual. It shall also ensure that construction works complies with the rules and regulations.

The law and subordinated regulations give requirements for:

- Area planning (zoning) procedures;
- Requirements for design and construction (mainly for geotechnical and civil installations);
- Regulations for building permit;
- Requirement for relevant competence of contractors (Norwegian civil contractors preferred);
- Requirement for third-party control.

The planning part of the law consists of demands related to area planning on national and regional level and locally with zoning plans. For projects that have a big impact on the environment or the society a zoning plan and an environmental impact assessment must be prepared.

For the building permit, the following regulations apply:

1. Technical building regulations (Byggteknisk forskrift - TEK17):

   The regulation controls the technical provisions for buildings, building density, safety against stresses for the environment/nature and all the required documentation. Chapter 8, 12, 13 and 14 apply.

2. Building application regulation (Byggesaksforskriften - SAK10):

The regulation controls the process related to the building permits. The regulation imposes requirements regarding competence, structure and content related to the building applications.

3. Regulations for environmental impact assessment (EIA):

   EIA regulations' purpose is to ensure that environmental and social impact is taken into consideration during the area and project planning. The regulation includes specific criteria for determining whether the EIA is required and its extent. The criteria list also defines the responsible authority for approval of the EIA.

   The regulations also contain a definition of the extent of the various assessments to be included in the EIA as well as the procedures to be followed. The baseline for the assessment is defined as "0-alternative", which is typically not to establish the new plant.

9.1.2 The Pollution Control Act and underlying regulations

The pollution control act is the general legislation for preventing and controlling pollution. The basic requirement/principle is that no pollution is allowed unless otherwise is given in more specific regulations or discharge permits.

The regulations related to pollution control are more specific for certain type of activities, and have separate chapters and/or separate underlying regulations for amongst other waste handling, tank storage etc. Their main purpose is to protect environment against pollution caused by chemicals and/or waste that are dangerous to health and environment.

Some key requirement related to a new plant such as a new carbon capture plant are:

- Requirement for the flue gas discharge permit;
- Requirement for environmental risk assessment;
- Requirement for environmental safety barriers to achieve risk as low as reasonably possible;
- Requirement for secondary tank containment;
- Requirements for using Best Available Techniques (BAT);
- Requirements for handling polluted soil;
- Requirement for relevant competences of all involved parties;
- Requirements for monitoring effluents/emissions.

Possible BAT requirements for CO_2 capture from Klemetsrud WtE plant will be based on the IPPC requirements [101]. Reference documents (BREFs) have been prepared for a number of applications and businesses to illustrate what technical solutions that can be regarded as Best Available Techniques. For Klemetsrud WtE plant, the Large Combustion Plants (LCP) BREF [101] is applicable, where CO_2 capture has been defined as an "emerging technique" and no specific standards or solutions have been defined as Best Available Techniques.

No specific BAT requirements for [redacted] or other flue gas treatment-/cleaning systems or equipment have been found applicable for the CC Plant. No specific requirements for emissions of solvent or other substances have been found. It should however be noted that the general "as low as reasonably practicable" requirement will apply with respect to emissions, which will require a thorough documentation and justification of the selected solutions relating to environmental control and pollution.

9.1.3 Fire and Explosion Prevention Act and underlying regulations

The object of the Fire and Explosion Prevention Act is to protect life, health, environment and material against fire and explosion. The most relevant regulation is the one related to handling of hazardous products. It regulates engineering, construction, production, business, installation, operation, change, repair, maintenance and control of equipment and installations in use while handling dangerous products.

The preventive requirements are listed below:

- Competence requirements for engineering, design, manufacturing, installation, operation, changes, repairs, maintenance and control;
- Risk assessment to eliminate undesirable incidents and reduce the probability and consequence for undesirable incidents;
- Technical demands for execution and barriers;
- Adequate emergency preparedness plans;
- Adequate documentation.

9.1.4 Working Environment Act and underlaying regulations

The Working Environment Act is the act relate to working conditions. It covers, amongst others, working hours and employment protection. The act primarily regulates the work conditions during the construction and operation of the plant. However, there are also requirements that are to be met during the planning phase - mainly in regard to the Construction Client Regulations (Byggherreforskriften). During the planning and preparation phase, the Construction Client (as defined in the regulation) is to evaluate the contribution to safeguard safety, health and working environment in connection with:

- The architectural, technical or organisational choices made;
- Risk factors relevant for the work to be carried out; these are to be described and considered;
- The time necessary for planning and executing the various work.

The Construction Client is also responsible to ensure that the designers comply with the responsibilities imposed by the regulations.

9.1.5 Climate Change Act and underlying regulations relating to quota duty and trading of allowances for greenhouse gas emissions

The purpose of this Act is to promote the implementation of Norway's climate targets as part of its process of transformation to a low-emission society by 2050. While the Climate Change Act and the underlying regulation will have no direct impact on the FOV CO_2 Capture Project, these regulations will affect the Final Investment Decision of the Norwegian Parliament.

The emission trading act and underlying regulation are the Norwegian implementation of the EU ETS Directive (2003/87/EC), which is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions. WtE plants incinerating municipal and/or hazardous waste are not covered by the quota sector, however, the individual Member State may choose to include such plants based on how it will influence the competitiveness in the market.

While the WtE plants are not covered by the quota sector in most of EU, WtE plants in Sweden are covered by the quota sector since they are considered as part of the energy sector and not the waste sector. Currently, only three WtE plant in Norway, that exclusively deliver energy to the industry, are included in the quota sector.

As part of the ongoing work to revise the Climate Change Act, a CO_2 tax on waste management has been proposed. Options discussed include the incorporation of all WtE plants in the quota sector, separate CO_2 tax on the WtE plant or a CO_2 tax on the products containing fossil material. The Ministry of Climate and Environment is currently assessing the different options, and a proposal is expected by end of 2019.

9.2 Status Environmental Impact Assessment

The EIA has been a part of the zoning documents for the proposed regulation for the area where the CC Plant will be located. The proposal also includes the relocation of the existing bus terminal, a potential service station rig area for the Norwegian Public Roads Administration and potential expansion in incineration capacity of the WtE plant.

The zoning documents including the EIA have been on a public hearing and some consultation statements were received. The EIA has been corrected and is sent for political processing as a part of the corrected zoning documents.

The political processing started according to plans in the end of August 2019, and the zoning plan will be approved by the city council within 1st November 2019.

9.3 Status Emission permit

The Norwegian Environment Agency (Miljødirektoratet) is the responsible pollution authority for the existing incineration plant and will have the same role for the new CC Plant.

For the WtE plant, FOV has applied in June 2019 for a revised emission permit (up to 410 000 ton waste). This process is outside of the scope of the FOV CO_2 Capture Project.

The application for a discharge permit for the CC Plant was sent in November 2018. After the submission there have been two meetings with the agency to clarify issues in the ongoing application process as well as to inform the authorities about the FOV CO_2 Capture Project status.

A list of required additional information has been received. Work is underway to obtain the information, as some of it is dependent on results of the pilot testing. New dispersion calculations based on data from the pilot plant, including the solvent and its degradation products and effects on emissions to air and water have been carried out September/October 2019.

Some of the requested information from the Norwegian Environment Agency related to the proprietary solvent will be exempted from public disclosure and therefore handled directly between the Licensor and the Agency.

In addition to the above mentioned additional information, it should be noted that the processing of the discharge permit cannot be completed before the new zoning plan for the area is approved. The project has planned the submittal of the complete emission permit within the end of 2019, expecting a granted permit within the end of 2020.

The CC Plant cannot be commissioned before an emission permit is granted. Commissioning is currently planned for 2023-2024.

9.4 Status other permits and consents

9.4.1 Zoning plan

An approved zoning plan is a pre-requisite for being able to process all other permit applications. The zoning plan (with the accompanying documents) has been on a public hearing; after administrative handling / correction will be sent for political processing at the end of August. The zoning plan will be approved by the city council within 1st November 2019.

The zoning plan will include documents fulfilling requirements such as:

- An outdoor plan;
- Quality program for environment and energy;
- Rig and security plan for the construction phase;
- A comprehensive plan for the Klemetsrud WtE plant visual expression;
- A revised noise report;
- Detailed solution for handling of surface water (presented for VAV for acceptance);
- Development agreement with the City of Oslo.

9.4.2 Building permit

The building permit can be obtained after the approval of the zoning plan. To complete the application for the building permit, a number of documents implementing the outcome of the zoning plan need to be presented; plant design needs to be started in order to prepare these documents.

The building application for the plant at Port of Oslo can be sent as soon as the design is complete enough to satisfy the requirement for the application; there is no need for a new zoning plan for the area at the harbour.

The process for obtaining a building permit includes work to fulfil the responsibilities detailed in section §12-2 of the Building Regulations (SAK) in building projects. The work includes the following:

- Pre-Conference with the Agency for Planning and Building Services, City of Oslo;
- Notification to neighbours;
- Application for permission to actions - outline planning permission (Rammesøknad);
- Application for start-up permit (IG);
- Application for temporary use permit - Coordination of responsible enterprises, clarification of liability documentation for other enterprises. The temporary use permit will not be granted before the emission permit is approved.

As already mentioned, a number of attachments to the application have to be prepared. These include documentation such as drawings of the plant (plan and sectional), information on the external framework and building specifications of planned actions, implementation plan, minutes of pre-conference, consent from The Norwegian Labour Inspection Authority.

The requirements of the zoning plan (as described in section 9.4.1) must be complied with.

The building permit application is scheduled to be sent within end of February 2020.

9.4.3 Consent from Directorate for civil Protection and Emergency Planning

While CO_2 itself is not covered by the Fire and Explosion Prevention Act and the associated regulations, the CC Plant is covered. There has been a clarification with the directorate weather a consent is needed according to the Major Accident regulation or other regulations under the Directorate for civil Protection and Emergency Planning (DSB) responsibility.

The scope of and terms of the application to DSB has been discussed with DSB in two meetings and it has been clarified that the scope of the consent DSB is limited to the locations where the CO_2 will be stored, both at Klemetsrud and at the Port of Oslo.

The scope is defined as such due to the high pressure and the quantity of CO_2 stored in such sites; regulations on Hazardous Substances (included Pressurized substances) apply.

The transport from Klemetsrud to the harbour does not need any specific permit or consent.

A central basis for the application is the quantitative risk assessment [68] of the storage at the two sites. The application for consent will be sent within 20th December 2019, with the expected consent received before end of Q1 2020.

9.5 Overview of the regulation processes

An overview (with timeline) of the regulation processes through all the FOV CO_2 Capture Project is presented in Figure 9-1. A status of the applications is presented in Table 9-1.

Table 9-1: Regulation process and application status.

Scope of the application	Regulatory body	Regulatory reference	Estimated time span	Obtained permit/approval
Prepare a zoning plan and clarify the conditions for establishing the CC Plant at Klemetsrud	Agency for Planning and Building Services, City of Oslo (PBE)	Planning and Building Act (and underlying regulations, such as Environmental Impact Assessment)	(08/2018) 08/2019 – 11/2019	Granted Zoning Plan
Clarify a building permit for the CC Plant	Agency for Planning and Building Services, City of Oslo (PBE)	Planning and Building Act (and underlying regulations, such TEK 17, SAK 10)	02/2020 – 09/2020	Building permit
Clarify requirements for operation and emissions from the CC Plant	Norwegian Environment Agency (Miljødirektoratet)	Pollution Control Act and underlying regulations	11/2018 – 12/2020	Emission permit
Clarify the terms and conditions of consent	The Norwegian Directorate for Civil Protection (DSB)	Fire and Explosion Prevention Act and underlying regulations	12/2019 – 04/2020	Consent from DSB

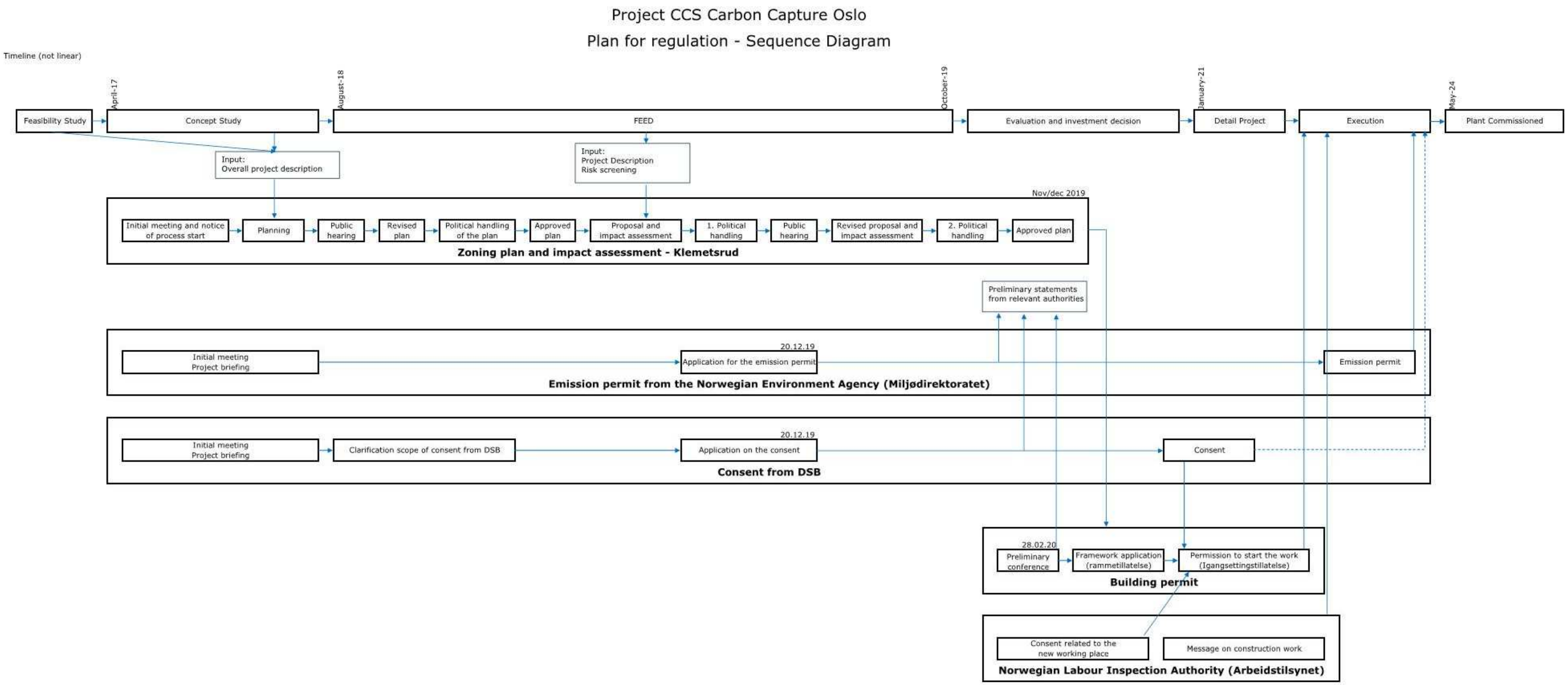

Figure 9-1: Sequence diagram - plan for regulations [102].

10 SCHEDULE

The schedule is developed based on the assumption that the Final Investment Decision will be taken in Q4 2020. This means that the project start-up will be earliest in January 2021. The schedule is developed and documented on a level as given in AACE RP 38R-06 "Documenting the schedule basis".

TechnipFMC will be responsible for most of the activities in the schedule and their detailed plan for the next phase is included as basis for the project's overall schedule [103]. In addition, information from other contractors – especially Civil Contractor and Transport Contractor – have been included.

Total project duration until plant ready for operation is 46 months.

10.1 Schedule for construction and operation (6c)

The schedule for the construction and operation phase [103] is established based on information from suppliers and the project team. The schedule takes into account the contractors' requirements and the requirements for necessary integration of the CC Plant to the Klemetsrud WtE plant. Information from contractors is included where available. The schedule from TechnipFMC is of vital importance for the development of the overall schedule and accounts for the majority of the activities details in the schedule.

The schedule for construction and operation is included in Figure 10-1.

ID	Task Name	Start	Finish
1	**Milestones**	**04 Jan '21**	**27 Oct '24**
77	**Project Management**	**04 Jan '21**	**15 Nov '24**
88	**Permitting (regulatory and zoning)**	**04 Jan '21**	**18 Nov '24**
97	**Procurement**	**18 Jan '21**	**18 Nov '24**
98	Civil contract notice to proceed	18 Jan '21	18 Jan '21
100	TechnipFMC notice to proceed	18 Jan '21	18 Jan '21
102	Transport contract notice to proceed	12 Sep '22	12 Sep '22
104	Integration Works Contract notice to proce	20 May '22	23 May '22
106	**Integration scope**	**08 Nov '21**	**30 May '24**
125	**Civil works scope**	**25 Jan '21**	**18 Jul '22**
147	**Transport contractor scope**	**13 Sep '22**	**17 Nov '23**
155	**Site (rigging)**	**09 Aug '21**	**02 Dec '22**
165	**Operation and Maintenance mobilization**	**10 Nov '23**	**25 Oct '24**
168	**TechnipFMC (EPCIC Contractor)**	**18 Jan '21**	**27 Oct '24**
169	**Engineering**	**18 Jan '21**	**13 Feb '23**
190	**Procurement**	**30 Mar '21**	**26 Jun '23**
202	**Construction**	**24 Jan '22**	**29 Feb '24**
223	**Commissioning/Start up**	**01 Mar '24**	**27 Oct '24**
224	Commissioning	01 Mar '24	28 Jun '24
225	Start-up	01 Jul '24	31 Jul '24
226	Trial run	31 Jul '24	29 Sep '24
227	Performance test	29 Sep '24	13 Oct '24
228	Taking over	13 Oct '24	27 Oct '24

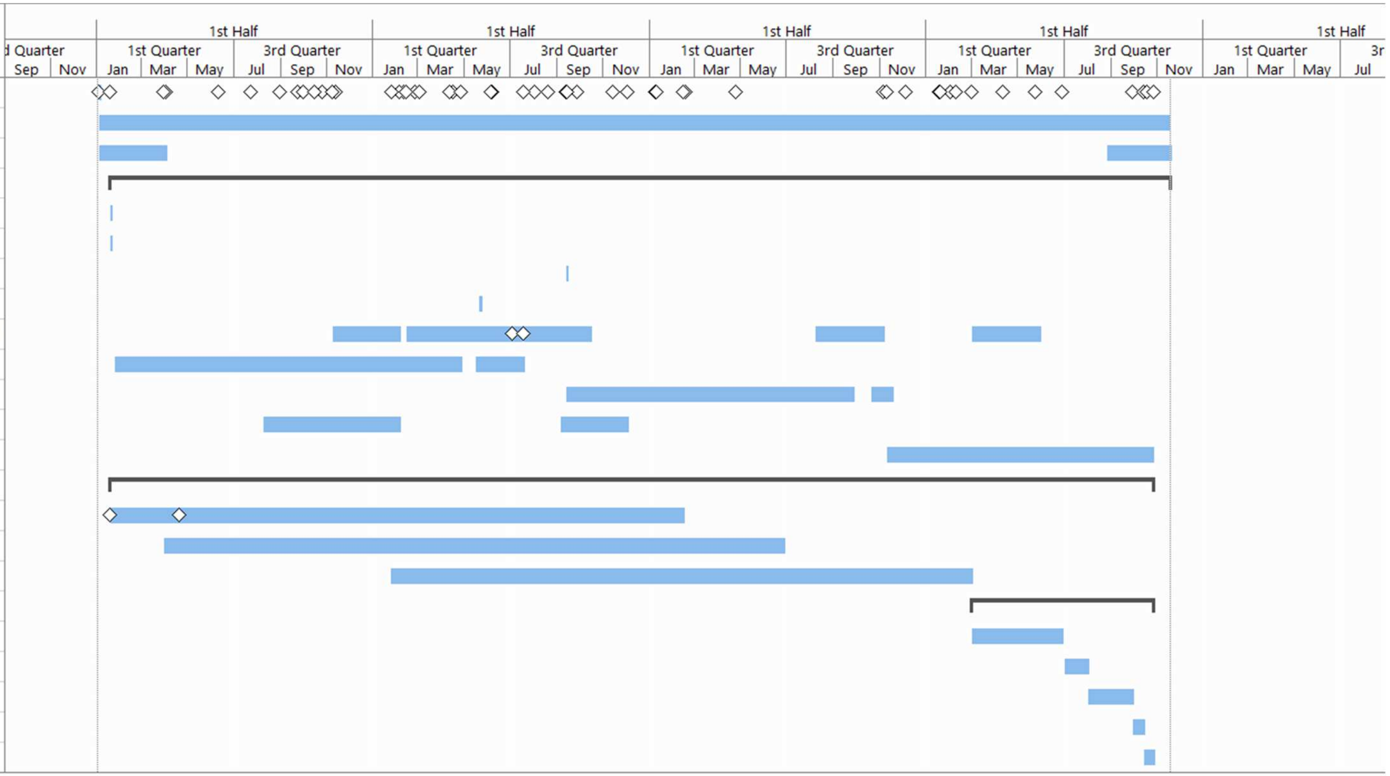

Figure 10-1: Schedule for construction and operation [103].

The Civil Contractor, TechnipFMC and the Owner's Engineer will be ready to proceed shortly after the Final Investment Decision.

Civil works including rock blasting will start shortly after contract award as this is a relatively time-consuming process. The first areas will be available for erection of steel structures and equipment late Q1 of 2022. Relating to process equipment erection, the Stripper Column is be the largest individual equipment delivered to Klemetsrud in one piece, and the delivery is scheduled in December 2022. Foundation work need to be adjusted for this delivery due to usage of large mobile cranes.

Engineering activities will commence from the contract award and will be concluded within 15 months after project start-up for the majority of the work. Engineering activities including workshop drawings, isometrics etc. will continue in parallel with construction work at Site.

The total construction period will have a duration of 24 months for the construction work at Klemetsrud. The construction work at the harbour facilities will go on in parallel for the last 12-18 months of the construction period.

The construction phase will be followed by a pre-commissioning/commissioning phase with a duration of approximately 8 months. The plant is scheduled to be Ready for Start-up in July 2024 and will be run through a test-run period of 8 week. Given a successful trial run, the plant will be ready for operation September 2024. The final performance test and the issuing of Delivery Acceptance Certificate will be performed when the plant have been in operation for some time, based on agreement with TechnipFMC and the Licensor.

10.2 Schedule risk analysis

A schedule risk analysis has been performed on the preliminary schedule for the construction and operation phase with the methodology described in the schedule document [103].

The risk analysis considers magnitude and probability of the occurrence of the risk and identify mitigation actions to lower the risk impact.

Where possible, critical activities are planned to allow for buffer and slack (with consideration to the cost/benefit), In addition, actions taken during the interim period will further contribute to reduce schedule risk (and therefore the need of schedule reserve beyond what already included).

A critical path analysis is performed at this stage by TechnipFMC, as its scope of work is identified as critical path. The main focus with regards to schedule reserve planning in the project is connect with the civil works at Klemetsrud, and this is achieved by means of conservative estimates based on experience.

Table 10-1 presents the top 5 risk that threaten the schedule for the construction and operation phase, as identified by the project team during the FEED phase.

Table 10-1: Top 5 schedule risks for construction and operation.

Rank	Risk	Mitigating Action
1	Delayed commission period. Performance test must be performed, before start-up of operational phase.	Good planning, and active involvement of plant personnel.
2	Project Mobilization: short duration from the contract signature until the team should be available/mobilized.	The negotiation with the contractors will continue during the interim phase in order

Rank	Risk	Mitigating Action
		to have Letter of Intent signed for all the major contracts. With regards to project organization, negotiation with the Owner's Engineer will take place during the interim period, to ensure that the Owner's Engineer can be mobilised effectively in short time after the contract with MPE is signed.
3	Plan and building permission delay might delay the beginning of the civil work (demolition) at Klemetsrud	Plan a step approach and continue with the work in the interim period.
4	Civil Work at Klemetsrud are on the critical path and delays will influence the delivery of the site to TechnipFMC.	Conservative planning including slack. During preparation of the detailed schedule (in execution phase) prepare a recovery plan where the activities on the critical path are accelerated.
5	Delayed information from TechnipFMC to the civil contractor on the loads and position on the foundations. The foundation can therefore be delayed	Engage the Civil Contractor early after project start-up. Include interface milestones with TechnipFMC (deliver of calculation for foundation). Establish during project mobilization an early warning system to monitor TechnipFMC in execution. Evaluate possibilities and methods for TechnipFMC acceleration if required (Plan B)

10.3 Milestone schedule – to start-up of capture plant (6d)

The project schedule for building and operation [103] defines milestones at several levels for the complete engineering, procurement, construction, commissioning and start-up of the CC Plant at Klemetsrud and harbour facilities.

The following major milestones and milestone dates have been defined for the project:

Table 10-2: Milestones to start-up of the CC Plant.

Milestone	Milestone date
Contract signing with MPE	04.01.2021
Civil Work Contract signed	18.01.2021
TechnipFMC Contract signed	18.01.2021
Owner's Engineer Contract signed	[redacted]
All LLI/Main equipment PO placed	[redacted]
Ship-shore interface detail design frozen (1)	[redacted]
Foundation ready (Klemetsrud) for first equipment	01.04.2022
Ship-shore interface detail design frozen (2)	[redacted]
Transport Contract signed	[redacted]
Stripper delivery	[redacted]
All LLI/Main equipment delivered at Site	[redacted]

Milestone	Milestone date
Chemicals and power available	[redacted]
Mobilization O&M team	[redacted]
Mechanical Completion	29.02.2024
Harbour facilities ready for ship-shore commissioning	[redacted]
1st CO_2 to absorber (filled with solvent Cansolv DC-103)	[redacted]
Commissioning finished and Ready for Start-up	[redacted]
Harbour facilities ready for ship-shore commissioning	[redacted]
Plant ready for operation	[redacted]
Performance test complete	[redacted]
Delivery Acceptance Certificate signed & commencement of normal operation	27.10.2024

10.4 Delivery schedule for construction and operation (6b)

The Master Document List Construction and Operation [104] presents a list of the type of documents to be prepared for the construction and operation phase. The main groups of documents included in the execution phase of the project are:

- Site management documents including documents related to HSE, quality, access, site organisation etc;
- Procedures, Instructions and Specifications for the construction phase as installation procedures, NDT procedures, storage and prevention procedures, cleaning and flushing procedures etc;
- Drawings and 3D model;
- Completion documents such as MC Check records, commissioning reports, trial run program etc.

For the operation phase the following document types will be delivered:

- Manuals, procedures and report such as user manuals, maintenance manuals, procedures, functional descriptions etc.
- Datasheets including relevant calculations and noise/vibration data for all mechanical components and safety data sheets for chemicals;
- Certificates for all relevant equipment and systems;
- List and indexes for relevant equipment and systems;
- As-built drawings, including updated 3D model.

11 PROJECT EXECUTION – CONSTRUCTION AND OPERATION

The project has implemented the Fortum project execution method including the relevant procedures and decision gates.

The project is planned to be executed with TechnipFMC as main contractor during the next project phase. In this model TechnipFMC will form its own organization which will report to FOV's Project Manager and Project Management Office. FOV's Project Management Office will also include the Owner's Engineer team. The Owner's Engineer team will supervise the deliveries from the contractors.

This section also includes information related to the organization of the project with key personnel, relevant subsuppliers and interfaces. Further FOV and TechnipFMC experience and references are given.

11.1 Engineering experience and reference list (7a)

This section provides a description of FOV and its main contractor (TechnipFMC with Licensor Shell) experience from design, construction and operation of large process plants (including CO_2 capture references).

11.1.1 Fortum international references

FOV as a part of Fortum has both international as well as local experience in managing large complex industrial projects.

On international level since 2006, Fortum has invested in 11 Combined Heat and Power (CHP) plants in different countries with total capacity of [redacted] and total value of approximately [redacted]. Fortum currently manages one complex industrial project in Kaunas (Lithuania) and has several large projects under development. All 11 completed CHP plants were executed in a so called EPCM (Engineering, Procurement, Construction Management) model, required by Fortum to ensure success of complex projects that involves advance project management.

By managing so many large industrial projects based on different technologies, Fortum has since 2006 developed project management practices and collected many lessons learned as well as formed experienced project managers team.

A list of the 11 projects is presented in Table 11-1.

Table 11-1: Fortum's key international CHP plant project references.

Description[1]	Period	Value (EUR million)
Espoo gas fired CHP plant (Finland) • CCGT technology • Capacity: 234 MWe, 214 MWth	2007-2009	[redacted]
Tartu biomass/peat fired CHP plant (Estonia) • BFB boiler technology • Capacity: 25 MWe, 52 MWth • total performed manhours: 511 442 • LWIF: [redacted] • No serious accidents	2006-2009	[redacted]

Description[1]	Period	Value (EUR million)
Pärnu biomass/peat fired CHP plant (Estonia) • BFB boiler technology • Capacity: 24 MWe, 45 MWth • Total performed manhours: 454 884 • LWIF: [redacted] • No serious accidents	2008-2010	[redacted]
Częstochowa biomass/coal fired CHP plant (Poland) • CFB boiler technology • Capacity: 64 MWe, 120 MWth • Total performed manhours: 2 239 820 • LWIF: [redacted] • No serious accidents	2007-2010	[redacted]
Klaipeda WtE CHP plant (Lithuania) • Grate boiler technology • Capacity: 20 MWe, 65 MWth • Total performed manhours: 1 207 296 • LWIF: [redacted] • No serious accidents	2010-2013	[redacted]
Järvenpää biomass/peat fired CHP plant (Finland) • BFB boiler technology • Capacity: 23 MWe, 60 MWth • Total performed manhours: 444 296 • LWIF: [redacted] • No serious accidents	2011-2013	[redacted]
Jelgava biomass/peat fired CHP plant (Latvia) • BFB boiler technology • Capacity: 23 MWe, 45 MWth • Total performed manhours: 568 000 • No serious accidents	2011-2013	[redacted]
Brista WtE CHP plant (Sweden) • Grate boiler technology • Capacity: 20 MWe, 60 MWth • Total performed manhours: 1 340 300 • LWIF: [redacted] • No serious accidents	2010-2014	[redacted](2)
Värtan biomass fired CHP plant (Sweden) • CFB boiler technology • Capacity: 130 MWe, 280 MWth • Total performed manhours: 2 978 869 • LWIF: [redacted] • 1 fatal accident	2012-2016	[redacted]
Naantali biomass/coal/peat fired CHP plant (Finland) • CFB boiler technology • capacity: 140 MWe, 250 MWth • total performed manhours: 982 438 • LWIF: [redacted] • No serious accidents	2014-2017	[redacted]

Description[1]	Period	Value (EUR million)
Zabrze RDF/coal fired CHP plant (Poland) • CFB boiler technology • Capacity: 75 MWe, 140 MWth • Total performed manhours: 3 324 000 • LWIF: [redacted] • No serious accidents	2015-2019	[redacted]

[1]: the following abbreviations are used in the table:
CHP: Combined Heat and Power
CCGT: Combined Cycle Gas Turbine
BFB: Bubbling Fluidized Bed
CFB: Circulating Fluid Bed
RDF: Refused Derived Fuel
LWIF: Lost Workday Injury Frequency, injuries per million working hours, absence of one or more (≥1) working day or shift excluding the day the accident happened
Serious accident is defined as following: fatality, accident causing permanent disability or at least 30 days of absence
[2]: [redacted]

All plants in Table 11-1 are today part of Fortum (own plants or co-owned in joint ventures) and the majority are operated by Fortum staff. Presented experience and references proves that Fortum is well positioned in managing execution and in operating of large and complex industrial plants.

Figure 11-1: The recently completed large complex industrial project by Fortum in Zabrze , Poland (during construction period on the left and after completion on the right).

With regards to Carbon Capture international references, Fortum has been involved in the Meri-Pori carbon capture and storage project (see Table 11-2).

Table 11-2: Fortum's key Carbon Capture international references.

Description	Period	Value (EUR million)
Fortum – Meri-Pori CCS project (cancelled)	2008-2010	Projected [redacted]

11.1.2 Fortum Oslo Varme references

The references presented Table 11-3 and Table 11-4 comprise references from the previous and current owners of the Klemetsrud WtE plant such as the Agency for household trash management, City of Oslo (Energigjenvinningsetaten, EGE), Klemetsrudanlegget AS, Hafslund Varme AS and Fortum Oslo Varme AS (FOV).

Klemetsrudanlegget AS was split off from EGE as a separate limited company, wholly owned by City of Oslo. Klemetsrudanlegget AS merged then with Hafslund Varme AS to became Fortum Oslo Varme AS (FOV), with 50/50% ownership between the City of Oslo and Fortum.

The City of Oslo, through EGE, Klemetsrudanlegget AS ad now FOV, has experience in managing large complex industrial projects. These includes projects such as the third line at the Klemetsrud WtE plant and the biogas plant in Nes. Table 11-3 and Table 11-4 presents an overview of the key project references from Klemetsrudanlegget AS, EGE and FOV.

Table 11-3: Key project references – Klemetsrudanlegget AS and EGE.

Description	Period	Value (NOK million)
EGE 2010 • 2 sorting plants • Biogas plant at Nes in Romerike • New WtE line (line 3) at Klemetsrud	2007-2014	[redacted]
Klemetsrud WtE plant • New flue gas cleaning systems for incinerator lines 1 and 2	2015	[redacted]
Klemetsrud WtE plant • Investment program for rehabilitation and power increase	2015-2016	[redacted]
Klemetsrud WtE plant • New heat pump for flue gas condensate from line 3	2016-2017	[redacted]
Klemetsrud WtE plant • Feasibility study for CO_2 capture, with 2 technologies	2015-2016	[redacted]
Klemetsrud WtE plant • CO_2 capture testing at site	2015-2016	[redacted]

Table 11-4: Key project references - FOV (earlier Hafslund Varme AS).

Description	Period	Value (NOK million)
Heat pumps Skøyen (Oslo) • Heat recovery from sewage • Capacity: 10+20 MW • No serious accidents	2005-2007	[redacted]
District heating pipe Klemetsrud- City Centre (Oslo) • Length: 14 km • Dimension 500-700 mm • No serious accidents	2007-2009	[redacted]
Heat only boiler, Rodeløkka (Oslo) • Bio fuel oil boiler • Capacity: 100 MW • No serious accidents	2010-2011	[redacted]
Haraldrud Varmesentral • Norway's largest wood pellet boiler (56MW)	2013	[redacted]

11.1.3 TechnipFMC references

TechnipFMC has built more than 50 installations for the removal of carbon dioxide and sulphur components from natural gases using a variety of technologies including membranes and physical / chemical solvents. This experience makes TechnipFMC particularly well-positioned to successfully design and execute carbon capture and storage projects.

With regards to post-combustion solutions where the aim is to capture CO_2 from the flue gas, TechnipFMC has a strong alliance with Shell, the selected CO_2 capture technology Licensor.

These projects also involve compression and CO_2 re-injection, and TechnipFMC has experience with various optimized schemes for CO_2 treatment, compression and reinjection.

Table 11-5 presents information regarding five recent large projects executed by TechnipFMC.

Table 11-5: TechnipFMC key references.

Description	Completion	Value
Peterhead Carbon Captive & Storage (Peterhead, Scotland) • Client: [redacted] • Value: [redacted] • Completion: Q1 2015 • Scope: FEED • Technical Details: Front-end engineering design for the onshore elements of the Peterhead Gas Carbon Captive and Storage Project at SSE Generations Power Station, Peterhead, Scotland. FEED scope includes a grassroots carbon capture and compression plant and modifications to an existing combined cycle gas turbine plant. The world's first commercial scale full chain gas carbon captive and storage project.	Q1 2015	[redacted]
[redacted] **Refinery** [redacted] • Client: [redacted] • Scope: Process License Technology Package for the existing Residua Fluid Catalytic Cracking (RFCC) and Other Refining Technologies to process heavier and more acidic crude. Technip assessed the performance of each of the Licensors Unit's major equipment for Sub-Licensors, prepared process duty specifications to allow licensors to assess the performance of their units. Update of sub-Licensor packages. • Technical Details: [redacted]	2015	[redacted]
[redacted] • Client: [redacted] • Scope: Conceptual study, feasibility study, licensor recommendation, FEED • Technical Details: [redacted]	2012	[redacted]
[redacted]	2009	[redacted]

Description	Completion	Value
• Client: [redacted] • Value: >$1 billion • Scope: Proprietary technology, engineering, procurement, construction, management and operational support • Technical Details: [redacted]		
[redacted] • Client: [redacted] • Scope: Feasibility Study & Front-End Engineering • Technical Details: [redacted] • [redacted]	2011	[redacted]

11.1.4 Licensor references

Shell's CANSOLV Technology has been part of Shell Global Solutions (Shell) since 2008. Shell's CO_2 Capture Technology development and deployment history follows along the same pathway as its SO_2 technology:

1. Laboratory testing and verification;
2. Piloting campaigns on real flue gas;
3. Small scale demonstration;
4. Small scale commercialization;
5. Large scale commercialization.

Laboratory testing started in 2000 with the objective of characterizing the properties of new and innovative amine molecules while developing new degradation inhibitors. After approximately four years of research, a first generation solvent formulation was developed, tailored for oxidative post-combustion applications and combining the following advantages:

- Excellent CO_2 loading capacity;
- Ease of regeneration with lower energy input requirements;
- High resilience against oxidative and thermal degradation.
- Low corrosivity.

Laboratory testing and lab-scale pilots on CO_2 capture started in early 2004 and continued into 2005. During this time a mobile pilot plant was constructed for the purposes of piloting the technology and over 10 000 hours of piloting ensued over the following ten years. Shell's CO_2 Capture Technology has been extensively piloted in Norway, at Technology Centre Mongstad and two other locations.

In addition to the qualification activities completed in 2019 at Klemetsrud WtE plant [4], there are currently two large scale plants in operation using Shell's CO_2 Capture Technology and they are presented in Table 11-6.

Table 11-6: Licensor key references - Commercial size plants with Shell' CO_2 Capture Technology.

Description	Completion
Lanxess CISA (New Castle, South Africa) • 62 100 t CO_2/year (170 t CO_2/day) • Natural Gas boiler • Solvent: Cansolv absorbent DC-103 • [redacted] • [redacted]	August 2013
Boundary Dam (Estevan, Saskatchewan) • Client: SaskPower • 1 200 000 t CO_2/year (3288 t CO_2/day) • Coal fired boiler • Solvent: Cansolv absorbent DC-103 • [redacted] • [redacted]	September 2014

The project subsuppliers engineering experience and reference list [105] contains more information about TechnipFMC and Licensor references.

11.2 Description of scope of work (7b)

The Scope of Work [15] document presented in section 4.5 includes the following main areas of activity:

- Modification of the WtE plant;
- Integration between the existing plant and the new CC Plant;
- New CC Plant;
- Site preparations, foundations and other civil work;
- Initial and normal operations;

All phases from engineering through purchasing, construction, installation and commissioning are included in the Scope of Work. TechnipFMC will be responsible for the majority of the Scope of Work.

Modification to the existing systems includes the following main items:

- Modification of the electrical supply, to have sufficient electrical power available for the operation of the new CC Plant;
- Modification/integration of the existing control system for the WtE plant.

Integration between existing plant and CC Plant includes:

- Integration of the flue gas system, to lead flue gas to the CC Plant;
- Integration to the existing district heating network;
- Integration of demineralisation-, process-, tap- water systems;
- Integration of other service and control systems.

The new capture plant includes the CC Plant at Klemetsrud, the Intermediate storage at Klemetsrud – including truck loading facilities – and the harbour facilities at the Port of Oslo. The following main items are included in the scope of work:

- Flue gas treatment, CO_2 absorption and solvent regeneration;
- CO_2 compression/liquefaction and conditioning;
- Truck transportation to the harbour storage at Port of Oslo;
- Harbour facilities and ship loading;
- Electrical power distribution;
- Process control system;
- Utilities.

The Initial operation phase covers the final stages until taking over and normal operation of the new CC Plant. FOV personnel will be mobilised in order to take part in the commissioning and start-up activities. The following main steps are included:

- Pre-commissioning and commissioning;
- Start-up of plant;
- Trial run of complete plant;
- Normal operation.

In addition to the scope of work, sections 6, 7 and 11.7 present an overview of the methods that will be used during the next project phase to execute the project. These sections are presenting information from the Project Execution Method [5] document, which contains more details about the methodology.

11.3 Organisation (7c)

The project organization will vary during construction and operation phases. This section summarises the content of the Project Execution Method [5] document.

11.3.1 Organisation in construction phase

During the construction phase, the project will be organized according to the organization chart in Figure 11-2:

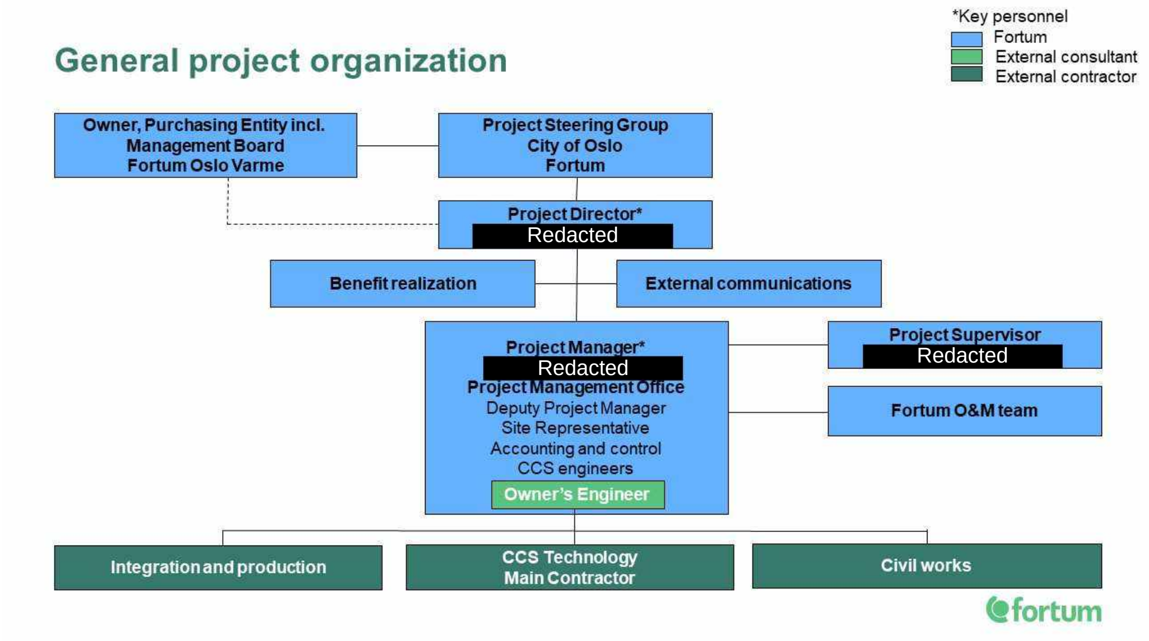

Figure 11-2: Preliminary project organization chart for construction phase.

Roles and tasks as presented in the following sub sections.

11.3.1.1 FOV Personnel

Owner, Purchasing Entity (FOV)

The Owner has a legal responsibility for the entire FOV CO_2 Capture Project and for reaching the agreed project goals. The Owner has also extended responsibilities outside of the project to reach the project goals.

The Owner appoints the members of the Steering Group and manage additional necessary recruitments for Operation & Maintenance (O&M) team.

Steering Group

The Steering Group (SG) ensures that the project's goals will be met.

SG approves all major procurements and decisions in the project. SG members advise and support the Owner, the Project Director and the Project Manager.

Project Director

The main tasks of the Project Director are overall responsibility of the project as well as processes connected to the dialogue with Ministry of Petroleum and Energy (MPE) and the responsibilities for benefit realization and external communication.

Project Supervisor

The Project Supervisor supports the Project Manager by ensuring the use of applicable Fortum's processes, instructions, templates, purchasing requirements in the project. In addition, the Project Supervisor participates as advisor, with knowledge and expertise in project management.

Project Manager

The main task of the Project Manager is the management of the project including overall time, cost, change and risk management as well as HSE. The Project Manager is responsible for:

- Organization of procurement activities for the scopes outside of TechnipFMC scope;
- Leading the Project Management Office;
- Supervision the Owner's Engineer services;
- Management of the project documentation with the Owner's Engineer;
- General management and control of suppliers and contractors;
- Reporting to the Gassnova;
- Reporting to the Project Director;
- Approving acceptance protocols and invoices.

Project Management Office

The following functions belong to the project Management Office and report to the Project Manager:

Table 11-7: Main tasks of the main functions of the Project Management Office.

Function	Main Task
Deputy Project Manager	• Organizing and leading Project Management Office; • Recruiting new Project Management Office members; • Approving acceptance protocols and invoices; • Executing any task delegated by Project Manager;
Site Representative	• Supporting Deputy Project Manager in leading Project Management Office; • Taking care of local requirements, norms, standards and authorities together with the Owner's Engineer; • General management and supervising of site operations together with the Owner's Engineer; • Health and safety management during construction and installation phase together with the Owner's Engineer; • General management of interfaces in the project with support of the Owner's Engineer; • Supply management and delivery control of local contractors and suppliers together with the Owner's Engineer; • Organizing O&M team training together with the Owner's Engineer and CCS Engineers; • Supervising the taking over/handing over procedure together with the Owner's Engineer;
Accounting and control	• Verification of invoices from formal point of view; • Ensuring that invoices are proceeded correctly in FOV's accounting systems; • Checking, storing and archiving guarantees; • Fixed assets breakdowns evaluation.
CCS Engineers	• Supporting the Project Management Office from technical point of view; • Technical documentation review;

Function	Main Task
	• Coordinating permit to work process for works on interface with the Klemetsrud WtE plant. • Ensuring communication between the WtE plant personnel, TechnipFMC, other contractors and O&M team; • Ensuring that technical lessons learned from Pilot testing period are taken into account on all project phases; • O&M manuals and documentation verification.

The Project Management Office is composed by both Fortum personnel and the Owner's Engineer personnel. Owner's Engineer organisation is further described in section 11.3.1.2. A preliminary organization Project Management Office organization team is presented in below chart, Figure 11-3.

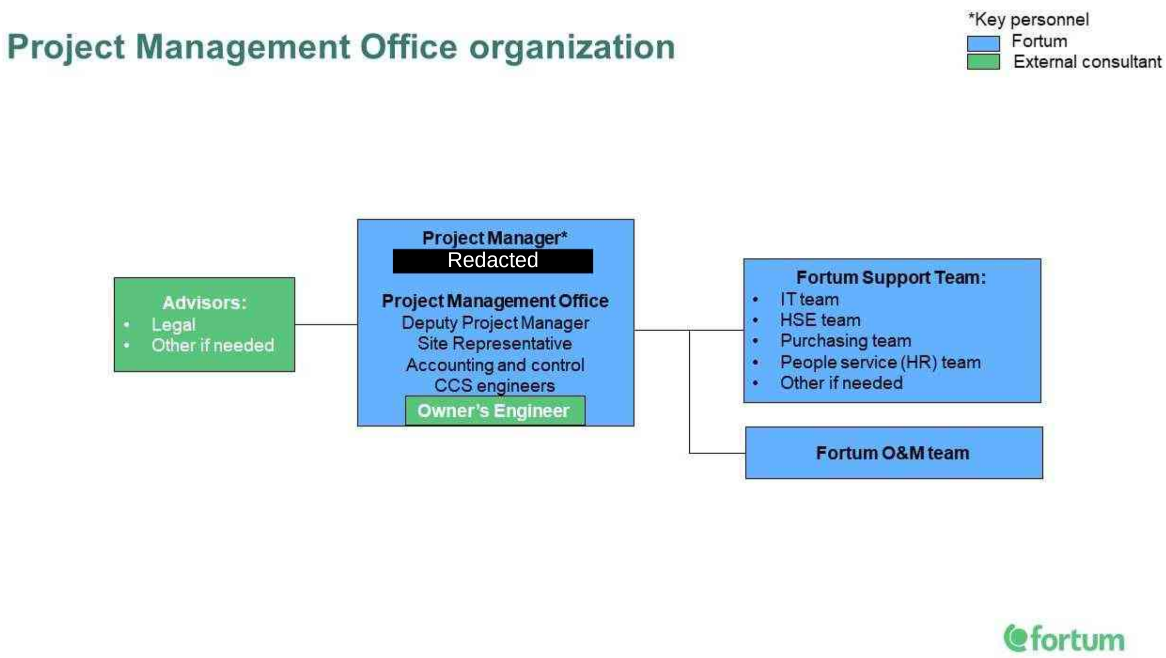

Figure 11-3: Preliminary Project Management Office organization.

Fortum Support Team

The Project Management Office will be supported by a Fortum Support Team consisting of experts and specialists in different areas:

- Fortum's IT team will support the project by providing necessary expertise needed for the integration of CC Plant to the Klemetsrud WtE plant IT infrastructure, and to perform adjustments in context of Fortum IT systems that are in use;
- Fortum's HSE team will support the Owner's Engineer HSE&risk Specialist in supervising HSE according to Fortum safety rules, practices and responsibilities regarding Client construction regulations (byggherreansvaret). Fortum HSE team will perform corporate HSE audits, on quarterly basis;
- Fortum's Procurement team will ensure support in context of sourcing, contracting and evaluating contractors and suppliers after execution of works;
- Fortum's People service (HR) team will support the Owner in recruitment of O&M team.

Other support teams will be engaged according to the needs.

External consultancy services (such as financial or legal advisory services) will be ordered by the project according to FOV's frame agreements.

FOV will order project management services from Fortum Corporation.

Operation and Maintenance team

The main tasks for the O&M team are:

- Preparing of detailed O&M philosophy based on inputs from TechnipFMC and other contractors;
- Participating in design, site and commissioning reviews, inspections and meetings;
- Attending all necessary O&M theoretical and practical trainings;
- Within their responsibilities manage HSE during the commissioning phase of the project;
- Operating the CC Plant during commissioning under supervision and in cooperation with TechnipFMC;
- O&M manuals and documentation verification;
- Participating in taking over protocol;
- Operating the CC Plant after taking over.

During construction activities (starting from pre-commissioning), the O&M team will have the same organization as during the operation phase. The organization is further described in section 11.3.2 and Figure 11-7.

11.3.1.2 Owner's Engineer

Owner's Engineer is the term used to define the consulting company providing technical supervision services to the project. The Owner's Engineer is employed by the Owner to bring the necessary competences needed to supervise TechnipFMC and all the other contractors and support the project management.

Owner's Engineer refers generally to the all the personnel included in Owner's Engineer organization working on the project. For this reason, the Owner's Engineer sets its own organization led by a Project Manager. A preliminary organization chart is presented in Figure 11-4.

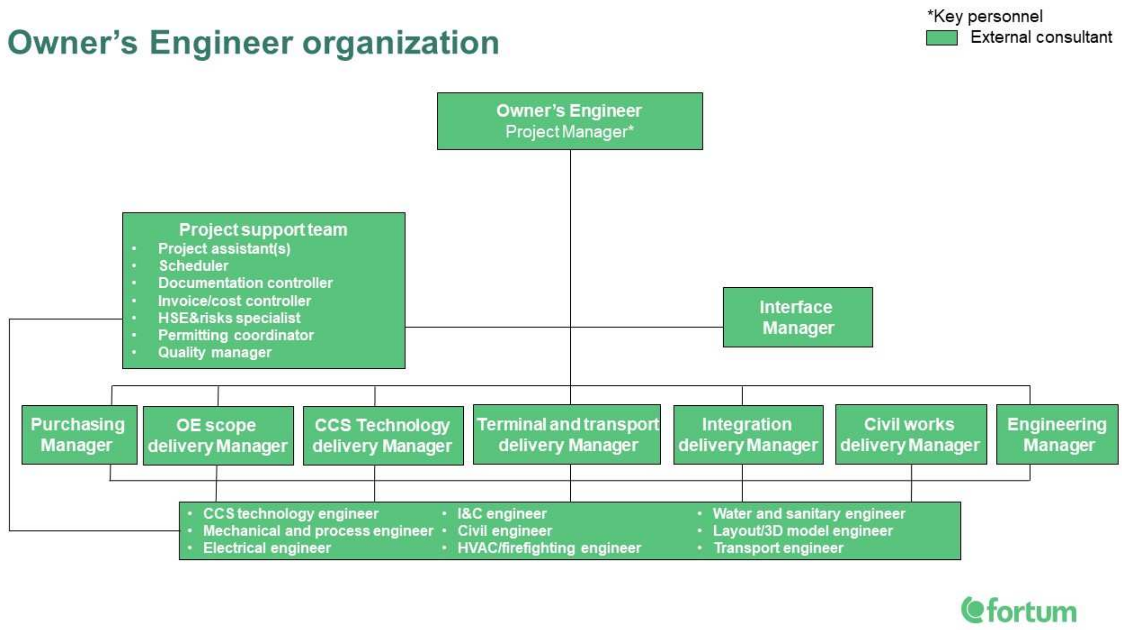

Figure 11-4: Owner's Engineer preliminary organization chart.

Owner's Engineer team structure is such that the main tasks can be carried out:

1. General project management:
   - Cost and time schedule planning, control and reporting to FOV and to Gassnova;
   - Organising the project meetings.
2. Engineering and document management:
   - Basic and detailed site organization and civil works design;
   - Detailed design for integration works;
   - Transport solution and interface towards CC Plant;
   - Documentation management, including document management system;
3. Quality Management
4. Interface Management
5. Procurement and supply management of equipment and services out of TechnipFMC scope, including delivery control;
6. Site activities:
   - HSE supervision and verification of compliance with Fortum's rules;
   - Construction and erection supervision;
   - O&M personnel training supervision;
   - Commissioning and taking over supervision.
   - Permitting: obtaining all necessary permits for construction and operation phase. For more information, see chapter 9.

The tasks, responsibilities and detailed organization of the Owner's Engineer will be defined in the Owner's Engineer agreement. The Owner's Engineer selection will be performed before the project execution start, during the interim period.

11.3.1.3 TechnipFMC

TechnipFMC project management and engineering team will be organized according to the organization chart of Figure 11-5:

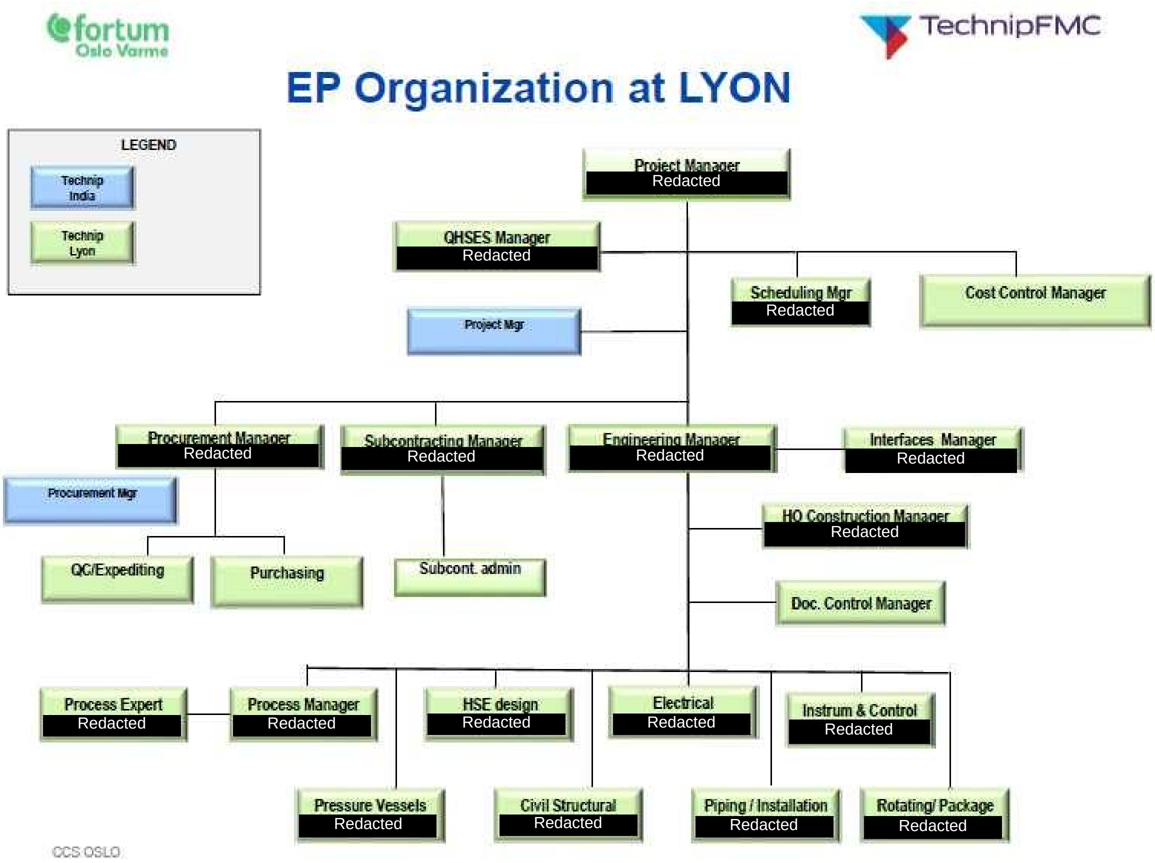

Figure 11-5: TechnipFMC project management and engineering preliminary organization chart.

TechnipFMC is contracted by the Owner and reports to Project Management Office (as per the chart in Figure 11-2).

One of the main responsibilities of TechnipFMC will be site management including site safety management. This activity will be delegated by FOV to TechnipFMC for all the work (including responsibility over all other contractors) while TechnipFMC is on Site. TechnipFMC will act as "Hovedbedrift" during the whole project period.

The Site Manager reports to TechnipFMC's Project Manager. A typical TechnipFMC site organisation during construction phase is depicted in Figure 11-6.

Concerning experience transfer from FEED phase to EPC phase, it is current practice for the TechnipFMC Project Offices (execution centres) to take into account transmitted FEED documentation. In addition, TechnipFMC Lyon, Milton Keynes and Paris have extensively exchanged information during the EPC proposal preparation (experience, history of the project, lessons learnt).

The Project Execution phase will be defined as a new project, for which the execution is validated by TechnipFMC management. The execution will be the most suitable one for the project.

Starting a project in more than one year from the end of FEED phase, will inevitably involve new key personnel. The engineering documents as well as project strategy is robust enough to support an efficient detail design in another TechnipFMC execution centre, especially with skilled people in terms of technology and project management.

FOV do not see any problems with this change of TechnipFMC organisation from FEED to Project Execution. Such a change (hand-over) is quite common in the industry and continuity will be ensured by overlapping participation of key personnel in the hand-over phase, good documentation and engineering basis according to TechnipFMC internal procedures.

There are also advantages related to change of team as the new team will have to do a thorough review of the engineering basis which will constitute a quality assurance of the executed engineering as well as an identification of possible areas of improvement and options for cost reduction.

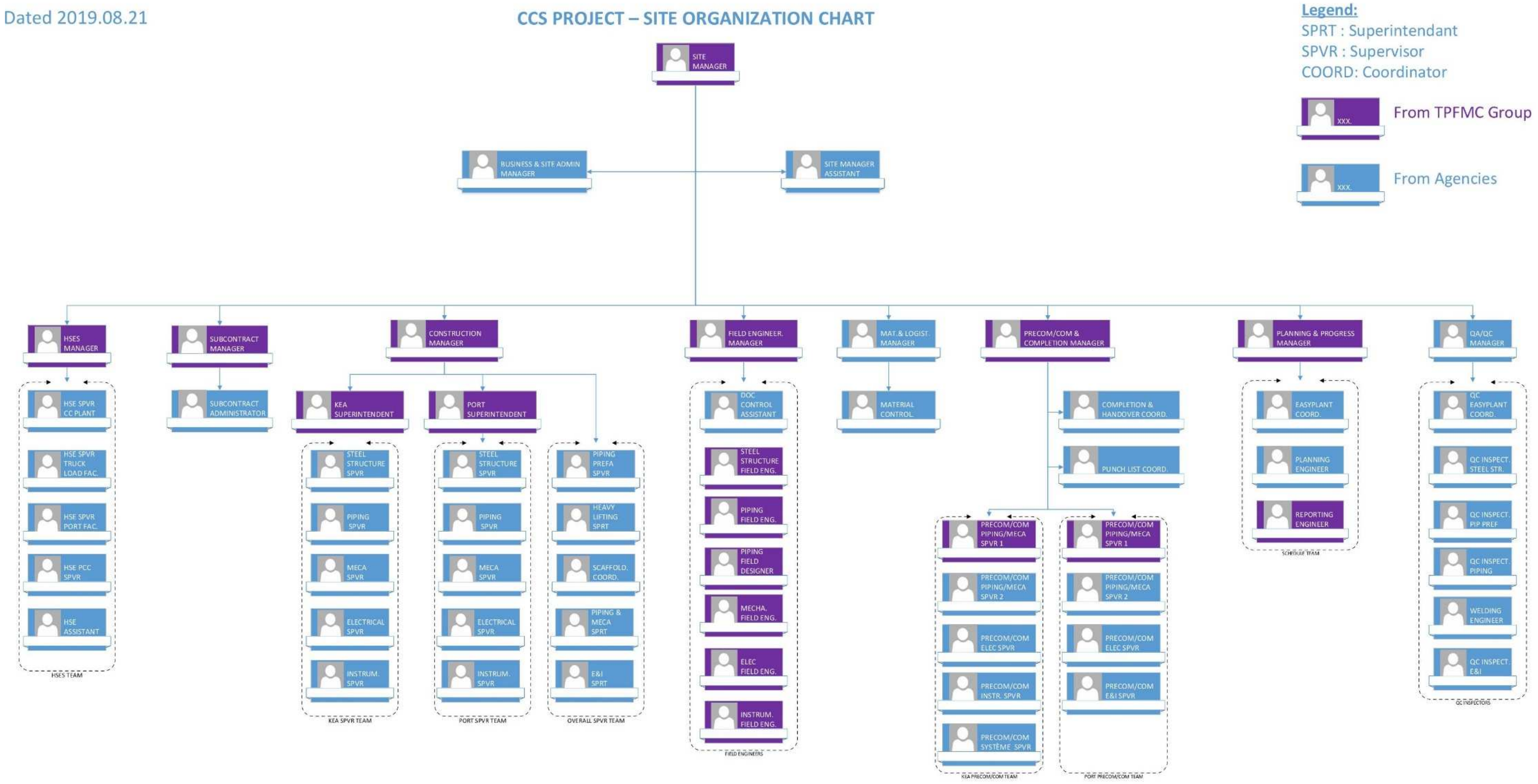

Figure 11-6: Preliminary/Typical TechnipFMC site team organisation chart.

11.3.2 Organisation in operation phase

During the operation phase, the O&M team will be organized in similar way as per commissioning phase. The organization is presented in Figure 11-7.

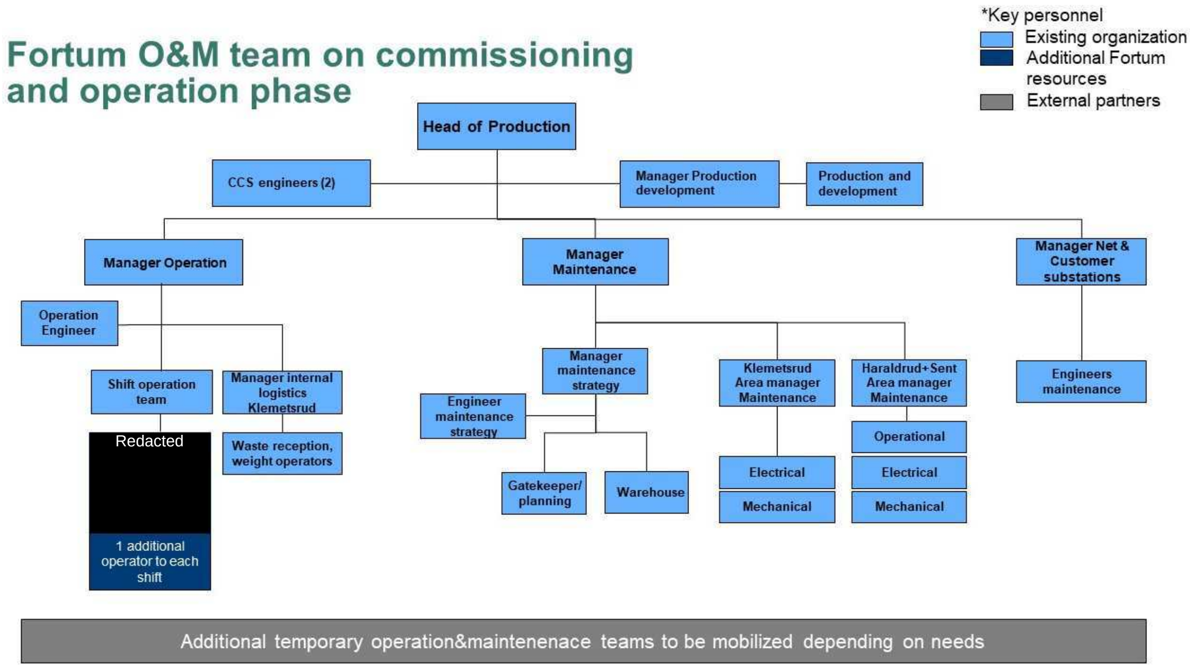

Figure 11-7: FOV O&M team during commissioning and operation phase.

With the current plan, the Head of Production with his team will be responsible for all plants/networks including the CC Plant.

According to Fortum practice, TechnipFMC will provide one specialist available at Site during the first 6 months of operation to support the O&M team in daily operation and to follow up maintenance activities related to the CC Plant. During the operation phase, TechnipFMC will report to Head of Production.

Before the operation phase starts, the Maintenance Manager will nominate a warranty responsible, who will manage all warranty related issues.

11.4 Key personnel (7d)

The project's key personnel is presented in the organizational charts included in section 11.3. FOV proposed key personnel are:

- Project Director: [redacted]
- Project Manager: [redacted]

The CVs are attached to the FEED Study Report (Attachment list is presented in section 14).

The Project Manager in the Owner's Engineer organization is defined as key personnel. Table 11-8 describes the competences level required for the role:

Table 11-8: Owner's Engineer Project Manager tasks and requirements.

Functional description	Competence requirements
• Overall project management of Owner's Engineer organization (people and tasks); • Project organization and resources management; • Communication with FOV (Project Manager and Project Management Office); • Reporting to FOV (Project Manager and Project Management Office).	• Master's degree and a minimum of 5 years relevant experience or bachelor's degree with more than 10 years relevant experience.

With regards to TechnipFMC personnel, the following roles are defined as key personnel:

- Project Manager: [redacted]
- Engineering Manager: [redacted]
- Site Manager: to be nominated. The requirements are presented in Table 11-9.
- Commissioning Manager: to be nominated. The requirements are presented in Table 11-10.

CVs for the proposed key personnel are attached to the FEED Study Report (Attachment list is presented in section 14).

Table 11-9: TechnipFMC Site Manager tasks and requirements.

Functional description	Competence requirements
• Management of all the Site works; • Overall responsible for HSE at Site; • Ensure that all the Site works are performed according Site Safety Plan. • Ensure that all the Site works are performed according to the contract.	• Master's degree and a minimum of 5 years relevant experience or bachelor's degree with more than 10 years relevant experience; • A similar role in at least one large industrial project.

Table 11-10: TechnipFMC Commissioning Manager tasks and requirements.

Functional description	Competence requirements
• Overall commissioning management; • Ensure that the plant is started-up on time and operates within the contractual parameters; • Directing Site commissioning activities; • Responsible to develop commissioning documentation; • Lead commissioning team at both home office and Site; • Ensure best practice implementation; • Ensure transfer of theoretical and practical knowledge to the FOV O&M team.	• Master's degree and a minimum of 5 years relevant experience or bachelor's degree with more than 10 years relevant experience; • A similar role in at least one large industrial project.

11.5 Subsuppliers (7e, 7f, 7h)

Identified suppliers as given in Table 11-11 are based on prequalification's of suppliers and specific tendering activities during FEED phase. TechnipFMC suppliers are under their responsibility, suppliers list is identified in TechnipFMC documentation.

Table 11-11: Main subsuppliers identified.

Supplier	Delivery
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Subsuppliers will be selected during interim phase and first phase of the execution project. Accounting records have been collected during the tendering activities. TechnipFMC is selected as main contractor and contract negotiations are ongoing. Technip France S.A. accounting records for 2018 are attached to this report.

11.6 Interface management (7g)

FOV, Fortum and TechnipFMC are all experienced in managing major EPC contracts. Experience gained in relevant projects (see section 11.1) will be utilised to ensure efficient interface management in the project.

The project has been making use of a procedure [88] to clarify communication lines, requirements and other information handling between the various interface parties.

The relevant definitions are presented below:

- **Interface Party:** any member of the CCS chain or a contractor undertaking a scope of work in the project or other work scope within a defined area. Each party is responsible for defining their need for interface information (own interface management system).
- **Interface:** a boundary across which two independent systems meet and act on or communicate with each other.

- **Interface Manager:** the person who has the overall responsibility to coordinate the flow of information about the respective interfaces via the Interface Management System.

The governing principles for the interface management are:

- Interface Parties are responsible for identification of their interface needs (what and when required from others);
- When in need of interface information, Interface Parties will raise Interface Query which will be recorded in the Interface Register;
- When needed, interface meetings will be arranged to discuss, conclude and resolve the outstanding interfaces between Interface Parties;
- The Interface Manager is responsible for maintaining the Master Interface Register, which also includes line and tie-in list;

The main interface parties and the interfaces between them are depicted in Figure 11-8 and Figure 11-9. The two directional arrows represent the interfaces.

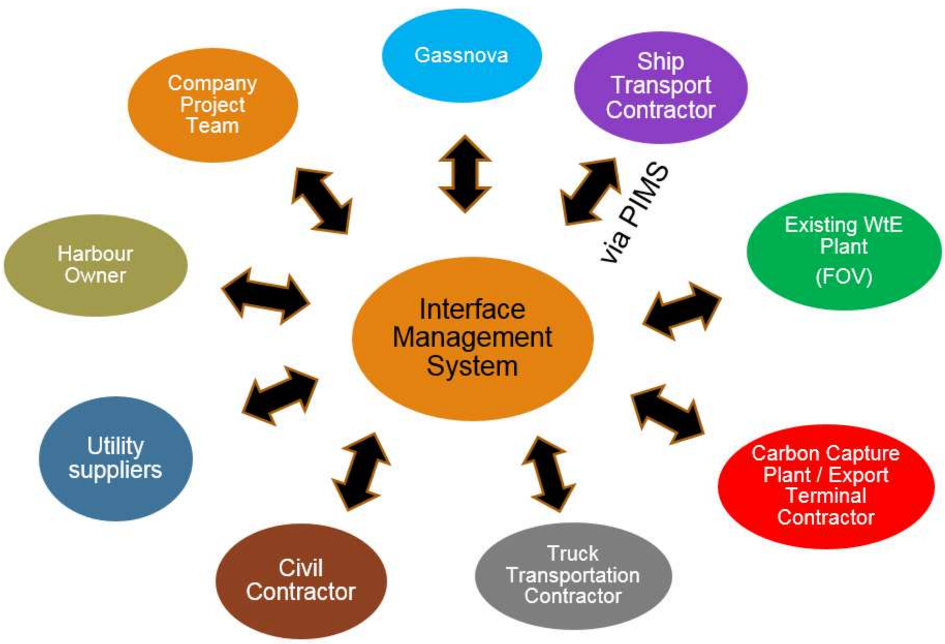

Figure 11-8: Management of technical information flow between the Interface Parties [88].

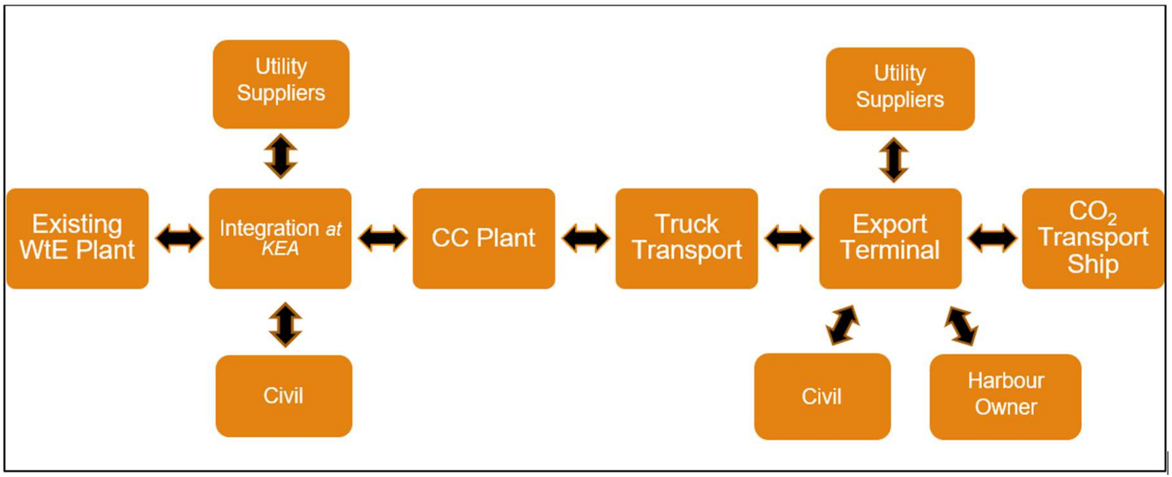

Figure 11-9: Main interface relationship between the Interface Parties [88].

11.6.1 Overall Interface Management

All interfaces between the interface parties are numbered according to numbering methodology fully described in the Interface Management Procedure [88], and all technical interfaces identified during FEED phase of the project are documented in the Master Interface Register [53].

While FEED phase focused on piping and instrument signal interfaces, the register will be updated in the next project phase to include electrical, civil/structural and other non-piping interfaces.

A suitable tool for Interface Management will be selected during the next project phase.

11.6.2 Interface Management for each contractor

Each contractor will define all interfaces for its scope of work and is responsible to ensure that the interfaces are properly managed.

Throughout the entire duration of the project each contractor is responsible for:

- All internal coordination between the contractor's departments and offices involved in the performance of the work. This includes coordination between the contractor and its subcontractor(s);
- All external interface communication via the FOV Interface Management System. This includes coordination between the contractor and third parties and any other contractors who interface with the contractor's Scope of work;

Each contractor will prepare its own Interface Management Plan and Interface Register to manage its interfaces and minimize risks to its scope of work. Each interface is to document the detailed nature and location of the interface and the proposed responsibility.

11.7 Project execution method

The Fortum project execution method is implemented in the FOV CO_2 Capture Project. The project model will be used in the next project phases and is described in more detail the Project Execution Method [5].

The Fortum project execution model includes major areas that are briefly described in the following sections.

11.7.1 Project execution strategy

A Fortum project management team and a contracted Owner's Engineer team are established. TechnipFMC has been selected as the main contractor and will form its own project management team. The contractors working for the project will be followed up by the Owner's Engineer team as an integrated part of the FOV Project Management Office.

11.7.2 Project organization structure

The project organization is described extensively in section 11.3.

11.7.3 Project execution phases

The project execution phases are identified in Fortum procedures. The following steps are identified with separate flowcharts, decision gates and procedures:

- Project establishment;
- Project Start-up;
- Project Execution;
- Verification of readiness for commissioning;
- Commissioning and taking over;
- Project closing.

11.7.4 Procurement and subcontracting

The majority of the purchasing activity will be handled by TechnipFMC. Smaller procurement packages which will be handled by the Owner's Engineer team with review/approval by the Project Manager.

11.7.5 Schedule management and progress monitoring

The Owner's Engineer establishes the overall time schedule with input from the schedules received by the various contractors. The schedule is then used to supervise and manage the project. Monthly progress reports (including HSE reporting) are prepared for reporting against the scheduled progress.

11.7.6 Cost management

Project cost is followed up against the project budget. Invoices from contractors are handled in the Fortum Maximo IT-system with functionalities for management of purchasing and invoicing activities. Owner's Engineer is responsible for the cost control and report to the Project Manager.

11.7.7 Methods and tools

Relevant procedures and systems for among others, Quality Assurance, document and data management, change management are based on Fortum procedures.

11.7.8 Communication

A meeting schedule including start-up, progress and close-out meetings with all relevant parties is established at project start. Progress meetings are scheduled as a minimum monthly. Meeting schedule is typically handled by Owner's Engineer with approval by the Project Manager or Deputy Project Manager.

External communication is coordinated by the Project Director.

11.7.9 HSE management

HSE is a top priority in Fortum, with Fortum's Safety and security handbook [1] implemented as basis for the project. The Project Manager is responsible for the HSE management. HSE goals are defined in section 6.1 and include zero accidents and zero lost working days.

11.7.10 Risk management

Risk management is performed in accordance with Fortum guidelines. The risk will be managed by the HSE&risks specialist, with monthly general follow up and quarterly detailed review with all the stakeholders.

11.7.11 Work Breakdown Structure

A preliminary Work Bread Down (WBS) structure has been prepared and will be confirmed during the project start-up phase.

12 BENEFIT REALIZATION

Benefit realization is an essential and central element for success for the Norwegian full-scale CCS Project and proving the potential in the respective industry is pointed out as an important evaluation criterium.

The overall goals of activities for benefit realization as outlined by Gassnova and the MPE are:

1) Demonstrate that CCS is feasible and safe
2) Reduce cost for coming CCS projects through learning curve effects and economy of scale
3) Give learnings related to regulating and incentivizing CCS activities
4) Contribute to new industrial opportunities

A key goal for the FOV benefit realization work is to inspire as many Waste-to-Energy (WtE) plant operators and owners as possible to investigate the possibilities of building new CO_2 capture facilities, both nationally and internationally, and to deliver their CO_2 to Northern Lights for permanent storage. It is particularly important to succeed internationally, as pointed out in both the previous and the current Government Declaration. The FOV CO_2 Capture Project has worked actively and will continue to work hard to create positive ripple effects of its completed feasibility, concept and FEED studies and the subsequent phases of the project.

The following paragraphs describe the massive waste challenges the world is facing and show how these challenges create a great potential for CCS in the WtE industry. CCS on WtE is an essential measure for cutting climate emissions on a global scale, closely connected to the worldwide transition towards sustainable waste handling, cities' climate work and a circular economy. It is also explained why CCS on WtE is important in order to reduce emissions from plastics that cannot be recycled, and the significant BIO-CCS (BECCS) potential in the WtE industry.

Waste is one of the world's biggest climate challenges

Every year the world dumps a more than two billion tons of waste [106]. If all this waste was put on trucks, they would go around the world 24 times, and a shocking 99 percent of the stuff we buy is trashed within 6 months.

Poorly managed waste contributes to global climate change through methane generation. Managing waste properly, including its greenhouse gas emissions, is essential for building sustainable and liveable cities [107]. Urban regions are rapidly developing without adequate systems in place to manage the increasing amounts and changing waste composition of citizens. The waste industry has a unique position and responsibility as a potential reducer of greenhouse gas (GHG) emissions as industries, countries and cities worldwide struggle to address their carbon footprint [108].

In 2016 an estimated 1.6 billion tons of CO_2-equivalent GHG emissions were generated from management of household waste alone, also called Municipal Solid Waste (MSW) management. This is driven primarily by disposing of waste in open dumps and landfills without landfill gas collection systems, and accounts for about 5 percent of global emissions [109]. Without improvements in the sector, MSW–related emissions are anticipated to increase to 2.6 billion tons of CO_2-equivalents by 2050. In the EU region, municipal waste management activities alone could potentially account for 18% of the 2012 Kyoto GHG reduction target set for the original 15 member states.

MSW is only one of several waste streams that countries and cities manage. Other common waste streams include industrial waste, agricultural waste, construction and demolition waste, hazardous waste, medical waste, and electronic waste. Some waste streams, such as industrial waste, are generated in much higher quantities than MSW. For the countries with available industrial waste generation data, the trend shows that globally, industrial waste generation is almost 18 times greater than MSW. Generation of industrial waste rises significantly as income level increases.

Globally more than 80 countries committed to reduce emissions through the 2017 Paris Agreement, and improving waste management is one of the most important measures of contributing to this effort. Over 90 percent of waste in low-income countries is still openly dumped or burned in open mounds resulting in toxic air pollution. Much of the fastest growth in modernization of waste management systems is occurring in Eastern Europe and Central Asia, where governments are focused on closing old dumpsites and building centralized facilities for treatment and disposal.

Waste-to-energy as an essential part of a circular economy

WtE plants' most important role is to burn waste that could not be prevented or recycled, and generate energy in the form of steam, electricity or hot water [29].

- The energy produced in WtE plants contributes to climate protection and security of energy supply, by replacing fossil fuels that would have been used to produce this energy in conventional power plants [29].
- Keeps the circle clean and improves the quality of recovered materials by dealing with unwanted components in the material cycles. In effect, WtE plants act as pollutant sinks and fulfil a hygienic task for the society.

WtE is the most sustainable solution today for residual waste that cannot or should not be recycled, and an important part of a circular waste system. WtE is not a contradiction to sorting and recycling, but a necessary addition. Sorted residual waste also offers a significant source of renewable energy [108]. WtE incinerators can reduce GHG emissions while generating electricity or thermal energy, when operated effectively and to strict environmental standards. Incineration with modern pollution controls and other thermal processes for WtE can play important roles in securing national energy balance based on national resources, while at the same time reducing fossil fuel consumption and GHG emissions.

Globally, more than 130 million tons of waste are incinerated every year at over 600 waste-to-energy plants, producing over 280 TWh of electricity per annum (almost at the level of Italy's electricity consumption, and equal to the electricity consumption in Norway, Sweden and Denmark combined). This is equivalent to the total energy demand of approximately 10 million European consumers (28 MWh per capita per annum). In Norway, waste incineration accounted for just under 2 per cent of total CO_2 emissions in 2017 [12].

Modern WtE plants are clean and safe, meeting the most strict emission limit values placed on any industry set out in the Industrial Emissions Directive [110].

The next step towards a sustainable waste cycle: CCS on Waste-to-Energy

As stated above, the main purpose of WtE plants is to handle sorted, residual waste in a sustainable and clean manner. From a climate and resource perspective it is also important to utilize the waste heat from the combustion with the production and utilization of district heating, cooling, industrial steam and electricity.

The transition from landfills to sorting, recycling and energy recovery of residual waste (WtE) significantly reduces GHG emissions and environmental impact. Waste incineration with energy recovery will by itself result in more than 75% GHG reduction compared to landfilling the same waste [30]. The reduction is due to the fact that the greenhouse gases generated by combustion are weaker than those formed on landfills (methane vs. CO_2), in addition to avoided GHG emissions from alternative (fossil) energy production. The reduction in GHG emissions by incinerating the waste with energy recovery instead of landfilling it is approximately 845 kg CO_2 equivalent per ton of waste. The transition from landfills to WtE also enables the capture of the still significant point sources of CO_2 emissions from the incineration and forms the basis for the development of CCS in the waste industry.

Complying with the strict emission limit values set out for the business, WtE has extensive experience in working for continuous reduction of emissions. Capturing CO_2 from waste incineration is the natural next step towards a sustainable and circular waste treatment. The FOV CO_2 Capture Project demonstrates how cities can cut large emissions, utilize local resources and mitigate climate change from waste handling as a part of sustainable city solutions. CCS from WtE can be an important part of cities' emissions reductions, as WtE is in many cities the single largest point of CO_2 emissions.

Solving the plastic challenge

The amount of plastics in the world is growing, and is expected to triple over the next 30 years [32]. As described in section 5.6.3, WtE is the most sustainable way of treating plastics that cannot be recycled at all, or has been recycled a number of times and is no longer possible to recycle [31]. Even with plastics actually sent for recycling, a lot is rejected at the recycling site. It has been thoroughly documented that plastics from the EU sent for recycling ends up dumped in Asian countries such as Malaysia, China and Vietnam [111].

If today's consumption patterns and waste management are not improved, by 2050 there will be around 12 billion tons of plastic waste on the world's landfills and in the environment [33].

This presents major challenges in both a short and long term perspective, even with extensive research and development of sorting systems, recycling technology and the development of more recyclable packaging solutions. With the decommissioning of polluting landfills and increased plastic quantities and types, new fractions must also be energy recovered in the future to ensure that pollutants are removed from the cycle (sewage sludge, dirty and contaminated plastics, mixed products etc.). These factors combined are increasing the future need for effective WtE facilities. By establishing carbon capture from incineration of plastics that can no longer be recycled, this challenge can be dealt with in a sustainable way.

Large potential for negative emissions

As pointed out in section 4.3.2, Waste-to-Energy with CCS can significantly contribute to achieve negative emissions. According to the EU legislation [112] the biodegradable fraction of municipal and industrial waste is considered biomass, thus a renewable energy source.

The sources of this biogenic CO_2 are residual food scraps, textiles, wood and paper products that were not sortable before incineration. Capturing the biogenic CO_2 is in effect removing CO_2 from the atmosphere. Thus, half of the captured CO_2 from the WtE flue gases constitute net removal from the atmosphere, which is often referred to as "negative emissions", i.e. reductions that have a greater benefit than reducing emissions from fossil fuel combustion. The energy output from WtE plants is about 50% renewable, and the CO_2 emissions from this energy output is part of the natural CO_2-cycle.

With waste being one of the few worldwide established value chains that produces energy from biomass, this gives a significant BIO-CCS (BECCS) potential for the WtE industry. Negative CO_2-emissions will also help neutralizing other emissions that are much harder to reduce or remove in a short-to-medium term perspective.

Potential for CCS from WtE in the EU

As pointed out in section 5.6.2, there is a growing demand for WtE capacity in Europe as EU moves away from landfills and towards increased sorting and recycling. 142 million tons of residual waste treatment capacity will be needed in EU by 2035 in order to fulfil EU targets on MSW, and assuming that ambitious recycling targets (65% material recycling and a reduction to 10% landfilling) will be achieved [29]. With the current European WtE capacity of 100 million tons, around 40 million tons of new capacity with prospects for establishing CCS has to be established in the EU.

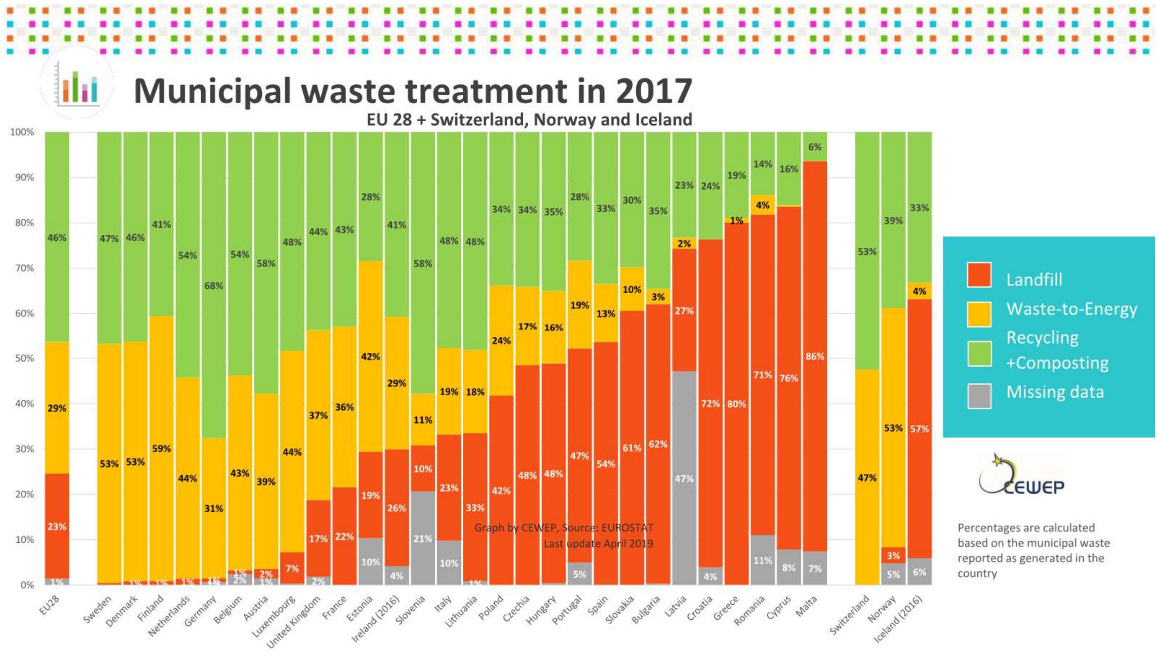

Figure 12-1. Overview of European municipal waste treatment by country and treatment type , CEWEP [113].

Worldwide potential for CCS on WtE

There is an overall global trend of increased recycling, composting and waste-to-energy, with Eastern Europe and Central Asia in the lead in the transition towards sustainable and circular waste management. In upper-middle-income countries WtE markedly increased from 0.1 percent to 10 percent, driven by China's shift from landfills to incineration [109]. Additionally, several high-income Gulf countries are pursuing waste-to-energy solutions and are planning properly designed waste management facilities, including incinerators.

A number of large WtE plants are under planning or construction in Asia, and also Africa has built its first WtE plant in Ethiopia. In Central America, Mexico City has a large WtE facility underway, scheduled to start operating in 2020 [114] (1.6 million tons). Examples in Asia are Dubai (1.83 million tons), Singapore (2.5 million tons), Istanbul (> 1 million tons), and Fortum's own WtE plant in Jakarta [115] (800 000 tons) is one of a number of plants currently planned or under construction in the Far East, including China [116].

Fortum's supplier of the newest combustion line at Klemetsrud (Hitachi Zosen Inova - HZI) is developing a carbon capture plant on coal power for the production of synthetic fuel, based on hydrogen and CO_2 [117]. This development is valuable and directly transferable technology for WtE plants.

Knowledge about and developing technology for CCS is an added opportunity to make significant climate improvement in the waste business, and is especially important towards cities and countries with emerging Waste-to-Energy. Based on the experience and knowledge from FOV, new WtE plants can be prepared for and in the future built with cost-effective and integrated CCS.

12.1 Communication and sharing of knowledge (9a)

As shown in section 4.3 (*Business case for the Beneficiary*) and in the Benefit Realization Plan [118], Fortum recognizes the unique potential that the FOV CO_2 Capture Project represents for Norway. Oslo and Fortum together, have a strong interest in developing the technology in the direction of cost-effective, safe and qualified solutions for decarbonization. Fortum aims to be at the forefront of developing both the industry, the technology and new green jobs. The FOV CO_2 Capture Project will generate great learning and international transfer value as well as an opportunity to develop carbon capture to become a shared European initiative.

As described over (*Large potential for negative emissions*), the FOV CO_2 Capture Project also has an added climate value because about 50% of the emissions from waste incineration – and 100% of the emissions from biomass plants – are biogenic and a part of the natural, short-term CO_2 cycle. A full-scale CO_2 capture plant at Klemetsrud will thus remove up to 200 000 tons of CO_2 yearly from the atmosphere in addition to reducing the fossil emissions. The WtE industry as a whole can contribute to extracting large amounts of CO_2 from the atmosphere, starting with learning and technology development at Klemetsrud.

FOV will work to secure the realization of the Norwegian full-scale CCS Project by:

- Contributing to demonstrate a full-scale CCS value chain;
- Building support for the Norwegian full-scale CCS Project and confidence in CCS as a mean to mitigate climate change;
- Prove potential ripple effects in the WtE business;
- Identifying the next full-scale projects that can be accelerated if the CCS Carbon Capture Oslo at Klemetsrud is realized:
    - Within the Fortum Group;
    - WtE industry internationally;
    - WtE industry in Norway.

Official goals to reduce GHG emissions on city, national and international levels require that all sectors implement solutions, including the WtE sector. The case for CCS retrofit on WtE is particularly compelling:

- WtE facilities have limited or no possibility to substitute their fuels with lower-emissions alternatives, as the main purpose is to treat waste that cannot or should not be recycled;
- WtE facilities are built to serve society's need for safe and environmentally secure waste treatment and represent large investments with long lifetime of operation;

- WtE with CCS can significantly contribute to achieve negative emissions (BIO-CCS/BECCS) and eliminate emissions from plastics not possible to recycle;
- WtE facilities are in many cases already fully integrated to provide heating and cooling services to large municipal markets;
- For several municipalities in Europe, WtE is one of the largest point sources of GHG emissions, as is the case for FOV in Oslo. Without CCS on FOV, Oslo will not be able to meet its emissions reductions targets, even if all transport and building sites are electrified.

Because there are almost 500 similar WtE installations across Europe, and many more planned, the case for Benefit Realization is also very promising. All knowledge and experience collected by FOV will be relevant for the next wave of CO_2 capture projects being evaluated for WtE. This includes the other WtE facilities within the Fortum portfolio (Sweden, Finland, Poland and Lithuania), as well as facilities operated across Europe by FOV's colleagues and competitors.

The ongoing activities started during the concept and FEED phases have contributed significantly to spread the promising opportunities related to CO_2 capture from WtE, and positive ripple effects with other players and other industries that are considering using CCS. The executed activities have established the foundation for Benefit Realization work in the next phases, and these will be matured and developed as shown in the Plan for further Benefit Realization work [118]. Please note that the initiatives and activities undertaken in FEED are thoroughly described in the Benefit Realization report [119].

Collaboration and activities within the Fortum Group:

- Studies and pilot testing at Stockholm Exergi;
- Studies at Fortum's WtE plants in Zabrze and Klaipeda;
- Fortum has established a voluntary market for certificates of CO_2 removal from the atmosphere; PURO, which will be fully operational as an independent entity in 2020.

Dialogue with the Waste-to-Energy industry:

- Amager Resource Center (ARC);
- Bergen area Inter-Community Renovation company (BIR);
- Lyse/Forus;
- Returkraft and the Eyde Cluster;
- Renova;
- The German Energy from Waste Group (EEW);
- International Solid Waste Association (ISWA) Network;
- Confederation of European Waste-to-Energy Plants (CEWEP).

Dialogue and initiatives towards external stakeholders, R&D and Academia:

- MOU between Fortum Group and Equinor, where the parties agree to enter further discussions to explore the possibility of cooperating in CCS development. This includes CO_2 capture and liquefaction at Fortum sites, and transportation to a CO_2

storage infrastructure which may be constructed by Equinor and its partners in the Northern Lights.

- FOV together with NL, has made an application to the EU PCI (Projects of Common Interest) program. This is further described in the Benefit Realization Plan [118];
- Participation in the Carbon Neutral City Alliance. The alliance membership includes Amsterdam, Helsinki, Copenhagen, Oslo and Stockholm. These have joined forces to collaborate on a project on evaluating carbon capture and storage (CCS) or usage (CCU), as part of their work in the city network Carbon Neutral City Alliance (CNCA).
- FOV is an active part of the communication network of participants in the Norwegian full-scale CCS Project. Gassnova coordinates the network and the participants engage in the activities of hosting CCS-safaris, media visits and other activities with the common goals to increase awareness, knowledge and recognition of CCS. Gassnova and the network represent the Norwegian full-scale CCS Project on the website ccsnorway.com.
- Feasibility study started at Borg CO_2 (former Øra CCS cluster).

FOV strives to leverage cooperation with external R&D communities to further improve CO_2 capture technology and solutions. The FOV strategy to cooperate on R&D is four-fold:

1. Participate in R&D consortiums with specific project plans for improving the overall CCS performance

a. The current funding application in the EU Horizon 2020 program with SINTEF leading the consortium. This application is a collaboration with Norwegian and European Industry and Research Institutes to submit a project proposal to the EU Horizon 2020 program in late August 2019. If the proposal is successful in its evaluation, an R&D consortium will begin its defined activities in late 2021. Evaluator results of this funding application are expected in Q1 2020. A positive outcome from this would allow project start-up in Q3-Q4 2020.

b. Several other WtE and district heating commercial units in the Fortum portfolio are performing their own CO_2 capture technology R&D activities. Examples of this are the CO_2 capture pilot at Stockholm Exergi (SE) and the concept evaluation studies at Fortum WtE units in Klaipeda (Lithuania) and at Zabrze (Poland).

   i. SE is currently investigating CO_2 capture using Hot Potassium technology, with a long-term goal of establishing full-scale CO_2 capture from the Värtaverket biomass plant (fuelled with woodchips), for subsequent transport and permanent storage connecting to the Northern Lights value chain. The goal is to capture and store up to 800 000 tons of CO_2 annually. SE has signed a Memorandum of Understanding with Equinor.

   ii. The focus of the pre-study in Klaipeda has been to assess lessons learned and results from the two studies performed by respectively FOV and SE. Based on this, a choice of technology will be done to perform a test program at the facility in Klaipeda.

   iii. In Zabrze, the pre-study has focused on investigating whether rail transport will be a technical, logistical and financially attractive solution for transporting CO_2 from this inland location to a quay on the Baltic coast.

iv. At Zabrze, Fortum is in addition collaborating with the University of Silesia in Katowice to perform a more detailed research study on CCS.

c. Feasibility study started at Borg CO_2 (former Øra CCS cluster), where FOV is a partner and a member of the steering group.

d. ZeroC: FOV is participating in a study with SINTEF, Chalmers and several other industrial actors to investigate the role of CCS/BECCS and supporting infrastructure for cost efficient transition to a zero carbon industry in Norway and Sweden.

2. Exchange knowledge in international networks aimed at promoting CCS technology improvement

a. FOV is a formal member of the EU CCUS project network and attended the latest network meeting on 16th October 2019.

b. FOV has close contact with The International CCS Knowledge Centre in Saskatchewan, Canada.

c. Additional research collaboration opportunities are generated in the FOV participation in the WtE sector networks CEWEP (Confederation of Waste-to-energy Plants) and ISWA (International Solid Waste Association). These potential research collaborations are considered on a case-by-case basis.

3. Give access to students and academic researchers working on CO_2 capture process technology and project improvement

a. The monitoring of trace emissions from the CO_2 capture pilot operations in 2019 was mainly performed by research specialists at the University of Oslo. This type of collaboration will be most relevant when the full-scale facility is operating and generating data which can be analysed and shared.

There may be opportunities in the construction phase for students' research, and these will be considered when possible.

b. FOV is collaborating with BI on seminars and study visits from the BI executive management programme.

c. FOV has contributed to PhD theses at the Oxford doctoral programme.

d. FOV is cooperating with Elvebakken High School and the Lektor 2-programme. The goal is to increase interest and knowledge about science, technology and mathematics for high school students.

4. Maintain an active dialogue with technology suppliers that perform their own research related to WtE and CO_2 capture.

a. FOV has a close collaboration with Shell, with the suppliers of incineration solutions (e.g. Martin GNVH), and dialogue with new technology suppliers such as CO_2 Solutions and Compact Carbon Capture.

b. FOV and the Fortum Group extensively utilize digital channels such as the respective homepages fortum.no and fortum.com, including project pages. These platforms are used to communicate to communicate the latest status of the FOV CO_2 Capture Project, the Norwegian full-scale CCS Project, CCS technology and the potential spread to other countries and markets. In addition, FOV is an active user of social media such as LinkedIn, Facebook and Twitter, to communicate news about the project, activities such as visits and distribute editorial media coverage.

12.1.1 Current status in Waste-to-Energy

During the FEED phase of the FOV CO_2 Capture Project, significant progress has been made in the effort to gain interest and support for the CCS technology as an important solution for WtE plants across Europe. The platforms for this work have been meetings within established European and Norwegian industry network organizations, bilateral meetings, invited workshops, seminars and larger project constellations. After spreading the experience and knowledge gained since FOV started to develop CO_2 capture at its plant, several WtE plants are now starting pre-studies or feasibility studies for new CCUS-projects, both nationally and internationally:

- The Fortum co-owned Stockholm Exergi has initiated studies and technology testing and is aiming towards a full-scale CCS plant, delivering CO_2 to the Northern Lights;
- Borg CO_2 (former Øra CCS cluster) has recruited several new partners and more CO_2 emission sources in addition to FREVAR, and has started feasibility studies;
- Concluded pre-studies at Fortum's WtE plants in Klaipeda and Zabrze;
- Amager Resource Center in Copenhagen has recognized CCUS as the most important measure to decarbonize their WtE plant, and has started studies aiming to realize a full-scale CCS plant;
- In the Netherlands, TWENCE aims to capture CO_2 on a large scale from the flue gases produced by their WtE plant and make it suitable for beneficial use in greenhouses. The intention is to capture 100 000 tons of CO_2 annually from spring 2021;
- Another Dutch waste recycling and WtE company; AVR, will start the construction of a large-scale CO_2 capture system as it seeks to reduce its greenhouse gas emissions. The construction of the CO_2 capture plant in 2019 means that 60 000-100 000 tons of CO_2 is expected to be captured and recycled. The captured CO_2 will be utilized in greenhouse horticulture areas;
- BIR (Bergen Interkommunale Renovasjonsselskap) has conducted a feasibility study on the usage of CO_2 rich-flue gas for producing a carbon fibre product, and is considering moving forward with studies in CCUS;
- The British energy company DRAX is currently testing CO_2 capture and BECCS with a pilot plant at their bioenergy plant in North Yorkshire;
- In Trondheim and Göteborg, the city politicians have adopted a goal to realize CO_2 capture on their WtE plants. FOV has initiated dialogue with both Statkraft Varme and Renova;
- EEW is planning to start CCUS studies, and the dialogue with FOV regarding a possible use of the CCS pilot is ongoing;
- The WtE company Returkraft in Kristiansand has conducted a desktop study on CO_2 capture considering business models and framework for CCUS in Norway. Returkraft is also a member of the Eyde Cluster, who has completed a pre-study on carbon capture amongst members of the cluster. The conclusion was that if the cluster members are to achieve climate goals, carbon capture is inevitable.;

- In Switzerland, the national WtE operators have asked ETH Zurich to assist them in conducting a conceptual design and feasibility study for a WtE plant within April 2020, and within 2023 to construct and build a demonstration plant designed to capture more than 100 000 tons CO_2 per year. The plan forward is to have infrastructure for CO_2 capture, transport and storage planned within 2028-2029, with some capture plants for large single point sources already built;

Although several of these projects are currently based on CCU as the main idea, they are still of great relevance for Norwegian full-scale CCS Project. From a climate perspective, storage is the main goal because it is more efficient and removes large volumes of CO_2. Nevertheless, the development of CCU will be important both to increase the focus on CO_2 capture in general, increase the quantities of CO_2 that must be handled, stimulate technology and market development and to open the dialogue towards the EU and Europe.

In addition to the materialized projects listed above, there is in general a growing interest for CCS in Scandinavian and Northern European industry. We also see that it is an increasing interest from Southern Europe (Italy and France), Asia (visits from China, Georgia and India) and Africa (Ethiopia).

- The FOV CO_2 Capture Project has a strong support from Norwegian research, business and industry players (Equinor, the Norwegian Oil and Gas Association (NOROG), Norsk Industri, Sintef, the Norwegian Confederation of Trade Unions (LO), the Confederation of Norwegian Enterprise (NHO) and others).
- Both dialogue and support have increased in strength from European (CEWEP) and international waste organizations (ISWA), respectively. Furthermore, there is a strong support from and cooperation with several NGOs, including ZERO, Bellona and others.
- A dialogue has been established with the EU Innovation Fund, EU ambassadors and DG Energy (Directorate-General for Energy in the European Commission). A special event was held in February 2019 at Klemetsrud for all EU embassies represented in Oslo, to promote the WtE plant and the CO_2 capture pilot, and plans for full-scale demonstration.
- Cooperation agreements covering CO_2 capture technology knowledge-sharing have been established or are being negotiated between FOV and a number of Norwegian, Scandinavian and German players in the WtE industry.
- A collaboration between capital cities in the Nordics and The Netherlands has been established for decarbonization in general, in addition to a specific collaboration between the WtE plants and the city representatives in Scandinavia, and we anticipate that our experience with CCS will be leveraged fully for this. A collaboration has also been established with CCS players and The International CCS Knowledge Centre in Canada and we have a good dialogue with new technology suppliers within CCS.

In conclusion, much of the groundwork for Benefit Realization has already been laid and is ready for continuation in the interim, construction and operations phases, and the FOV CO_2 Capture Project is fully prepared to move rigorously ahead.

12.1.2 Plans for Benefit Realization work going forward

Moving forward, FOV will work actively to secure the realization of the next CO_2 capture projects within the WtE business in Europe and globally.

The description below of the planned benefit realization activities has been structured slightly differently and broadened in scope compared to the Gassnova master plan. This is done to also meet the needs of the Fortum corporate reporting and decision-making, since this is where any future decisions will be taken on implementing CCS in its portfolio of facilities outside of Norway. Therefore, the summarizing text below does not directly map to table 1 of planned activities in the Benefit Realization plan [118], which is structured to facilitate the confirmation of compliance with the Gassnova master plan for Benefit realization work. However, the described activities in the two tables are similar, and there are references below to the T-categories from Gassnova's Benefit Realization system.

Activities within five work areas have been defined as follows:

1. Knowledge sharing, increased acceptance and learning about WtE and carbon capture by other industry players and key stakeholders:
    - Participation in conferences and seminars in Europe, and selected geographical areas assessing WtE and CCS (T03, T08, T13, T17, T21, T28);
    - Develop dialogue and initiate specific collaborative projects with industry organizations (ISWA, CEWEP, GCCSI) and other stakeholders to accelerate development towards WtE with CCS (T03, T13, T17, T28);
    - Guided tours of the pilot, the WtE plant and the CCS plant at Klemetsrud (T03, T08, T13, T17, T28);
    - Find new use of the pilot for testing at other plants, for further learning and awareness around CCS (T03, T12);
    - Active use of Fortum web sites and social media to promote both the FOV CO_2 Capture Project and the Norwegian full-scale CCS Project (T28, T13).
2. Contribute to technology development:
    - Collaboration with Academia and R&D initiatives within CCS (T08, T12, T13);
    - Industrial cooperation with SE and Borg CO_2, active support for FEED and technology testing as well as realization of full-scale capture plants (T08, T12, T13);
    - Technology workshops with partners, new CCS initiatives and emerging technologies (T03, T08, T12, T13, T28);
    - Facilitate testing of new/emerging technologies at Fortum plants (T03);
    - Dialogue with various technology suppliers establishing transparency and knowledge sharing related to design and integration (as far as possible) (T03, T08, T28).
3. Further develop cooperation with established and new partners within WtE:
    - Follow up and develop annual seminars (Bilbao and Dusseldorf) for European WtE plants/constructors and WtE/CCUS technology suppliers (T03, T08, T12, T13, T17, T28);
    - Industrial collaboration with EEW on the study and testing of capture technology, and the construction of EEW's first CO_2 capture plants (T03, T12, T13, T17);
    - Industrial cooperation with EEW's owners; City of Beijing, on the development of CCS at WtE in China (T03, T12, T13);

- Industrial collaboration with ARC Copenhagen on studies and testing of capture technology and the construction of a CO_2 capture plant (T03, T12, T13, T17);
- Develop cooperation with Swiss and Swedish WtE facilities on the development of CCS (T03, T08, T12, T13, T17, T30);
- Dialogue with Eastern European waste industry; work for transition to sustainable waste management and WtE with CCUS (T03, T12, T13, T17).

4. Develop urban cooperation
   - Active participation in big cities networks (T03, T12, T28, T17);
     - C40
     - Carbon neutral Cities
     - Scandinavian industrial city dialogue
   - Actively communicate with and recruit new partners for big cities networks and industrial cooperation between large WtE plants (T03, T12, T30);
   - Initiate dialogue with Eastern European cities and politicians; focus on transition to sustainable waste management and WtE with CCUS (T03, T12, T17, T30);
5. Develop CCUS further in the Fortum Group
   - Contribute to completing concept and FEED studies Klaipeda and Zabrze, and the realization of capture plants at Klaipeda, Zabrze and other Fortum sites (T12, T13);
   - Plan, establish and develop Fortum's CCS Centre of Excellence at Klemetsrud (T03, T12, T13, T28, T17);
   - Contribute to developing current business models for BECCS and CCUS in PURO (T21);

Please note that the initiatives and activities planned in the interim, construction and operation phases are more thoroughly described in the Benefit Realization plan [118]. In this document, the activities are aligned with Gassnova's Benefit Realization plan and T-system.

12.2 Lessons learned (9b)

A lesson learned report [120] has been developed for the project. The purpose of the report is to describe the lessons learned in the FEED phase of the project in order to facilitate for improvements in the coming phases.

The document presents lessons learned along with improvement suggestions that are to be taken into account in potential new phases.

Table 12-1 to Table 12-7 document the learning that has been accomplished.

Table 12-1: Lessons learned – Knowledge items – Technical Solutions and Performance.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
Reliability	Results from the RAM report	Two RAM analyses have been performed during	A new RAM analysis is to be performed during the

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
		FEED phase of the project. One is performed by TechnipFMC and one by FOV.	next project phase, when more detailed information on the equipment is available. Optimization and coordination of maintenance with the WtE plant will also improve the overall Availability.
CO_2 Capture	Capture efficiency Delivered CO_2 amount	The pilot plant operation has shown that a capture efficiency in between 90 and 95% is achievable.	Implement the learning from the extended pilot testing to ensure that the same capture efficiency is achieved.
Performance	Capture efficiency and purity of CO_2 at different operational conditions Performance guaranty	The pilot plant has shown that CO_2 purity according to spec can be achieved as expected. This was documented through various spot sampling and continuous measurement. Pilot testing (weekly reporting) has provided good knowledge about CO_2 capture efficiency and about what level of performance can be guaranteed (also in terms of solvent degradation).	Implement the learning from the extended pilot testing to ensure that the same capture efficiency is achieved.
CO_2 Purity	Purity of CO_2 Expected solvent consumption on an aggregate level.	Pilot plant has not confirmed the CO_2 specification. The pilot plant confirms very low levels of amine in CO_2 product stream (3 ppbv).	Implement the learning from the extended pilot testing to ensure that the same capture efficiency is achieved.
Energy requirements per ton CO_2 as a function of incineration rate	Energy requirement per metric ton of CO_2 reported per quarter (given the total amount of waste incinerated in that quarter) (Returned) heat supply to the district heating system per metric ton of waste, before and after the establishment of CO_2 capture	Pilot plant is not representative of a full-scale plant with respect to energy required per ton captured CO_2. However, energy requirement is discussed in the DNV GL Technology Qualification Report (see section 5.7.3) as some work has been performed (simulations and evaluations).	This learning will be followed up during next phase, however it is expected that the full-scale plant will be more efficient as the pilot plant did not have an MVR.
Key input, output and	Input: flue gas amount,	Further sampling on flue gas (line 3) verified that	Commissioning of the CC Plant will allow to tune the

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
design parameters	composition, temperature and pressure at CC Plant boundary, waste incineration amount Output: Flue gas composition after treatment, produced CO_2 quality and quantity, number of transports by truck Design: Dimension of main components related to storage and transportation, area requirements for the entire plant, number of operating days per year, safety systems / safety measures	previous measurements of aerosols being low. Pilot plant has confirmed very low levels of amine in CO_2 product stream. Disturbance in WtE plant affects in flue gas, which may affect emissions for shorter periods	achievable CO_2 quality in relation to the CO_2 specification. Learning form the pilot can be implemented to simply this operation.
Questions for future R&D	Integration with existing facilities Discharge and dispersion of hazardous components CO_2 neutral transportation alternatives It is expected that additional items will be recognized during the concept phase.	VIP are reported and assessed in the project, see section 7.4 of this report.	Identified and accepted VIPs will be followed up in the next project phase.

Table 12-2: Lessons learned – Knowledge items – Operations.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
Manning	Number of personnel required to operate the plant	Necessary manning has been evaluated and OPEX estimate has been prepared. [redacted] Additional staffing	Feedback and learning from FOV alarm philosophy (reduce number of alarms and focus on optimizing the process).

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
		will be detailed as a part of FOV overall O&M optimization.	Core competence on operation, maintenance management and optimization inhouse,
Competence level	The need for employee training	Several employees have been trained to operate the Pilot Plant operation.	The specific training course that is necessary for operating the CC Plant capture plant will be a prepared and held in the next phase.
Maintenance	Maintenance requirements	An Operation, Flexibility & Maintenance Philosophy has been developed by TechnipFMC.	The preliminary maintenance philosophy and program will be further developed in the next project phase.

Table 12-3: Lessons learned – Knowledge items – Cost.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
CAPEX and OPEX for the value chain	Aggregated CAPEX and OPEX for integration, capture, transport and storage	CAPEX and OPEX have been further updated and amended to reflect project changes. They are presented in chapter 4 of this report.	Firm cost for installation and integration as this is based on inhouse estimates.

Table 12-4: Lessons learned – Knowledge items – Environment impact.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
Efficiency: Reduction in CO_2 emissions per unit of industrial production	Avoided amount of CO_2 per unit produced heat or electricity	A better estimation on the amount of flue gas and therefore of captured CO_2 (see section 5.5)	A new RAM analysis is to be performed during the next project phase, when more detailed information on the equipment is available. This will allow for calculation on the actual avoided amount of CO_2 per unit produced heat or electricity
Other environmental impacts from CO_2 capture during normal operation	Results from ENVID report	No major external environmental issues identified. Noise is an issue but found manageable at this point with mitigating efforts (see section 6.3.1.10)	Additional evaluations, as described in section 6.3.1.10.

Table 12-5: Lessons learned – Knowledge items – Health and Safety.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
Significant events and near accidents (abnormal operation)	Modelling of CO_2 leaks with CFD modelling tools specifically developed and verified for CO_2 (developed as part of the CLIMIT project).	Detailed assessment for credible worst-case scenarios and more probable process leaks has been performed using CFD simulation and used as input to QRA.	The need for further consequence simulations will be evaluated in early part of next project phase.
Significant events and near accidents (abnormal operation)	HSE reports / statistics and audits	HSE reports and statistics (including safety walks and HSE visits) for the pilot project are reported in the FOV and Fortum system.	The HSE reports and statistics will be further developed and harmonized with Fortum system, with some of the scope will be delegated to TechnipFMC.
Monitoring and systems for security monitoring	Security systems, measures and operational procedure (The detail of Site security procedures needs to be kept confidential for security reasons)	Safety system design philosophies have been prepared by TechnipFMC.	Site Security systems and access will be based on the philosophies prepared at FEED.
Health consequences of CCS during normal operation	QRA-reports HSE-reports	Risk for FOV personnel and third party has been assed, with substantial work to investigate and calculate CO_2 accident frequencies, and consequence calculations. Consequence simulations has been performed for flue gas release, containing small amount of amine. HSE Studies has been performed – see section 6.3.	The status of the studies will be assessed in the next project phase and some of the studies might be re-performed as needed.

Table 12-6: Lessons learned – Knowledge items – Business model.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
Business model assessment	Positive and negative consequences of the chosen business model	Complex negotiation with both MPE and TechnipFMC. Negotiations with MPE are ongoing and the plan is to conclude them by the end of the FEED phase.	Implementation of the negotiated agreements.
Suggestions for business	Any recommended changes to future business models	Complex negotiation with both MPE and TechnipFMC.	Implementation of the negotiated agreements.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
model improvements		Stakeholders expectations have not always been aligned.	
Rationale and motivation for the establishment of carbon capture plants (economy vs. environment)	Description of economic and environmental benefits and how this has been emphasized in decision-making of the project	Continued work with Gassnova to clarify business model.	To be followed up in next phase.

Table 12-7: Lessons learned – Knowledge items – Project execution.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
Legislation / permits	Emissions Permits	Application for emission permit issued. Revised dispersion analyses of flue gas are performed. Emission permit is linked to the emission permit for the WtE plant.	Achieved emission permit.
Technology Qualifications	Summary of the need for Technology Qualification	Technical qualification by DNVGL of the Licensor proprietary amine-based solvent (Cansolv DC-103).	As full technology qualification is achieved, management of the residual risks and opportunities (as defined in section 5.7.3.6) is expected.
Dialogue with stakeholders, including interaction with government agencies	Process with the Environmental Directorate for emission permits for full-scale CO_2 plants in densely populated areas Stakeholder analysis and communication plan for dialogue with stakeholders Experience from dialogue with stakeholders	Zoning has been updated and issued for public hearing Two neighbour meetings have been held to keep neighbours informed and to present the zoning plan. The zoning plan will be put forward to political handling at the end of August. Application for consent to DSB. Meetings with PBE to clarify requirements and information.	Follow up political handling of Zoning plan, applications for consent to DSB and emission permits. Prepare application for building permit early enough.
Planning	Summary of planned items that contributed positively to the implementation	Long time for preparation of procedures contributed negatively to the implementation.	Procedures to be prepared during interim phase and available at start-up of the project.

Subcategory	Knowledge items	What was achieved in FEED phase	What could be expected in the next phase
	Summary of planned items that contributed negatively to the implementation Overall project plan and actual completion time Experience with a political process around planning and construction	Too short time planned in the beginning for pilot commissioning, winter conditions were not fully taken into account. Initial schedule agreed with Gassnova assumed DG3 report submission in highly holiday period. Final investment decision is far away from the time when procurement is organized, the project have a challenge to keep contractors motivated to submit offers and get enough competition. Submitted offers most probably include a lot risk margin included by the contractors due to long waiting time and changing market conditions.	Enough time with back up times for commissioning assumed in schedule at the beginning. Weather conditions analysis will be performed during scheduling. Construction phase will include planning of Holidays.
Construction, commissioning and operation	Experience with contract model and cooperation in the various phases Experiences with logistic, construction and model construction Experiences and challenges with respect to commissioning and start-up	For the pilot, TechnipFMC and the Licensor have not been as active as expected. FOV has been involved in clarifications for issues that should have been done between Shell, TechnipFMC and Kanfa. Winter conditions could be a real challenge, both for construction, commissioning and start-up	Critical actions will be planned during summer, to allow for better weather window.

12.3 Technology development (10a, 10b)

The technological (CO_2 capture) solution provided by TechnipFMC and the Licensor has been commercially proven on a large scale (see section 11.1.4 and [105]). However, this does not mean that there are no opportunities for technological development, especially considering the overall CO_2 chain from Klemetsrud to Oslo harbour. This section gives an overview of specific areas identified that could contribute to the technological development of CCS in general.

CO_2 capture plant operation as a flue gas cleaning step. In addition to large scale operational experience from a coal fired power plant, the CO_2 capture technology in question has been tested on the actual flue gas from Klemetsrud using a purpose-built pilot plant. The obtained results (see section 5.7) have confirmed the possibility to safely operate the CC Plant despite the stringent emission requirements placed on the Klemetsrud location.

CO_2 post combustion capture from an existing WtE plant. By integrating the CC Plant with the WtE plant, FOV aims to demonstrate and prove that safe and environmentally friendly handling by incineration of reclaimer waste (and other waste streams) generated during the capture process in the CC Plant is possible.

Heat integration. Further, FOV wants to demonstrate synergies between the WtE plant and the new CC Plant in terms of heat integration towards a district heating network. This is obtained by utilizing heat pumps on a large scale.

Liquefied CO_2 transportation by truck between Klemetsrud and Oslo harbour will provide important information for the many potential CO_2 capture sites located inland around the world. In addition, the use of the harbour storage at Port of Oslo, a centralised hub to where CO_2 is transported by Truck, will provide experience in operating a CO_2 export terminal that could be shared between several CO_2 capture sites. Transportation of the captured CO_2 to the Port of Oslo will be done by CO_2 neutral (possibly electric) heavy-duty trucks.

Standardization of design elements of the capture plant has potential for cost and schedule savings in the future. However, for the Klemetsrud plant, the logistics constraint limits the size of the modules and reduces the applicability, although included as far as possible. Still, some equipment modules are more prone and mature for standardizing, among them the following contributions are available:

- Standard design for CO_2 liquefier trains;
- Modular design for the TRU with the possibility of implementing a packaged solution;
- Standard design of CO_2 storage units.

These issues have been considered during the FEED design, working in collaboration with equipment vendors.

12.4 Next in kind capture project (10c)

12.4.1 Stockholm Exergi (SE)

Stockholm Exergi (SE) is owned 50% by Fortum and 50% by the City of Stockholm, and as in Oslo Fortum is cooperating closely with the city of Stockholm to decarbonize the waste handling and district heating system in the city. SE has increased focus on GHG emissions, driven by general opinion trends in Sweden to more actively support national emissions goals and by the interest among its customers. SE has therefore completed and published a "roadmap towards climate positive district heating" which identifies carbon capture as the most important means of action.

SE is currently investigating CO_2 capture with a long-term goal of establishing full-scale CO_2 capture from the Värtaverket biomass plant (fuelled with woodchips), for subsequent transport and permanent storage. The goal is to capture and store 800 000 tons of CO_2 annually. SE has a case with many similarities to the FOV CO_2 Capture Project, but has the advantage that the plant is located close to the Stockholm Harbour.

The Swedish Government has recently decided to give SEK 100 million to projects that aim to complete pre-feasibility and pilot plant studies of using CO_2 capture on biomass-based processes. Part of this has now been awarded to SE for feasibility studies for full-scale development of CO_2 capture and for the building and operation of a pilot plant [121].

SE has carried out screening studies of various technologies and solutions broader than CO_2 capture on their combined heat and power plants (CHP) installations. These covered a range of emissions-reducing actions for all sectors in Stockholm, including production of biochar, modified diet, energy efficiency, electrifying transport, and more. SE is now carrying out feasibility studies. The focus is on designing a concept description of a full-scale CO_2 capture plant at Värta including solution for transport and storage, as well as the design of a demo plant. The study includes lab-scale testing in collaboration with KTH. The SE project has been funded to build a demonstration plant in industrial scale for testing of Hot Potassium capture technology, and a decision on the way forward for possibly moving on to a full-scale plant is expected 1st quarter 2020.

SE has signed a Memorandum of Understanding with FOV. SE points to the realization of FOV CO_2 Capture Project as an important starting point for learning and developing their own project, and as a critical reference project in order to gain national and international support and funding for a similar capture plant in Stockholm. SE is dependent on Northern Lights to be able to realize their project. Northern Lights needs both Norwegian CO_2 capture projects to achieve a critical mass for realization and be able to offer transport and storage to foreign players. The SE project is therefore interdependent on the FOV CO_2 Capture Project, and as a consequence SE expects FOV to start demonstrating CO_2 capture at Klemetsrud for SE to be able to realize their own capture project.

12.4.2 Amager Resource Center (ARC)

ARC in Copenhagen, with CO_2 emissions of about 480 000 tons per year, has recognized CCS as the most important measure to decarbonize their WtE plant as CCU will not mitigate enough CO_2 volume in foreseeable future. ARC has started studies aiming to realize a full-scale capture plant at their WtE plant Amager Bakke in 2025. Representatives from ARC has participated in a number of FOV's meetings and workshops, also in Bilbao and Dusseldorf, and the parties have an active dialogue. ARC has signed a Letter of Intent with FOV and is scheduled for a visit to FOV in the Fall 2019.

12.4.3 Fortum's WtE plants in Lithuania and Poland

Pre-studies have been completed at Fortum's WtE facilities in Klaipeda, Lithuania, and its WtE plant in Zabrze, Poland. The studies are internally financed by the Fortum Group, with the FOV CCS Director participating in both steering groups and with appointed project managers from FOV in Klaipeda and from Fortum in Zabrze.

The focus of the pre-study in Klaipeda has been to assess lessons learned and results from the studies of respectively FOV and SE. Based on this, a first sorting of candidate capture technologies will be used to perform a test program at the facility in Klaipeda. Depending on the chosen technology to be tested and sufficient external funding for the next phase, the plan is to complete pilot testing in Q2 2020 - or Q2 2021 if a new pilot has to be built. Concept and FEED studies may be completed by Q4 2022/23, with a possible prospect of realizing a full- scale plant by the end of 2025/2026. The study report will also advise on recommended way forward and possible means of funding for next phases.

In Zabrze, the pre-study has focused on investigating in addition whether rail transport will be a technical, logistical and financially attractive solution for transporting CO_2 from this inland location to the quay on the Baltic coast. The most feasible candidate for this is at Gdynia, which lies about 560 kilometres from Zabrze. Depending on the results in the initial study and sufficient external funding for the next phase, possible concept and FEED studies may be completed by Q4 2023, with a possible prospect of realizing a full-scale plant by Q2 2027. The study report will also advise on recommended way forward and possible means of funding for next phases.

FOV has been contributing actively in both projects to ensure that learning and competence from the Klemetsrud studies and pilot testing is utilized, and to further develop the cooperation and dialogue between Klaipeda, Zabrze and the CCS project in SE. FOV will continue to share experience and learning and contribute into both studies in close cooperation with SE.

12.4.4 Borg CO_2

Borg CO_2 (former Øra CCS cluster) has recruited several new partners and more CO_2 emission sources in addition to FREVAR. FOV has contributed actively since autumn 2017 to the creation of a new project for a CO_2 capture cluster in Østfold, currently managed by the limited company Borg CO_2 AS. The project has conducted a pre-feasibility study funded by CLIMIT and project partners, and has started a feasibility study aiming to map out the local and regional capture potential. After completion of the feasibility study in June 2021, the phase 2 will include a pilot project running in the period 2021-2022.

The goal is to establish a demonstration plant in a "half industrial scale" with operational start in the autumn 2025. The demonstration plant will serve as a building block for building commercial, modularized, industrial and cost-effective small-scale CCUS solutions worldwide. The project will exchange experience and technology, and seek to develop technology and value chains for significantly reduced operational expenses and investment costs. This includes developing business models, financing solutions and legal frameworks for predictable operations with acceptable profitability.

FOV will actively participate in and follow up the Borg CO_2 feasibility study, both to transfer knowledge and experience and for future coordination of shared and complementing transport solutions and logistics for CO_2. This could potentially reduce CO_2 transport costs for both FOV and Borg CO_2.

12.4.5 Twence

In the Netherlands, the WtE company Twence aims to capture CO_2 on a large scale from the flue gases produced by their WtE plant and make it suitable for beneficial use in greenhouses. The intention is to capture 100 000 tons of CO_2 annually from spring 2021.

Twence and FOV have an open dialogue, have signed a Letter of Intent and are actively cooperating; and FOV will continue to transfer knowledge, experience and learning to develop the collaboration on CCS in the WtE industry. If the capture unit from Aker Solutions (Just Catch) is successful, Twence may decide to invest in more CO_2 capture and connect to the Northern Lights for handling of new volume.

13 INTELLECTUAL PROPERTY AND PATENTED TECHNOLOGY (11A)

This chapter contains a list of confidential information and the Licensor patents relevant for the CC Plant at Klemetsrud.

While FOV do not have any confidential information with regards to the Klemetsrud WtE plant relevant for the FOV CO_2 Capture Project, TechnipFMC with Licensor as technology partner has confidential information as listed in the sections below.

The text in this chapter in *italic* is the original Licensor text [122] is presented below and, thus, the terminology may be different than the rest of the Report.

13.1 Intellectual property

The following type of information is confidential:

No	Description
1	*"**Absorbent**" means* [redacted]
2	*"**Classified Absorbent Information**" means* [redacted]
3	*"**Critical Equipment**" means* [redacted] • [redacted] • [redacted] [redacted]
4	*"**Licensed Process**" means* [redacted]
5	[redacted] • [redacted] • [redacted] • [redacted] • [redacted] [redacted] • [redacted]

No	Description
	• [redacted] [redacted]

13.2 Patented technology

These are the Norway patents for the CANSOLV CO_2 capture process (top tier relevance):

Jurisdiction	Process	Application / Patent number	Application Date
Norway	RECOVERY OF CO_2 FROM GAS STREAMS	20055902 / 335887	June 8, 2004
Norway	PROCESS FOR THE RECOVERY OF CARBON DIOXIDE FROM A GAS STREAM	20092701 / -	December 14, 2008
Norway	PROCESS FOR THE RECOVERY OF CARBON DIOXIDE AND SULPHUR DIOXIDE FROM A GAS STREAM	20140030 / 336005	June 8, 2004

These are the patents for the CANSOLV CO_2 capture process in other countries (2nd tier relevance):

Jurisdiction	Process	Application / Patent number	Application Date
Europe	RECOVERY OF CO_2 FROM GAS STREAMS	7105911.7	April 11, 2007
Europe	RECOVERY OF CO_2 FROM GAS STREAMS	7105916.6	April 11, 2007
USA	PROCESS FOR THE RECOVERY OF CARBON DIOXIDE FROM A GAS STREAM	7,601,315B2	December 28, 2006
Europe	PROCESS FOR THE RECOVERY OF CARBON DIOXIDE FROM A GAS STREAM	7855621.4	September 1, 2008

These are the valid patents that are no longer relevant since these are not considered in the line-up:

Jurisdiction	Process	Application / Patent number	Application Date
USA	REGENERATION OF ION EXCHANGERS THAT ARE USED	7,776,296	March 10, 2006

	FOR SALT REMOVAL FROM ACID GAS CAPTURE PLANTS		
Europe	*REGENERATION OF ION EXCHANGERS THAT ARE USED FOR SALT REMOVAL FROM ACID GAS CAPTURE PLANTS*	*7710646.6*	*September 1, 2008*
USA	*PROCESS FOR THE REGENERATION OF AN ION RESIN USING SULFURIC ACID*	*8,063,112 B2*	*December 8, 2008*
USA	*METHOD FOR TREATING A DIAMINE ABSORBENT STREAM*	*8,097,068*	*November 6, 2008*
China	*PROCESS FOR THE REMOVAL OF HEAT STABLE SALTS FROM ACID GAS ABSORBENTS*	*201180020399.4*	*March 17, 2011*
USA	*METHOD AND APPARATUS FOR NO_x AND Hg REMOVAL*	*7,416,582*	*July 30, 2004*
USA	*WASTE GAS TREATMENT PROCESS INCLUDING REMOVAL OF MERCURY*	*7,384,616*	*June 20, 2005*
USA	*PROCESS FOR PRODUCING SULFURIC ACID FROM SOUR TAIL GAS*	*61/847,953*	*July 18, 2013*

14 LIST OF ATTACHMENTS

Table 14-1 and Table 14-2 contain a list of the attachments to the FEED Study Report DG3.

Table 14-1 contains documents that have not been delivered prior to DG3 report as standalone project documents.

Table 14-2 contains a list of the project documents needed for a complete description of the project. The list is a selection of the most important documents produced during the FEED phase.

Table 14-1: List of attachments – documents not delivered prior to DG3 report.

Att. #	Document
Attachment list not relevant for redacted version	
[redacted]	

Table 14-2: List of attachments – main documents delivered to Gassnova during the project.

Att. #	Document number	Rev.	Title
Attachment list not relevant for redacted version			
[redacted]			

Att. #	Document number	Rev.	Title

Attachment list not relevant for redacted version

[redacted]