KLEMETSRUD-
ANLEGGET

PROJECT CCS
CARBON
CAPTURE
OSLO

Issued for public use	03	06.03.2018	JO	EB	PM
Issued end Concept	02	15.09.2017	JO	EB	PM
Issued For Review	01	16.08.2017	JO	PT	EB
Reason for Issue	**Client's Rev.**	**Rev. Date**	**Prep. By**	**Checked**	**Approved**

Fortum Oslo Varme - Klemetsrudanlegget (KEA) - Carbon Capture Oslo		
Document Title: Concept Study Report		
Client's Document No: NC02-KEA-A-RA-0002	**Rev:** 03	**Number of pages: 137**
KI:		
[redacted]		
	Attachments:	

Revision History			
Reason for Issue	**Rev.**	**Date**	**Change**
Issued For Review	01	15.08.2017	
Issued for Concept	02	15.09.2017	Updates after Gassnova comments and maturing of the concept.
Issued for public use	03	06.03.2018	Edited for public use

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1 EXECUTIVE SUMMARY

Klemetsrudanlegget (KEA) has conducted a concept Study, termed "Project CCS Carbon Capture Oslo", at KEA which is a Waste to Energy (WtE) plant comprising a CO_2 capture plant, liquefaction plant, transport to Oslo harbour and intermediate harbour storage including associated onshore infrastructure. Flue gas, delivered through duct pipeline arriving at the CO_2 capture facility on the site is pre-treated. CO_2 is captured and the CO_2 is continuously transferred to the harbour through duct pipeline. At the harbour the CO2 is liquefied, and intermediate stored, before being offloaded to CO_2 carriers for transport to the storage operator. In the truck, optional and back-up, case liquefaction is performed at Klemetsrud with additional intermediate storage to ensure good truck logistics.

The main objective has been to define viable concepts, develop a +/-30% CAPEX/OPEX estimate and answer the Client's expectations.

The Study has established key safety philosophies and various HSE workshops were conducted to identify safety and environment hazards and mitigating measures. A risk and opportunity register has been developed and will be used as a management tool also in the FEED phase.

Current operation involves incineration within lines K1, K2 and K3, at present with emissions of about 400 000 t/yr of CO_2. There are in place plans and on-going work with the aim of increased incineration capacity in the years to come - the design production is 460 200 t/yr of CO_2.

With respect to transportation of CO_2, the Concept study evaluated two different concepts; truck transportation and pipeline. The preliminary findings for the transport study has led to the decision to continue with pipeline as the selected transport concept. KEA has engaged two different Contractors for the capture plant, liquefaction and intermediate storage. The two Contractors are Apply Sørco with Carbon Clean Solutions as technology partner and TechnipFMC with Shell Cansolv as technology partner. The KEA Study organisation has performed the concept Study for transport, integration, civil works and zoning applications.

The concept report has been developed with the presumption that the CC plant is a standalone process with well identified battery limits to the existing incineration plant. However a number of value improvement practices (VIPs) have been identified and will be developed further in FEED. [redacted]

The concept report is also including the possibility for a future fourth line design and its results as well as truck transport. As an outcome of the Concept study it has been decided that the FEED design shall continue on the basis of the existing three lines only and pipeline transport. Pipeline is the selected option and feasible in the timeframe of the project realisation. Pipeline is also the preferable option from a safety and environmental point of view.

[redacted]

Company has identified several areas of considerable improvement potential through the course of the Concept study as detailed under the VIP overview, some of which will be carried further into FEED. [redacted]

The Concept study has confirmed the major conclusion from the previous Feasibility study, i.e the feasibility and integration of a carbon capture plant at KEA. The study has also verified that pipeline solution for transporting CO_2 to the harbour is feasible, and that truck transport is an option and back-up alternative. Oslo harbour is committed to the project and have confirmed they will provide the project with a suitable plot space and port facilities.

Location of the Terminal will depend on technical suitability and the risk evaluation for a major spill of CO_2 from the intermediate tank farm. [redacted] Further risk evaluations will be included in the FEED phase and might influence on the selected location of the terminal.

CCS at KEA will give great potential for cost reduction, industrialisation, and standardization of next of kind CCS projects in the WtE industry. It will demonstrate contribution to technological development of CO_2 capture on an existing WtE plant. This has not been done previously in this scale (note Saga City project in Japan is a reference but on a much less scale and missing liquefaction and intermediate storage) and will provide a great opportunity to prove the concept for other such sites / WtE plants. Heat integration (heat pumps) and other synergistic integration opportunities between the existing plant and the new CC plant will be demonstrated for others to learn from. Items such as integration into the district heating system and the combination of all WtE plant flue gas streams with regards to operational flexibility and turn-down requirements will be developed. Thus, this activity can widen the scope and applicability of CCS technology on a global scale; for Norway's CCS-related industry it implies a strengthening of a leading role in the field of CCS development.

Besides the actual CO_2 capturing and condition facilities at Klemetsrud, another significant technological contribution comes from obtaining information and experience on the different options for transporting CO_2 (in what form and what infrastructure) to Oslo harbour. Various options have been and are considered, the final candidates are pipeline transport (implementing horizontal directional drilling) and so called "CO_2-neutral" trucks.

This Concept Study report is not a comparison report between the different capture technologies, it is a description of the scope of work undertaken as part of the study. [redacted]

1.1 Project Setup

KEA has organised the Study as a project, with an owner's organization. KEA has attached a strong network of qualified suppliers, all committed to continue into possible construction and operation. The KEA organisation maintains a strong focus on HSE, government approval, learning, supplier and technology development, knowledge transfer, implementation, cost control, technical integrity and technical quality assurance.

The scope of work has been divided into separate work packages, managed by the KEA. KEA will manage the various subcontracts as well as manage interfaces, regulatory approvals, prepare operations and necessary engineering work within own battery limit. The integration of the capture plant into existing facilities will be controlled by KEA.

KEA has chosen two capture contractors for the concept / FEED Study. The two Contractors are Apply Sørco with Carbon Clean Solutions as technology partner and TechnipFMC with Shell Cansolv as technology partner.

[redacted]

A key area will be to develop an optimal concept for emission-free transport from the capture plant to Oslo harbour. Transport by truck or pipeline was evaluated as part of the Study.

In addition, the concept of adding a possible future fourth incineration line at Klemetsrud (in close cooperation with the selected carbon capture suppliers) where considered.

KEA performs all Study work except:

- Carbon capture plant, liquefaction and intermediate storage
- Geotechnical surveys
- Cost - uncertainty analysis
- Architectural services (Selberg Arkitekter) in Concept. FEED to be decided
- HAZID & CRA (LilleAker Consulting)
- Consequence modelling (ComputIT)

KEA is responsible for the following areas:

- Engineering for EPC offers under KEA framework agreements
- Civil works Klemetsrud
- Transport (truck)
- Transport (pipeline)
- Integration with existing plant, interfaces and technical assistance
- Zoning, Government involvement and applications
- "EPCIC turnkey" contract for complete construction and commissioning of the capture plant and terminal in Oslo harbour.
- Develop an optional Operation and Maintenance agreement

A Project Execution Philosophy [1] has been developed in the concept phase, detailing how KEA will conduct studies and construction as well as areas of responsibility for the future phases.

1.1.1 Project Description

The focus is to develop a robust and integrated technical solution ready for FEED, focusing on major cost drivers, schedule, HSE risks and feasible constructability and operability.

As part of the Concept/FEED Study Contractor shall develop an independent and self-sufficient full scale concept for capture of CO_2 from the flue gas of the Klemetsrud Waste to Energy plant. Further the carbon capture plant needs to be integrated to the existing plant such that the primary delivery of heat to the district heating network is not negatively impacted, i.e. Contractor must allow for heat conservation measures such that steam condensate return temperatures are commensurate with the district heating network. Customer expects close cooperation with Contractor in developing an overall feasible concept.

The Contractors scope also includes the truck-loading/ unloading station and intermittent storage at Klemetsrud and Oslo harbour. The transport and logistics is part of KEAs scope of work. The CC Contractor shall allow for during the Concept phase for both transportation alternatives, pipe- and truck transport.

Contractor shall include the provision of all necessary and incidental supplies, consumables, utilities (except electricity, steam and municipal water) and tools, labour, facilities (including temporary facilities), equipment, services, documentation, licenses (IP) and other elements as may be inferred. The CO_2 capture plant must be self-sufficient and provide all needed utilities (e.g. instrument air, nitrogen etc.) and treat all emissions and discharges to meet all Authority requirements. This includes flue gas pre-treatment, flue gas conditioning prior to the release to atmosphere, CO_2 product conditioning and auxiliary systems (such as chemical storage, cooling systems, steam- and condensate systems).

Current operation involves incineration within lines K1, K2 and K3, at present with emissions of about 400 000 t/yr of CO_2. There are in place plans and on-going work with the aim of increased incineration capacity in the years to come - the design production is 460 200 t/yr of CO_2. If a possible future fourth incineration line is implemented, this output is expected to increase to 652 600 t/yr. The pipeline are dimensioned to receive up to 652 600 t/yr.

1.1.2 Project Goals

The Ministry of Petroleum and Energy have the overall responsibility for the full scale CO_2 capture and storage. Gassnova SF is project coordinator and responsible for capture and storage, Gassco AS responsible for transport. The Ministry of Petroleum and Energy will have overall responsibility for the development of framework conditions and incentives. In order for a full-scale project to gain socio-economic returns it has to contribute to the reduction of barriers and costs for the next CCS projects. The following aspects from the Government form the basis for evaluating the benefit from a CCS project:

"Demonstration of the full scale CO_2 capture and storage shall provide the necessary development of CO_2 handling, such that the long-term climate targets in Norway and the EU can be reached at the lowest possible cost. "

The target of the commitment is divided into four elements:

1) *The project shall provide knowledge that demonstrates that it is possible and safe to implement full scale CO_2 handling*
2) *The project shall provide productivity gains for future projects through learning and scaling effects*
3) *The project shall provide learning related to the regulation and incentivization of CO_2 handling activities.*
4) *The project will facilitate business development of CO_2 capture and storage"*

The next phase (FEED) will be used to optimise concepts to find the best suited solution for a CCS chain, i.e,:

- Clarify technical requirements in the chain
- Develop a technical and commercial basis for an investment decision
- Preparing for the construction phase is also part of the task.

Three different capture sites are part of the concept Study where KEA is one of the sites. The concept phase is also a phase where Gassnova may deselect one of the capture sites. Selection criteria communicated by Gassnova for next phase are as follows:

- Capture capacity, suitability of the plant
- Progress plans presented
- Execution capability
- Costs for studies, including own contribution from Beneficiary
- State risk and costs during the construction and operation phase
- Contribution to technological development
- Facilitation of knowledge transfer

Correspondingly and to answer Client objectives as well as KEAs objectives the following main objectives have been formulated:

- Evaluate the different concepts and technologies
    - Capture Technology
    - Integration
    - Transport
    - Intermediate Storage
    - VIP studies
    - A possible future Line 4
- HSE
- Quality
- Meet Client's expectations with respect to develop a CCS chain.
- Risk identification
- Develop Project Execution Philosophy
- Regulatory requirements
- Develop sufficient details for FEED
- CAPEX/OPEX at +/- 30% definition level
- Freeze the main concepts
- [redacted]

1.1.3 Conclusions, Findings and Recommendations

Through the course of the Concept Study the project has identified several findings and conclusions. Some of these will be further matured through the coming FEED phase. The main identified items are summarized below:

- The findings from the Concept Study coincide with the findings from the Feasibility Study and no major discrepancies have been discovered besides that other conceptual choices have been made as the study has matured.
- It is feasible to integrate a carbon capture plant into the WtE plant at KEA. Similarly, carbon capture plants can be integrated into other existing WtE plants, with potential capture of more than 60-70 million tons of CO_2 in the EU alone (CEWEP Energy Report 3, status 2007-2010).
- The Concept study has demonstrated that the capture plant will match the available plot space at site.

- WtE is an internationally growing industry that is subject to increasingly stricter regulation and environmental requirements. There is greater reason to expect wide adaptation to proven carbon capture opportunities here than in many other industries.
- Carbon capture on WtE facilities provides future opportunities for the sale of CO_2 quotas from the biological share of captured CO_2.
- Carbon capture from waste incineration in Oslo will build local expertise locally and have a high level of knowledge and regulatory transfer value.
- Establishment of carbon capture at KEA has broad political support in the municipality of Oslo.
- Carbon capture at KEA is a safe choice; There is no risk that the business closes or moves. KEA has extensive experience with the establishment and operation of advanced processing plants, including handling of chemicals and control of emissions.
- With the existing incineration capacity, approx. 350.000 tons of CO_2 per year can be captured. There are in place plans and on-going work with the aim of increased incineration capacity in the years to come. Future (design) capacity are therefore capture of approx. 414 200 tons of CO_2 per year (90% capture of 460 200 tons of CO_2). Of this, a significant proportion is carbon neutral (about 60% has biological origin).
- Carbon capture has no negative impact on KEA heat supplies. District heating supplies to Fortum Oslo Varme is maintained, and may be increased if a full scale capture plant is established at Klemetsrud. There is potential for additional heat input to the district heating plant of [redacted] beyond the net contribution when installing additional heat pumps. There is still need for further work on energy flows, in particular optimized removal of excess heat and summer season cooling.
- [redacted]
- The project will move into FEED with the capture plant sized for three lines and pipeline transport.
- There is potential for capturing an additional approx. 150,000 tons of CO_2 annually from the established combustion plants at Haraldrud (bio and waste).
- KEA used Apply Sørco and TechnipFMC as main Contractors in the Concept phase. [redacted]
- Carbon capture at KEA will provide great potential for cost reduction, industrialization and standardization of CCS projects in the WtE industry. It will demonstrate contributions to the technological development of CO_2 capture at an existing WtE. This has not been done earlier (with the exception of a much smaller project in Japan), and will provide a good opportunity to prove the concept of other such facilities. Heat integration (heat pumps) and other integration possibilities between existing plants and the new carbon capture plants will be demonstrated for others to learn from.

2 ABBREVIATIONS AND DEFINITIONS

2.1 ABBREVIATIONS

ALARP - As Low As Reasonably Practicable

BAT - Best Available Techniques

CAPEX - Capital expenditures

CC – Carbon Capture

CCS - Carbon Capture and Storage

CCSL – Carbon Clean Solutions Limited

CEWEP - Confederation of European Waste-to-Energy Plants

CFD - Fluid Dynamic Models

CRA - Concept Risk Analysis

DDC - Direct Contact Cooler

DH – District Heat

DM - Demineralised Water

DSB - The Norwegian Directorate for Civil Protection

EGE - Energigjenvinningsetaten

EIA - Environmental Impact Assessment

ENVID - Environmental Impact Identification

EPCIC - Engineering, Procurement, Construction, Installation & Commissioning

ETP - Effluent Treatment Package

FEED - Front-End Engineering Design

FG - Flue Gas

GGE - Gas-Gas Exchanger

GWP - Global Warming Potential

HAZID - Hazard Identification

HCl - Hydrochloric Acid

HF - Hydrofluoric Acid

HOK - Activated Carbon

HSE – Health, Safety and Environment

HSEQ - Health, Safety, Environment, and Quality

HSS - Heat Stable Salts

HSS - Heat Stable Salts

IAS - Integrated Automation System

IP - Intellectual Property

KEA - Fortum Oslo Varme - Klemetsrudanlegget

LP - Low Pressure

MVR - Mechanical Vapour Recompression

OPEX - Operating Expenditures

QA – Quality Assurance

RAM - Reliability, Availability and Maintainability

SCR - Selective Catalytic Reduction

SNCR - Selective Non-Catalytic Reduction

TCP/IP – Transmission Control Protocol/Internet Protocol (Ethernet)

TRU - Thermal Reclaimer Unit

TSA - Temperature Swing Adsorption

VIP - Value Improvement Practices

WEHRA – Working Environment Risk Assessment

WSAC - Wet Surface Air Coolers

WtE – Waste to Energy

WWTP - Waste Water Treatment Plant

ZLD - Zero Liquid Discharge

2.2 DEFINITIONS

Klemetsrud WtE plant / Fortum Oslo Varme KEA AS / KEA referred to as Company

Technip and Apply referred to as Contractor

Current capacity referred to as 3 lines case

Future capacity referred to as 4 lines case

CO_2 transportation in pipeline referred to as Pipeline Option

CO_2 transportation in tanker trucks referred to as Truck Option

3 GENERAL INTRODUCTION

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

A pre-feasibility study of possible full-scale CCS projects in Norway was completed in May 2015. Gassnova (Client) was responsible for studying capture and storage and identified several sources of land based industrial emissions that could be candidates for CO_2 capture as well as offshore areas with potential for geological storage of CO_2. Gassco was responsible for studying transportation of CO_2 between capture plant and storage site, including transportation both by pipeline and by ship. A feasibility study was completed by Client and Gassco July 2016, providing development scenarios that could establish a full chain CCS project in Norway by 2022 and costs estimates within +/- 40% uncertainty.

KEA has been selected as one of the capture sites providing CO_2 to Client. As part of the Concept/FEED Study KEA shall develop a full scale concept for capture of CO_2 from the flue gas of the Klemetsrud WtE Plant. Further the carbon capture plant needs to be integrated to the existing plant such that the primary delivery of heat to the district heating network is not negatively impacted.

The scope also includes a pipeline to Oslo harbour, a truck-loading/ unloading station and intermittent storage at Klemetsrud and Oslo harbour. The preferred CO_2 transportation alternative is pipe transportation, with truck transportation as an option and back-up solution.

The Klemetsrud WtE plant, located in Oslo, Norway, converts municipal and industrial residual waste from both national and international customers to heat and power. The conversion takes place in three incineration lines and results in significant amounts of flue gases. While the flue gases are cleaned to meet the stringent requirements set for waste incineration in Norway, the emitted CO_2 amount remains unaffected. However, the target for the plants future operation is to capture as much of the CO_2 as possible, while minimizing the impact on the existing plant operation (district heat (DH) - and electricity production).

Originally the WtE plant was taken into operation in 1985, but in 2011 it was expanded with a new independent line (K3) for waste incineration. Today 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, Sentrum, Holmlia and Bjørndalen. As of August 2017 the complete value chain, from waste customer to heat customer, are owned 50/50 by Oslo and Fortum in the new Company "Fortum Oslo Varme AS".

Reference is made to the CO_2 source description [2].

3.1 WASTE INCINERATION LINES K1 AND K2

All three lines consist of individual grate fired boilers, i.e. waste is fed via a feed hopper to a slowly moving grate where the combustion of the waste takes place. Air for incineration is primarily provided through the grate, but additional air is also provided at other locations to ensure an excess of oxygen for complete combustion. The temperature in the furnace is typically between 850 and 1 100°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.

After the primary heat recovery has taken place and the flue gases have passed through the boiler, the temperature of the flue gas has been reduced to around 200°C. This temperature is however still too high for the following flue gas treatment steps and the temperature is reduced further by two heat exchangers (providing heat to the DH network).

Downstream of the two flue gas heat exchangers, called "RKG Nedre" and "RKG Övre", the flue gas is treated with calcium hydroxide ($Ca(OH)_2$) slurry and activated carbon (HOK) in order to remove acidic- and other harmful components. Nitrogen oxide emissions are reduced already in the boiler using a method called selective non-catalytic reduction (SNCR) that involves aqueous urea injection. The final flue gas cleaning step for lines 1 and 2 consists of a series of bag filters for reducing the particle amount down to the allowed emission level.

A schematic flow diagram with indicative temperatures of the flue gas treatment system has been given in Figure 1.

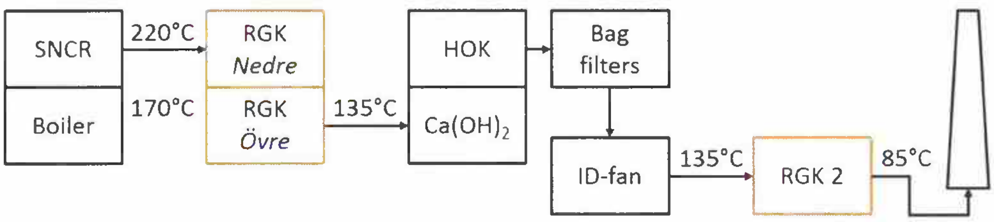

Figure 1. Schematic flow diagram of the flue gas system for K1 and K2.

3.2 Waste incineration line K3

While the basic setup (incineration, heat recovery, flue gas treatment, disposal through stack) of the waste incineration line 3 is similar to that of K1 and K2, 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, then the flue gas is passed through a 4-stage wet scrubber and finally it is treated in the selective catalytic reduction (SCR) reactor, again using aqueous ammonia.

Besides the differences in flue gas treatment it should be noted that K1 and K2 have different energy recovery systems as well, both for heat and for power. A schematic flow diagram of K3 with indicative temperatures is given in Figure 2. During summer 2017, a heat pump is installed utilising the heat in the scrubber circuit, removing approx. 10 tons/h water and cooling down the flue gas to approx. 43 °C at the scrubber outlet. The heat pump is planned to be in operation during wintertime to supply heat to the district heat net, but will also considered kept in operation during summer as a pre-treatment for the CC-plant with use of auxiliary cooling.

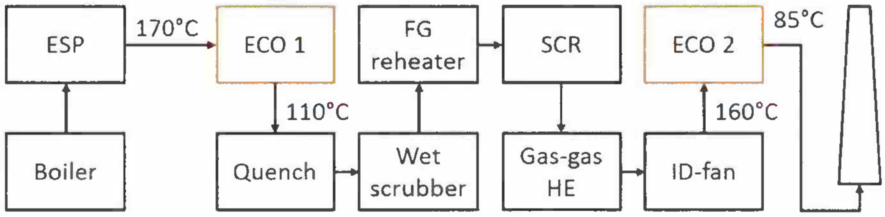

Figure 2. Schematic flow diagram of the flue gas system for K3.

3.3 Waste incineration line K4

It has been considered that a possible future addition to the existing plant could be made in the form of a new multi fuel incineration line (K4). This line would be designed for 169 kt/year fuel incineration capacity. (For a simplified estimation of the impact on emitted CO_2 amount, one can consider that 1 ton of the fuel generates 1.14 ton of CO_2.). Introduction of a possible future line K4 would therefore give approx. 190.000 t/yr of emitted CO_2.

The possibility for adding line K4 are still under consideration and evaluation by the Company but as a result of the concept phase line K4 is not part of the CCS-concept to be developed further at this stage. An exception from this are the dimensioning of the pipeline, which are dimensioned to have the capacity for a possible future line K4. This is done to keep the possibility for CCS from a future possible line K4 open, - at a relatively low cost.

3.4 Concept Phase Execution

The Concept Study is being executed by KEA and Contractor(s) in two phases, Concept Phase and FEED phase. Concept phase is a 'proof of concept' phase with an objective to arrive at a preferred development concept and design basis while FEED phase will focus on maturing the concept and prepare for the execution phase.

KEA had the responsibility of the overall study management and Contractor the technical development of the CO_2 capture plant and harbour terminal/onshore facilities. The Study was executed by Apply in their offices in Stavanger and Technip in their offices in London. Contractors have been monitored by weekly status meetings and frequent meetings at KEA as well as daily informal communication. KEA consider this has been successful and have been able to support the Contractor(s) team and provide clarifications in a timely manner. Other technical leads from KEA were present for reviews and meetings, and provided back-office support and Contractor(s) document reviews.

3.5 Design Basis

The Concept/FEED study design basis document [3] forms the Scope of Work provided by the CC Contractors undertaking the Concept study. It should be noted that several options were evaluated during the Concept phase. The option selected for the FEED phase is as follows:

- 3 incineration lines with a capacity of 460 200 tons CO_2 per year
- Liquefaction and intermittent storage at Oslo harbour
- Captured CO_2 transportation via pipeline from Klemetsrud to Oslo harbour

- The interim storage tanks and related systems shall be sized for:
    - 2-day (low) or 4-day (high) ship arrival frequency

In addition, the Concept phase design also evaluated the option of adding a (future possible) new incineration line (line K4 case) at Klemetsrud and truck transportation of CO_2 to Oslo harbour.

All design cases have been presented (as far as available) in this report in order to document the most important parts of the work performed during the Concept phase. However, as the basis for moving into FEED this case has been selected, i.e. Pipeline and 3 lines case will be emphasized throughout this document and other alternatives (considering Truck and 4 lines) are referred to. It should be noted, however, that the Pipeline will be built to facilitate for CO_2 captured from a possible future 4th incineration line.

3.5.1 CO_2 source description

The flue gas emissions from KEA WtE plant are presented in detail elsewhere [2], but a brief summary of the main elements are given here.

The flue gas emissions from the KEA WtE plant are routed to three separate ducts (and a possible fourth duct from a future Line 4) that together form the basis for the incoming flue gas to the CC plant.

The amounts considered are presented in Table 3-1 below. The 18/19 (2018/2019) data represents the design basis going into FEED.

Table 3-1. KEA WtE plant design data.

	Description	Sum K1 & K2	K3	K4 (planned)	Total
2017	CO_2 amount	193 300 t/y	234 500 t/y	-	427 800 t/y
2017	FG amount (avg.)[1)]	144 000 Nm^3/h	186 600 Nm^3/h	-	330 600 Nm^3/h
2017	90% capture	174 000 t/y	211 100 t/y	-	385 100 t/y
18/19	CO_2 amount	201 900 t/y	258 300 t/y	-	460 200 t/y
18/19	FG amount (avg.)[1)]	151 600 Nm^3/h	204 300 Nm^3/h	-	355 900 Nm^3/h
18/19	90% capture	181 700 t/y	232 500 t/y	-	414 200 t/y
2025	CO_2 amount (incl. K4)	Unchanged	Unchanged	192 400 t/y	652 600 t/y
2025	FG amount (avg.)[1)]	Unchanged	Unchanged	165 400 Nm^3/h	521 300 Nm^3/h
2025	FG amount (dry)[2)]	108 000 Nm^3/h	135 800 Nm^3/h	109 900 Nm^3/h	353 700 Nm^3/h
2025	90% capture	Unchanged	Unchanged	173 200 t/y	587 400 t/y
	Operational time	8 050 h	8 150 h	7 500 h	-
	Organic fraction	60%	60%	60%	60%

[1)] Nm^3/h: dry gas, 0°C, 101.3 kPa, 11 vol% O_2
[2)] Nm^3/h: dry gas, 0°C, 101.3 kPa, target stack O_2 conditions (7% K1 and K2, 6% K3 and K4)

The main components of the flue gas are represented by carbon dioxide, oxygen, water and nitrogen as presented in Table 3-2.

Table 3-2. Design CO_2, O_2 and H_2O content of the flue gas at KEA WtE plant.

Line	Unit	K1/K2	K3/K4
CO_2 (target O_2-level)	vol% (dry)	11.9	11.9
O_2 (target)	vol% (dry)	7.0	6.0
H_2O	vol% (dry)	15.6	14.8
N_2 + Ar	-	Balance	Balance

All three incinerators are always operated at full load, except during periods of scheduled or unscheduled maintenance. Typically maintenance is performed so that all 3 lines are out of operation for a period of 3 weeks every year. The operational time is given in Table 3-1.

3.5.1.1 CO_2 delivery plan

All the captured CO_2 from Klemetsrud WtE plant will be delivered to Oslo harbour for continued transportation by ship to the final storage location. The expected variations in CO_2 delivery are a function of the operational time and will be developed further in conjunction with the ship transportation design.

The Concept phase interim storage tank design basis accounted for either 2-day or 4-day CO_2 production capacity only.

3.5.2 Design limitations

Because this project focuses on implementing CO_2 capture to an existing plant, much of the limitations and preconditions are set by the existing plants location and current operational conditions.

The existing plant is a waste treatment facility consisting of three separate waste incineration lines and three separate stacks for flue gas to atmosphere. To capture CO_2, the three different flue gas streams need to be diverted to the capture plant and the CO_2 free flue gas returned/released to the atmosphere either directly from the absorber, through the existing stacks or from altogether new stacks. The returned, CO_2 depleted, flue gas needs to meet the flue gas dispersion requirements set by the existing plant location.

It is important to minimize the impacts, resulting from a CC operation, on the existing plant. Currently the WtE plant is producing a considerable amount of heat for the district heating network and adding a CC plant is not allowed to reduce the overall district heating supply.

CO_2 capture from a WtE plant represents a new opportunity for CC technology developers and the composition of the flue gas is an important precondition. In this case the flue gas is a combination of three different streams, but due to the already strict requirements on flue gas cleaning and the high standards at Klemetsrud, the flue gas quality is well aligned (subject to further confirmation during FEED phase) with the requirements of the CC technology suppliers without the need for additional flue gas treatment (except cooling).

The location of the WtE plant limits the size (vicinity to existing roads, buildings etc.) of the planned CC operations, but has been found sufficient. Furthermore, the available space requires modifications before being suitable for construction works. Also, because the WtE plant is located close to populated areas, particular attention needs to be placed on plant appearance, noise- and chemical emissions. During the construction phase, space will also be limited, but a suitable location for a laydown area has been identified in the vicinity of the WtE plant.

The chemical emissions and effluents from the planned CC plant are limited by the same rules and regulations as the existing WtE plant. Where a new emission/effluent stream is introduced and not covered by the existing limitations, foreseen requirements will be presented.

Another limitation deriving from the location of the WtE plant is easy access to cooling water (river, lake, sea). Dry air coolers have been the comparative / primary choice thus far, but other possible opportunities for cooling and cooling integration such as wet coolers or hybrid coolers are being investigated.

The location of a liquefaction plant and truck loading station was also addressed during the concept phase of this project.

3.5.3 Selection of design bases for FEED phase

Chapter 3.5 represents the design basis for the Concept phase and based on the information obtained during the Concept phase a selection for the FEED phase BoD has been made.

The FEED phase design basis is:

- Pipeline transportation and flue gases from 3 incineration lines

3.6 OVERALL FACILITY CONFIGURATION

3.6.1 Klemetsrud Waste to Energy plant

For description of existing plant, refer to chapter 3 - 3.2.

3.7 OVERALL LAYOUT (INCL MASTERPLAN)

3.7.1 General

The carbon capture plant is being planned for an existing WtE plant, thus the size and layout of the CC plant needs special attention. In addition, any modifications to the unbuilt/ undeveloped site areas need to comply with building authorities' requirements and municipal regulations which are the responsibility of Company. One key aspect of the Company site is that the WtE plant is located close to populated areas and stringent restrictions on emissions, appearance and available space apply. The planned CC plant must also be visually acceptable which is why an architect has been involved in the design (Company scope).

The activities related to CO_2 capture from Klemetsrud WtE plant are not limited to the location of Klemetsrud only, instead there is also a need for interim storage and CO_2 liquefaction depending on the selected mean of transportation of captured CO_2. The CO_2 will be transported from Klemetsrud to Oslo harbour by means of either 1) tanker trucks or 2) pipelines and the selected transport will determine the location of interim storage and liquefaction plant accordingly:

- Truck transportation: interim storage at both WtE and Oslo Harbour, conditioning and liquefaction at WtE

- Pipeline transportation: Conditioning at WtE, interim storage and liquefaction at Oslo Harbour

This section describes plot plans related to the activities planned solely at WtE location (i.e. Klemetsrud). The layout of the activities located at Oslo Harbour is described in Chapter 9.2. An image showing the relative position of the different areas under development can be seen in Figure 3.

Figure 3. Location of Klemetsrud WtE plant and Oslo harbour.

The plot plans for the two different locations, Klemetsrud and Oslo Harbour are presented below. In addition it should be noted that the exact setup of the two different areas depends of the selected transportation alternative and this is also accounted for below.

3.7.2 Capture plant at Klemetsrud

The land designated for carbon capture plant at Klemetsrud WtE site is shown in Figure 4. It is marked as area 2 in the illustration on the left side. The indicated land is of ~ 5 000 m^2 size and is a property of Company. As can be seen from Figure 4, right image, the principal area (2) considered for the CC unit is located on a small hill next to the WtE plant therefore the available space requires modifications before being suitable for construction works. Company will, however, provide a level ground with concrete foundation to an agreed elevation with Contractor specified requirements and drain/effluent interfaces. A suitable location for a laydown area has been identified in the vicinity of the WtE plant which will be available during construction phase, Figure 6. Areas 1 and 3 shown in Figure 4 are not available for consideration at this stage.

Figure 4. The land designated for carbon capture plant, Area 2 (left image), at Klemetsrud WtE site, and a close view of Area 2 (right image). The numbers represent height above sea level [4].

The Conceptual plot plan developed by Apply, Fig 5a, is based on the information collected from the equipment suppliers and the prepared layout, Fig 5, is intended to primarily serve as an indication of plant footprint and possible interfaces. The placement of the equipment has been done based on the available area, process flow, piping, maintenance requirement, access, Installation and Safety. Stacking of equipment has been considered as one of the key elements in reducing space requirements. One of the options considered is the stacking of Coolers, Heat Exchangers and Pumps in a five floor building of approximately 18 x 15 x 20 m. By housing this equipment in a multi-level structure, a saving of up to 500 m^2 could possibly be achieved. Layout will be optimised further based on equipment vendor information, equipment sizes and site location.

According to the plot plan presented by Technip, Fig 5b, the layout of the plant will be arranged from North to South in the following order:

- Flue Gas Pre-Treatment
- CO_2 Absorption
- Absorbent Regeneration
- Thermal Reclamation
- Heat Pump
- Water Treatment
- Substation

To lessen the vertical impact of the CCS Plant, the Plant layout has been arranged to try and keep the taller structures grouped as close as possible together, near the current WtE Plant Stacks. This also means that the connections to the current Stacks, for the CO_2 Ducting, are kept as short as possible. The 60 m high CO_2 Absorber, the tallest structure on the CCS Plant, has been positioned to be inline and adjacent to the WtE Plant Main Building. It is assumed to lessen the visual impact [5, p. 64].

Currently Apply is extending approximately 300 m^2 and Technip 1000 m^2 outside the allocated area of 5000 m^2. Note, however, that these plots are based upon the 4 line design and it is expected that for the 3 line design case the allocated area will be sufficient. In addition, there is a potential of additional 5000 m^2, if need be, by utilising the area north, the car park and the administration building.

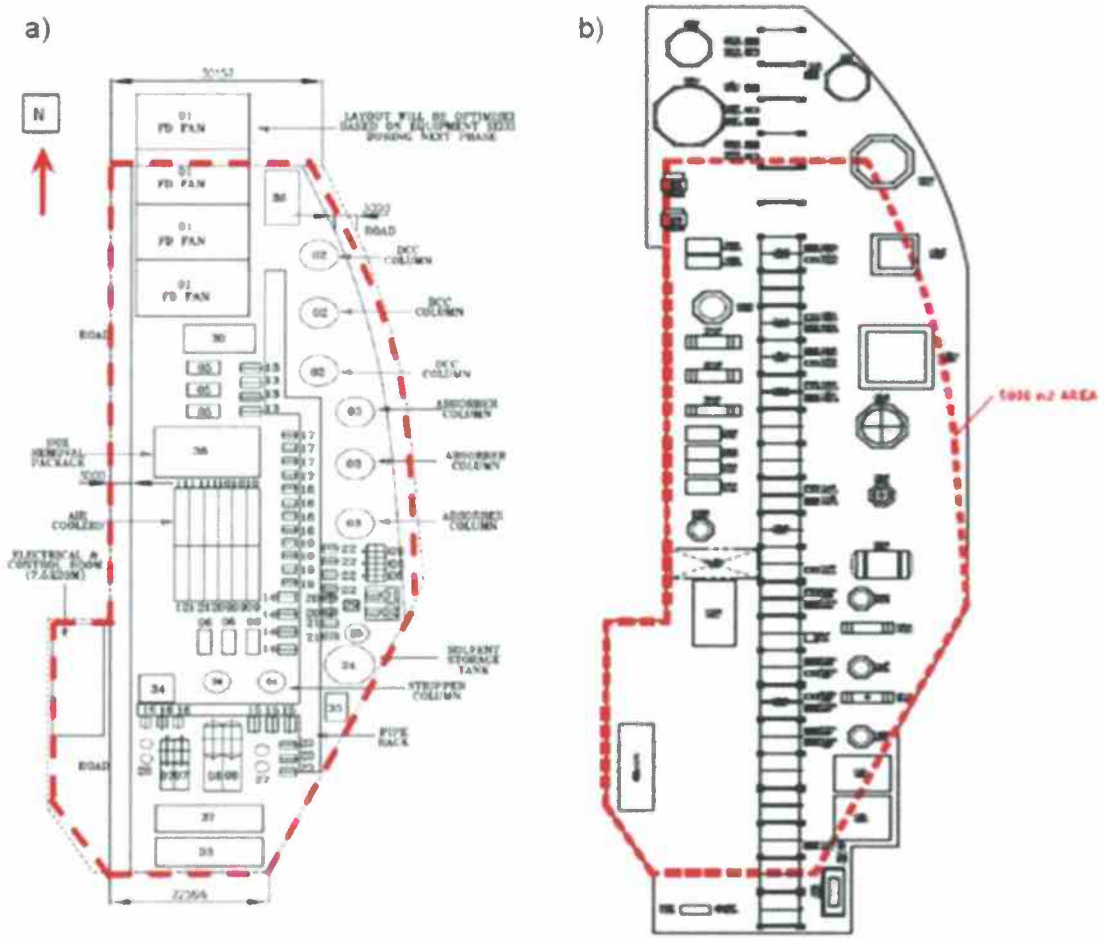

Figure 5. Conceptual plot plan of CCS Plant a) Apply [6, p. 34], b) Technip [5, p. 481].

3.7.3 Storage and loading station at Klemetsrud

In case of the truck transportation option, a design shall accommodate a conditioning and liquefaction plant, intermediate storage and loading station of liquefied CO_2 in a designated area of 6 660 m^2 at WtE plant. The solution is presented in Figure 6. The layout of a carbon dioxide storage facility shall be developed to minimise risk and maximise safety of any personnel and local population. The areas which could collect high concentrations of CO_2, such as pits, ground depressions and buildings are to be avoided. The road access to the plant is well developed due to the high amount of trucks transporting waste to and from (waste separation facility) the plant.

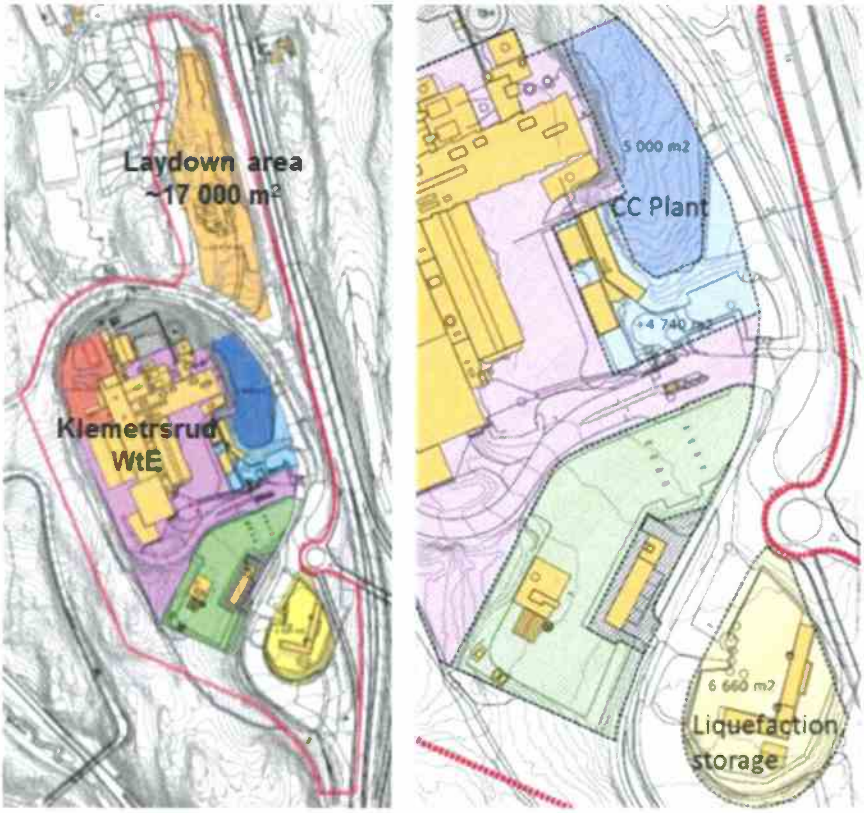

Figure 6. Overview of WTE plant (left) and the designated area of 6 660 m^2 (right) at WtE plant for intermediate storage and loading station/truck handling.

Apply's conceptual plot plan drawing localizing liquefaction unit, intermediate storage and truck loading station at KEA is shown below in Figure 7. Layout is intended to serve primarily as an indication of plant footprint and possible interfaces. Details are expected to vary depending on the equipment vendor, site location, and further detailed design development [6, p. 63].

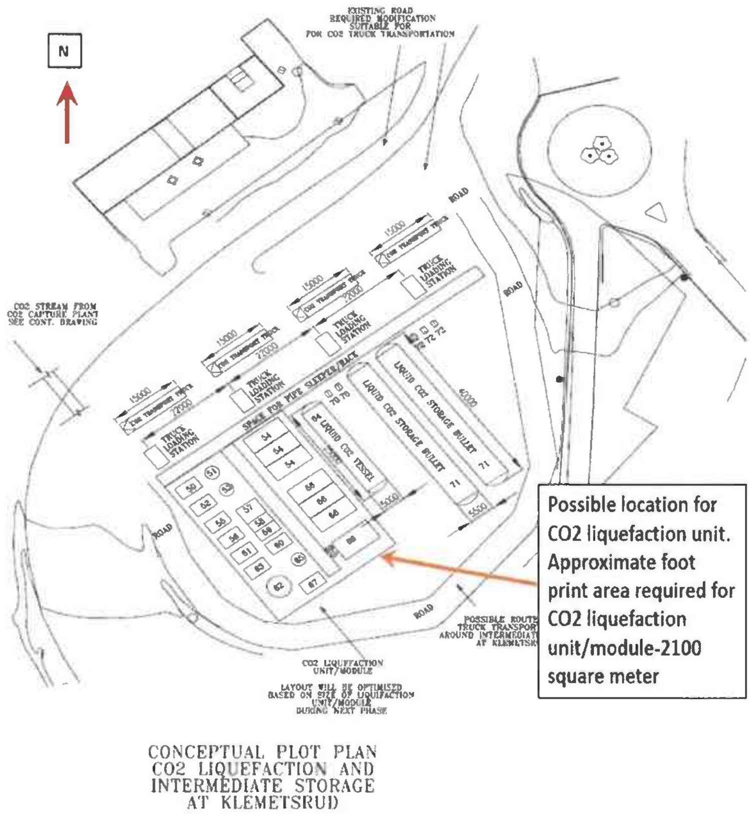

Figure 7. Conceptual plot plant of a Liquefaction and Storage facilities at WtE as per Apply's design [6, p. 55].

The CO_2 Liquefaction and Storage facilities plot plan presented by Technip will contain the following Units:

- Extra Air Coolers for use by CCS Plant
- CO_2 Liquefaction Trains
- CO_2 Storage Bullets/Towers
- Custody Metering
- Road Tanker Loading
- Substation

The layout of the Liquefaction and Storage facilities will be arranged as such to shorten the pipe runs to Process Units as much as possible. All Storage Tanks for the CO_2 will be located in the least hazardous area, downhill of the main plant areas. In the case of the truck scenario, a separate loading area (accommodation 4 trucks at the same time) has been allocated adjacent to the CO_2 Storage Tanks. It is anticipated that a new access road will be provided from to the existing roundabout on the main road. This is to allow for the access and egress of the trucks without interfering with the current traffic [5, p. 65].

Table 3-3 presents the summary of facilities planned to be located at KEA.

Table 3-3. Summary of the planned locations and space for CCS plant facilities.

Facility	Location	Available Area
CC plant	Eastern part of KEA	5 000 m^2 (additional area of ~5 000 m^2 available)
Liquefaction &storage at KEA (truck option)	South-East part of KEA	6 600 m^2
Laydown area (construction phase only)	Northern part of KEA	17 000 m^2

3.8 Battery Limits and Interface

The Concept Study has included the full Carbon Capture Plant, from the tie-in points on flue gas streams K1, K2, K3 and K4 (future) to the transfer of liquefied CO_2 at the harbour onto the incoming vessel. During the Concept phase two CO_2 transport options were evaluated, truck transport and pipeline transport. The two alternatives do have the same battery limits at CC plant towards existing WtE plant. The alternative transport solutions will have some different interfaces, mainly related to the intermediate storage at Klemetsrud. However, based on the result of the evaluation of the Concept phase, Company will continue into the FEED phase based on pipeline transport.

The battery limits are described in the Main flow diagram [7]. The diagram shows the solution based on a truck transport and will be revised in FEED. Additional connections with sewage are further being developed in the Interface Register [8] (Apply) and [9] (Technip)

The following main battery limits apply:

- Company is responsible for all ground works at KEA and in Harbour. Battery limit is top concrete foundation at ground level. Any concrete and steel constructions above ground level (top concrete) is Contractor supply.
- Water to and waste water/sewage from plant at Klemetsrud and in Oslo harbour is delivered by Company to one point at fop concrete foundation.
- Electricity is delivered to main switch at HV incoming to CC plant at Klemetsrud and in Oslo harbour.
- Battery limit for flue gas from each incineration line is at existing flue gas duct. Dampers for flue gas out/in and bypass is included in Contractor scope.
- Steam and condensate to be provided at flange at wall to turbine hall.
- District heating water for feed-back of thermal energy is to be at existing district heating line, either on "Sentrum line" or "Bjørndalen/Holmlia line"
- CO_2 transport battery limit is at inlet /outlet flange of pipeline (exact location not defined). Company deliver pipeline including pigging stations.
- Battery limits towards ship is as defined in Client's design basis. Further details to be clarified early FEED.

More detailed description of the battery limits are given in Technip Basis Concept of Design [10, pp. 14-17] and Apply Study report Carbon Capture [6, p. 124]

Integration is further described in the document:

- NC02-KEA-O-A-0002 Construction and integration philosophy [11]

Interface points and tie-ins are further described in the following documents:

- NC02-KEA-O-LA-0001 Interface Register - CC Plant 1 (APP) [8]
- NC02-KEA-O-LA-0002 Interface Register - CC Plant 2 (TECL) [9]

Optimisation with regards to using existing established systems will be evaluated in the FEED phase.

Location of the physical connection points can be seen from the documents:

- NC02-KEA-L-XE-0001 Turbine hall K1/K2 connection points [12]
- NC02-KEA-L-XE-0002 Control room K1/K2 connection points [13]
- NC02-KEA-L-XE-0003 Plot connection points [14]

4 CONCEPT DEFINITION [redacted]

One of the key objectives of the Concept phase was to define the key concepts and try to freeze the concepts moving into the FEED phase. KEA considers the following design elements as concepts that were explored in the Concept phase and their conclusion:

1. Integration with WtE plant considering Current (3 lines) and Future (4 lines) cases respectively.
2. [redacted]
3. CO_2 transportation by Pipeline Option or Truck Option
4. Location and plot space

4.1 INTEGRATION WITH WTE PLANT CONSIDERING CURRENT AND FUTURE CASES RESPECTIVELY

The design basis at the start of Concept was given as follows:

Concept phase: The plant shall be prepared for the possible future capacity of 652 600 (at 100%) tons of CO_2 per year with 90% capture rate, averaged over the total yearly CO_2 emissions from Klemetsrud WtE plant. The plant will initially operate with a capacity of 460 200 (at 100%) tons CO_2 per year but will be increased after start-up of line 4.

During the maturation of the project in the concept phase the number of alternative cases have been reduced. The design base at end of concept phase is to capture CO_2 from the existing lines 1 to 3 and transport by pipeline, i.e. the CC plant, transport, liquefaction and intermediate storage is to be optimised for this capacity and not prepared for future increase with a possible additional incineration line, - with the exception of the dimensioning of the pipeline.

The overall philosophy for integrating the CC plant with the WtE plant is described in chapter 7, Integration to existing plant.

The concept selections associated with the integration can be summarized as follows:

- 3 lines only and future maximum 460 200 tons of CO_2 produced per year, 414 200 t CO_2/y captured
- 90% capture rate over the year
- Pipeline prepared for a future possible 4th line
- CC plant shall be able to handle all flue gas variations. By-pass of CC plant if required. Conditions for bypass shall be specified and agreed upon between Company and Contractor
- CC plant is not to impact incineration plant in a negative way
- Use wet/hybrid coolers for utilizing of excess waste water and condensate production at plant (reduced OPEX, potentially reduced CAPEX, reduced plot space and noise)
- Precooler /acid gas washer included
- New steam turbine probably included, but only pressure reduction also to be considered
- Existing supply to DH shall be maintained, heat pumps to be optimized in regard to temp and media
- Internal treatment of hazardous waste from CC plant
- CC plant to be on non-prioritized power supply in order to contribute to local grid flexibility
- Sharing of common facilities (workshops, warehouse, offices, control room)

- Design based upon large degree of automatization, one operator per shift for CC plant
- Subcooling in existing scrubber K3 in continuous use
- Included in CC plant, flue gas measurements out of CC plant
- Optimize cooling to allow for full incineration capacity and carbon capture during summer
- For civil works, use of secondary materials where possible to contribute to circular economy
- Fossil free building site as far as practically possible
- All national regulations with respects to tariffs and labour contracts shall be adhered to

[redacted]

[redacted]

4.3 CO_2 TRANSPORTATION BY PIPELINE OPTION OR TRUCK OPTION

The transportation of CO_2 from Klemetsrud to Port of Oslo for further transport by ship to final storage area has been evaluated. Two main options exists namely truck transportation by tractor truck and tank for liquefied CO_2 transport or pipeline transport.

For the pipeline option, the CO_2 will be transported in Gas form and liquefaction must be moved from Klemetsrud to Port of Oslo. Intermediate storage at Klemetsrud will not be required for the pipeline transport option.

A pipeline alternative is feasible when some conditions are met. These conditions are mainly related to obtaining some sort of early approval from all stakeholders in order to reduce risk of, possibly uncontrollable, extended permitting processes. To facilitate this process extended use of directional drilling and the use of existing tunnels has been proposed as the most promising.

Directional drilling is strongly dependent on hard solid rock and its applicability in mountains with a lot of cracks and loose stones is limited. Focus in the next phase should be to obtain approval as early as possible and investigate the rock quality on the proposed routes. This processes could lead to adjustments of the route or the technologies used. In the absolute worst case scenario it could lead to exclusion of the pipeline alternative. In that case the truck alternative should be established.

This study shows that the pipeline option is the preferred transport solution. An early design freeze for a pipeline option is needed to start the permitting process in due time. It is recommended that until this certainty is obtained the truck alternative is kept as an option but no further work for the truck alternative is required in FEED phase. All further engineering activities should be focused on confirming the preliminary conclusions for the pipeline option as included in this study.

The concept selections associated with the transport can be summarized as follows:

- Pipeline is base concept

- Intermediate storage size in harbour to be evaluated early FEED (also pending Gassnova to freeze CO_2 carrier arrival frequency)
- Gas phase CO_2 in pipe
- Pressure and temp to be optimized
- Liquefaction in harbour
- Truck is the fall-back option

4.4 LOCATION AND PLOT SPACE

The KEA site has been evaluated with respect to compability with the plot space need of the capture plant. In Oslo harbour three different sites for intermediate storage has been considered. The Concept Study has arrived at the following conclusions moving into FEED:

- CC plant
  - Move ahead with current location east of incineration and 5000 m^2 as allocated area
  - Architectural consideration to be included. Noise abatement and fencing, but process plant shall be open
  - Red barracks area at KEA to enable fall back on trucks
- Harbour
  - Move ahead with [redacted]n FEED.
  - Relocation to an area south in [redacted] is proposed. Positive with regards to dispersion analysis

5 CO_2 CAPTURE TECHNOLOGY

5.1 INTRODUCTION

KEA has had the opportunity to choose between several experienced CO_2 capture technology suppliers (from now on referred to as Contractors) during the tendering phase of this project of which two Contractors participated in the Concept phase of this project.

The CO_2 capture technologies in question are similar in nature (amine based), but for the sake of clarity, two separate descriptions (one for each Contractor) have been given in Chapter 5.3. For more details, where appropriate, the reader is referred to relevant Contractor specific documentation.

The two Contractors participating in the Concept phase were (in alphabetical order):

- Apply Sørco, partnering with Carbon Clean Solutions Limited (referred to as Apply)
- TechnipFMC, partnering with Shell Cansolv (referred to as Technip)

5.2 PROCESS DESIGN PHILOSOPHY

As part of the Concept study, Contractor has developed an independent and self-sufficient full scale concept for capture of CO_2 from the flue gas of the Klemetsrud Energy-from-Waste Plant. In order for KEA to evaluate the best concept going forward into FEED, the Concept phase has considered several flue gas flow alternatives.

Another important concept/design philosophy is that the CC plant is designed to be integrated to the existing plant such that the primary delivery of heat to the district heating network is not negatively impacted, while minimising the overall power consumption. A clear distinction is also made between operation during the summer months (low district heating demand) and winter months (high district heating demand). Particular attention is given to the summer months (increased cooling demand) due to the lack of cooling water in the vicinity of the WtE plant.

The Contractors scope also included the CO_2 truck-loading/ unloading stations and intermittent storage at Klemetsrud and Oslo harbour, but also the option of pipeline transport has been accounted for by Contractors. Truck transportation was initially considered as the CO_2 transportation alternative from Klemetsrud to Oslo harbour in the short term, which is why it also needed to be included in the Contractors scope. However, the pipeline transportation has been studied (by Company) in parallel during the Concept phase and a single transportation method has been selected for going into FEED.

All new emissions/effluents/discharges are being carefully evaluated to meet the existing and possible future authority requirements. This involves flue gas pre-treatment, flue gas conditioning prior to the release to atmosphere, CO_2 product conditioning and auxiliary systems (such as chemical storage, cooling systems, steam- and condensate systems). At the same time, much attention is given to the impact of flue gas components and variations on the capture plant operations and emissions. The design should be robust enough, but not overdesigned.

Company maintains the right to approve key equipment and components. At the same time, Contractor needs to allow for Company standardization of equipment/components across various subsystems, typically flood lights, and light fixtures, compression fittings, field instruments, low voltage electrical motors, vibration monitoring, Fire&Gas detectors, and pressure safety valves.

[redacted]

5.3 PROCESS DESCRIPTIONS

This part of the report is to provide a process description for the CC Plant, which consists of Flue Gas Pre-Treatment, Carbon Capture, Conditioning, Liquefaction and Intermediate Storage at KEA and/or Oslo Harbour.

5.3.1 CO_2 capture plant

A generic amine-based CO_2 capture process is presented in Figure 8. The actual solutions provided by the Contractors differ, but the overall concept is the same. Where there are significant changes compared to the generic process shown in Figure 8 this has been described in the text. In addition, all the main equipment and differences between the generic and two contractors' technologies are also presented in

Table 5-2. The description of the CC process as presented by the Contractors is described below.

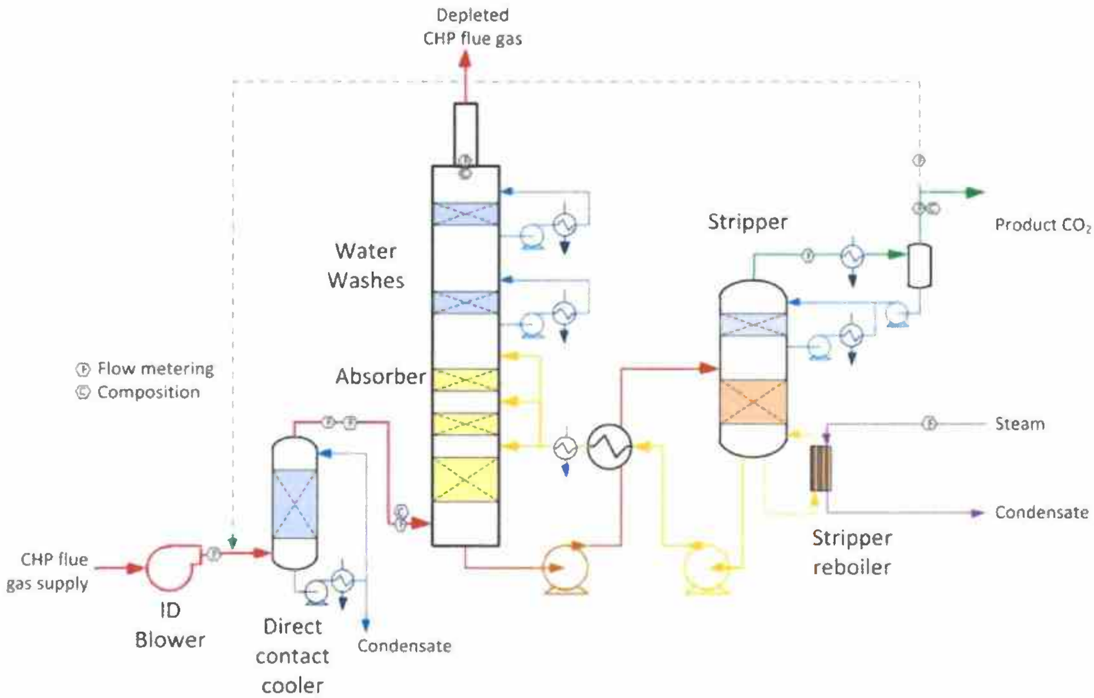

Figure 8. Schematic picture of a representative CO_2 capture process using amines [16].

Technip:

The reader may find it beneficial to read this section in conjunction with the schematic drawing included within Appendix 1, however, for the most part Figure 8 is sufficient for following the description. Flue gas (FG) from all 3 current incineration lines (4 lines - future case) at Klemetsrud Waste to Energy plant (WtE) will be extracted upstream of the existing flue gas into the Booster Fan (ID Blower in Figure 8). The Booster Fan will raise the pressure in order to overcome the pressure drop through the entire CO_2 capture plant. The FG is then directed to the Gas-Gas (heat) Exchanger (GGE)[1], which is not represented in Figure 8. The GGE cools FG to roughly 70 °C whilst heating treated FG to ~75 °C before being released to the atmosphere. Preheating of the treated FG ensures good buoyancy and dispersion. The GGE is a rotary regenerative heat exchanger in which rotating element transfers heat from the hot to the cold side. After the GGE, the FG is directed to the Pre-Scrubber (Direct Contact Cooler in Figure 8) where further cooling to 40 °C by direct contact with recirculating water and saturation is performed. The proper saturation and cooling of a FG is critical for efficient CO_2 absorption. In the Pre-Scrubber NH_3 is absorbed in the water what decreases amount of ammonia in the FG down to 0.3 ppmw (not absorbed, residual amount of ammonia is emitted from the process with the treated FG). Also such compounds as HF, HCl, and SO_2 are highly soluble and are removed in the Pre-Scrubber[2]. NO_2 is not readily removed in the Pre-Scrubber. NO_2 acts as a nitrating agent, causing

[1] The need for a GGE will be further investigated during FEED

[2] H_2S is not present in significant quantities in the KEA flue gas (to be confirmed by additional emission measurements in the FEED phase) and is therefore unlikely to contaminate the CO_2 product significantly (< 10 ppm).

nitrosamines and nitramines to form. These compounds are, however, continually removed in the Thermal Reclaimer waste stream. [redacted] Any heavy metals present in the FG are also removed in the thermal reclaiming unit (not shown in Figure 8) and are directed to one of the KEA incinerators (subject to further evaluation in FEED phase). Thus, an increased quantity of heavy metals would affect only amine degradation while not having any influence on CO_2 product quality [17]. After the pre-treatment step the quenched and cooled FG is ducted to the bottom of the CO_2 Absorber Column.

In the Absorber Column, absorption of CO_2 from FG occurs by counter-current contact with the Cansolv Absorbent [redacted] in a multi-level packed-bed tower. The CO_2 absorption is an exothermic process. The temperature increase in the Absorbent Column reduces absorption capacity and would also increase water evaporation from the amine into the heated flue gas what would cause a water imbalance in the process. Thus, the generated heat must be removed. The hot amine is collected and directed to the Intercooler (not shown, but similar to the water wash sections shown in Figure 8). The cooled amine is returned to the Absorber to resume CO_2 absorption.

The CO_2-depleted flue gas passes the Water Wash section (two shown in Figure 8) where it is washed out of any entrained solvent and cooled before being routed back to the GGE where it is reheated to 75 °C before being released from the WtE Plant existing stack.

After CO_2 absorption the CO_2-rich amine solution is withdrawn from the Absorber Sump and pumped through the Lean-Rich heat exchanger, where the temperature is increased, before entering the Stripper. The rich amine solution stream enters the Stripper Column where it undergoes solution regeneration and CO_2 recovery by the addition of heat in a form of water vapour. The water vapour required for the CO_2 desorption is generated by the Stripper Reboiler and by compressed vapour from the MVR compressor (MVR not shown in Figure 8). Heat supply to the reboiler is preferably low pressure steam, which is condensed. The flow of steam to the Reboiler is proportional to the rich amine flow to the CO_2 Stripper.

A two-phase mixture of lean amine solution and water vapour leaves at the bottom of the Stripper and is fed to the Reboiler and flows back to the Stripper Sump. The lean absorbent flows to the Lean Absorbent Flash Tank (not shown in Figure 8) where it is also flashed in order to remove vapour for reuse in the CO_2 Stripper though the MVR compressor. The lean solution is then directed to the Lean-Rich Heat Exchanger (described earlier already). From there the lean solvent is directed to solvent treatment units which consists of filtration and thermal reclamation sections (not shown in Figure 8).

The Steam Condensate Flash Pot (not shown in Figure 8) present only in Technip's design flashes the LP steam condensate from the Reboiler which is then directed to the bottom of the Stripper through the MVR compressor. Using the LP steam condensate flash as a stripping medium minimizes steam and energy consumption.

The Stripper Column produces overhead vapour which is condensed in the Stripper Condenser and two phases separate. These phases are: the condensate also referred to as a reflux water and CO_2 product gas. The Condenser is cooled using a heat pump with circulating loop of certain refrigerant what allows the heat to be rejected to district heating network. The condensate is collected in the Reflux Accumulator and send back to the Stripper.

The lean absorbent, as it flows through the various units of the CO_2 Capture System, may pick up dust or other insoluble contaminants which could accumulate in the system and foul the heat exchanger surfaces in the long run. Thus, the filtration section is required (not shown in Figure 8). The non-regenerable Absorbent Filtration Unit (AFU) consist of Cartridge type Mechanical filter, Activated carbon filter and Cartridge type Mechanical after-filter. After filtration the Lean Solvent is fed to the Thermal Reclaimer Unit (TRU) which removes accumulated Heat Stable Salts (HSS) and non-ionic absorbent degradation products from the solvent before being sent to the Absorber. The TRU is based on a vacuum distillation process, which boils off water and amine from a slip stream of the lean absorbent, and concentrates the degradation products. The degradation products will (subject to further study) be directed to the WtE Plant for incineration [redacted] The TRU is designed to operate in a continuous mode. The absorbent feed is heated in Thermal Reclaimer Feed Preheater (not shown in Figure 8) using MP condensate before introducing to the bottom of the TR Column's packed section where it is further heated with MP steam [18].

Apply:
The reader may find it beneficial to read this section in conjunction with the schematic drawing included within Appendix 2, however, for the most part Figure 8 is sufficient for following the description. For the CO_2 capture plant, flue gas from WtE will be tapped from three existing flue gas lines (K1-3) going to two flue gas stacks and will be joined into one common header. One spare tapping will be left for the future K4 line. The FG is split into three equal trains and directed to the Blower which compensates for the pressure drop in the CC plant. Downstream the Blower, the flue gas passes through the Direct Contact Cooler (DCC) where the FG is cooled to 30-40 °C. In the DCC, flue gas flows counter-currently to water in a packed bed. The water is recycled via a circulation pump and a cooler. The recirculating water is cooled by a refrigerant in a circulation cooler. This refrigerant will transfer heat to the district heating network. The flue gas is cooled beyond its dew point and the DCC is therefore a net water producer. After DCC, the FG flows to the SOx removal package (not shown in Figure 8) where 95% of SO_2, HCl and HF is removed thanks to efficient gas-liquid contact. [redacted] A bleed from the SOx Removal Package is be sent to the Effluent Treatment Plant (ETP) (not shown in Figure 8).

After the pre-treatment step the FG is divided in between two (or three for the 4 lines case) CO_2 Absorber Columns and fed at the bottom of each of them. [redacted] In the Absorber Column, CO_2 is selectively removed from the FG by counter-current contact with CDRMax® solvent [redacted] The CO_2-depleted flue gas enters two stage Water Wash section where the FG is washed and cooled to recover any entrained solvent. [redacted]

After CO_2 absorption the CO_2-rich [redacted] solution is withdrawn from the absorber sump and pumped through Lean-Rich heat exchanger, where the temperature is increased, before entering the stripper.

The rich solvent is pumped through the Lean-Rich Heat Exchanger and heated to around 100 °C by the lean solvent on the other side of the heat exchanger. The lean solvent coming from the stripper reboiler is at around 120 °C. The rich solvent is then fed in the top of the Stripper Column. This packed stripper column is connected to the Reboiler where further heating to liberate the CO_2 takes place. The heat supply to the Reboiler is LP steam. The stripper column overhead vapour at approximately 2 bar(a) and 100 °C is condensed and cooled to around 38 – 42 °C by clean water of indirect secondary cycle as part of Heat Pump (not shown in Figure 8). This clean water shall exchange heat with refrigerant of Heat Pump which will transfer the rejected heat into the district heating network.

Lean solvent at approximately 120 °C leaves the bottom of the stripper reboiler. The lean solution is further directed to the Lean-Rich Heat Exchanger (described earlier already) and to the Lean Solvent Cooler for additional cooling. From there the lean solvent is directed to solvent treatment units (not shown in Figure 8) which consists of filtration and thermal reclamation sections before being sent to the top of the Absorber Column.

The Filtration Section (not shown in Figure 8) consists of an activated carbon filter which is meant to remove the high molecular weight degradation products formed in the solvent. The Thermal Reclaimer System (not shown in Figure 8) operates when the concentration of HSS and other contaminants in the solvent is more than 1 wt%. If that is the case, a bleed (~5m^3/h) at the Lean Solvent Cooler outlet is taken to the Thermal Reclaiming Section. [redacted] the solvent is vaporized in the reboiler using [redacted] and impurities and HSS remain in the residue. The residue will be mixed with DM water before withdrawal and disposal as hazardous waste (0.93 kg/h). The treated solvent is fed back to the Absorbent Column [19].

The philosophy behind multi-train design presented by Apply:

- Ease of scale-up
- 1 absorber and 1 stripper results in very large diameter and height of columns bringing challenges into transportation and installation. Also, an onsite fabrication of equipment would have resulted into higher costs.
- Flexibility of operation and reliability for single train solution is lower compared to two train solution
- Standardization of the carbon capture solution so that it can be applied to next of kind solution to the industry [20].

The separated CO_2 stream is routed towards the CO_2 conditioning equipment (not shown in Figure 8) to meet the requirements of CO_2 purity downstream. Besides the purity requirements, the CO_2 also needs to be conditioned to meet the transportation requirements from the Klemetsrud WtE plant to the harbour from where the CO_2 will be further transported to its final storage destination. Liquefaction plant is supplied in both Contactors' cases by Vendor and description of the liquefaction process can be found in Section 5.3.3.1.

It should be noted that cooling utilities are not readily available at Klemetsrud and below are two descriptions from the Contractors around this topic:

Technip has proposed air cooling as an option for the liquefaction and storage area at the WtE facility and Oslo Harbour. Using wet cooling towers, either conventional package forced draft cooling towers or Wet Surface Air Coolers, could result in a cost reduction as cooling to low temperature using air coolers is relatively expensive. The optional cooling technologies will be further investigated in FEED phase [5].

Apply's design considers a cooling water loop for CO_2 streams cooling in liquefaction process. The cooling water system considered is based on a closed water loop cooled by air-coolers and distributed round the network by pump [6].

The storage capacities are based on mass flow rates of produced liquefied CO_2 provided by each of the Contractor, as seen in the Table below.

Table 5-1. Mass flow rates of produced liquefied CO_2.

Contractor	CO_2 flow	3 lines case	4 lines case
Technip **[5]**	Mass flow rate of captured CO_2 (t/y)	414 200	587 400
	Volumetric throughput of CO_2 (m^3/day)	1 132	1 655
Apply **[6]**	Volumetric throughput of CO_2 (m^3/day)	1 200	1 700

The study is based on CO_2 amounts as provided in Company's Description of the Assignment [3] i.e. 460 200 t/y of total CO_2 (3 lines case) and 652 600 t/y of total CO_2 (4 lines case).

Table 5-2. The main equipment in generic CO_2 capture process and in CO_2 capture technologies presented by two contractors (Apply and Technip).

Generic solution	Apply	Technip	Role
ID Blower	FD Fan	Booster Fan	[redacted]
Gas-Gas Exchanger	-	Gas-Gas Exchanger	[redacted]
Direct Contact Cooler with SO_2 removal	3 x Direct Contact Cooler	-	[redacted]
-	SOx Removal Package	Pre-Scrubber	[redacted]
CO_2 Absorber	3 x Absorber Column	CO_2 Absorber	[redacted]
Lean Amine Solution	CDRMax®	Cansolv Absorbent DC-103	[redacted]
Absorbent In-built Inter-stage cooling	Absorbent In-built Inter-stage Cooling Section	Intercooler	[redacted]
Water Wash 1&2	[redacted]	[redacted]	[redacted]
Acid wash	[redacted]	[redacted]	[redacted]
Heat exchanger	Lean-Rich Exchanger	Lean-Rich Exchanger	[redacted]
CO_2 Stripper	2 x Stripper Column	CO_2 Stripper	[redacted]
Stripper Reboiler	Stripper Reboiler	Stripper Reboiler	[redacted]
Stripper Condenser	Stripper Condenser	Stripper Condenser	[redacted]
	Stripper Reflux Drum	Reflux Accumulator	[redacted]
-	-	Steam Condensate Flash Pot	[redacted]
-	-	Lean Absorbent Flash Tank	[redacted]
-	-	MVR Compressor	[redacted]
-	Lean Solvent Cooler	-	[redacted]
-	Filtration Section	Absorbent Filtration Unit	[redacted]
Thermal Reclaimer	Thermal Reclaiming Section	Thermal Reclaimer Unit	[redacted]
-	-	Thermal Reclaimer Feed Preheater	[redacted]

5.3.2 CO_2 conditioning and liquefaction

5.3.2.1 Truck option

The CO_2 produced by capture unit is sent to the conditioning and liquefaction unit, where it is get compressed, purified from oxygen, dehydrated, cooled and liquefied for ease of transport and stored in the intermediate storage on-site at WtE plant. The saturated CO_2 rich feed gas is sub-cooled to liquid temperature (-26 °C) by means of Ammonia refrigerant. The CO_2 conditioning and liquefaction units are in both Contractors cases supplied by Vendors and are described in more details in Section 5.3.3.1.

5.3.2.2 Pipeline option

In the preferred pipeline scenario, there is no liquefaction facility at WtE plants. This option also requires only one set of storage facilities at Oslo harbour and does not require any intermediate storage at WtE plant. The conditioned CO_2 (compressed, after oxygen removal and dehydrated) in gaseous phase (40 °C, 40 bar(g), [5]) is transported through the pipeline to harbour where CO_2 is to be liquefied and stored in pressurised tanks (-29 °C, 15 bar(g) - Apply [6], -27 °C, 15 bar(g) - Technip [5]) prior to loading to ships.

5.3.3 Vendor packages

A number of areas within the Contractor scope of work have been further sub-contracted in this project. The areas or packages in question are:

- Liquefaction
- Heat pump
- Waste water treatment plant

Below is the detailed process description of technologies to be provided by Vendors as per suppliers' specification.

5.3.3.1 Liquefaction

Technip: A separated in CC plant CO_2 rich stream is routed to the conditioning and liquefaction plant. An operating pressure of a CO_2 gas is increased by Booster Blower, further the CO_2 passes Blower Aftercooler to reduce temperature and remove any further water. The stream is then directed to a separator where liquids are directed back into the CC Plant and the vapour is sent for precooling (Ammonia). The vapour is then routed to the few-stages compressor. Any resulting boil-off gas is returned to the process for recovery. After the final stage of compression, the stream is passed to an oxygen removal reactor[3] in which Hydrogen (in excess) is used. An actuated control valve will be used to control hydrogen injection rates. The Hydrogen dose rate will be very small thus even if valve fails the injection is unlikely to create and issue. The specification of the liquefied CO_2 indicates that only minor quantities[4] of H_2 will be present in liquid CO_2 product [5, p. 458]. After oxygen removal, the stream is further cooled in a De-superheater and an Aftercooler which use a high and medium temperature refrigerant. Water condensed from the stream is directed back into the process. In order to reduce the water content of the CO_2 the vapour is heated in a Gas Heater before being dried. The plant is designed to operate a dual vessel dryer system. It means that whilst one bed is being online the other is being regenerated. For the regeneration either boil-off gas or dry process will be used. The gas treatment is completed by a

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[3] An oxygen removal package was put on hold to gain further understanding of its requirement - therefore, it was not included within the scope.

[4] Preliminary (communicated by Technip) information: "H_2 content after the reactor will be about 50 ppm molar"

single non-regenerative carbon bed and particulate dust filter to remove any potential impurities during unexpected operating conditions out of the design range [5, p. 27].
For the current operating scenario, the Technip's Vendor has suggested that the capacity is accommodated by two parallel trains of liquefaction. This allows a further train to be added in the future to accommodate incineration line K4 [5, p. 37].

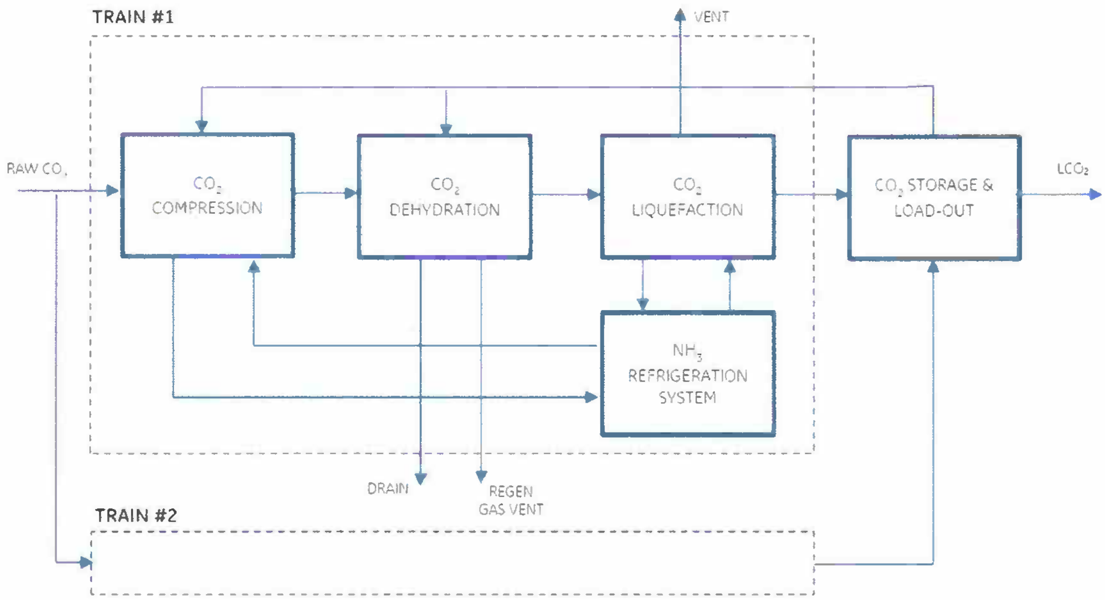

Figure 9. Liquefaction capacity for the current operating scenario (two parallel trains of liquefaction (Technip) [5, p. 38].

Apply: The carbon dioxide (CO_2) captured from current K1-3 incinerator lines and proposed future line K4 stream by the CCSL module is to be liquefied, temporarily stored at KEA and transported to Oslo harbour intermittent storage tanks via trucks from where it is to be transported by Cargo/ship for geological storage. The liquefaction process overview is presented in Figure 10.

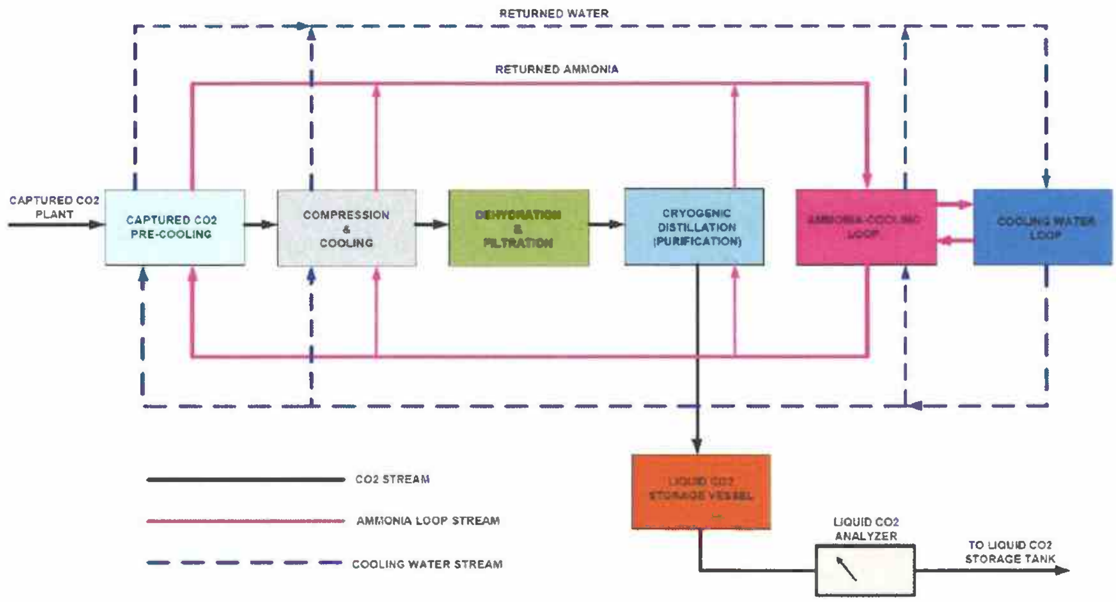

Figure 10. Liquefaction Process Blocks Overview [6, p. 46].

A CO_2 separated in CC plant is routed to the conditioning and liquefaction plant where the CO_2 rich stream is first directed to the pre-cooling system which consists of the gas cooler with water as cooling medium and afterwards for further cooling in a Pre-cooler, which uses ammonia as the cooling medium. The cooled CO_2 enters the compressor at 5 °C and is compressed in two stages compressors to approx. 22 bar before feeding it to the Dehydrator. The compressors uses oil to cool the gas which is then separated in oil coalesce leaving CO_2 stream with less than 1ppm oil content. To prevent oil carryover to the product, an oil coalescing filter arrangement is installed. The coalescing filter is placed at the outlet of the compressor. The filter arrangement secures removal of oil down to less than 0.1 ppm by weight. This type of filters are being used in numerous CO_2 recovery plants around the world supplying food grade CO_2 according to beverage industry standards [20]. The CO_2 from the Oil coalescer is sent to after cooler where the CO_2 is further cooled down using water as cooling medium. The cooled CO_2 stream is sent to the dehumidifier unit which removes most of the water before entering the Dehydration unit. The cooling of the CO_2 stream is by using ammonia as refrigerant. The CO_2 stream is sent to the Temperature Swing Adsorption (TSA) unit where any free water content in the CO_2 stream is removed to prevent hydrate formation in the cryogenic distillation column. The CO_2 stream flows to Carbon filter and Particle filter for deodorization and any particle removal. The CO_2 is then sent to the Cryogenic distillation column purification which consists of the Reboiler and condenser unit. In this unit, all non-condensable gases such as O_2, NOx, and Ar are removed so as to meet CO_2 purification specifications for storage and transportation [19, p. 47].

5.3.3.2 Heat pump

The base case for the Vendor design was the future, 4 lines case, however, until the K4 incineration line is installed any additional capacity is not required. The phased installation (e.g. installing fewer compressors) presented by Technip's Vendor allows potential savings and installation of capacity adjusted to 3 lines. Technip's recommended working fluid is R-1234ZE as it limits global warming potential (GWP) and process hazards. For the selected heat pump working fluid, the Vendor has advised the compressor power, CoP and the amount of heat that is required to be extracted from the cold sink. Heat exchangers A and B, as seen in Figure 11, will be required on the existing DH networks (Holmlia and Bjørndalen, and Centrum) to meet the heating requirements of current case (K1-3). When additional capacity is installed (design case K1-4) an additional exchanger will be required (marked C in the sketch).

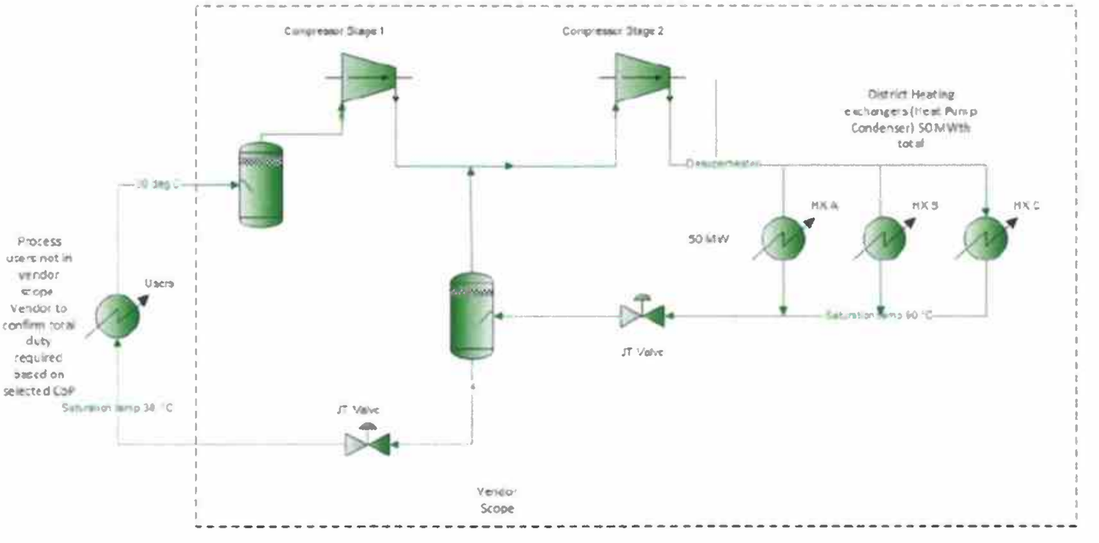

Figure 11. Schematic of a Technip's Vendor Heat Pump [5, p. 265].

Apply's Heat Pump selected supplier is Friotherm. A more details will be provided in FEED study [6, pp. 24,126].

5.3.3.3 Waste water treatment plant

In case of Technip, a functional specification for the waste water treatment plant (WWTP) has not been produced as the package but has been developed internally.

Effluent from the pre-scrubber meets all sewage water requirements with the exception of ammonia (68 vs. limit 60 mg/l) [5, p. 154]. With this limit a WWTP is required to remove the excess ammonia. A number of options have been considered for treating the pre-scrubber unit wastewater. The investigated alternatives are presented in Figure 12 (where "+" is the least favoured option and "++++" is the most favoured option. If the "do nothing" approach is deemed unacceptable due to existing emission permits, the CC plant will use ion exchange unit for treating waste water to reach demineralised water (DM) specification.

TREATMENT OPTION / CRITERIA	Biological Nitrification	Air Stripping	Ion Exchange	Do Nothing	Remarks
Relative Costs: CAPEX	+	+++	++	++++	
OPEX	+	++	++	++++	• If permit can be negotiated, discharge costs may increase slightly. • Ion exchange requires chemical addition and periodic change-out of the resin beds. • Air stripping option uses large blowers.
Footprint	+	+++	++	++++	• Biological treatment has a very large footprint compared with the other options.
Operational Complexity	+	+++	++	++++	
Utilities: Electrical Power	++	++	+++	++++	• Biological nitrification and air stripping use large blowers.
Chemical Use	++	++	+++	++++	• Ion exchange uses a greater number of different chemicals, but in much smaller quantities.
Waste Stream Disposal Requirements	+	+++	++	++++	• Biological treatment requires sludge disposal. • Ion exchange requires periodic disposal of the ion exchange resin.

Figure 12. Waste water treatment options matrix [5, p. 40].

It was suggested that dilution of stream could lower the ammonia levels sufficiently to remove the requirement for a WWTP package.

It is intended to mitigate or remove the need for a WWTP by maximising the following opportunities:

- Incinerate semi-solid waste on site (existing licence in place)
- Waste water from the CC Plant shall primarily be utilised as process water in the WtE Plant
- An alternative - to combine the stream with the wastewater treatment line from the WtE
- Plant to dilute ammonia > investigated in VIP

The waste water treatment unit proposed by Apply is a zero liquid discharge (ZLD) unit. The output streams from the package will be a solid waste and treated water with the required quality to be sent to WtE plant. It is considered that the process water quality requirement at WtE plant can be achieved comfortably in a conventional ZLD systems.

The bleed streams from the DCC, the SOx scrubber and from the acid wash will be combined to the waste streams and sent to the WWTP where it will undergo pH adjustment with sulphuric acid/ caustic solution as required to achieve a pH of 6 – 8 [19, p. 9].

5.3.3.4 SCR

The SCR Study performed by Technip at the Concept Stage revealed that an additional SCR package was not required for this facility. NOx compounds are present in small amounts within the K1/K2 flue gas, however, the level is not expected to affect the absorbent. Due to there being no requirement for an SCR package, a functional specification was not prepared for a Vendor. KEA will take this further as a VIP.

5.4 HEAT AND POWER REQUIREMENTS

5.4.1 Introduction

The existing WtE plant at Klemetsrud currently generates both district heating and power. The addition of a CC plant to this WtE plant necessarily requires energy, but one of the primary goals of this project is and has been to minimise the parasitic load that the CO_2 capture operation places on the WtE plant by clever heat integration concepts.

The following definitions are to be considered while reading chapter 5.4:

- Existing WtE plant — The existing plant prior to updates done during the past years. The values are based on plant measurement values extracted during 2015. These values are the same as used in the CCS feasibility study
- Updated WtE plant — The updated version of the existing plant still including three incineration lines, however taking into account updates made to all three incinerators, the replacement of the K1K2 steam turbine, the steam connection between K3 and K1K2 steam headers as well as the addition of the scrubber heat recovery heat pump.
- Extended WtE plant — The extended version of the WtE plant with four incineration lines, where line 4 is assumed to be a copy of line 3. However, with a larger turbine able to take all the steam produced by the incinerator. Additionally all updates presented for the updated plant is also taken into account.

Figure 13 below shows a simplified illustration of the internal steam, condensate and district heating cycle of the WtE plant after a possible extension (i.e. line 4 addition). For detailed information around heat integration alternatives see document reference [21].

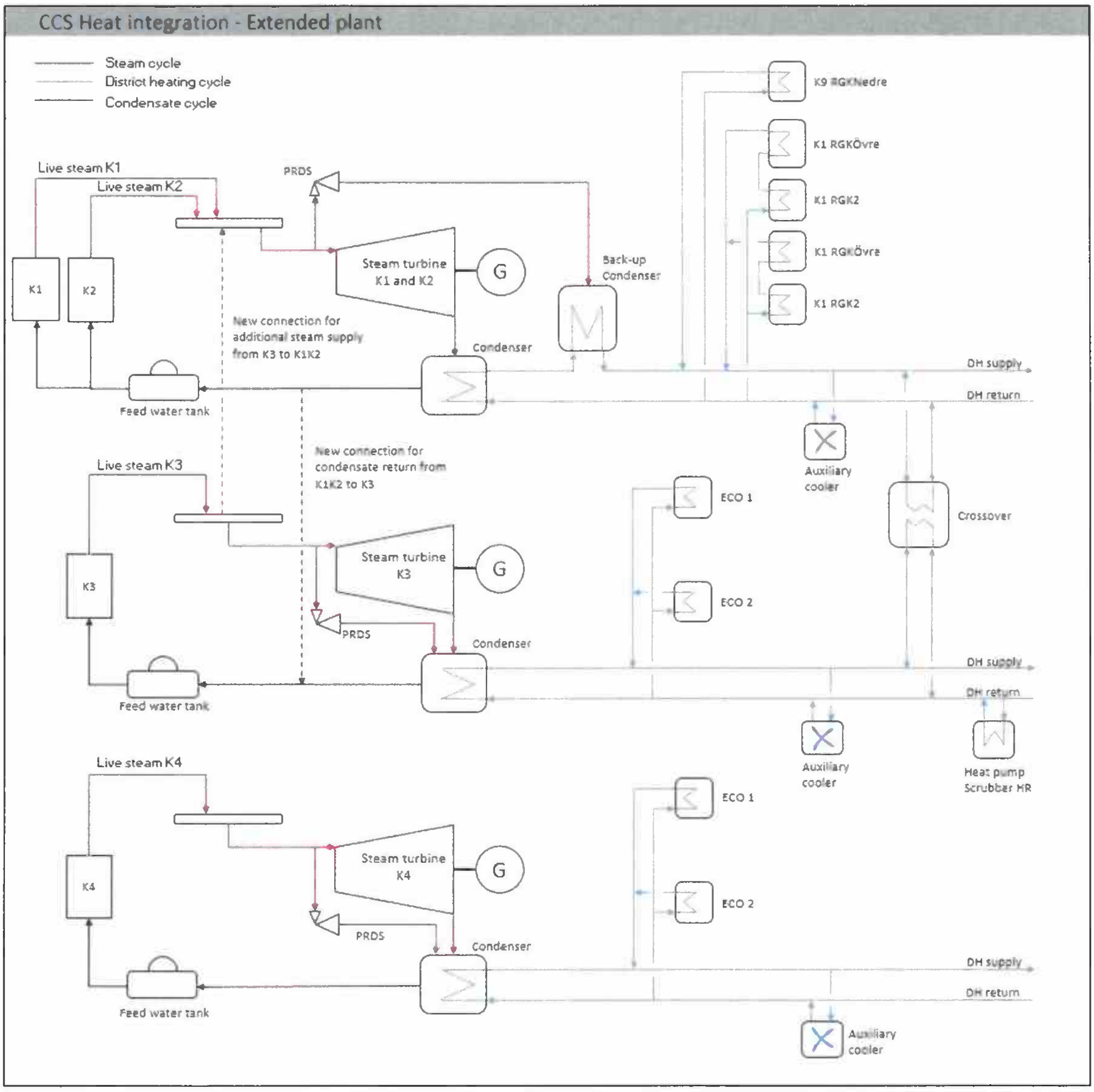

Figure 13. Simplified illustration of the extended WtE plant [21].

5.4.2 Plant energy balance

The heat and power requirements of integrating the existing WtE plant with CO_2 capture can conveniently be described by a set of simplified energy balance block diagrams as seen the Figures below. The selected figures represent the 3 lines and truck transportation concept [redacted] Additional representative figures of the various cases are available in the Concept study reports by the Contractors.

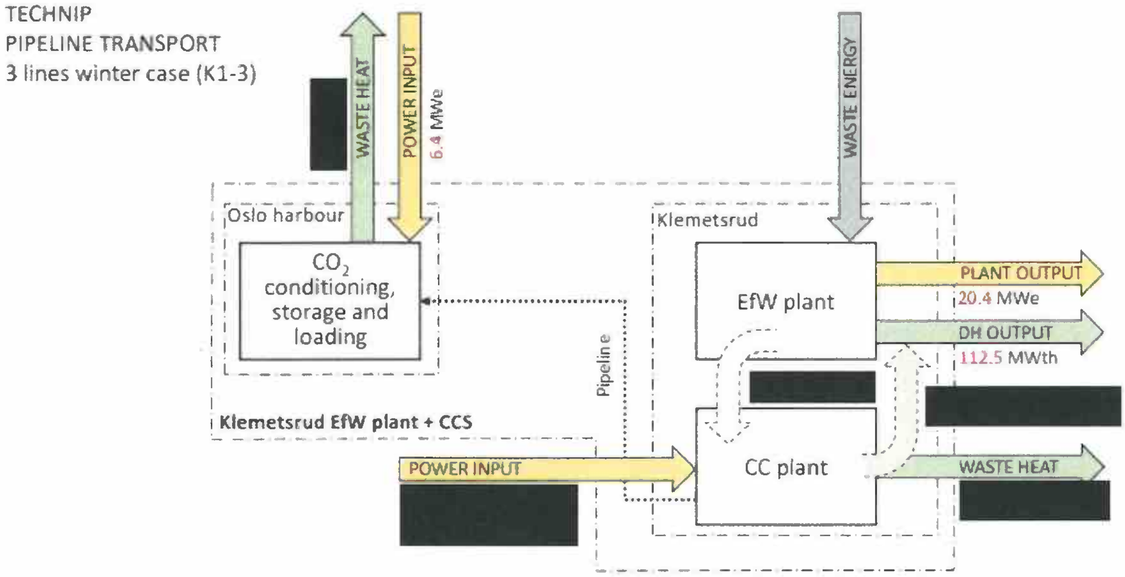

Figure 14. Simplified energy balance diagram of the Technip CCS concept - 3 lines, pipeline, winter.

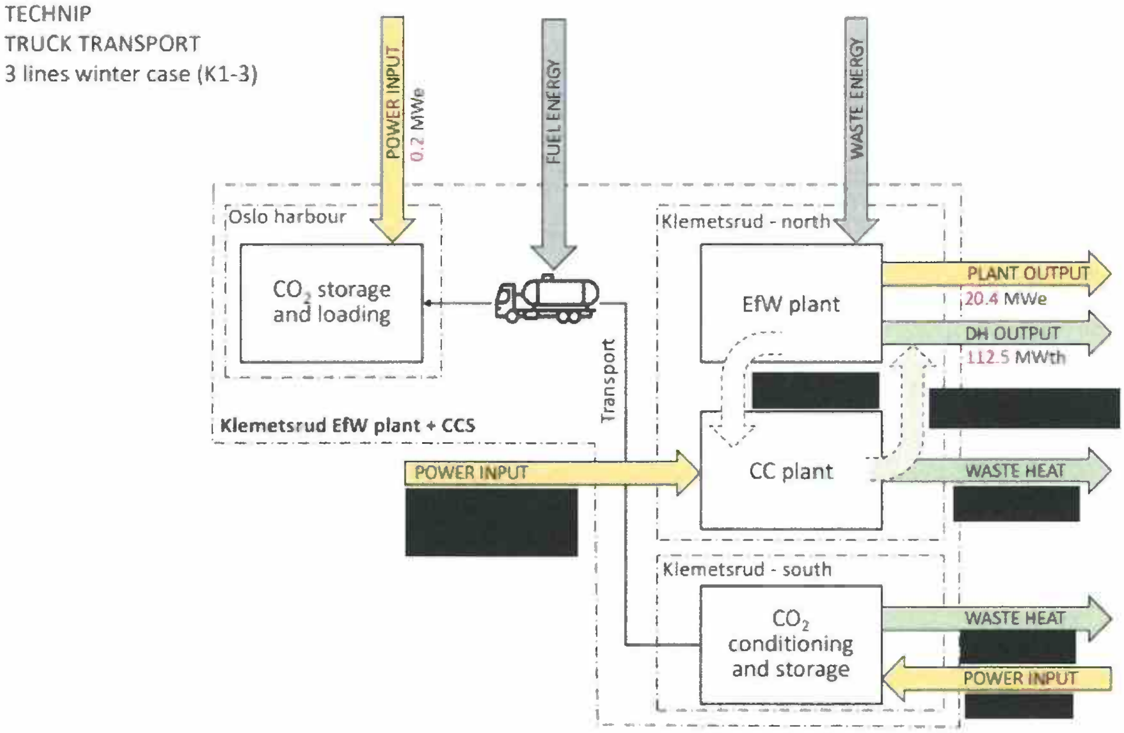

Figure 15. Simplified energy balance diagram of the Technip CCS concept - 3 lines, truck, winter.

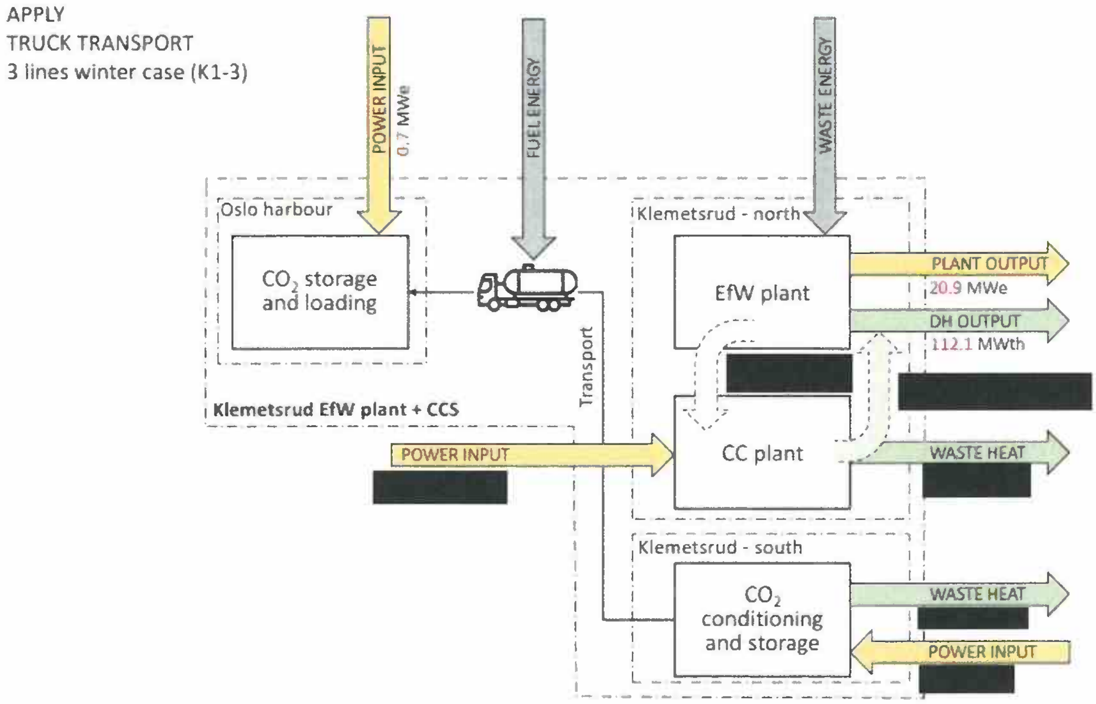

Figure 16. Simplified energy balance diagram of the Apply CCS concept - 3 lines, truck, winter.

5.4.3 Heat integration alternatives

An evaluation of six main heat integration solutions have been investigated for this report. The main objective of all different solutions are to fulfil the heat demand of the CC plant while minimizing the effect on the performance of the existing waste to energy plant. The different heat integration solutions are listed below, but the details have been presented elsewhere [21].

1. Solution 1a, 1b and 1c: All three solutions represent the extended plant with four incineration lines and three steam turbines.
2. Solution 2: This solution represent the extended plant with four incineration lines, however, with a complete re-build of the steam- and condensate cycle as well as the internal district heating network where all incinerators are feeding one single steam- and condensate cycle as well as the internal district heating network.
3. Solution 3a 3b and 3c: These three solutions represent the existing plant with three incinerator lines and two steam turbines.

Solutions 1 and 2 are not discussed further in this report, instead the preferred solution is presented below.

5.4.3.1 Heat integration solution 3a, 3b and 3c

Heat integration solution 3a, 3b and 3c represent the existing WtE plant with three incineration lines all connected to the CC plant. The difference between these two solutions is the way the heat demand of the CC plant is fulfilled. A common factor for alternatives 3a and 3b is that the steam turbine for line 1 and line 2 is replaced by a new steam turbine optimized to fulfil the steam demand of the CC plant. In heat integration solution 3c on the other hand the existing steam turbine for line 1 and 2 is used even after the heat integration of the capture plant.

Heat integration solution 3a: Steam to the CC plant is fed from a new extraction turbine on line 1 and 2. This means that part of the steam fed to the steam turbine on line 1 and 2 is fed to the CC plant. As a result of the lower heat demand of the capture plant when only connected to three incinerators, the steam extraction from line 1 and 2 is enough to fulfil the requirements of the capture plant. The return condensate from the CC plant is consequently in turn fed back to the condensate cycle on line 1 and 2. Additionally in order to maintain the district heating output of the WtE plant heat pump solution is installed within the CC plant to recover waste heat from the CC plant. However, as this solution is considering only the existing incineration lines the heat recovery from the capture enabled by the heat pump will be returned to lines 1, 2 and 3 instead of line 4. By returning the heat recovered by the capture plant to the internal district heating network on line 3 the inlet temperature to the condenser will increase. This increase will exceed the maximum inlet temperature of the condenser, which will therefore need to be replaced. A simplified illustration of heat integration solution 3a is included as Figure 17.

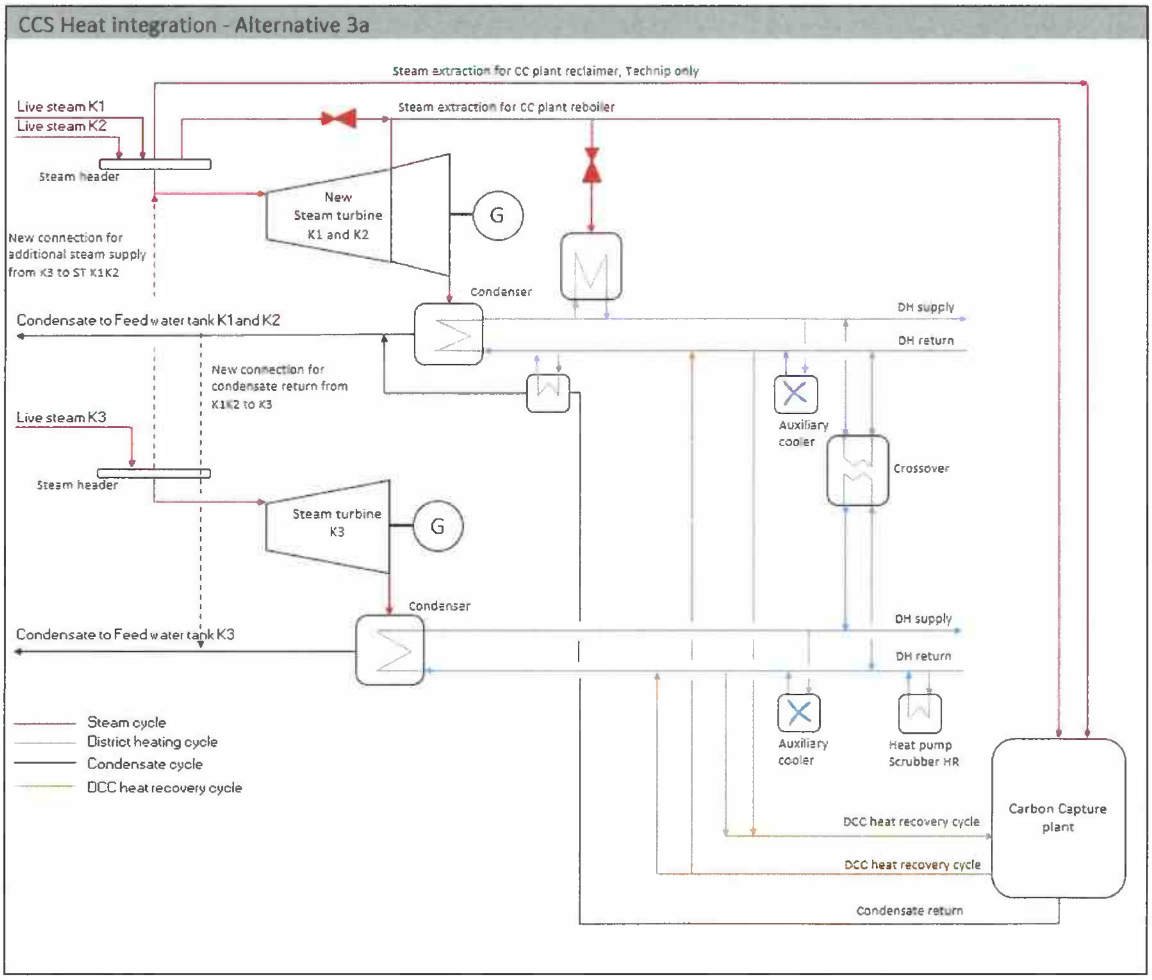

Figure 17. Simplified illustration of heat integration solution 3a.

As for solution 1a and 1c, an advantage with heat integration solution 3a is that all steam turbines are running at their design point during the new normal operation when the CC plant is in use. By oversizing of the steam connection between lines 1, 2 and 3 this could potentially be used to compensate for the loss of steam production during maintenance or shutdown of line 1 or 2, thus enabling a continued operation of the CC plant.

Another advantage with this solutions is that since the steam turbine is of extraction type it will always have steam flow even through the last low pressure stage, therefore producing district heat. Even though steam is extracted for the capture plant, therefore, decreasing the district heating production through the steam turbine condenser, the internal district heating network for line 1 and 2 is almost able to maintain the district heating production at the level of the existing plant by utilizing the heat from the DCC heat recovery heat pump within the capture plant. On the other hand the district heating production on line 3 can exceed the production of the existing plant by utilizing the DCC heat recovery. Therefore the lack district heat production on line 1 and 2 can be compensated by transferring heat from line 3, thus maintaining the district heating production of the existing plant.

Operational data from the two past winters shows that the district heating demand in the Holmlia and Bjorndalen networks is less that the heat production capacity of line 1 and 2 in the updated WtE plant. Consequently the cross over can also with the integrated capture plant be utilized in the same way as for now, i.e. transferring heat from line 1 and 2 to line 3 and further fed to the Sentrum network.

Heat integration solution 3b: In heat integration solution 3b, steam to the CC plant is fed from a new back-pressure turbine on line 1 and 2. As for solution 3a the steam production on line 1 and 2 including the additional steam being fed from line 3 to the steam cycle on line 1 and 2 is enough to fulfil the requirements of the capture plant. The return condensate from the CC plant is consequently in turn fed back to the condensate cycle on line 1 and 2. Additionally in order to maintain the district heating output of the WtE plant, a corresponding heat pump solution as for integration solution 3a is installed within the CC plant to recover waste heat from the CC plant. A simplified illustration of heat integration solution 1a is included as Figure 18.

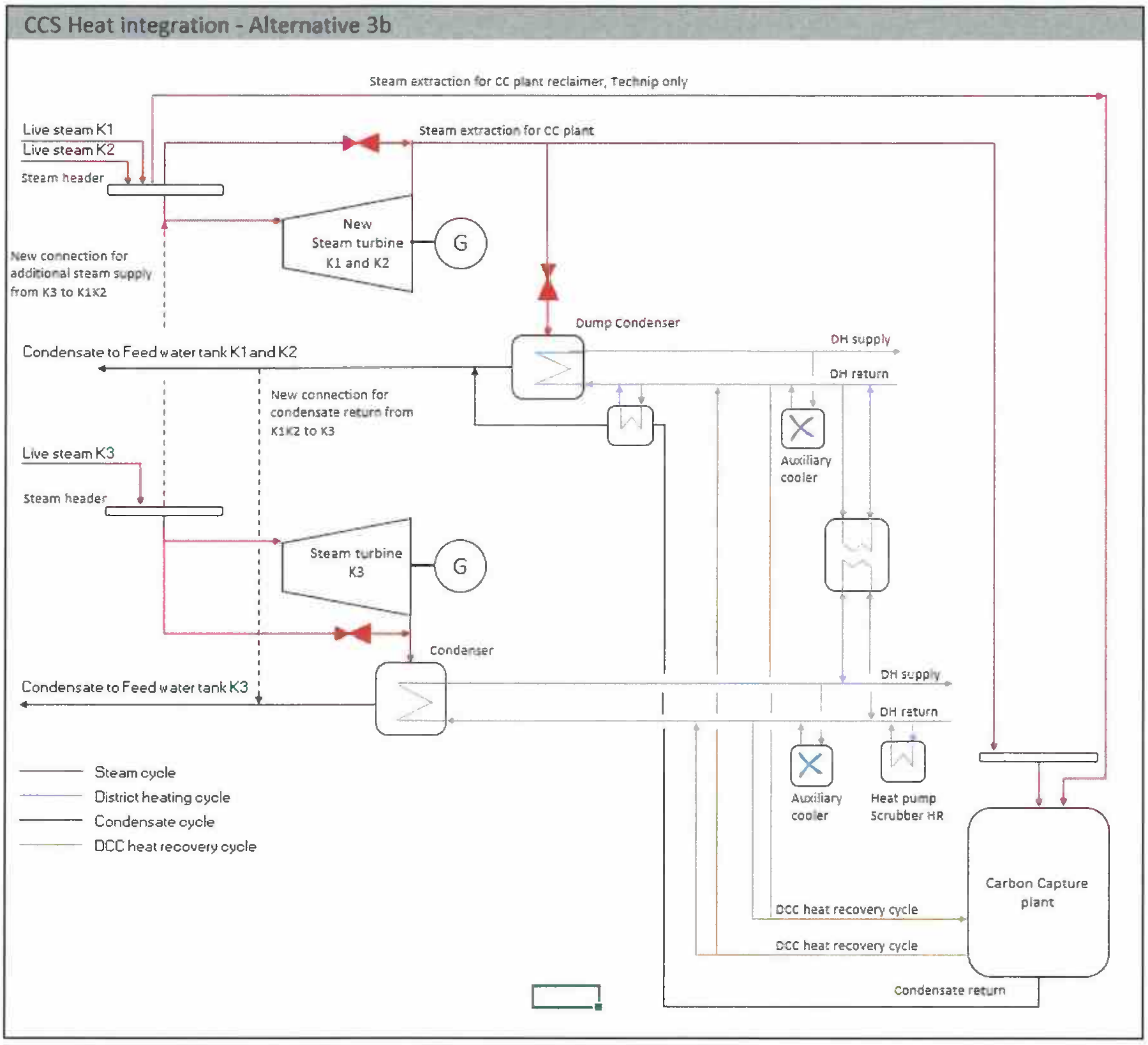

Figure 18. Simplified illustration of heat integration solution 3b.

One advantage of heat integration solution 3b is that all steam turbines are running at their design point during the new normal operation when the CC plant is in use. Another advantage is that by using a back-pressure turbine on line 1 and 2 the downstream system becomes more simple since no condenser is needed for the steam turbine on line 1 and 2.In case of maintenance or shutdown of line 1 or 2, a continued operation of the CC plant can be enabled by either oversizing the steam connection from line 3 or by including an back-up steam connection from the steam header of line 3 to the capture plant. This way the capture plant could be fed also during shutdown of both line 1 and 2. This would be done through a pressure reduction and de-superheating station to ensure suitable steam pressure and temperature to the capture plant.

One disadvantage with heat integration solution 3b is that by installing a back-pressure steam turbine on line 1 and 2 there is virtually no district heating production from these incinerators during normal operation. The only district heating produced is from the existing flue gas heat recovery system as well as the condensate heat recovery from the CC plant as well as the DCC heat pump heat recovery from the CC plant. However, this can be compensated by utilizing the existing crossover between line 1, 2 and line 3, enabling district heat to be transferred to the Holmlia and Bjorndalen networks.

Another disadvantage with solution 3b is that the steam flow in the steam cycle of line 1 and 2, also taking into account the additional steam being fed from line 3, exceeds the requirements of the capture plant. This means that part of the steam, i.e. the excess, needs to be continuously fed to the dump condenser. This steam will of course help to produce district heat but since not expanded all the way in the steam turbine it will lower the electrical efficiency of the WtE plant.

Heat integration solution 3c: In heat integration solution 3c, steam to the CC plant is fed directly from the steam header on line 1 and 2 through a pressure reduction and de-superheating station, thus by-passing the steam turbine altogether. This solution would enable utilizing the existing steam turbine, however, due to by-passing a large part of the steam past the steam turbine the electrical output will be considerably lower compared to solution 3a and 3b. As for solution 3a and 3b the steam production on line 1 and 2 including the additional steam being fed from line 3 to the steam cycle on line 1 and 2 is enough to fulfil the requirements of the capture plant. The return condensate from the CC plant is consequently in turn fed back to the condensate cycle on line.

5.4.4 Comparison of selected heat integration alternatives

This section presents the performance of the existing WtE plant with 3 incineration lines, utilizing heat integration solutions 3a and 3b. The calculated performance utilizing the capture plant from Technip is presented in Table 5.3 below.

Table 5.4 presents the corresponding results utilizing the capture plant solution from Apply.

Table 5-3. Performance of existing WtE plant in combination with Technip capture plant.

	Unit	Updated WtE plant	Solution 3a	Solution 3b	Solution 3c
Plant output excluding CC plant	MW_e	24.210	[redacted]		
Steam turbine K1K2	MW_e	13.351			
Steam turbine K3	MW_e	10.858			
District heating output	MW_{th}	111.773			
District heating output K1K2	MW_{th}	31.409			
District heating output K3	MW_{th}	80.364			
[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]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

1) The calculated output the steam turbine on line 1 and 2 for heat integration solution 3c, i.e. the existing steam turbine is based on a thermodynamic model of a turbine designed for the amount of steam available when applying solution 3c. The actual steam output of the existing steam turbine will in fact be lower as the steam flow through the turbine will be far below the design flow of the turbine, therefore affecting the efficiency of the steam turbine.

Table 5-4. Performance of existing WtE plant in combination with Apply capture plant.

	Unit	Updated WtE plant	Solution 3a	Solution 3b
Plant output excluding CC plant	MW_e	24.210	[redacted]	[redacted]
Steam turbine K1K2	MW_e	13.351	[redacted]	[redacted]
Steam turbine K3	MW_e	10.858	[redacted]	[redacted]
			[redacted]	[redacted]
District heating output	MW_{th}	111.773	[redacted]	[redacted]
District heating output K1K2	MW_{th}	31.409	[redacted]	[redacted]
District heating output K3	MW_{th}	80.364	[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]

1. The simulation results for heat integration solution 3a and 3b for the capture plant solution from Apply does not take into account the district heating crossover utilization. Therefore the district heating output shown for K1K2 and K3 represent the actual output form each internal network instead of showing the actual output to the three external networks [redacted] As can be seen from the table above the total district heating production of the WtE plant can be maintained at the same level even with the integrated capture plant.

5.4.5 Heat integration alternatives applied to the Contractor CC plants

This section includes an evaluation of the heat integration alternatives as applied to the different CC Contactors. As also elsewhere in the report, the heat integration concept will concentrate on a plant with only three incineration lines. Based on the evaluation of heat integration solutions 3a and 3b, the conclusion is that solution 3a is the one giving the most benefits. Primarily since the electrical output is approximately [redacted] higher compared to solution 3b when using Technip's solution and [redacted] higher when using Apply's solution. [redacted] Therefore the below section around the performance of the two capture plant suppliers is based on heat integration solution 3a.

5.4.6 Performance analysis for the two CC Contractors

This section includes a performance analysis of the Concepts presented by Technip and Apply, using values supplied by the Contractors. The results are presented in Table 5-5 below. The basis for the comparison is to maintain the DH production of the updated plant after integration of Capture plant. Technip values has a discrepancy in the heat to CC plant compared to heat recovery due to the use of the K3 Scrubber heat pump. If K3 Scrubber is not utilized then the difference can be made up by the DCC heat pump.

Table 5-5. Analysis results from Technip and Apply using actual values

		Updated plant	Technip	Apply	Δ
Heat integration solution			Solution 3a	Solution 3a	Solution 3a
Operational mode		Winter	Winter	Winter	Winter
Plant output	MW_e	24.210	20.315	20.873	0.5
Steam turbine K1K2	MW_e	13.351	9.489	9.988	0.5
Steam turbine K3	MW_e	10.858	10.825	10.885	0.0
District heating output	MW_{th}	111.773	111.871	112.141	0.3
District heating output K1K2	MW_{th}	31.409	31.487	54.306	22.8
District heating output K3	MW_{th}	80.364	80.383	57.835	22.5
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
DCC heat pump heat recovery	MW_{th}	-	[redacted]	[redacted]	[redacted]
Condensate heat recovery	MW_{th}	-	[redacted]	[redacted]	[redacted]

[redacted]

5.4.7 Operational modes

Since the WtE plant is operated in different operation modes the capture plant and its integration into the WtE plant also needs to be able to operate in different operational modes. The biggest impact on the operation of the WtE plant is the varying demand of the district heating network. During winter time the district heating demand is at its highest, i.e. both regarding the total output as well as supply temperature. This means that during this time the WtE plant is operated to maximize the district heating output to fulfil the demand of the network. During summer time on the other hand the district heating requirements is considerably lower, both concerning total output and supply temperature.

This means that the exhaust steam temperature of the condensing steam turbines can be slightly lowered, lowering the district heating supply temperature. Also due to the lower district heating output demand there is some excess heat produced by the steam turbine condensers that the district heating network is not able to utilize. This excess heat therefore needs to be cooled off.

On the other hand during periods of lower district heating demand there is no point in recovering heat from the capture plant through the DCC heat pump. However, this will require other means of cooling within the capture plant itself. The required performance of the auxiliary cooling system is presented in Table 5-6. The results presented in Table 5-6 represent the summer and winter operation of the existing WtE plant combined with the capture plant solution from Technip and utilizing heat integration solution 3a.

Table 5-6. WtE plant performance comparison for winter and summer time operation.

		Technip	Technip	Δ
Heat integration solution		Solution 3a	Solution 3a	Solution 3a
Operational mode		Winter	Summer	
Plant output	MW_e	20.315	20.388	0.1
Steam turbine K1K2	MW_e	9.489	9.457	0.0
Steam turbine K3	MW_e	10.825	10.932	0.1
District heating output	MW_{th}	111.871	26.000	85.9
District heating output K1K2	MW_{th}	31.487	6.000	23.1
District heating output K3	MW_{th}	80.383	20.000	55.4
Auxiliary cooling demand	MW_{th}	0	38.763	38.8
Auxiliary cooling demand K1K2	MW_{th}	0	12.022	12.0
Auxiliary cooling demand K3	MW_{th}	0	26.741	26.7
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
DCC heat pump heat recovery	MW_{th}	33.968	0	34.0
Condensate heat recovery	MW_{th}	0	0	0

5.4.8 Possible future extension of the district heating network

All results presented so far have been aiming for maintaining the current district heating production at Klemetsrud, i.e. to be able to recover a heat effect from the capture plant equal to the heat effect lost by the steam extraction. As the CC plant has a large amount of low quality waste heat the most feasible solution found is to using a heat pump boost the low quality to levels sufficient for use in the internal district heating network. Unfortunately the heat pump is only able to produce hot water at temperatures of 85 °C, so the remaining heat needed to reach the district heating supply temperatures is to be supplied by the plant. However, in case the district heating network supplied by the plant could be expanded there is more waste heat available within the capture plant that potentially could be utilized for increasing the district heating production. Table 5-7 below shows the maximum district heating production that can be produced by maximizing the amount of heat the plant can receive from the capture plant heat pump while still being able to further increase the district heating water temperature to the supply temperature set-point from the 85 °C produced by the heat pump.

Table 5-7. Evaluation of maximum district heating production by capture plant heat recovery.

		Updated plant	Technip	Technip	Δ
Heat integration solution			Solution 3a	Solution 3a	Solution 3a
Operational mode		Winter	Maintained DH production	Max DH production[1]	
Plant output	MW_e	24.210	20.315	20.315	0.0
Steam turbine K1K2	MW_e	13.351	9.489	9.489	0.0
Steam turbine K3	MW_e	10.858	10.825	10.826	0.0
District heating output	MW_{th}	111.773	111.871	131.722	19.8
District heating output K1K2	MW_{th}	31.409	31.487	42.975	11.5
District heating output K3	MW_{th}	80.364	80.383	88.747	8.4
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
DCC heat pump heat recovery	MW_{th}	-	33.968	53.241	19.3
Condensate heat recovery	MW_{th}	-	0	0.0	0.0

1. For the maximum district heating output case the scrubber heat recovery heat pump output is restricted to 13 MW_{th}

5.5 UTILITIES AND OTHER MATERIAL STREAMS

5.5.1 Utilities

During the concept phase of this project, the design guideline for the Contractors has been that the CC plant shall be self-sufficient in terms of most utilities (except steam, electricity and tap water). Thus, much of the utilities required for the CC operation are included in the Contractors' scope (e.g. demineralised water, instrument air, plant air, nitrogen, hydrogen and other technology related), while utility services such as steam (low/high pressure), process water and electricity will be provided from the existing WtE plant. [redacted]

Please note that overall energy requirements and thus also electrical power is discussed under Chapter 5.4.

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 5-9. Utilities not supplied by KEA, but used within the CC plants (4 lines, Truck Option)

Utility	Apply	Technip
Process water (t/h)	28	N/A
Instrument air (Nm^3/h)	200 (+ TBD)	600 (+ 600 at harbour)
Plant air (Nm^3/h)	TBD	255 (+ 255 at harbour)
Nitrogen (Nm^3/h)	65	TBD

5.5.2 Chemical consumption

In addition to the primary chemical, i.e. the solvent used for CO_2 capture, the CC plants have need for other chemicals as well and a summary of these have been provided in the table below (Table 5-10).

Table 5-10. Chemicals used during the operation of the CC plants (3 lines, truck transport case).

Chemical	Area of use	Apply	Technip
Solvent make-up (kg/h)	Absorber/stripper	[redacted]	[redacted]
NaOH (kg/h)	Solvent treatment	0.9 (20%) [6)]	2.6 (20%)
[redacted]	SOx scrubbing	77	N/A
NH_3 (kg, first fill)	Liquefaction	1200	TBD
Refrigerant (kg, first fill)	Heat pumps	TBD (NH_3)	TBD (4th gen)
Hydrogen (kg/h)	CO_2 cond.	-	0.41
Acid (kg/h)	ETP/WWT	[redacted]	[redacted]
NaCl (kg/h)	WWT	-	23.5
NaOH (kg/h)	ETP/WWT	TBD	TBD

[redacted]

Chemical	Area of use	Apply	Technip
Na_2CO_3 (m^3)	Cleaning during commissioning	[redacted]	[redacted]

5.5.3 Effluent streams

Below is a table of the primary waste/effluent streams generated by the addition of a CO_2 capture plant to the existing WtE plant.

Table 5-11. Effluent/waste streams produced during the operation of the CC plants (3 lines, truck transport case).

Chemical	From where	Apply	Technip
Reclaimer waste (kg/h)	Solvent reclaiming	[redacted]	[redacted]
Solid waste (kg/h)	CC plant	97.6	N/A
Treated FG (kg/h)	Absorber	TBD	301 012
Process Water (t/h)	Mainly absorber pre-scrubber	19.6	20.4

6 CO_2 TRANSPORTATION AND STORAGE

6.1 CONCEPT DESCRIPTION, CHALLENGES, IMPACT OF ALTERNATIVES, PROGRESS/SCHEDULE

The transportation of CO_2 from Klemetsrud to Port of Oslo for further transport by ship to final storage area has been evaluated. Two main options exist namely truck transportation by tractor truck and tank for liquefied CO_2 transport or pipeline transport.

For the pipeline option, the CO_2 will be transported in gas form and liquefaction must be moved from Klemetsrud to Port of Oslo. Intermediate storage at Klemetsrud will not be required for the pipeline transport option.

A pipeline alternative is feasible when some conditions are met. These conditions are mainly related to obtaining some sort of early approval from all stakeholders in order to reduce risk of, possibly uncontrollable, extended permitting processes. To facilitate this process extended use of directional drilling and the use of existing tunnels has been proposed as the most promising.

Directional drilling is strongly dependent on hard solid rock and its applicability in mountains with a lot of cracks and loose stones is limited. Focus in the next phase should be to obtain approval as early as possible and investigate the rock quality on the proposed routes. This processes could lead to adjustments of the route or the technologies used. In the absolute worst case scenario it could lead to exclusion of the pipeline alternative. In that case the truck alternative should be established.

This study shows that the pipeline option is the preferred transport solution. An early design freeze for a pipeline option is needed to start the permitting process in due time. It is recommended that until this certainty is obtained the truck alternative is kept as an option but no further work for the truck alternative is required in FEED phase. All further engineering activities should be focused on confirming the preliminary conclusions for the pipeline option as included in this study.

6.2 INTERMEDIATE STORAGE PHILOSOPHY

During the Concept phase, two different transportation options were investigated, namely Truck and Pipeline. These alternatives formed the basis for the intermediate storage solutions together with the sizes being dictated by the ship arrival frequency (2 or 4 days).

- **Truck Option**: "a liquefaction package and associated storage will be installed at the CC Plant before truck transport of the CO_2 to Oslo Harbour. Liquid CO_2 will be offloaded to an additional storage terminal before transfer offshore for geological storage" [22].
- **Pipeline Option**: "a pipeline would negate the requirement for storage at the CC Plant. All product would be transported, in gaseous phase, to Oslo harbour before liquefaction and storage on-site" [22].

6.2.1 Apply

Storage at Klemetsrud (4 lines): "The purpose of the interim Storage Tanks at KEA is to receive liquid CO_2 from the liquefaction plant via transfer pumps. The storage tanks are sized to handle 1-day liquefaction plant full production" [6, p. 60]. The proposed storage tank solution (bullet type) for the 4 lines case is 2 x 1 000 m^3 [6, p. 25].

Storage at Oslo harbour (4 lines): "The liquid CO_2 transported from KEA via Trucks will be stored in intermittent storage Tanks at Oslo harbour. The Storage Tank is designed to handle 2 and 4-days liquefaction plant full production" [6, p. 66]. The capacity of the tanks (spherical) has been selected as 3 x 1350 m^3 or 3 x 2 700 m^3 depending on the ship arrival frequency.

6.2.2 Technip

Storage at Klemetsrud (3 and 4 lines): "The storage scenario has been selected based upon the ability to modularize the facility, the volume to be stored, constructability, transportability, risk reduction and maintenance. To allow one-day worth of storage at the WtE Plant, 3 bullets of 450 m^3 capacity are recommended for the current flowrate, with the addition of a fourth bullet tank should line K4 be commissioned" [5, p. 190].

Storage at Oslo harbour (3 and 4 lines): "The storage situation at Oslo Harbour is greatly dependent upon the export vessel capacity and frequency of arrivals. If the vessel was to dock every 2 days for loading, it is recommended that 2 Horton Spheres at 15 m in diameter [1 767 m^3] be constructed at Oslo Harbour – a third Horton Sphere can then be installed upon completion of line K4. For the lower arrival frequency of 4 days between exports, 2 Horton Spheres of 18 m in diameter [3 053 m^3] are suggested for the Harbour. To allow for modularization, a third Horton Sphere can be installed once the CO_2 throughput is increased" [5, p. 190].

Table 6-1 presents a summary of Contractors' designs regarding the interim storage capacity at Klemetsrud and Oslo harbour.

Table 6-1. Summary of Contractor differences [6.2.1 and 6.2.2].

	Design criteria	Apply 4 lines, [5]	Technip 3 lines / 4 lines, [5]	
Liq. CO_2 production		1700 m^3/d	1132 m^3/d	1654 m^3/d
Truck option	Nb of storage tanks at KEA	2 x 1 000 m^3	3 x 450 m^3	4 x 450 m^3
	Actual CO_2 storage capacity at KEA (1 day production of liq. CO_2 to be stored)	1 700 m^3	1 215 m^3	1 620 m^3
	Nb of storage tanks at Oslo harbour	3 x 1 350 / 2 700 m^3	2/3 x1 767 m^3	2/3 x 3 053 m^3
	Actual CO_2 storage capacity at Oslo harbour (2/4 days production of liq. CO2 to be stored)	3 442 / 6 885 m^3	3 180 m^3/ 4 770 m^3	5 495 m^3/ 8 243 m^3
Pipeline option	Nb of storage tanks at Oslo harbour	3 x 1 350 / 2 700 m^3	2/3 x1 767 m^3	2/3 x 3 053 m^3
	Actual CO_2 storage capacity at Oslo harbour (2/4 day production of liq. CO2 to be stored)	3 442 / 6 885 m^3	3 180 m^3/ 4 770 m^3	5 495 m^3/ 8 243 m^3

6.3 Pipeline

The upstream battery limit for the pipeline evaluation of this concept study is the export flange behind the gas compressor. The downstream battery limit is the import flange of the liquefaction plant at Oslo Harbour.

For this phase of the project indicative steady state pressure drop calculations have been performed based on an isothermal flow assumption of vapor phase CO_2 at the upstream and downstream battery limit conditions

Pipe wall thickness is normally designed to cope with stresses from internal (and external) pressure. For the given design pressure this would result in a thin wall thickness in the range of 3-4 mm. Other factors such as external loads, accidental loads and corrosion may dictate a higher wall thickness.

However, it is assumed that the installation method will be the governing factor in wall thickness design. Pipe insertion in bore hole induces forces on the pipeline during installation. Contractors indicate good experience with similar pipe sizes with a wall thickness of ca. 10 mm.

A standard approach for route selection for hydrocarbon pipes can be applied for CO_2 transport pipes. Due care must be given to:

- Population density along the proposed route
- Possible health effects due to (accidental) release of CO_2
- Possible environmental effects due to (accidental) release of CO_2
- Cost evaluation of different alternatives
- Overall risk profile of the total life cycle of the pipeline (permitting, construction, operation and maintenance, decommissioning)

[redacted]

[redacted]

[redacted]	
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

[redacted]

Alternative construction technology and use of existing tunnels are evaluated in order to find the most suitable pipeline routing. Small Full profile Tunnel boring Machines and rock drilling solutions are included in the evaluation of the different routing alternatives. Owners of the existing tunnels have been contacted [redacted]

Leakage from pipeline between KEA and the port of Oslo is identified as potential risk. In this phase of the project differences between the alternative routing is not looked into. Hazardous concentrations of CO_2 is expected to be within relatively small areas.

For the project schedule, it can be concluded at this stage that the engineering and construction of the pipeline systems do not seem to be driving the overall project schedule, - if given preconditions are fulfilled.

[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]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

The preliminary project planning for the pipeline alternative shows that an early design freeze is needed to start the permitting process in due time. When an investment decision is reached, a considerable amount of certainty should have been reached, so that a permit can be obtained.

It is recommended that until this certainty is obtained the truck alternative is kept as an option. All further engineering activities should be focused on confirming the preliminary conclusions of the pipeline option.

6.4 TRUCK TRANSPORT

The truck alternative in this study reviews a transport solution where CO_2 is planned captured and liquefied at Klemetsrud WtE plant, transported by truck from Klemetsrud to a new Terminal at Oslo Harbour, and exported by ships to final storage in the North Sea.

[redacted]

The upstream battery limit for the truck transport evaluation of this concept study is the hose connection behind the pump. The downstream battery limit is the hose connection at the unloading plant at Oslo Harbour.

The distance between Klemetsrud and Oslo harbour is 12.1 km, using the route E6 north from Klemetsrud to Ryen, Ekeberg tunnel, Vålerenga tunnel, Grønlia, E18 to Oslo-port. Driving time estimated by vegvesn.no is approx. 13-minute driving time. 2 hours for loading and unloading is estimated and including unforeseen incidents average of 3 hours will be spent on each round trip

Both loading at Klemetsrud and unloading at Oslo harbour is expected to have capacity to handle three trucks simultaneously.

With the close dialogs with contractors and suppliers, a tractor trailer setup with total weight 50 tons has been the design bases. For this weight class, contractors and suppliers recommend a tractor with a minimum of 400 hp. An operational lifetime of 15 year is assumed for trailers and 5 years for trucks.

Both companies use a solution with dedicated driver and dedicated loaders/unloaders. This minimizes driver waiting time and makes the loading and unloading of trailers effective. Conventional diesel powered trucks are used as basis for the cost estimates.

Following Assumptions is used by the suppliers for the transport:

- Vehicle parking and driver facilities provided free of charge at loading and discharge points
- Current costs for driver/fuel
- Tractors based on 5 year lease and 0 residual value
- Semitrailers based on 15 year depreciation and 0 residual value
- A 50 ton truck has the capacity to transport 30.3 tons

A CO_2 neutral transport solution is the main goal for the transport of the captured CO_2.

The CO_2 emissions on the truck alternative rely very much on the choice of driveline. A substantial emission reduction compared to traditional diesel trucks is possible but requires a study of the production and origin of the raw material, and the refining process.

Unfortunately electric, hybrid and fuel cell alternatives in the truck transport industry is still not mature for 50 ton truck trailers. Suppliers have alternatives at lower weight classes but don't expect to have commercially available truck of this size by the project start. These fuel and driveline alternatives should be in constant review throughout the project life span.

As of now a solution with a biogas, biodiesel or bioethanol fuel would be the optimal starting point and is achievable in regards to time and planning as of today's date. This gives a fully feasible CO_2 transport alternative with low CO_2 emissions.

7 INTEGRATION TO EXISTING PLANT

7.1 GENERAL AND INTEGRATION PHILOSOPHY

Integration of the CC plant with the existing WtE plant is managed by the Customer project team. The integration shall have focus on

- Clear responsibility by well-defined integration points
- Operation of the WtE plant with energy delivery to district heating and electrical production independent of operation of the CC plant.
- Heat integration, i.e. return same amount of heat, or more, to district heating network as was taken out from WtE and delivered to CC plant.
- Utilising the possible benefits of integrated functions. Integration to be based on risk evaluation.
- Possibility to operate the CC plant with the same personnel operating the WtE plant. This means a high level of automation and skilled workers. Operation of the facilities in Oslo Harbour is per end Concept not defined and will depend on Client decision on integration regarding loading of CO_2 to ship. However, with CO_2 transport via pipeline as base case for FEED phase, there is not foreseen permanent manning in harbour. Regular inspection, sampling etc. should be carried out by operation staff for the complete plant.
  O&M agreement with the Contractor is being discussed and is to be developed further through the next phase.

During the Concept phase, a number of potential value added integration point have been detected. These will be detailed further during so called VIP studies [23] in the early FEED. Based on the result of these studies integration of additional systems and equipment will be evaluated.

Integration is further described in the document:

- NC02-KEA-O-A-0002 Construction and integration philosophy [11]

Interface points and tie-ins are further described in the following documents:

- NC02-KEA-O-LA-0001 Interface Register - CC Plant 1 (APP) [8]
- NC02-KEA-O-LA-0002 Interface Register - CC Plant 2 (TECL) [9]

7.2 SYSTEM UPGRADE

The following main systems and parts of the existing plant will be modified for integration of the CC plant.

7.2.1 CC Flue gas inlet, bypass, conditioning and outlet

The flue gas from the different waste incineration lines are collected to the CC plant from the connection points at the incineration plants. Return and bypass of CC plant is established to lead flue gas back to existing stack. Connection is part of Contractor scope.

7.2.2 Steam and condensate, new steam turbine

A continuous low pressure steam supply is needed to heat the stripper reboiler to facilitate the release of captured CO_2. The steam is supplied from the incineration plant steam system conditioned to the parameters required by the contractor.

New steam turbine design is under investigation and will be of extraction type to ensure a suitable steam supply to the CC plant. As the turbine will be installed on existing foundations discussions are ongoing with the manufacturers to ensure that the new turbine will fit on the existing foundation with a minimum of modifications. Modifications to steam turbine and systems is part of Company supply. The possibility of only pressure reduction will also be considered.

7.2.3 Heat recovery system

In the existing plant the energy extracted from the condensers at the turbines is used to supply the district heating (DH) network with heat, but as steam will now be used in the CC plant the energy lost has to be compensated to ensure DH supply to the municipality. The use of heat pumps are foreseen to extract waste heat from the CC processes and revert it back into the DH network. Connection points for the heat recovery will be provided inside the existing turbine hall and on the pipe rack outside K3 line to facilitate the return of energy.

7.2.4 Fresh water, waste water/process water

Fresh water supply is foreseen to come from the municipality system to the CC plant and not to be integrated with existing plant.

Reject water/treated process water from CC plant is under investigation for reuse in the WtE plant to reduce tap water consumption. The amounts of possible process water reuse from the CC plant is greatly exceeding the current use of water at the WtE plant and further investigation is done to use this water as feed stream for a potential cooling tower.

7.2.5 CC plant electrical integration

Minimal integration is foreseen between WtE plant and CC plant on the electrical systems. Separate HV cable will be established from Hafslund local transformer station to feed all el to plant. Company/Hafslund will install the new cable up to Main switch / transformer in CC plant.

7.2.6 System Topology Diagram

The CC plant with sub systems, including intermediate storage in harbour, shall be separate standalone system with individual Operating & Monitoring station, but will be designed for a possible future integration into the Companies ordinary O&M operations and systems.

The WtE plant Integrated Automation System (IAS) can be connected to new CC & steam turbine system via Ethernet (TCP/IP) or Optical communication cable based on detailed design study.

Plant to be operated from Main control room in WtE plant.

7.2.7 Other systems

CC plant is to be self-supplied with all other utilities. Optimization by possible utilization of existing systems like NaOH tanks etc. will be evaluated in the FEED phase, and has been highlighted in the VIP report [23].

8 TECHNOLOGY SELECTION ACTIVITIES

This chapter addresses the selection criteria for the various technological solutions proposed during this study. The main areas are formed by:

- CO_2 capture technology
- Liquefaction technology
- CO_2 storage facilities
- Heat pumps
- Waste water treatment plant
- Cooling alternatives

In general both Contractors have followed / are following standard tendering management procedures for obtaining competitive offers for the various vendor packages.

Apply has stated that: "Market leading suppliers have been contacted in obtaining procurement cost. The same effort must be in place in FEED and early design phase until PO is issued. Suppliers with higher risk of pricing are identified and covered with norms accordingly in the estimate." [6, p. 125]

8.1 CO_2 CAPTURE TECHNOLOGY SELECTION

(At the time of writing, the final selection of the Contractor has not been done, topic to be addressed separately at a later stage)

[redacted]

8.2 LIQUEFACTION TECHNOLOGY SELECTION

[redacted]

8.2.1 Apply

"The proposed Technology for the CO_2 Liquefaction will be based on proven, safe and cost effective process using ammonia (R717) as a refrigerant. Considering the size of the proposed plant (approx. 76 Tons/h), a well proven technology which is being employed in numerous plants worldwide, has been chosen." [6, p. 46]

"The proposed liquefaction Technology had been developed by [redacted] with some modification to make it adaptable to KEA plant and to meet liquefied CO_2 product specifications for storage and for Cargo transportation." [6, p. 46]

8.2.2 Technip

"Market support for this project was low and only one vendor was found to be cooperative. For the current operating scenario, the Vendor has suggested that the capacity is accommodated by two parallel trains of liquefaction. This allows a further train to be added in the future to accommodate incineration line K4. The size of each train has been optimized in order to leverage standard components (compressors, evaporating condenser, etc.), optimizing the CAPEX/OPEX ratio." [5, p. 37]

8.3 CO_2 STORAGE FACILITIES SELECTION

8.3.1 Apply

Apply has received cost input from Halvorsen and in addition the following companies will be contacted during the FEED phase: Randaberg Industries, Rosenberg Worleyparsons [6, p. 126].

8.3.2 Technip

For Technip the CO_2 storage facilities are part of the liquefaction package, for more information see reference [26] or [5, pp. 450-462].

8.4 HEAT PUMP SELECTION

8.4.1 Apply

"The DCC circulation cooler and stripper condenser are part of a heat pumps system. The refrigerant will be evaluated and finalized in the next stage. There could also be an opportunity of system integration with a new heat pump that will be installed at KEA plant during summer of 2017" [6, p. 32].

8.4.2 Technip

"The base case for the Vendor design was the future case, however, any additional capacity is not required until the K4 incineration line is installed. Therefore, the Vendor has advised potential savings that could be made by phased installation (e.g. installing fewer compressors). The Vendor has recommended that the working fluid is R-1234ZE as it limits global warming potential (GWP) and process hazards. For the selected heat pump working fluid, the Vendor has advised the compressor power, CoP and the amount of heat that is required to be extracted from the cold sink." [5, p. 39].

8.5 WASTE WATER TREATMENT SELECTION

8.5.1 Apply

"The combined waste stream is sent to the Effluent Treatment Package (ETP) where it will undergo pH adjustment with sulphuric acid/ caustic solution as required to achieve a pH of 6 – 8. The effluent treatment unit is a zero liquid discharge (ZLD) unit. The output streams from the package will be a solid waste and treated water with the required quality will be sent to WtE plant. It is considered that the process water quality requirement at WtE plant can be achieved comfortably in a conventional ZLD systems." [6, p. 30].

8.5.2 Technip

"A functional specification for the WWT has not been produced as the package has been developed internally. The expected composition and discharge limit of the waste water has been used to develop a treatment solution for the CC Plant. A number of options have been considered for treating the pre-scrubber unit wastewater. These include:

- Biological nitrification;

- Air stripping (at high pH);
- Adsorption onto ion exchange resin;
- Membrane treatment;
- "Do nothing" approach." [5, p. 39].

As the quality of the generated waste water is relatively high, the "do nothing" approach was studied and is an option to be investigated further as part of the FEED phase. For the concept phase, the ion exchange option was considered the best solution.

8.6 Cooling Alternatives Selection

8.6.1 Apply

An approach was taken "to recover the heat from the largest heat producers on the CC plant and transfer the heat to the district heating network. It was found that by recovering heat from the DCC circulation cooler and the stripper condenser, the demand from the district heating network could be met. For the other heat sources air coolers were selected" [6, p. 29]. These heat sources comprise of the following:

[redacted]

8.6.2 Technip

"Using air coolers to cool to low temperature is relatively expensive. If site restrictions can be relaxed, using wet cooling towers, either conventional package forced draft cooling towers or Wet Surface Air Coolers (WSACs), might offer a cost reduction." [5, p. 34] This and other opportunities for reduced cost, electricity consumption and footprint will be further investigated in the FEED phase.

9 OSLO HARBOUR

9.1 GENERAL DESCRIPTION

The captured CO_2 from Klemetsrud is transported to Port of Oslo for intermediate storage and export to permanent storage at west coast Norway.

The scope of this study includes the definition of an actual location of the export terminal in Port of Oslo. The captured CO_2 will be transported from Klemetsrud either in liquid form by trucks or in gaseous form through a dedicated pipeline. The requirements at the port terminal are slightly different as the truck transport option will require truck unloading station and the pipeline option will require a liquefaction plant.

The following split of responsibilities is applied for the port and ship loading solution:

Port of Oslo responsibilities:

- Availability of required area for installations
- Location for mooring of ship and all quay side operations
- Foundation for loading arms
- Utility support as
    - Potable Water
    - Waste handling
    - Security

CC technology supplier responsibilities:

- Liquefaction of CO_2 for pipeline solution
- Unloading stations for truck solution
- CO_2 storage tanks
- CO_2 loading arrangement including pumps, piping, loading arms etc.
- Fiscal metering of loaded CO_2
- Shore power for ship

KEA Responsibility:

- Interface flange on truck or pipeline
- Foundation for equipment and storage tanks

LNG supply to ships will be a mobile solution with supply from trucks. Similar to what is used today for fuelling local ferries in Oslo.

9.2 HARBOUR LAYOUT AND ARRANGEMENT

The area requirement for the port terminal is dependent on the actual supplier and the transportation alternative.

Only preliminary layouts for the port terminal are available from the technology suppliers at present, Figure 20 and Figure 21. The layouts are intended primarily as an indication of plant footprint and possible interfaces. Details are expected to vary depending on the site location, equipment sizes, equipment vendor and further detailed design development.

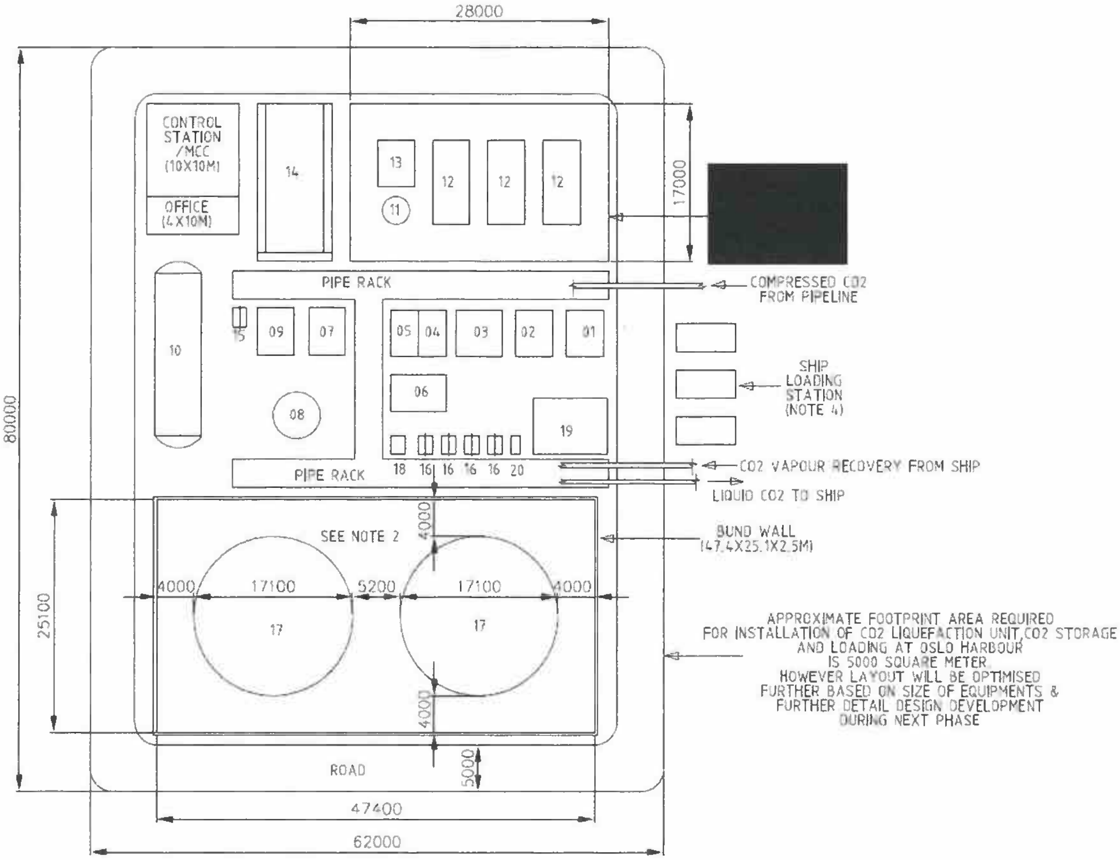

Figure 20. Conceptual plot plan-(3 lines case) CO_2 liquefaction, Intermediate storage and loading at Oslo harbor for pipeline option proposed by Apply [27].

Apply:

The harbor layout presented in Figure 20 shows that an area of approximately 5 000 m² will be required to accommodate the CO_2 liquefaction unit, 4 days storage and loading at Oslo harbor [27, p. 83].

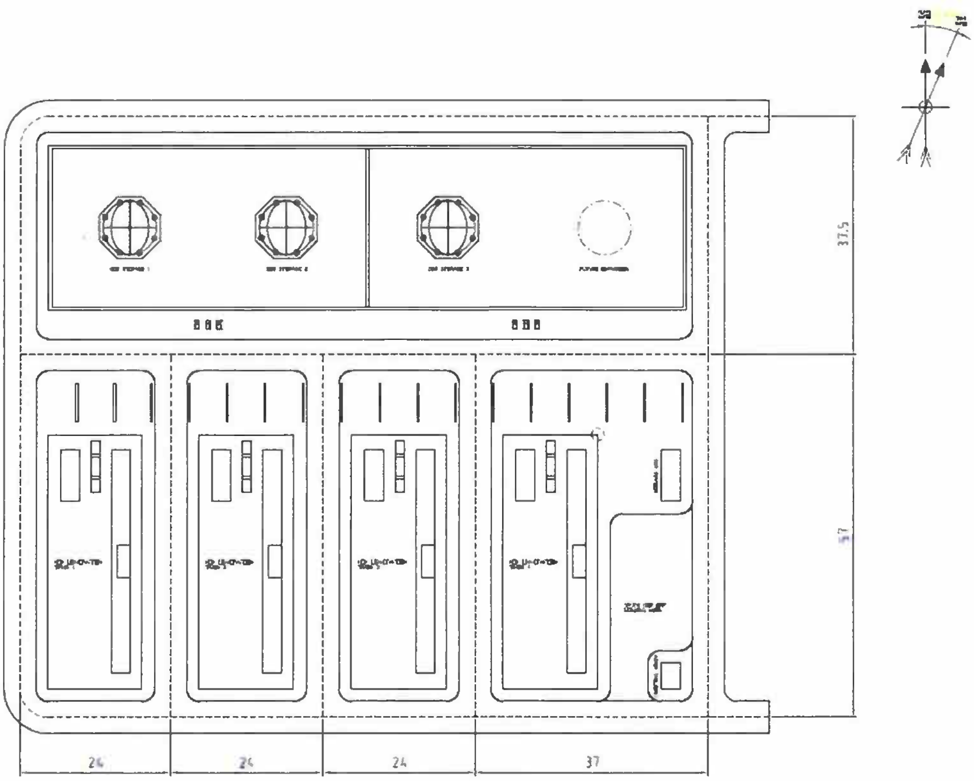

Figure 21. Conceptual plot plan-CO_2 liquefaction and Intermediate storage (3 and 4 lines case) at Oslo harbor for pipeline option proposed by Technip [5, p. 484].

Technip:

Figure 21 shows the plot space at Oslo harbor for pipeline transportation as presented by Technip. The plot space indicates that approximately 10 000 m^2 would be required.

These preliminary layouts indicate higher area requirement but discussions have revealed that area optimizations are possible (as also evident from Figure 21) and further detailed design will be developed in FEED phase.

Requirements to additional safety zones is not included in the area requirements and will be handled based on results from the risk assessment studies.

9.3 POTENTIAL LOCATIONS IN SYDHAVNA

[redacted]

Location of the Terminal will depend on technical suitability and the risk evaluation for a major spill of CO_2 from the intermediate tank farm. [redacted] Further risk evaluations will be included in the FEED phase and might influence on the selected location of the terminal.

9.4 Mooring Arrangement

[redacted] Port of Oslo have looked into alternative solutions in order to offer suitable mooring capacities in the area including building of a complete new quay front.

[redacted]

9.5 Offloading

Flexible hoses will be used for transfer of CO_2 from shore to ship if a floating mooring buoy solution is selected. Floating hoses for low temperature transfer of Liquids are readily available, and qualification for CO_2 service is ongoing,

Conventional loading arms will be used for jetty and fixed mooring solution. Loading arms are readily available and qualified for low temperature services including CO_2.

9.6 Proposed Location

[redacted]

[redacted]

[redacted]

[redacted]

The ongoing quantitative Risk evaluation study for large spill of CO_2 might lead to changes in risk levels related to residential areas, and hence preference for location.

Further work will include discussions with Port of Oslo in order to establish a safe and reliable mooring alternative for the [redacted] location, and discussions related to interference with other port operations for [redacted]

9.7 Client interfaces and utilities

Company will have a number of interfaces with Client. Physical interfaces will be in harbour for loading of CO_2 to ship, but other interfaces must be handled to ensure a robust and complete total CCS chain.

In general the Client design basis is setting the requirements. During FEED a number of clarifications need to be discussed and clarified:

- CO_2 gas specification. Possible changes to specifications and components given in Client Design basis for the CCS chain in order to optimize the process must be discussed early FEED.
- Ship arrival frequency - for optimisation of the intermediate storage
- Loading procedures. Is loading to be handle by the ship crew or will assistance from Company personnel be required?
- Utilities:
    - CO_2 loading capacity = 600 tons/hour. One connection point via loading arm
    - CO_2 vapor return. One connection point via loading arm
    - Ship electrical consumption during loading. 690V/480 kW is informed by Client.
    - LNG loading directly via truck. No intermediate LNG storage in harbour.
    - Potable water – flow/quantity to be clarified during FEED
      No requirements is set to sewage and waste reception in harbour.
- Sampling and approval procedures of CO2 in intermediate storage as well as vapour on ship tanks before start loading (refer IGC code - International Gas Carriers). Consequences if off-standard to be clarified.
- Standards and specifications may be standardized between the parties involved in the chain. Client to instruct.

Areas of cooperation between all parties in the CCS chain in order to optimize the concept may be discussed during FEED as a part of Client Interface coordination.

10 ARCHITECTURAL CONSIDERATION

10.1 GENERAL

Klemetsrudanlegget is located close to residential areas, close the one of the main roads (E6) to Oslo which also serves as the main route passing Oslo on your way north.

As a part of the history, Oslo kommune and EGE (as the company was named in 2007-2011) put a lot of effort into the architecture when building incineration line 3. This also serves as a logo for the company Klemetsrudanlegget AS. It is therefore of high value to establish a CC plant that "blends in" with the existing plant in a cost efficient way

As a part of the zoning process, location of the CC plant with intermediate storage/truck loading station have been evaluated together with road and access to the plant as a total, future line 4 and other future possible activities that may be located close to the WtE plant. The process have concluded that the plant should be located east of the WtE plants as shown in the visualisations below. Transport efficiency for existing and new activities is focused. Moving of local roads may be included in the zoning to achieve better transport and movement of transport to/from Klemetsrudanlegget as well as local traffic.

The visual impact, especially from the main road (E6) shall be considered and measures taken to

- Reduce the visual impact of the CC plant in combination with
- noise reduction from the plant

Key elements in the architectural consideration:

- The plant shall recognised as a good place to work
- Close to main roads – lots of people will see the plant passing by
- Minimize possible conflicts with neighbours related to noise, smell, visual impact and risk
- Consider and find the optimum solution for location, space requirement for O&M
- Interaction between existing plants and activities and new CC plant
- The CC plant is a highly focused plant and must allow for visitors
- Future development, expansions and changes

The various options and single items must be seen in context as they will make up a whole.

10.2 3D VISUALIZATION

Based on the plot plans as per July 2017 the architect have made a visualisation of the plant. Since the Company have had two Contractors in the Concept phase, the visualisation have focused on the overall dimensions, not one specific Contractor.

The visualisation includes the CC plant, the intermediate storage and loading station at Klemetsrud (blue colour) and the future line 4 (red colour). Since the visualisation was developed, work with the plant and equipment arrangement have continued and a more detailed visualisation is on hold until we have selected one Contractor. As a result of the concept study and the selection of pipe transport, the intermediate storage and loading station is not foreseen to be established.

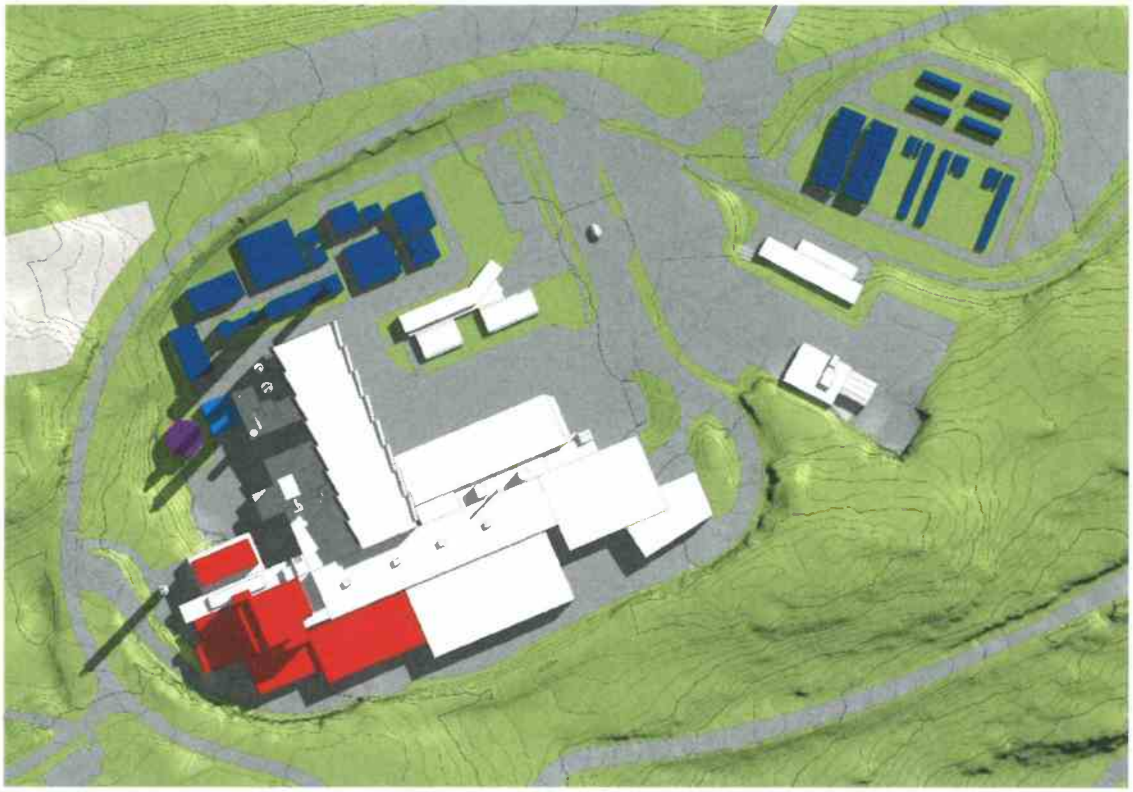

Figure 23. CC-plant at Klemetsrud WtE plant. Top view.

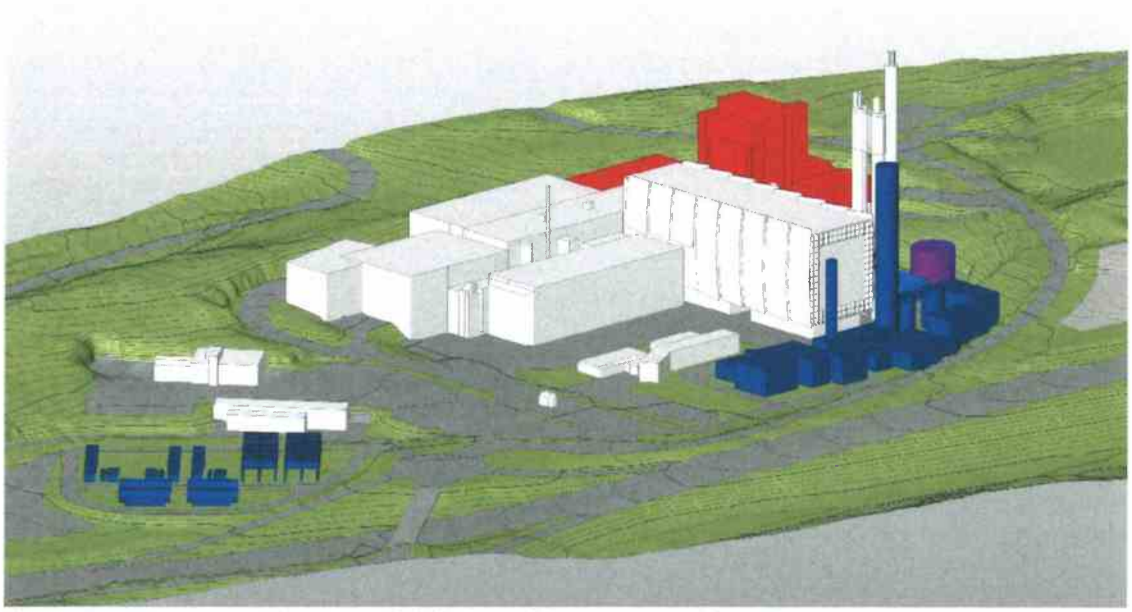

Figure 24. CC-plant at Klemetsrud WtE plant. View from south-east.

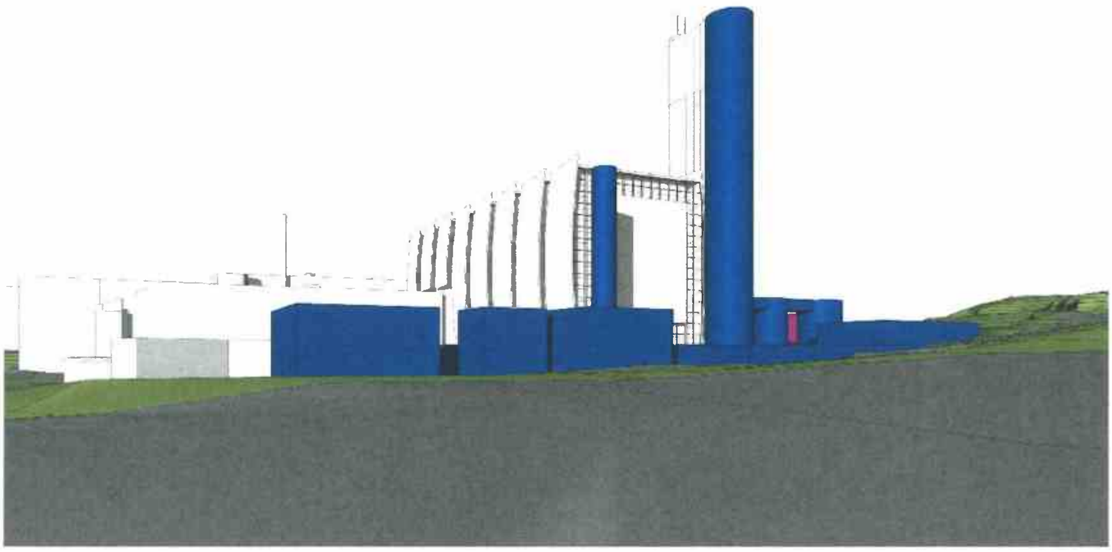

Figure 25. CC-plant at Klemetsrud WtE plant. View CC plant from main road (E6).

11 CIVIL WORKS

11.1 CIVIL WORKS KEA

Blasting of area for CC Plant

The area at Klemetsrud is a medium to large industrial project (in terms of volumes). In terms of engineering geology there is a mainly a need for extensive blasting operations as well as slope stability protection measures in close proximity with existing industrial structures, and existing main motorway (E6). There are several limitations that apply to this project and will dictate the progress work and final cost.

Blasting operations so close to an existing motorway E6, imply closing of the motorway up to twice a day, between the hours of 07:00 and 23:00. The closing operations of a major motorway in a rather expensive affair. This limitation is a dimensioning factor for the whole project. With careful planning and coordination the contractor could maximise efficiency by blasting other fronts (faces) in the area that do not require closing the E6 or by performing mechanical hammering in several locations on the site, while "waiting" for the next blasting round.

There is no information so far on the existence of sensitive equipment within the industrial building that requires reconsideration of the peak particle velocity limits. The peak particle velocity limits chosen so far, are considered to be on the conservative side. There is not much experience worldwide for blasting operations of this type of rock, close to these types of structures. New and more accurate expert assessments of the peak particle velocity limits will be needed in the next project stage. This could eventually reduce the volume of zone 1 and increase respectively the volume of both zone 2 and 3, These means easier and cheaper blasting operations in a higher speed. Concerning the diesel tank and the 82 m high chimneys, there are assumed to be founded on competent rock, but any further evaluation of the foundation conditions has not been performed so far. This will be done in the next stage and could result in a re-evaluation of the peak particle velocity limits.

The depth (in terms of meters a.s.l.) of blasting operations on the CO_2 site are designed to accommodate all necessary equipment (pipes, culvert, cables etc.) below the foundation of the future CO_2 plant. This is done by adding about 1 m to the blasting depth. Final total height after blasting is at 133.6 m a.s.l.

Is has not yet been decided where and how the debris from the blasting operations will be disposed. This is a task for the next stage of the project. The rough cost estimate provided in chapter 7 includes only the uploading of the debris to trucks.

The blasting operations must in general be smooth and cautious and must consider the existing pipeline system/water pipes or other installations in the area. The blasting operation will lead to noise issues, which need to be further evaluated in FEED phase.

Preliminary schedule estimate for the blasting operation are assumed to be about 8 months but the exact duration of blasting operations will depend on further studies related to interaction with road authorities and requirements from sensitive equipment in FEED phase.

For additional information refer to document NC02-KEA-P-RA-012 Geological Evaluation and Blasting Study.

Geotechnical Survey Klemetsrud Liquefaction and storage area

From a geotechnical perspective the foundations of the large storage tanks for CO_2 in liquid form which is of most interest.

COWI has performed field investigations at Klemetsrud, with no further investigations deemed necessary. The ground profile in the area is typically characterized with a relative hard top layer of filling and dry crust clay material underlain by a clay layer below.

The foundations of the storage tanks at Klemetsrud could be achieved with standard foundation designs and thus could be constructed with relatively low cost.

COWI has performed a technical environment report of the ground at Klemestrud. The report concludes that the cost related to allocation of soil in the area is low.

Site Preparation Klemetsrud

The preliminary assessment recommends that equipment in the Carbon Capture plant should be founded on several concrete foundation slabs, cast directly on to bedrock. The size of the main site required to establish the carbon capture facilities is approximately 8.000 m², including areas surrounding the equipment's foundation slabs. These areas shall have a gravel surface.

The preliminary estimate for the thickness of the foundation slabs is approximately 300-350 mm for the majority of equipment, such as the cooling plant, pumps, drums, packages, etc. Strengthening should be provided locally for larger concentrated loads. It may also be necessary to anchor the foundation under the absorber tower with tension bolts due to its height and tension forces that may occur in the foundation.

The preliminary assessment is that equipment in the Liquefaction and storage area should be founded on several concrete foundation slabs, cast directly on the ground. The size of the main site required to establish the interim storage facilities is approximately 3.500 m², including roads and areas surrounding the foundation slabs, tanks and equipment. The roads shall be asphalted and suitable for usage by trucks for transportation of goods.

The preliminary estimate for the thickness of the foundation slabs is approximately 350-400 mm for the majority of equipment, such as the cooling plant, truck and storage loading pumps, etc. Strengthening should be provided locally for larger concentrated loads and areas supporting the storage tanks.

In order to enable drainage of surface water all foundation slabs shall be cast with fall, minimally 1:100. Several conduits must be cast for drainage to outlet water in the foundation slabs as well as installation of subsurface drainage pipes and drainage pits for access and maintenance. It is also necessary to build a retention basin. The pipes shall be connected to the existing drainage system. The treatment of contaminated water is not considered and should be evaluated in the next stage of the project.

For additional information regarding to the structural foundation refer to document NC02-KEA-P-RA-003 Site Preparation Input and Study.

Other Structural Work at Klemetsrud

A temporary working place and a storage plant will be established in an area to the north of the Klemetsrud WtE plant. Total area is expected to be approximately 10.000 m^2.

In connection with building of Carbon Capture plant, it will be necessary to make some structural interventions in existing buildings at Klemetsrud WtE plant. The scope of that work is not yet known and will be further detailed in the FEED phase.

Upgrading or newbuilding an administration building including a visitor center at Klemetsrud Wt E plant is also included, and will be further detailed in the FEED phase.

For additional information refer to document NC02-KEA-P-RA-003 Site Preparation Input and Study.

11.2 Civil works Oslo Harbour

From a geotechnical perspective the foundations of the large storage tanks for CO_2 in liquid form, which is of most interest.

[redacted]

[redacted]

[redacted]

[redacted]

The preliminary assessment is that equipment in the terminal for the storage and shipment should be founded on a concrete foundation slab, cast directly on the ground. The size of the main site required to establish the equipment in the terminal construction is approximately 3.500 m^2. In addition, approximately 1.500 m^2 of asphalting is required to build roads for transport.

The preliminary estimate for the thickness of the foundation slab is approximately 300-350 mm for the majority of equipment, such as truck unloading pump, ship loading pump, etc. Strengthening should be provided locally for larger concentrated loads as well as concentrated loads under the columns of storage spheres.

In order to enable drainage of surface water the foundation slabs shall be cast with fall, minimally 1:100. Several conduits must be cast for drainage to outlet water in the foundation slabs as well as installation of subsurface drainage pipes and drainage pits for access and maintenance. The pipes shall be connected to the existing drainage system, or possibly be laid directly to the sea.

For additional information regarding to the structural foundation refer to document NC02-KEA-P-RA-003 Site Preparation Input and Study.

12 ECONOMICAL ASPECTS

Description of CAPEX and OPEX together with Contractor selection criteria is addressed in the Cost Estimate Report [15].

13 Health, Safety and Environment (HSE) & Quality Assurance

13.1 General

The CCS project is committed to maintain and achieve a high standard towards health, safety and environment in all phases of the CCS project in line with Company's corporate policies and guidelines for HSE. This includes documenting all risk imposed by the CCS project and making sure that all risk acceptance criteria set by DSB and other applicable parties are met. To achieve this, HSE have had high priority in planning and execution of work in all aspects in the CCS project.

The CCS project has as far as possible adopted Company's existing work processes, systems and procedures related to HSE. Company has a management system in place, which has contributed to ensure that the CCS project is managed and controlled by defined goals, adopted values and strategies. Further, the CCS project has implemented a risk management system where HSE risk is systematically identified, assessed, and mitigated.

The HSEQ Manager have had the overall responsibility for HSE and quality aspects in the CCS project during Concept phase. The HSEQ Manager is responsible for identifying and managing the HSEQ risks in the project, as well as preparing related plans and mitigating measures. The HSEQ Manager have had an active role against the authorities and other parties in the project.

The HSE philosophy, HSE goals and related risk management procedures are documented in the HSE Plan [29], Quality Plan [30] and Risk procedure [31].

13.2 HSE Goals

The HSE goals set for the Concept and FEED phase of the Project is described in the HSE Plan [29]. With regards to risk to personnel, the project goals will follow Company's established goal of no injuries or near-injuries. Company's environmental policy shall contribute to ensure that the project's activities will not lead to excess emissions and acute emissions, as well as minimize negative environmental impact.

With respect to project execution, project specific goals have been defined based on the specific nature and challenges relating to the CCS projects. The CCS project specific HSE goals are defined in the HSE plan [29] and can be summarized as follows:

1. Ensure compliance with emission requirements for air, water and ground
2. Strive to reduce the negative environmental impact for the neighbouring area
3. Emphasize the environment when choosing suppliers and contractors
4. Continuous improvement focusing on reduced environmental impact
5. Ensure good communication with local interest groups regarding the CCS project's environmental work
6. Inherent safe solutions shall be the preferred safety strategy. 3rd party personnel shall be affected as little as possible by the CCS project.

The goals above have had high focus during the Concept phase and will be further follow-up during FEED phase.

13.3 PROJECT HSE PHILOSOPHY

The projects HSE philosophy is to avoid all injuries and keep a strong focus on inherent safety and risk reduction / ALARP principle. The principles for inherent safety and ALARP is summarized below. A description of the safety philosophy is also included in the projects HSE Plan [29].

Inherent Safety

Throughout the Concept phase, the design of Inherent Safe solutions has been focused. The Inherent Safety concept is a design approach where the target is to eliminate, or minimize, hazards during design. This is typically done by:

- Replacing dangerous substances with safer options
- Minimize amount of chemicals and size of equipment
- Reduce pressures and temperatures
- Place dangerous areas/ activities at the safest location
- Keep design simple and uncomplicated.

The inherent safety principle is illustrated in the figure above

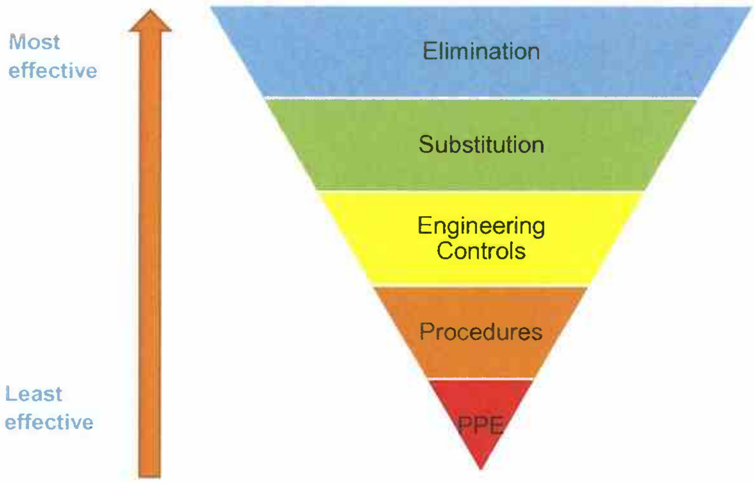

Figure 26. Inherent safety principle.

The alternative to Inherent Safe design, is to accept the hazards, and then design safety systems to mitigate and control the risk. A Inherent Safe methodology do not exist, but this is regarded as a key task in the project, and have had focus in all design work. This will continue into the FEED phase.

ALARP (As Low as Reasonably Practicable)

The project follows the ALARP (As Low as Reasonably Practicable) principle. This means that even if the risk is found to be acceptable, the project will aim to reduce it further, it if it is reasonable to do so. The criteria for further risk reduction will be considered in relation to the cost of the measure.

The ALARP process will be implemented as part of the risk register. The ALARP triangle is illustrated in Figure 27.

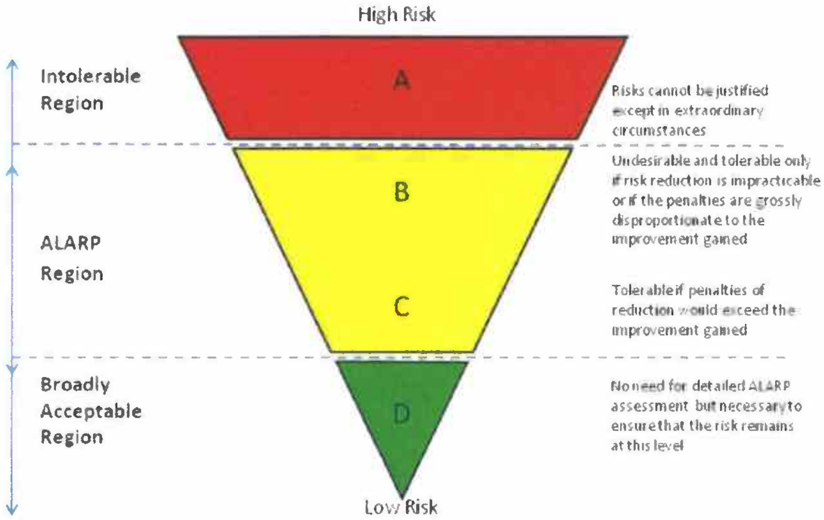

Figure 27. Risk pyramid.

The ALARP process is connected to the inherent safe process, where the safest option always will be the preferred one, if not grossly disproportionate to cost.

13.4 RISK MANAGEMENT

13.4.1 Principles for risk management in CCS Project

A detailed description of Company's risk management system is described in the Quality Plan and Risk procedure.

Risk management is a key feature for successful management of the CCS project and is an integral part of project management in the CCS project. The objective of the risk management system is to systematically and periodically identify, classify and mitigate risk that may prevent or reduce the probability of achieving project objective and project goals.

Company has a framework for managing risk in line with the principles described in NS-ISO 31000, ref. [32] and NS-ISO 9001 / NS-ISO 14001 ref. [32], [33] as described in Company's management procedures. The CCS project has followed and implemented the same framework and principles for risk management where the risk management process consists of a series of steps that enable continual improvement in decision making. These can be summarized in the following sub-processes.

- Risk identification
- Risk analysis
- Evaluation of risk and risk ranking
- Monitoring and mitigating measures

The main steps are also illustrated in Figure 28 below.

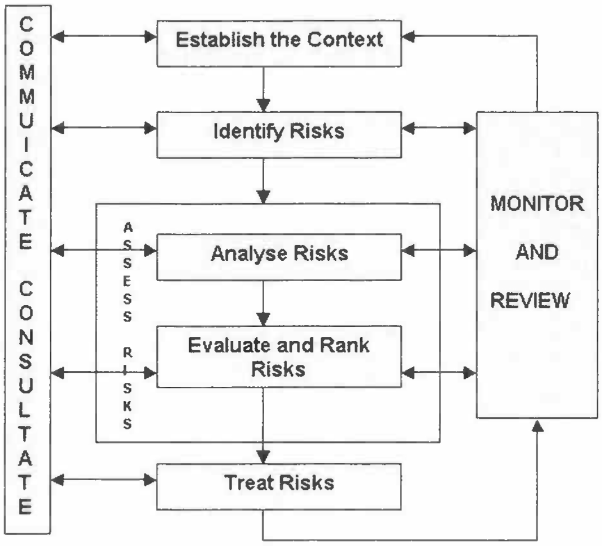

Figure 28. Risk assessment process (ref. ISO-31000).

Contractor's risk management system:

Apply's risk management system is performed according to the ISO 31000 "risk management guidance standard" principles according to the Concept Study report. A description of the Project HSE management system, ref. [35], including a description of risk management, has not been provided at the time of this report. However, Chapter 9 of the Concept report, ref. [6] provides an overview of risk management. Apply has also supplied a risk and opportunity register as part of the Concept report. The principles described in this overview are generally in line with expectations and Apply has extensive experience with engineering projects. It is therefore considered that all required risk management documentation and procedures will be available upon start-up of FEED phase. This will be subject to follow-up by CCS project in early phase of FEED.

Technip has submitted a risk management plan as part of the Concept Study Report, Appendix 10.3 [5]. The risk management plan appears generic and not project specific. However, the template for the risk management plan is otherwise comprehensive and detailed and is considered to be well suited for the FEED phase. No risk and opportunity register available to CCS project has been established for Concept phase. However, this is a deliverable in the FEED phase.

13.4.2 Risk and Opportunity Register

As part of the risk procedure, [30], Company has a risk and opportunity register where main risk and opportunities are recorded, ranked and tracked. The risk and opportunity register is a "live" document valid for the Concept and FEED phase and is updated by Project Management/ HSEQ manager at regular intervals, typically bi-weekly. The risk and opportunity register is used to prioritize allocation of resources and work, including input to the audit and examination plan. The risk register also contains risks and opportunities relevant for the construction, installation and operational phase of the project.

The risks are classified according to the tables below.

Table 13-1. Risk matrix applicable for project execution risk in the CCS Project.

Likelihood		Consequences				
		1	2	3	4	5
		Insignificant (Minor problem, easily handled)	**Minor** (Some disruption possible, e.g. damage equal up to 5M kroner	**Moderate** (Significant time/resources required, damage equal to 5% cost overrun	**Major** (Project severely disrupted, e.g damage equal to 20% cost overrun	**Catastrophic** (Project survival is at risk, damage equal to 50% cost overrun
5	Almost certain (>90%)	Moderate (5)	High (10)	High (15)	Extreme (20)	Extreme (25)
4	Likely (50-90%)	Low (4)	Moderate (8)	high (12)	High (16)	Extreme (20)
3	Moderate (10-50%)	Low (3)	Moderate (6)	Moderate (9)	High (12)	High (15)
2	Unlikely (3-10%)	Low (2)	Low (4)	Moderate (6)	Moderate (8)	High (10)
1	Rare (0-3%)	Low (1)	Low (2)	Low (3)	Moderate (4)	Moderate (5)

Table 13-2. Definition of consequences for each risk category.

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
Cost	Minor problem, easily handled)	Damage equal up to 5M kroner	Significant time/resources required, damage equal to 5% cost overrun	Project severely disrupted, e.g damage equal to 20% cost overrun	(project survival is at risk, damage equal to 50% cost overrun
External environment	Very small environmental damage.	Small environmental damage. Short recovery time	Considerable environmental damage. Local damage potential	Very serious environmental damage. Local damage potential	Very serious environmental damage. Regional damage potential
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

More details of the definitions are found in the risk procedure [30].

Company's top 10 risk is shown in Figure 29 below. The top risk is concerned with in knowledge of flue gas specification. In addition, there are risks related to planning permissions and implementation of pipeline as well HSE risks related to large CO2 leaks, noise and public resistance.

The top three (3) risks are classified as "high" according to the risk matrix and requires high focus and attention also in the FEED phase. The technical risks relating to technology and system design in general are expected to be clarified in FEED phase as the design matures and testing on flue gas is performed. Other risks related to planning and discharge permissions and public resistance are more long-term risks likely to follow the project through the FEED phase.

	RISK IDENTIFICATION & MITIGATION					RISK ASSESSMENT	ACTION PLAN
	Discipline	Risk / Opportunity	Risk / Opportunity description	Potential Consequences	Mitigating measures (to date)	Risk score	Action
1	design	Risk	Insufficient knowledge of flue gas composition and amount (wrong design basis)	wrong design of CC plant	some testing performed -meeting and visit to TCM (13th of June) -Design basis has been revised to be more robust- bi-weekly emission reports to supplieres	16	testing and additional flue gas measurement. RFQ to supplier out now. Expected testing in period from 24th of July to august. Results not yet recieved Dialogue with suppliers and TCM
2	design	Risk	Large requirement for air coolers taking up a lot of space due to large surplus of energy from CC plant during summer time.	-cooling fans generate noise in an area where noise is already close to maximum level allowed -not optimal wrt. energy conservation		15	evaluate seawater cooling as alternative to air fans evaluate cooling tower s alternative to air fans evaluate use of district cooling evaluate related VIP studies regarding energy conservation
3	operational	Risk	Flue gas emissions exceeding limits allowed during short periods limits	Environmental issues. Project delays. Changes in project costs	System design in accordance with relevant safety standards including monitoring and detection systems -meeting with MDIR before summer holiday	12	-New dispersion calculations. System design in accordance with relevant safety standards including monitoring and detection systems -Establish emission limits for new components -ensure robust design and stringent limits. Inherent safety -additional separation if required
4	HSE	Risk	Resistance from: local residents and/or other local parties	reputation and delays	Conduct stakeholder survey. Information to and communication with relevant stakeholders.	9	-perform stakeholder analysis -generate stakeholder engagement/ communication plan in cooperation with KEA AS. Request communication plan from Oslo harbour keep KEA informed of project development
5	transport	risk	implementation of pipeline is more complex than anticipated due to property right, access, regulatory approvals etc.	-project delays and increased cost due to high public resistance	-alternative transport required -ensure robust plan for alternative transport -coordination with Hafslund DH line -investigate directional drilling -investigate potential coordination with new E6	9	further work with defining alternative routes and optimization. Truck transportation will be kept as a back-up
6	HSEQ	Risk	large CO2 storage at Oslo harbour close to neighbours / planned housing development [redacted]. Also potential LNG storage	potentially large safety distances (hensynssoner). Neighbour protests. May required design / layout changes and / or possibly relocation to different location at Oslo Havn	Personnel risk will be handled according to DSB requirements '-Detailed risk assessment and consequence modeling.	9	Investigate other mitigating measures such as reduction of leak frequencies, reduction in intermediate storage capacity etc. possibility of relocating storage [redacted]urther south
7	design	Risk	Area available for CC plant is smaller than optimal	sub-optimal layout and construction	Site survey. Detailed design. Construction/ equipment delivery scheduling (laydown area size). -Hafslund area probably available according to pål	9	-potential relocation of admin building -High focus on layout. Engaged COWI and architect -one of the CC suppliers require less space -laydown and rigging area north of site could be available
8	engineering	Risk	Unfamiliar novel technology	Delays. Increased costs. Low availability	Conservative design parameters. Selected vendors with proven technology agreement with TCM for consulting and experience transfer. First round with lessons learned performed	8	Check further testing with MTU. Experience transfer from previous projects and involve TCM
9		Risk	New zoning for the area is neccessary for building the CC plant. New zoning also includes EIA. It is not given that the new zoning will be accepted.	Authority handling can affect schedule, (cost) and worst case be a project stopper if zoning/EIA is not "approved"	Authority handling started in early phase of the project. KEA communication with authorities shows positive signals from authorities. Positive comments from PBB	8	High priority from the project both administrative and politically.
10		Risk	New/updated discharge permit from Environmental agency is neccessary for operating the CC plant.It is not given that the new discharge permit will be approved.	Authority handling can affect schedule, (cost) and worst case be a project stopper if dischage permit is not "approved"	Authority handling started in early phase of the project.	8	-Early meetings with Environmental - Communcate requirements with CC contractors - additional technical equipment for reducing emissions

Figure 29. Top 10 Risk.

Contractor's Risk and Opportunity Register:
Apply's risk and opportunity register is included as part of Chapter 9 in the Concept Study Report [6]. Many of the identified risks and opportunities are related to technology, installation and commissioning. No risk is identified towards inherent safety and risk related to leaks from intermediate storage. Results from the CRA and dispersion modelling will be made available to the Contractors as soon as possible after these reports have been issued.

Technip has not provided a separate risk and opportunity register for the Concept phase although a template is shown as part of the risk management plan shown in Appendix 10.3 of the Concept Study [5].

A risk and opportunity register a required deliverable in the FEED phase.

13.4.3 Regulatory Compliance

The regulatory manager is the overall responsible for ensuring regulatory compliance. Contractor is responsible for implementing all applicable Norwegian laws and regulations. Regulatory strategy and legislation is further described in chapter 14. HSEQ manager, in conjunction with regulatory manager, is responsible for implementation of applicable HSE Regulations.

HSE regulations have been addressed in several HSE studies during the Concept phase. These are described below in chapter 0.

Company has not had a predefined set of codes and standards applicable for the Concept phase. However, it has been a requirement that all codes and standards used as a minimum shall according to applicable Norwegian laws and regulations where such codes are defined. In general codes and standards used shall be internationally recognized and considered "best practice".

A number of codes and standards have been applied and identified as "best practice" by Contractor during the Concept phase. Company has issued a document [36] with an overview of applicable regulatory requirements in the Concept and FEED phase as well as an overview of the standards and codes used by Contractors in the Concept phase. This is a document that will be further developed in the FEED phase.

In order to ensure regulatory compliance in the project, an audit of "regulatory compliance" in the project is planned for in the FEED phase and will include HSE regulations. The timing and detailed scope for this audit has not yet been defined, but is defined in the projects audit and examination plan [36].

13.5 HSE Studies

13.5.1 General

A number for HSE studies and workshops have been performed to identify, document and mitigate risk, as well as providing input for the purpose of optimizing layout, design and operations. These reports have typically been performed by 3rd party and have been performed because of regulatory requirements and / or as part of Company's risk management process.

A summary of results and conclusions from key HSE studies is provided in the chapters below, focusing on results considered important for concept selection and risk.

13.5.2 Hazard Identification (HAZID)

Hazard identification studies (HAZID) were performed for each of the two capture technology contractors. These HAZIDs cover the CC plant, liquefaction, intermediate storage and export facilities at Oslo Harbour. Both the truck option and the pipeline option were addressed in the HAZIDs. The HAZIDs are documented in two separate reports [37] and [38].

The HAZID reports focus primarily on major accident hazards. These are hazards that could potentially cause multiple casualties at the facility, or expose 3rd party outside the plant area to accident effects such as suffocating, toxic and flammable gases. Working environment issues and occupational risks are only briefly addressed in the HAZIDs. These aspects are covered in more detail by the WEHRA [40].

With respect to major accident risks, large releases of CO_2 are the primary concern. These are scenarios with a high release rate from a large inventory. In practice, these will be releases of liquid CO_2, or a pipeline rupture scenario.

Ammonia (NH_3) can be used as a refrigerant. Since ammonia is a toxic gas, releases of ammonia could represent a major accident risk. Ammonia is also flammable at concentrations of about 15% to 25%. This will trigger additional safety measures. Only Apply has used ammonia as the main refrigerant.

Technip has proposed using hydrogen for oxygen removal after the final stage of compression. Hydrogen will introduce fire and explosion hazards which will trigger risk reduction measures (fire and gas detection, etc.)

For the pipeline transport, leak scenarios from sections of the pipeline not tunnelled (if applicable) could expose adjacent areas to hazardous CO_2 concentrations. For the truck option, road transport accidents represent significant risks in addition to the leak scenarios related to the risks potential from major CO_2 releases. Accidents with massive releases of CO_2 are considered a low frequency scenario.

13.5.3 Consequence modelling

Since CO_2 is a heavy gas and a release initially can be in liquid state, dispersion is to a large extent determined by the local topology. A liquid release may also form particles of solid CO_2 which upon sublimation will keep the CO_2 gas cloud dense for a longer distance. The use of a simulation model that can reflect such effects is therefore considered essential. Leak and dispersion modelling have been performed by ComputIT on behalf of Company for selected accidental releases using computational fluid dynamic models (CFD).

The CFD model was developed as part of the CLIMIT project and is specifically developed for simulating liquid CO_2 leaks. Using available data, a geometry model of KEA and the surrounding topography, including Oslo Harbour area, has been established.

The dispersion analyses are documented in a separate report [40].

Large leak scenarios of liquid CO_2 from the intermediate storage options at KEA and Oslo Harbour have been analysed. These are scenarios with low frequency, but potentially severe consequences. An example of simulation results can be seen in the figure below. The CFD simulations show that hazardous CO_2 concentrations can expose 3rd party personnel.

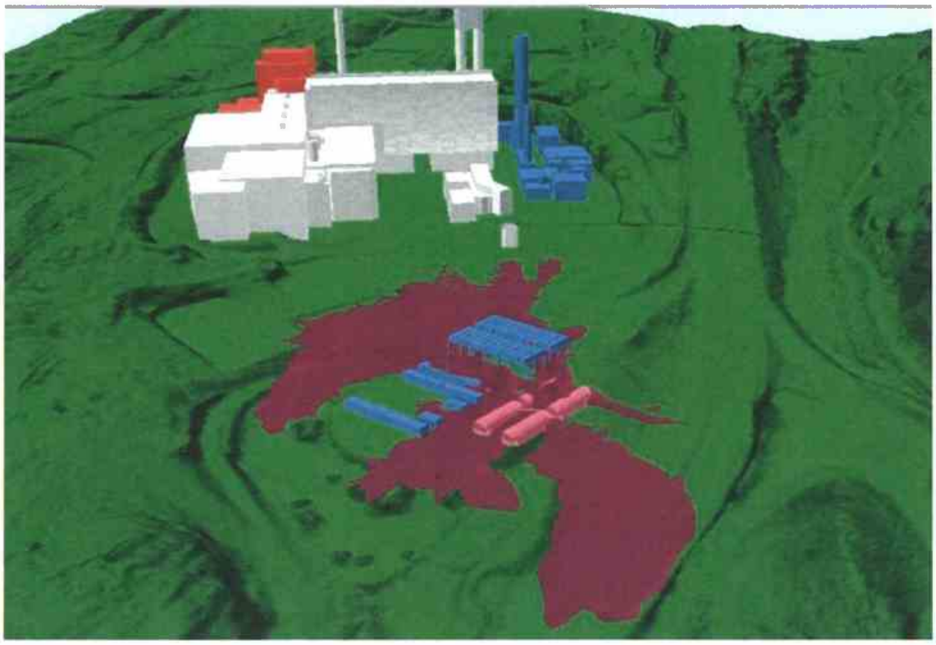

Figure 30. Gas dispersion scenario – large CO_2 leak from intermediate storage.

In addition to CO_2 leaks, some ammonia leak scenarios have been modelled. If ammonia is used as a refrigerant for the liquefaction or the heat pump, the CFD simulations show there will be sufficient quantities to expose the plant surroundings to hazardous gas concentrations.

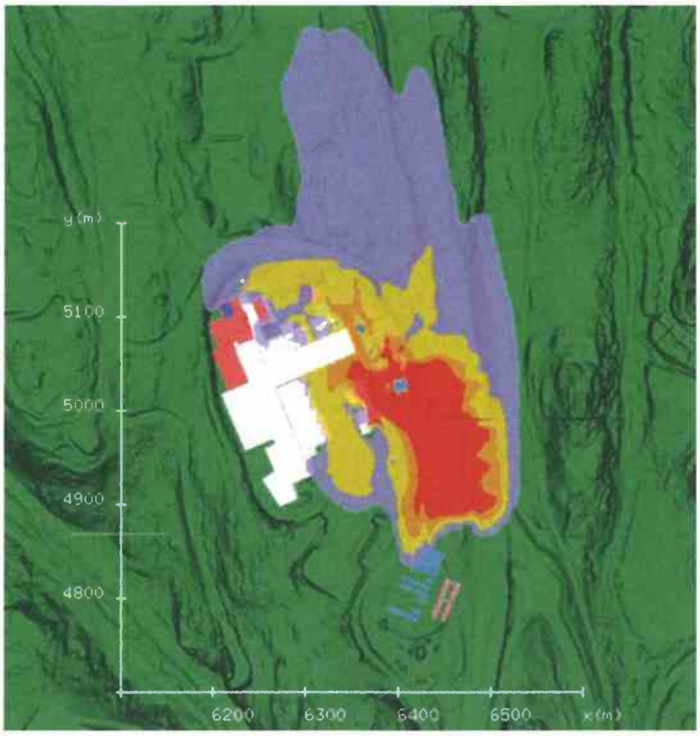

Figure 31. Gas dispersion scenario – large CO_2 leak from intermediate storage. (The figure shows an example, and should not be interpreted as a Hazard zone).

13.5.4 Concept Risk Analysis (CRA)

13.5.4.1 General

A concept risk analysis (CRA) has been performed for each contractor's concept, [41] and [42]. The CRAs reflects the proposed design for each Contractor, but at a coarse level since many of the design details are not available in the concept phase. As for the HAZIDs, the CRAs focus on major accident scenarios.

The CRA is quantitative. A set of specific accidental scenarios are defined based on hazard identification and the frequency for each scenario to occur is quantified based on generic experience data. These frequencies are combined with the assessed accident consequences for the scenarios. It should be noted that massive releases from large pressurized storage tanks are rare and it is challenging to establish reliable data for these scenarios, applicable for the specific storage option. The gas dispersion analyses performed has provided important input for the consequence modelling part of the CRA. Data for toxicity and human response are applied to establish the potential accident consequences. The risk picture presents the accidental scenarios with their likelihood and expected consequences.

13.5.4.2 Risk Acceptance Criteria

The risk picture has been assessed considering applicable risk acceptance criteria. Company has not established specific risk acceptance criteria for 3rd party. A risk analysis for the WtE plant was performed in 2008[7]. This report describes three objectives for risk management;

- Risk to personnel (limited to personnel at the facility)
- Risk to assets
- Risk to external environment

The risk matrix in [36] is useful for risk assessments at the site, but not for the accidental scenarios that could expose 3rd party. These low frequency scenarios with severe consequences fall outside the risk matrixes applied.

General criteria for risk acceptance for the surroundings of facilities are given in a guideline issued by DSB. DSB has published a guideline that includes proposed risk acceptance criteria for facilities that handle hazardous material [43] page 12. These are:

- Individual risk shall be less than 10^{-5} per year for personnel outside the facility
- For 3rd party persons in residential areas, individual risk shall be less than 10^{-6} per year
- For particularly vulnerable persons in residential areas, individual risk shall be less than 10^{-7} per year
- Identified accident scenarios with a frequency 10^{-8} per year or less are considered broadly acceptable

In addition, the rules for restricted areas are included as part of the risk acceptance criteria. These zones are defined in accordance with the regulation concerning handling of flammable, reactive and pressurized substances, [44].

DSB has used the term "hensynssoner" for restricted areas outside the facilities, and proposed risk acceptance criteria as shown in Table 13-3. Based on the safety studies performed this far, the restricted area zones appear to be the governing risk acceptance criteria for the CCS facilities.

[7] *Risikoanalyse Klemetsrud forbrenningsanlegg,* Rambøll, rev. 0, 22.04.2008.

Table 13-3. Restricted areas.

Restricted area	Frequency for fatal accidental exposure	Objects and activities accepted within the area
Inner zone	-	This should be inside the plant's ground (inside fence)
Intermediate zone	< 10^{-5} per year	Road, railway, Harbour area industry and offices.
Outer zone	< 10^{-6} per year	Residential areas, shops, smaller accommodation services
Outside outer zone	< 10^{-7} per year	Schools, kindergarten, hospitals, malls, hotels, sport arenas

13.5.4.3 Contractors design

Some differences between the two concepts from Apply and Technip which may have importance for safety are discussed below. Technip has chosen a configuration with one large absorber and stripper, while Apply has chosen parallel trains of 3 smaller absorbers and 2 strippers. The intermediate CO_2 storage configuration also differs between the two concepts, but should not be used as a measure to differ the two concepts at current stage. The tank configuration will depend on the final required storage capacity, and both study reports discuss various tank capacities dependent on truck- and ship loading frequencies. Ammonia will be used as refrigerant in Apply's liquefaction module, which introduces additional safety measures to cope with the increased risk of toxic/ flammable gas releases. Dispersion simulations shows that safety measures in terms of ignition control and hazardous area classification may be required for adjacent areas. However, liquefaction based on ammonia is considered a standard design and it is assumed that this module can be engineered to be safe even though replacement of ammonia for another refrigerant is inherently safer and will be subject to an ALARP evaluation.

Technip has not addressed the use of ammonia in the HAZID or directly in study report, but it may still be used according to vendor info shown for the liquefaction package. In the Technip concept, hydrogen will be used downstream the compression stage for oxygen removal. Hydrogen introduces fire and explosion risks, and possibilities for accident escalation. In Apply's design flue gas treatment is introduced to avoid the oxygen removal reactor, and introducing hydrogen is not found necessary.

13.5.4.4 Risk picture and preliminary conclusions

The assessment of possible risks at the carbon capture plant concludes that the individual risk for personnel at the plant will be low. There are several release scenarios of gases that could cause asphyxiation, but as long as the leak sources are outdoors, the risk is found low.

The major accident risks identified are dominated by liquid CO_2 releases. The liquid leaks are more likely to result in dense gas dispersion that can expose large areas to hazardous gas concentrations. The gaseous CO_2 leaks considered were found to be more effectively diluted and the hazardous zones correspondingly smaller.

As for other process plants, occupational risk is an issue. This includes risks such as falling objects, fall from height, confined space entry and high voltage equipment. This risk contribution has not been quantified in this CRA. No specific scenario has been identified as a particularly high-risk scenario.

The truck transport option includes some additional risks. The high number of manual loading and offloading operations means that the risk for operation or equipment failure during such operations. In addition, there is risk for traffic accidents. The potential loss of lives from these operations is however not found alarming. None the less, the pipeline option is preferable to the truck option both from a safety and environmental point of view. Risk related to intermediate storage at KEA will be eliminated since liquefaction and storage is no longer required for the pipeline option. In addition, traffic noise associated with the truck option is eliminated.

Ammonia could be used as a refrigerant. Ammonia is toxic, and leak scenarios could affect the restricted area zones. This risk will need to be controlled, or ammonia will be replaced by a less or non-toxic refrigerant. Replacement of ammonia as refrigerant will be subject to an ALARP assessment in the FEED phase. Ammonia risks are not reflected in the iso-risk contours.

Hydrogen could be used for product purification (oxygen removal). Hydrogen introduces fire and explosion risks, and accident escalation is a possibility. Hydrogen risks may be excluded as part of further project development.

[redacted]

[redacted]

13.5.5 Reliability, Availability and Maintainability (RAM) Analysis

A RAM (Reliability, Availability and Maintainability) analysis is performed for the concept phase for the capture part of the full-scale CCS chain. The main purpose of the study is to document that availability is according to the 96% target specified in the basis of design.

The methodology of the RAM analysis is based on the ISO 20815 "Petroleum, petrochemical and natural gas industries – Production Assurance and reliability management". Specifically, the description in Annex D has been used as direct guidance for this study.

To cater for reduced CO_2 production during planned maintenance on the WtE plant lines (K1/K2, K3 and potentially K4), the RAM study considers an availability value relative to the planned CO_2 production (reference level), instead of considering a time-dependent only parameter. This means that the unreliability contribution is relative to planned annual CO_2 capture of 414 200 tons (or potentially 587 400 tons). This enables the study to differentiate the unavailability contribution from planned maintenance on the CCS chain during full and reduced CO_2 production.

An illustration of the RAM model with the main units for the basic concept (pipeline only transport from WtE plant to Oslo Harbour) is shown in the below figure.

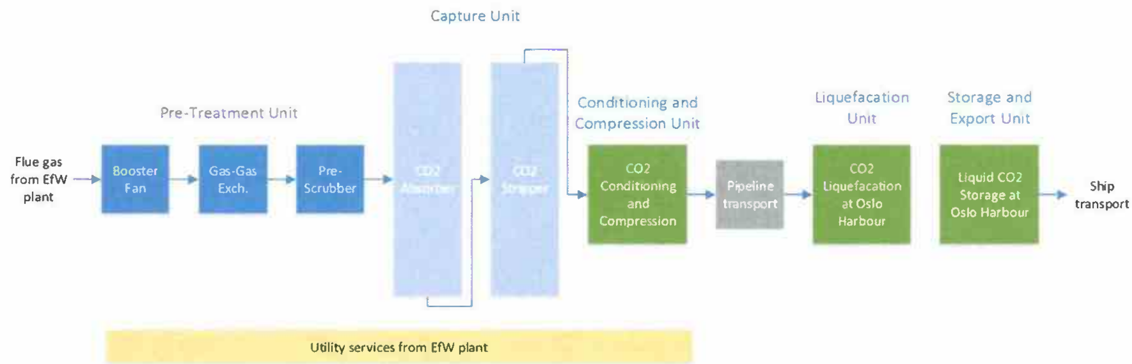

Figure 33. Schematic representation of RAM model – Basic Concept (pipeline transport).

The main contributor to CO_2 capture unavailability is expected to be upstream the liquid storage tanks, i.e. upstream the CO_2 storage at Oslo Harbour for pipeline option, or upstream intermediate storage at WtE plant for truck option. This is because the storage tanks can be utilized as "buffers" during downstream failures to prevent shutting-in and/or reducing CO_2 capture at the WtE plant.

Based on a high-level evaluation of the unavailability contribution from the main systems, the figures provided in the table below. These can be used as guidance for the future work.

Table 13-4. RAM model output.

[redacted]

Note that the above figures are sensitive to changes in configuration of the process system (serial and/or parallel set-up, interface with WtE plant, etc.).

In addition to the contributions from unplanned failures, planned maintenance (PM) can contribute significantly to the unavailability. An average annual contribution between 1 – 5% can be used as guidance. To minimize the planned contribution, it is important that PM activities for the CCS plant are performed during maintenance of the WtE plant and that the periods are minimized, e.g. by parallel maintenance activities.

No unavailability contributions have been quantified from the transport and transfer systems. The pipeline option (basic) is considered to have a higher availability than the truck transport options (a and b). However, due to the storage tanks ("buffers"), the unavailability contribution from the truck transport options are expected to be low. No details have been available for the harbour loading arm(s), but they are a potential source for failures and should be followed-up in FEED phase. Planned maintenance of all transport and transfer systems should be performed during reduced CO_2 production from WtE plant (or between loading operations for ship transfer systems).

No unavailability contributions have been quantified for the storage units. Due to the static nature, redundancy and purpose of the storage tanks, the unavailability contribution is expected to be low/negligible. It is, however, important that planned inspections/maintenance of the tanks are performed during reduced CO_2 production from the WtE plant to minimize the reduction in "buffer" capacity.

Based on the above values, an availability in the region of 90% to 95% is expected for the capture part of the full-scale CCS chain. This is a preliminary estimate based on coarse estimations, and should be revisited during the FEED phase when more details are available. Measures may be taken in design to improve availability if required.

Apply and Technip:

[redacted]

Apply has performed a RAM analysis as part of the Concept Report and has established a RAM model. The results from this is an overall system availability of 99,89%. [redacted]

13.5.6 WEHRA

A coarse Working Environment Health Risk Assessment (WEHRA), ref. [39], has been performed with participation from the CCS project and the operations team from the existing WtE plant.

The WEHRA method for the concept phase was limited to following main topics;

- Storage and handling of chemicals and hazardous waste, required safety equipment
- Identification of high noise equipment identification of potential high-risk equipment/zones (moving mechanical parts, handling of hazardous substances, potential leaks, high pressure, high temperature etc.)
- Identification of heavy materials and equipment, particular focus on frequency of transportation
- Main material handling routes and required handling equipment
- Manual handling – accidents and potential for and musculoskeletal injuries
- Weather exposure in outdoor/semi outdoor areas of the planned installation
- New/unfamiliar work tasks

No major issues were found. However, valuable information regarding operations of existing facilities were provided and a number of actions related to issues such as material handling, handling of chemicals, working conditions outdoors etc. were recorded and will be followed up in the FEED phase.

13.6 EXTERNAL ENVIRONMENT

13.6.1 General

The environmental risk assessments performed as part of this concept study have been performed to ensure compliance with the overall authority requirement related to systematically follow up of HSE (Internkontrollforskriften). Further relevant authority regulations related to environment is the Pollution Act related to protection of external environment, the Product Act related to marking and classification of hazardous substances, the Substitution principle related to hazardous substances and the Waste Act related to handling, disposal and re-use of waste. The existing WtE plant has a Discharge Permit, and special attention has been given to factors not already included in existing Discharge Permit.

As documented in the HSE Plan [29] the Project has a clear goal to minimize impact on the environment. This is in line with Company's environmental policy which implies that the project's activities shall not lead to excess emissions and acute emissions, as well as minimize negative environmental impact.

Company established early on a plan for the environmental risk assessments to be performed as a part of the concept phase. The activities are listed in the table below.

Table 13-5. EnvID/ BAT activities in concept phase.

Activity	Scope	Planned	Performed	Doc. Ref.
Initial project workshop	A workshop performed with core project members, focusing on the overall technical solutions, local challenges and interface with existing facilities at Klemetsrud.	June 2017	09.06.2017	2017-183-MOM-01
Workshop with potential vendor Apply	Workshop performed with vendor with a smaller team from the project group. Focus on vendor supply and assessment and discussions related to vendor technology and suitability and compatibility with existing facilities and project requirements	June 2017	21.06.2017	2017-183-MOM-03
Workshop with potential vendor Technip	Workshop performed with vendor with a smaller team from the project group. Focus on vendor supply and assessment and discussions related to vendor technology and suitability and compatibility with existing facilities and project requirements	June 2017	15.06.2017	2017-183-MOM-02
Project Sum Up workshop	Workshop with similar group as for the initial workshop, discuss and agree the input, discussions and conclusions from the vendor workshops.	Aug 2017	TBA	TBA

13.6.2 Main findings and conclusions

The environmental mapping and risk assessments performed during the concept stage did not identify any critical environmental risks considered not possible to be controlled.

The workshops discussed the two transport alternatives at a high level, and from an isolated environmental point of view the pipe transport is considered beneficial as it reduces the potential accidental risks both at KEA and at Oslo Harbour.

Majority of the findings identified and discussed during the workshops were related to either premature design and design updates or optimisation of interfaces related to heat, energy, chemicals, consumptions between existing WtE plant and the CCS plant itself.

There are however some uncertainties related to external environment in both vendor design recommended for further follow up and documentation in the following FEED phase. The recommendations / findings from the ENVID / BAT reviews are listed in Table 13-6 below. For the full overview of all items from the workshops, reference is made to respective Minutes of Meeting [45], [46].

Table 13-6. Main findings from Concept EnvID /BAT workshops.

Vendor	Finding/recommendation	Ref.
Apply	Solvent – CDR Max. [redacted] • [redacted] • [redacted] • [redacted] A risk assessment related to ensuring the handling and barriers for potential leakage of chemical should be done as design matures. [redacted]	[redacted]
[redacted]	[redacted]	[redacted]
Apply	Refrigerant – R717 For the CO_2 liquefaction ammonia (R717) is planned used as refrigerant in the external cooling loop. Vendor has informed that the technology is well proven and being used in numerous of plants of similar size. Benefits given is less capital intensive than the traditional compression, cooling, expansion method. R717 is classified as a hazardous substance, with risks related to fire, personnel and the environment. MSDS for R717 lists following hazards; - *Flammable gas* - *Contains gas under pressure, may explode if heated* - *May cause frostbite* - *May form explosive mixture in air* - *Harmful if inhaled* - *Causes severe skin burns and eye damage* - Very toxic to aquatic life A risk assessment/BAT assessment related to ensuring the handling and barriers for potential leakage of chemical should be done as design matures. With respect to the fire and health hazards, reference is made to CRA [49], and WEHRA [48].	2017-183-MOM-03, item 4.1
Technip	Water treatment plant. The design includes a dedicated water treatment plant to ensure that the ammonia level in the waste water is below given requirement (60 ppm). Calculations done indicates that the ammonia content will be slightly higher than requirement, 66 mg/l. It was discussed in the workshop the possibility of using waste water from the existing plant for	2017-183-MOM-02, item 2.6

[redacted]

13.6.3 Flue Gas Emissions and Flue Gas Dispersion analysis

The largest air emission source from the CC plant will be the treated gas stream exiting the CO_2 Absorber. Dispersion analysis will be carried by University of Oslo on behalf of Contractor in the FEED phase. The results will be supplied directly by University of Oslo.

The dispersion analysis is a critical delivery and it is envisaged that Company will utilize the experience and support from Test Centre Mongstad (TCM) for this purpose.

<u>Apply:</u>

The concentration of emissions of products of degradation in the depleted flue gas that is released to atmosphere are shown in Table 1 and 2 below (ref. NC02-APP-R-RA-0003). [redacted] The concentration of degradation products is generally lower than what has been observed at TCM. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

13.6.4 Noise

A noise evaluation of the CC plant has been done. This was done as a workshop, and documented with a coarse evaluation [51].

The noise level from the existing plant is barely within the limit values at the nearest houses. Therefore, it is probably necessary to do some noise reducing measures on the existing equipment as well as the new facility.
Careful planning must be done to ensure that the overall noise level from the plant meets the requirements given in the discharge permit.

The primary noise sources at the plant are different types of cooling fans. Most of the other sound sources are possible to encapsulate in some way to prevent external noise.

When installing new dry air cooler, fan type with lower noise levels should be considered if possible. Lay-out and location of dry air coolers should be planned also with respect to noise issues. [52]. Gathering of coolers in groups can be better than spreading them out, as this gives better possibilities for establishing noise screens. Existing buildings, terrain etc. should be used as noise screens wherever possible.

The following actions are recommended for the FEED phase:
- Identify noise levels from new equipment
- Perform detailed noise simulations
- Identify potential noise reduction installations
- Evaluate water cooling to replace air cooling

13.7 Quality Assurance (QA)

13.7.1 General

Company has established a project Quality Plan [30] for the CCS project. The purpose of the project Quality Plan [30] is to document the Quality Management System for the scope of Work that ensures that the delivered documentation and services are in accordance with the project requirements as specified by the Oslo Carbon Capture and Storage (CCS) project.

Company is certified according to NS-EN ISO 9001 (Quality Management) and has a corporate policy for quality and risk management. This policy is also governing for all work and services performed by the CCS Project.

It is a clear objective that the CCS project as far as possible shall use the framework for risk and quality management already established for KEA, including associated procedures. However, the CCS project requires procedures that are appropriate for a Concept and FEED stage engineering projects and these differ from some of the procedures adopted for an operating environment at KEA. Some project specific procedures have therefore been established and these will be further developed in FEED.

It should also be noted that Company will be fully integrated and part of Fortum Varme Oslo AS during the summer of 2017. Changes to the management of quality and risk at Company can therefore be expected. It is expected that this will have no impact on the CCS project in the short term but where possible the CCS project will seek to take advantage of Fortum's competence and experience with risk and quality management in larger projects.

13.7.2 Quality Goals

The quality objectives for the CCS project have been defined as follows as detailed in [30]:

- Ensure that project activities are in compliance with applicable regulations, codes, standards and specifications and in accordance with good industry practice
- Ensure that project documentation, including vendor / supplier documentation, have the required quality.
- Minimize errors and deficiencies by ensuring that individuals perform their duties in a systematic manner.
- Ensure that individuals have the necessary qualifications, experience, and training to perform their duties in a satisfactory manner

- 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
- Prevention of quality problems through risk management and auditing
- Ensure feedback of project experiences and incorporation of lessons learned
- Ensure alignment between the Oslo CCS project and the NCD project in total

Overall the quality goals are considered to be achieved. An internal design review [52] of the FEED Contractor was performed in September 2017in order to ensure that all project goals and specifications are achieved and incorporated and to identify potential improvements to be further investigated in FEED phase. Further, a session on "lessons learned" [52] was performed in September 2017.

13.7.3 Audits and examinations

Audits and examinations are an essential management tool that will be used to verify that quality targets and objectives have been met. Examples of areas subject to audits and examination may include regulatory compliance, work processes, document control, design targets, safety etc. Quality targets and further defined in the CCS projects Quality Plan.

In the Concept Phase a number of examinations towards subjects such as safety, working environment and external environment has been performed. Most of these have been facilitated by 3rd party and have also included participation by Apply and Technip.

The audit and examination program valid for the Concept and FEED stage of the project is documented in the audit and examination plan [53], doc.no NC02-KEA-Q-TA-0001.This is a live document and gives details regarding purpose, schedule and participation for the various audits and examinations.

The audit and examination plan is risk based, i.e. audits and examinations are performed in order to enhance opportunities, reduce or eliminate risk.

Apply and Technip has not provided an audit and examination plan for the Concept phase of the project.

14 REGULATORY STRATEGY

This chapter summarizes regulatory work in the project and gives an overview of most relevant legislation, authorities and required permitting. For further details see separate document NC02-KEA-K-TA-0002 Plan for authority approvals [54].

Key objectives for the regulatory work in the concept phase have been to:

- Establish a plan and strategy for the relevant regulatory work,
- Identify process of getting the necessary permits,
- Start the permitting processes, and
- Evaluate project risks related to the permitting process

14.1 LEGISLATION

In general, the plant shall comply with all relevant Norwegian legislation. Compliance with the legislation will be handled at different levels as the project moves forward. Focus in this phase of the project is the most relevant authorities, legislation and required permits.

Table 14-1. Most relevant authorities in Norway for this type of project.

Norwegian name	Translated name
Direktoratet for samfunnssikkerhet og beredskap (DSB)	Directorate for civil Protection and Emergency Planning
Miljødirektoratet (MID)	Norwegian Environment Agency
Plan- og bygningsetaten i Oslo kommune	Planning and construction office in the municipality of Oslo
Fylkesmann	County Major
Arbeidstilsynet	The Norwegian Labour Inspection Authority
Norges Vassdrag- og Energidirektorat (NVE)	The Norwegian Water resources and Energy directorate

An overview of the most relevant legislation are given in the following.

14.1.1 The Planning and Building Act

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 single person. It shall also ensure that construction works complies with the rules and regulations.

The law and subordinated regulations gives 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 of 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 has a big impact on the environment or the society a zoning plan and an environmental impact assessment has to be prepared.

For the building application part the regulations consists of the following two regulations:

Technical building regulations (Byggteknisk forskrift - TEK17):

The regulation controls technical demands for buildings and demands for documentation, building density, safety against stresses for the environment/nature. The technical demands in the regulation will be effective for an industrial plant like this. Chapter 8, 12, 13 and 14 extend as far as they are applicable.

Building application regulation (Byggesaksforskriften - SAK10)

The regulation controls the progress related to building permits and the regulation requires competence, configuration and content related to building applications.

14.1.2 Regulations for environmental impact assessment (EIA)

EIA regulations have the main purpose to ensure that impact on environment and society is taken into consideration during area planning and project planning.

The regulation include lists of specific plans/project with criteria for were an EIA shall be done, and a list of plans/project were an EIA shall be considered done. Proposed plan/project at Company includes several topics/criteria on the "shall be done" list, and an EIA is concluded necessary. The criteria lists also defines whom to be responsible authority for the EIA.

The regulations define scope for what the EIA should include of evaluations, and strict procedures for the execution of an EIA. In the EIA the plan/project shall be evaluated and compared to a "0-alternative". The 0-alternativ is normally and typically for a project like this not to establish the plant.

14.1.3 The Pollution Control Act and underlying regulation

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 activity, and have separate chapters and/or separate underlying regulations for amongst other waste handling, tank storage etc.

Main purpose of the regulations 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 like this:

- Requirement for 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 of soil pollution
- Requirement for relevant competence of all involved parties
- Requirements for monitoring effluents/emissions

14.1.4 Fire and Explosion Prevention Act

The object of Fire and Explosion Prevention Act is to protect life, health, environment and material against fire and explosion. The most relevant regulation is *Regulation relating to handling of hazardous products.* It regulates engineering, construction, production, business, installation, operation, change, repair, maintenance and control of equipment and plants that is used while handling dangerous products.

The superior requirements is 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
- Sufficient emergency preparedness plans
- Sufficient documentation

14.1.5 Regulations related to Emission Trading System (ETS)

The Government has formally informed the WtE industry that they are considering introducing of a CO_2 tax in WtE market. Either as a tax in the "none ETS market", or by an "opt-in" to the "ETS market". Client has so far indicated a "zero value" of the CCS policy, i.e that the saved tax will be deducted from the payment of delivered CO2.

14.2 PERMITTING

14.2.1 Zoning plan – Oslo municipality

The existing zoning at Company does not allow for further development at the area. More or less all area planned for the capture plant is outside the borderlines for where it is accepted to build in the existing zoning. New zoning is started to facilitate the planned capture plant, and the plan will also allow for a future new incineration line (line 4).

The potential pipeline from KEA to Oslo harbour will also require a separate zoning to ensure that the pipeline are taken into consideration in future planning of the areas above the pipeline routing.

Intermediate storage at Oslo harbour is expected possible to establish within the existing zoning. This will be verified during FEED when scope and location is defined.

14.2.2 Environmental impact assessment (EIA) – Oslo municipality/ Environment Agency

According to the regulations for environmental impact assessments, an EIA will be required for the project. As the project results in several criteria's in the regulation applicable it can be both the Municipality of Oslo and the Environment Agency that will be the responsible authority for the EIA. As the regulation changed July 2017 this clarification is still not final, but it is expected that the Municipality will be the responsible authority.

An environmental impact assessment is normally an integrated part of a zoning plan progress towards the municipality and has strict formal requirements for the process (zoning program, consultations, political processing and so on).

The time it takes to complete a zoning plan and EIA is typically 18 months. Program for the zoning & EIA is carried out during concept phase and the EIA itself during FEED phase.

14.2.3 Building permit

Planned installations at Klemetsrud, Oslo harbour and pipeline needs to have a building permit given by Oslo Municipality. This will be separate applications on each site. The applications will be split in frame approvals for the projects and following start-up approvals for the execution.

Building permits require zoning to be finished. Applications can be started at the end period of FEED, but authority handling and follow up of the permitting process will need to be done after FEED phase.

The different disciplines within design and executing of the installations that is comprised by the Planning and Building Act must declare the right to accept responsibility their work. This according to Norwegian rules and regulations. When the work for the different disciplines is finished a declaration of conformity has to be issued by the responsibly contractor for the different disciplines.

14.2.4 Consent from the Directorate for civil Protection and Emergency Planning (DSB)

Regulation relating to handling of hazardous products is applicable due to pressurized CO_2 (and chemicals in auxiliary systems). For plants with potential for major accidents a consent from DSB is needed.

The regulation sets demands to establish limitations of the spatial planning around the industry. A risk assessment will set the demands for the spatial limitations.

If dangerous zones extends beyond your own property line, it is important to establish zones requiring special considerations.

14.2.5 Discharge permit - Norwegian Environment Agency

Existing plant at Klemetsrud have a discharge permit. Due to changes in the emissions/effluents it will be required to apply for a new/updated discharge permit for the project. The progress related to discharge permit will be carried out to the Norwegian Environmental Agency.

Before the plant is in operation, the discharge permit must be approved. Typically, it will take around 6 month for the process for application. However, it is desired from the authorities to be included in an early stage in the process. On the other hand it is presumably that you need documentation from the detail engineering to get a complete application.

To summarize the progress for the discharge permit application it will be necessary to involve the authority in an early phase. In addition, it will be needed to send the application for discharge permit early as a draft. The application must be complemented during the progress. The permit will not be given until further out in the project, but the project can expect preliminary statements from the pollution authority.

15 BENEFITS REALIZATION STRATEGY

Company is committed to sharing all available knowledge and experience (not restricted by IP rights) and fully support Client's intentions on knowledge sharing and learning. Company will work to also be able to publish knowledge and experience covered by the Contractor's IP rights, but in cooperation with Contractor and Client. The main strategy for achieving this is to inform and influence other WtE plants and companies through national and international industry organizations and various political bodies in Norway and the EU.

The Incineration plant at Klemetsrud is representative for a great number of incineration plants throughout the world. CO2 capture from a WtE plant with grate fired plant, a fluidized bed plant as CFB (Circulating Fluidized Bed) or BFB Bubbling Fluidized Bed) is in principle no different. Therefore, the knowledge and experience gained form a CC plant at Klemetsrud WtE plant is valid for all other WtE plants.

As an example of ongoing interest work and dissemination of knowledge, the following activities have been completed or planned for the future:

- Presentation at the "CO_2-conference" in Trondheim, 10th of January
- Presentation at "Climit Summit", Gassnova, 7th of February
- Presentation at UNFCCC "Thematic session on innovative policy and technology solutions for sustainable urban development" in Bonn, 9th of May
- Presentation on a seminar for 'Svenske Riksdagen' in June
- Presentation in annual meeting Norsk Energi, 8th June
- Participation in panel debate IEA Bioenergy Task 41 on Bio-CCUS - EU Sustainable Energy Week 22th June
- Presentation for the City of Oslo and a high-level delegation from Shanghai, 26th June
- Participation on Gassnova/TCM meeting with the energy councillors in the EEU 29th June
- Participation on Gassnova 'CCS-safari', 9th August.
- Presentation at Gassnova arrangement, 15th August - during 'Arendalsuka'
- Presentation for the ambassador for Canada and CO_2 Solutions, 18th August
- Presentation for administration from City of Oslo and international/Brussels office 22th August
- Presentation at 'Nordiskt Förbränningsmöte i Göteborg' 23-24th August
- Presentations Washington/Austin, arranged by MPE, week 37.
- Visit from the Embassy of Netherland, CCS part of the program, 12th September
- Visit from 'Svenska Miljö- och Energidepartementet, Klimatenheten' 21th September.
- Presentation at Oslo Innovation Week; CCS-forum (Bellona, City of Oslo) 26th September.
- Visit from fourteen Nordic Energy journalists 27th September.
- Visit from the board of GASSCO 3th October.
- Week 40, five presentations for Gassnova in the USA, including US Senate.
- Site visit from the Environment Agency, approx. 50 persons, 9th November.

- Possible presentation from Fortum representative in a Bellona breakfast meeting 7th December

In addition, a lot of presentations has been held by the Company's representatives, in particular by the Project Portfolio Manager in connection with his activity towards ISWA, academia - and the waste business in general. He currently holds the chair of IWSA's working group of energy recovery. One additional item is the increasing activity on LinkedIn, and KEA comments about CCS on WtE.

Reference is made to the deliverable "Gevinstrealisering [55] for further information

16 VIP STUDIES

As part of this project and the Contractors scope of work, the Contractors, have been encouraged to systematically carry out and document processes / exercises for added value in the construction and operating phases (VIP - value improvement practices) in co-operation with KEA.

As part of the VIPs, the Contractors together with KEA have been obligated to study (and report) all synergistic integration opportunities between the CO_2 capture plant and the WtE plant at Klemetsrud. The studies / documentation will eventually also include risk assessments and scope split descriptions, but during the Concept phase, work has mainly focused on identifying opportunities for value improvement.

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17 LESSONS LEARNED

17.1 THIS PROJECT

Reference is made to the Concept phase lessons learned report [52], which will be developed further during the FEED phase in close collaboration with the selected CC Contractor.

The knowledge sharing / lessons learned will be divided in according to seven main categories: (1) technical solution and performance, (2) operation, (3) costs, (4) environmental impact, (5) health and safety, (6) business model and (7) project implementation. For further information around these categories and expected learnings, see the Concept phase lessons learned report [53] and the "Gevinstrealisering" document [55].

17.2 PAST PROJECTS

The purpose of this section is to capture the lessons learned from past CCS projects based on CDRMax® or Shell Cansolv Technology. This document may be used as part of new project planning for similar projects in order to determine what problems occurred and how those problems were handled and may be avoided in the future.

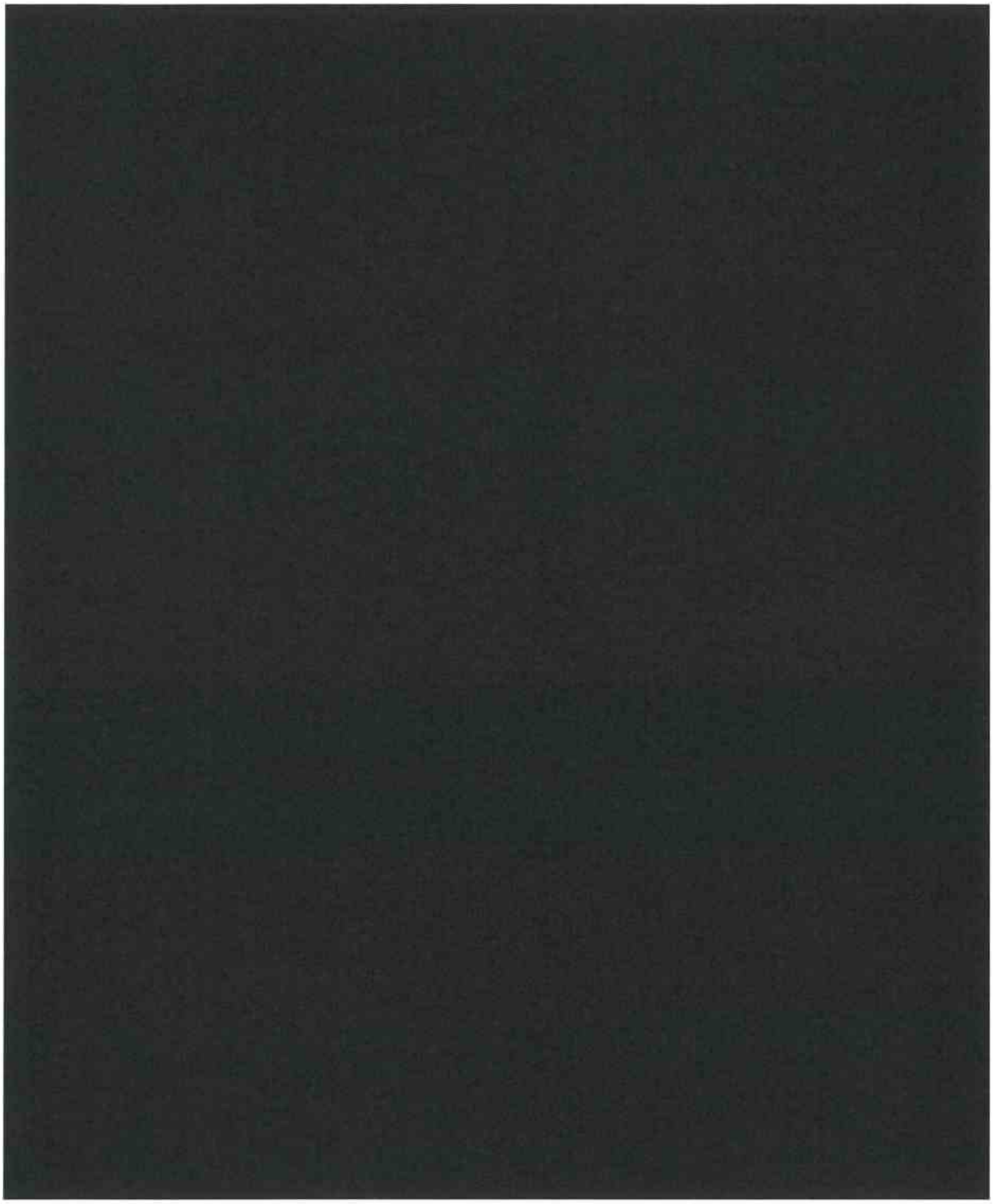
The CCS Project utilized several lessons learned from past projects. This part gives overview of key lessons learned from the plants and test carried out using CDRMax® [redacted] and Shell Cansolv Technology [5, pp. 90-92] (Table 17-1). The listed items referring to the projects using Shell Cansolv Technology were identified as of high importance. It is worth noting that the full list, the items with lower importance level and more details can be found in Klemetsrud CCS Concept Phase Report by Technip [5, pp. 90-92]. These lessons indicate project specific problem/issue described as item and further description/impact/recommendations are provided for consideration on similar, future, new construction projects.

Table 17-1. Lessons learned from previous projects using CDRMax® or Shell Cansolv Technology for CC Plants.

CDRMax® Item	Description/Impact/Recommendations
Trace components in the flue gas	A detailed assessment of trace components including aerosols, dust and acid gases in flue gas should be undertaken since it can have a significant effect on the solvent degradation and on emissions to atmosphere. Preventing trace components present in the flue gas from entering the CC plant is considered to be more effective than dealing with the products of degradation and making up more solvent.
Products of degradation	An optimal solvent reclamation process has been determined based on the experience of testing at many different sites, there is a detailed knowledge of the products of degradation which occur in the solvent. From this
Fluctuating CO_2 compressor operation	This can have effects on the performance of the CC plant stripper. Therefore, it is important that the stripper is protected from such fluctuations.

Solvent analysis	Analysis of the solvent's water content should be carried out daily on-site to assure efficient operation. Solvent composition can be carried out at less frequent intervals at an off-site laboratory.
Team members training & engagement	It is essential that members of the host site's team are engaged with the new development from the outset.
Environmental permits	Permits can take a long time to obtain so work on establishing the permit should start early in an engineering project.

[redacted]



18 Construction, Pre-commissioning and Commissioning

18.1 General

The construction shall be done so that a minimum of interruptions to the normal operation of the WtE plant is realised.

For detailed information on the construction philosophy please refer to the construction philosophy that can be found in the document [11] NC02-KEA-O-KA-0002

18.2 KEA Existing Facilities and Integration

18.2.1 Modification of existing buildings

From construction point of view the only major impact to existing KEA existing facilities is the replacement of the steam turbine. To enable removal of the old turbine for the new CC plant compliant turbine the existing turbine hall needs to be opened up without damaging the integrity of the building.

When the building is open the existing equipment and piping needs to be removed to facilitate the installation of the new equipment. Once installation is completed then the building needs to be restored to original condition. As the steam, condensate and DH connections are taken from the turbine hall these are foreseen to be included in the modification works.

A control room extension is foreseen as necessary to facilitate the added equipment

Minor modifications to existing buildings are foreseen to facilitate the installation of the exhaust gas ducts.

18.2.2 Pre-commissioning and commissioning

The auxiliary equipment for the steam turbine will be tested at factory prior to delivery.

The Commissioning procedure for the Steam turbine and auxiliaries will be described in the manufacturer's documentation

18.3 Pipe line

18.3.1 Construction of pipe line

The transport pipe line will be constructed along the route deemed most feasible with minimum impact to the environment. Further investigation into this will be done in the FEED study.

18.3.2 Commissioning of the pipe line

The pipe line commissioning procedure will be evaluated in the FEED phase.

18.4 Harbour Facilities

18.4.1 Construction

As the Liquefaction, storage and loading area will be constructed in a public harbour area close work together with the harbour authorities is foreseen as a high priority to avoid interruptions to the daily workings of the harbour.

As the harbour is foreseen to be unmanned as few facilities as possible for human occupancy will be provided.

18.4.2 Commissioning of Harbour facilities

The equipment for the liquefaction will be pre-commissioned at the manufacturers before delivery to site and commissioning of the completed installation will be performed according to guidelines from the manufacturers.

In order to be able to hand over the plant ship loading procedures will have to be tested when the ship is available

18.5 CAPTURE PLANT

18.5.1 Construction of Capture plant

The site area designated for the CC plant will be levelled and all subsurface works will be prepared by Company for the CC contractor to begin the mechanical installations. In the le Equipment needed for the installation works shall be provided for by the CC contractor and a designated area is prepared for storage of transport containers.

In general the works and logistics shall be performed with minimal interruptions to the existing operations.

For detailed information on the construction philosophy please refer to the construction philosophy that can be found in the document [11] NC02-KEA-O-KA-0002

18.5.2 Commissioning of Capture plant

The equipment to be installed shall be pre-commissioned at the manufacturers factory to as high degree as possible to minimise time spent on site testing the individual components.

Commissioning of the capture plant will be in accordance with the guidelines provided by the manufacturer and shall ensure that installed equipment is in order to begin the performance testing

Performance tests shall be in agreement with the contractual requirements for capture rates.

19 OPERATION

This chapter will in brief approach the operation and maintenance of the carbon capture chain, further information is available in the Operation and maintenance philosophy document NC02-KEA-O-KA-0001 [56].

All operations for the Carbon capture chain, including ship loading, is expected to be carried out from the central control room at KEA WtE plant.

19.1 CARBON CAPTURE PLANT

19.1.1 Operation

The CC plant is expected to be in operation at all times when the WtE plant is in operation and the capture rate is expected at 90% of produced CO_2 regardless of amount of incineration lines in operation.

All control of the CC plant is done from the central control room at KEA with daily inspection rounds carried out by the operator of the CC plant.

Sampling of chemicals from the plant must be carried out at the intervals set by the contractors and while some is automatically done the sampling of the solvent must be taken by the operators and sent off site for analysis.

19.1.2 Maintenance

All major maintenance to the CC plant is expected to be carried out during the yearly shutdown of the KEA WtE plant while minor maintenance will be enabled by redundant equipment.

All equipment are expected to have sufficient access to perform maintenance unhindered and that lifting arrangements are provided where heavy lifts are expected in accordance with HSE requirements

19.1.3 Safety

The CC plant shall be provided with shut-off valves and CO2 gas detection so that any leaks can be quickly identified and isolated from the process. Active fire protection will be provided according to fire risk. Operational safety will be considered in more detail in the FEED phase when more details are available. General safety requirements are otherwise approached in Chapter 13 of the report and will not be further approached in this chapter.

19.1.4 Manning

The CC plant will be designed and automated to minimize the number of operators required. During the testing phase of the plant additional personnel is expected to facilitate the testing and training of personnel.

19.2 CO_2 TRANSPORT

19.2.1 Operation

Operation of the pipe line will be continuous based on the production from the CC plant and only monitoring from the central control room is required during normal operation.

19.2.2 Maintenance

The pipe line will be cleaned periodically via means of pigging and during the pigging operation manual supervision of the launch and receival is needed. During the pigging operation two operators will need to be present to handle the pig first at KEA WtE site and then later at the harbour. Other maintenance of the pipe line is not foreseen except for regular inspections and touch-up paint of above surface parts which can be carried out simultaneously with the pig operation.

19.2.3 Safety

The pipe line needs to have continuous monitoring with gas detectors in inspection pits and also follow up / monitoring of mass flow. Leaks and breaks needs to be identified immediately if they occur as the release of CO_2 will not be noticeable to the general public. Isolation of pipeline using segmentation valves upon a detected leak will be further investigated in FEED.

19.3 CO_2 LIQUEFACTION

19.3.1 Operation

The liquefaction trains are expected to be automatically operated (subject to vendor discussions) and monitored from the KEA WtE main control room. Local control panels shall be available for local control of the units if required for maintenance and checking needs.

19.3.2 Maintenance

All major maintenance to the CC plant is expected to be carried out during the yearly shutdown of the KEA WtE plant while minor maintenance will be enabled by redundant equipment such as pumps which require regular maintenance, fans or PSVs to facilitate online maintenance. The redundant equipment will be reviewed in FEED.

All equipment are expected to have sufficient access to perform maintenance unhindered and that lifting arrangements are provided where heavy lifts are expected in accordance with HSE requirement.

19.3.3 Safety

The liquefaction unit shall be provided with shut-off valves and gas detection so that any leaks can be quickly identified and isolated from the process. Active fire protection will be provided according to fire risk, depending on type of refrigerant to be used. Operational safety will be considered in more detail in the FEED phase when more details are available

Safety requirements are otherwise approached in chapter 13 of the report and will not be further approached in this chapter.

19.4 CO_2 STORAGE

19.4.1 Operation

Tank selection shall be automatic by the loading from the liquefaction trains and also from the unloading operations. Monitoring of the operation will be done from the KEA WtE control room and manual override of the same shall also be available from the central control room and also from local panels at the harbour.

19.4.2 Maintenance

The tanks shall be regularly inspected for leaks and damages but no regular maintenance is expected for the tanks.

19.4.3 Safety

The tanks are to be equipped with safety shutoff valves to be able to isolate them in case of a leak or pipe break to prevent large spills. The tanks shall be located in a bunded area to prevent uncontrolled spread of liquefied CO_2 and enable a controlled environment for evaporation to occur in. Leak points associated with the tank inventory shall be reduced as far as possible and may involve welded connections etc.

The bunding cannot contain very large leaks. Spread of CO_2 will be modelled to avoid possible low points for larger accumulation of liquid gas in the immediate vicinity of the tanks.

19.5 CO_2 LOADING

19.5.1 Operation

The loading operation is expected to be automatically operated with the securing of connections and possible other minor operations to be done by the ships personnel. To be discussed and clarified with Client.

19.5.2 Maintenance

All major maintenance to the CO_2 loading equipment is expected to be carried out during the yearly shutdown of the Company WtE plant while minor maintenance will be enabled by redundant equipment.

19.5.3 Safety

The loading system shall be provided with isolations valve(s) / quick disconnect system so that a leak can immediately be isolated from the tanks. A more detailed safety analysis will be performed in the FEED phase.

19.6 KEA AUXILIARY SYSTEMS

19.6.1 Steam system

The existing steam turbine at Company lines K1/K2 will possibly be replaced with a new turbine suitable to the need of the CC plant but no major changes to practical operation or maintenance schedules are foreseen.

The safety aspect will be further evaluated after final selection of turbine and equipment.

19.6.2 District Heating network

The DH network will be modified with new connections and heat recovery from the CC plant as well as from the new condensers for the new steam turbine.

The control of the DH network and the load variations will be handled internally at Company by balancing heat recovery from CC plant and by use of auxiliary coolers at Company.

Control of the heat balancing will require update of control philosophy at Company.

19.6.3 Auxiliary cooling

As the steam system and district heating network connections are modified additional auxiliary cooling is required to maintain and improve operations for balancing the heat during the year to enable maximum output at all times.

The operation of the auxiliary cooling system will be automatically controlled depending on the availability of the DH network to receive additional heat and also on the output of heat from the incineration lines. Overall, operation philosophy will be that the auxiliary cooling system will be controlled from the central control room without additional requirements for personnel.

Safety aspects to be evaluated further when final selection of equipment is done during FEED phase.

19.7 Operational preparedness

19.7.1 Preparation for operations

The plant needs to be prepared for continuous operation before handing over. The following activities are foreseen as necessary and all are subject future negotiations.

- First fill of chemicals
- Commissioning of equipment
- Running in and performance testing
- Training of personnel

19.7.2 HSE objectives and goals

The HSE is detailed in chapter 13 and will not be further evaluated.

19.7.3 Organisation and manning

Organisation of manning are subject to future negotiations.

19.7.4 Asset integrity & maintenance

Define further in FEED in cooperation with Contractor.

19.7.5 Terminal operation

Terminal operation will be developed together with Client.

20 FUTURE PHASES

The scope of work for the FEED scope is associated with maturing the selected concepts from the Concept study to such a level that +/- 20% CAPEX and OPEX estimates will be made and minimal design risk remains for next phase.

There are some changes to the scope of work for the FEED phase and the agreed deliverables and timeline as described in the "Studieavtale" between Company and Client. And as a result some adjustments to the budget must be made.

The FEED schedule and Master document list has been updated as part of project development. The various decision milestones and Company decision processes are identified Please refer to [57],

The design basis for FEED has been issued to Contractor.

The possible implementation of KEA governing documents is under discussion internally and with Contractor.

An interface management plan has been developed, please refer to [58].

The following areas are focused on as critical for integration in the next phases:

- Heat integration
- Evaluation of VIP studies
- Noise (technical solution)
- Emissions to air
- Turbine upgrade with optimization considering all operational modes (winter/summer, CC plant in /out of operation, etc.)

21 PROJECT EXECUTION

Project Execution assumes that the development is led by Company with Technip or Apply as main EPCIC contractor and comprises the CO_2 capture facilities, intermediate storage and terminal facilities. KEA will be responsible for site civil works as well as execution of the transport of CO_2 from KEA to Oslo harbour.

Project execution will be managed by Company utilising the services of Contractor as main contractor for the FEED and EPCIC for the assets.

In managing the work, Company's objectives are to:

- Design and construct a safe and environmentally acceptable facility
- Set appropriate expectations and deliver according to agreements
- Exercise appropriate governance over all activities
- Build strong and constructive relationships with all stakeholders
- Demonstrate integrity and adherence to Company values.
- In addition answer Client expectations to demonstrate:
    - Capture capacity, suitability of the plant
    - Progress plans
    - Execution capability
    - Costs for studies, including own contribution from Beneficiary
    - State risk and costs during the construction and operation phase
    - Contribution to technological development
    - Facilitation of knowledge transfer

Please refer to [1] for further description of the Project Execution Philosophy describing the philosophy in more detail including the Contract Strategy.

21.1 PROJECT MASTER SCHEDULE

The project schedule is established based upon input from the Contractors and considering zoning, pipe transport and the integration work. The various decision milestones and Company decision processes are identified. Please refer to Project Master Schedule [59].

22 DELIVERY REQUIREMENTS 1A AND 1F

As per agreement with Gassnova on the 15th of August 2017, the delivery requirements 1a and 1f in accordance with appendix 1-1 in the Study agreement is placed on HOLD.

23 LIST OF REFERENCES AND APPENDICES

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[4] KEA, "Waste-to-Energy Agency, Feasibility study - Carbon capture and transportation from a waste to energy plant".

[5] Technip, "Klemetsrud CCS Concept Phase Report," NC02-TEC-P-RA-0015.

[6] Apply, "Study Report Carbon Capture," NC02-APP-Z-RA-0001.

[7] KEA, Main flow diagram, NC02-KEA-P-XA-0001_01_.

[8] KEA, Interface Register - CC Plant 1 (APP), NC02-KEA-O-LA-0001.

[9] KEA, Interface Register - CC Plant 2 (TECL), NC02-KEA-O-LA-0002.

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[13] KEA, "Control room extension and connection points," NC02-KEA-L-XE-0002.

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[20] Apply, "Concept report - comments," KI 17-63 - Additional questions/comments to Concept report (eRoom), September 5, 2017.

[21] KEA, "New steam turbine study," NC02-KEA-P-FD-0005.

[22] Technip, "Intermediate Storage Tank Study," NC02-TEC-P-RA-0010.

[23] KEA, "VIP assessment," NC02-KEA-P-RA-0001.

[24] KEA, "Technological maturity plan," NC02-KEA-P-TA-0003.

[25] KEA, "CCS experience and reference lists," NC02-KEA-P-LA-0001.

[26] Technip, "Functional Specification – Liquefaction Package," NC02-TEC-P-SA-0002.

[27] Apply, "Klemetsrud CO2 Capture and Interim Storage Study Report - K3 Optimization with Pipeline," NC02-APP-Z-RA-0002.

[28] KEA, "HMS Program," NC02-KEA-S-TB-0001.

[29] KEA, "Quality Plan," NC02-KEA-Q-TB-0001_02.

[30] KEA, "Risk and opportunity Procedure," NC02-KEA-Q-LA-0001.

[31] ISO, "NS-ISO 31000:2009 - Risk Managment - Principles and guidelines".

[32] ISO, "NS-EN ISO 9001:2015 - Quality Managment Systems - Requirments".

[33] ISO, "NS-ISO 14001 - Environmental managment systems - Requirments with guidance for use".

[34] Apply, "Project HSE Managment System," NC02-APP-A-LA-0005.

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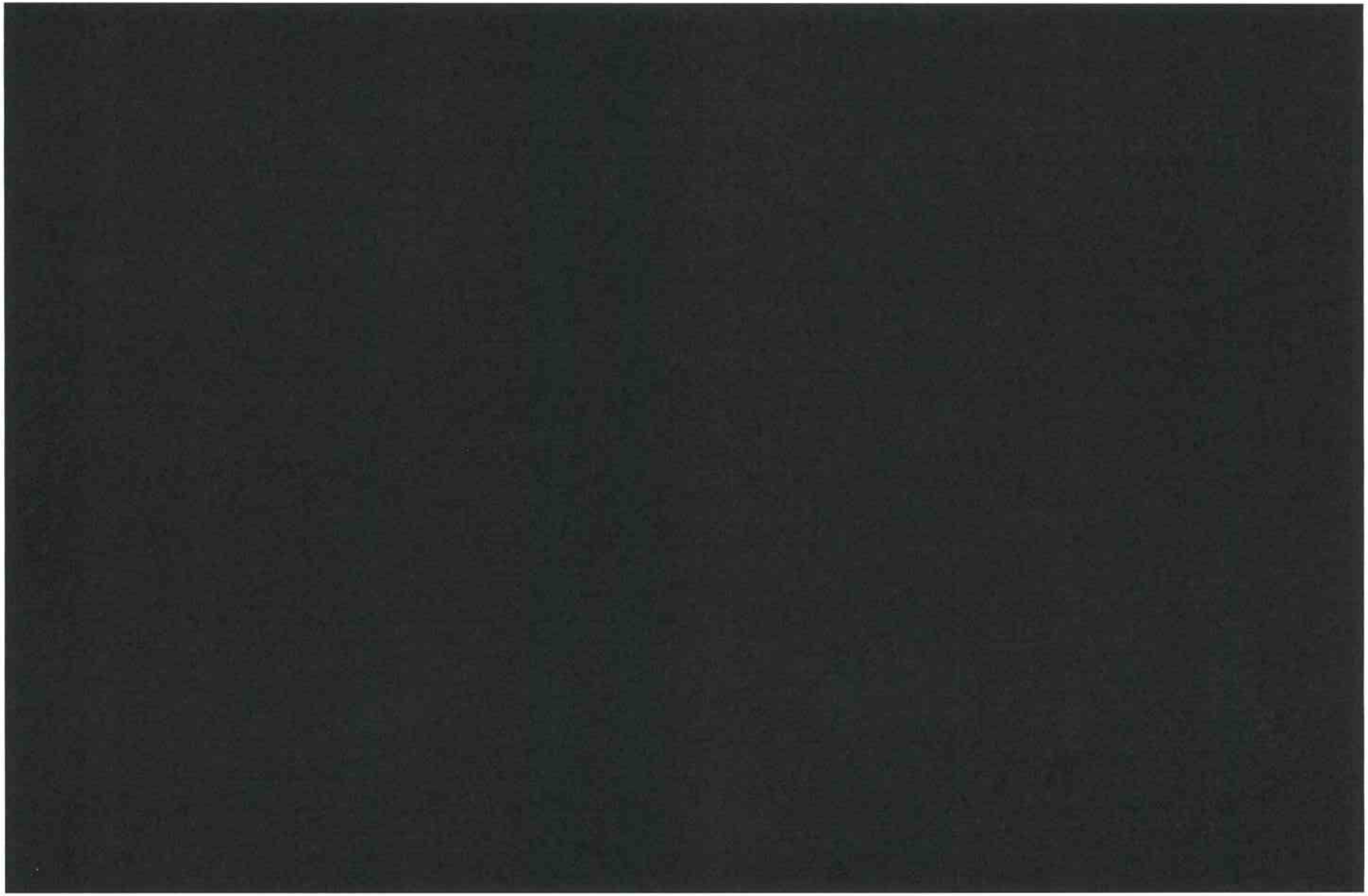

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