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1 INTRODUCTION

1.1 Purpose

The Fortum Oslo Varme (FOV) Longship Oslo Carbon Removal (LOOCR) project has learned important lessons during the concept, FEED and Interim phases which will be of great value for future CCS projects. This report documents the major learning points collected by the FOV LOOCR project so far, and suggested learning points that other CCS projects and future developments can use, to increase the benefit for the sector.

One important target of the Longship project and for LOOCR project is to inspire and assist other plant operators to implement CCS to reduce their greenhouse gas (GHG) emissions. Projects that follow the lead of the LOOCR project should benefit from the learnings and experiences collected in the project; how to improve overall cost effectiveness, project progress and technical and environmental performance.

FOVs participation in the Longship project as presented by the Norwegian Government in September rely on conditional financing, and FOV is hence seeking external financing of the project. Application to the EU Innovation Fund is deemed to be one important source for the total financing of the project. FOV has focused on submitting a full and thorough proposal to the first stage (Expression of Interest) of the EU Innovation Funds first call. FOV has strengthened the team working with the application with EU-application specialist PNO Consultants. The lessons learned from this process is therefore included in this report.

Chapter 4 of the report will describe in more detail learnings within the following eight areas:

- Technical Solution and Performance
- Operation
- Cost
- Environmental impact
- Health and Safety
- Business model
- Project execution
- EU application.

For more and specific learning, please contact FOV management.

2 MAJOR LEARNING POINTS FOR FUTURE PROJECTS

In the following list, the most important learning items from the LOOCR project are briefly summarized. It is anticipated that plant owners and potential new projects will benefit from these learnings.

1. Generally, for CO_2 capture technologies and plants, energy requirements (GJ/ ton CO_2 captured), solvent degradation, CAPEX and OPEX are considered the most essential performance parameters. However, for the Klemetsrud CC plant, the level of emissions to air of entrained solvent is essential to performance in order to confirm there are no negative health effects of nitrosamines and nitramines (solvent degradation- and reaction products). Limited information is publicly available regarding the emission levels from operating plants. Thus, the pilot test campaign was specifically tailored to document the actual, observed emission levels, which was also crucial for the technology qualification program. New projects with flue gases within the design envelope used for the Klemetsrud plant should be able to utilize the results from the FOV Pilot campaign more or less directly, and thus save both cost and time. Other flue gases and/or other solvents may require testing with a pilot to document emission levels.
2. FOV has operated the CC pilot plant for a specific amine system and specific flue gas. The flue gas content is assumed to be representative for flue gas in other WtE plants. The results from pilot testing are very promising and offer valuable learning for other future full-scale plants in general, and for WtE plants in particular. These plants can now achieve better design reliability by fine-tuning their advanced process simulation models to a broader set of empirical data which includes FOV pilot plant performance.
3. FOV has demonstrated that WtE plants are suitable for retrofit with Carbon Capture facilities, and it is documented through both pilot testing and detailed analyses that it is safe for plant employees and neighborhood residents to establish and operate a CC plant. The specific project at Klemetsrud is a retrofit to an existing WtE plant, but the results will be valid for new-built plants as well. The capture plant and local storage facility will be safe both for plant workers and for the surrounding neighbourhood.
4. The project has demonstrated that transport of CO_2 from Klemetsrud to Port of Oslo is feasible both via pipeline and by trucks. For highly populated areas, FOV has found the regulation risk to be high for pipeline and therefore less likely to be accepted. The transport solution with pipeline is hence not used for this project. Truck transportation is selected as the preferred alternative, and it is documented that emission-free heavy-duty trucks can be used. This is a flexible solution and easily scalable, which will be particularly interesting for projects with several small CO_2 capture sources. As there are several candidates for CO_2 capture both in Norway and Europe that are not located at a port area, transport is a vital part of the CO_2 chain. Learnings from the transport studies done in the FOV CCS project can be utilized in these coming projects, as well as valuable learning from the full-scale plant provided it is realized.
5. Selection criteria for evaluating potential suppliers of carbon capture technology are important. FOV has learnt that focus should primarily be on technical maturity and security of supply. Commercial and contractual requirements should then be discussed and clarified with the short-listed suppliers. Strict requirements to fixed price compensation and strict performance guarantees may lead to unintended abatement of qualified suppliers for the first wave of capture projects.
6. Selection of technology providers for the carbon capture process should preferably be completed as late as possible in order to realize the full benefits of healthy competition. In this project, the selection of technology was done prior to start of FEED phase. Strong contractual link between EPC contractor and Technology provider gave no

potential for competitive bidding for the EPC phase. In the future it is believed that the EPC contractor will be able to provide more than one CC technology and the actual technology selection can be made after the FEED phase as part of the EPC tendering phase.

7. Applying for funding from an EU fund is a specialized process, that require high attention and good planning. LOOCR used PNO as a specialist consulting, and this is highly recommended to be able to establish a good application within a short timeframe. FOV underestimated the extent of the requirements and the required level of details for an EU application, and the amount of work and resources this would require from FOV. In the beginning of the process, it was assumed that many of the documents could be reused from other documents that FOV had prepared. The adaption of the documents to the tender requirements showed up to be substantial.

3 ABBREVIATIONS

CAPEX	Capital Expenditure
CC	Carbon Capture
CCS	Carbon Capture and Storage
CERC	Central Electricity Regulatory Commission
CFD	Computational Fluid Dynamics
DG	Decision Gate
DSB	Directorate for Civil Protection
EIA	Environmental Impact Assessment
ENVID	Environmental Identification Analysis
EPC	Engineering Procurement and Construction
ETS	Emission Trading System
EU IF	European Union Innovation Fund
FEED	Front End Engineering
FMECA	Failure Mode Effect and Criticality Analysis
FOV	Fortum Oslo Varme
GJ	Gigajoule
HAZID	Hazard Identification Analysis
HAZOP	Hazard and Operational Analysis
LC-MS	Liquid Chromatographic Mass Spectroscopy
LOOCR	Longship Oslo Carbon Removal
LOPA	Layer of Protection Analysis
MPE	Ministry of Petroleum and Energy
MVR	Mechanical Vapor Recompression
MW	Mega Watt
NE	Norsk Energi
NEA	Norwegian Environmental Agency
NGO	Non-Governmental Organization
NILU	Norwegian Institute for Air Research
NIVA	Norwegian Institute for Water Research
OPEX	Operational Expenditure
PBE	Plan and Building Authorities
QMS	Quality Management System
QRA	Quantitative Risk Assessment
RAM	Reliability, Availability, Maintainability
SIL	Safety Integrity Level
TCM	Test Centre Mongstad
TRU	Thermal Reclaimer Unit
TQ	Technology Qualification
WEHRA	Working Environment Health Risk Assessment
WtE	Waste to Energy

4 LEARNING ITEMS

The following chapters provide more detailed descriptions of the learnings achieved in this project

4.1 Technical Solution and Performance

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.1	Need for Technology Qualification	In order to have an independent 3rd party opinion about technology performance and applicability of the pilot test results for a possible full-scale plant, DNVGL were engaged to perform a Technology Qualification (TQ) process according to their Recommended Practice DNVGL-RP-J201. The TQ was requirements in the contract. FOV defined the acceptance criteria and DNVGL evaluated information and evidence to confirm the technology provider and FOV statements about the performance. FOV experience is that the TQ process is very useful since it will improve the confidence of the conclusions and raise critical questions which must be solved during the process. The technology is fully proven, and a Statement of Qualified Technology is issued by DNV-GL stating that emissions to air is below 0.2 ppmv.	If pilot testing or lab testing is performed, it is recommended to have a 3rd party review to confirm that the conclusions and use of results in a larger scale are reliable and reasonable. A 3rd party review process is probably a new experience for most WtE and future CC plant operators and therefore heavy involvement by the project owner in this process will be required. The goals of the process as well as acceptance criteria for successful technology qualification needs to be well understood. In this respect, the DNVGL report prepared for Klemetsrud gives a good picture of information required, timeline and the content of such a process.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.2	Need for pilot testing	Although the selected CO_2 capture technology was claimed to be proven, documentation on specific performance related to CO_2 capture, solvent degradation and potential solvent emissions to air when applied on the specific flue gas from a WtE plant, were not available. Hence it was decided to invest in a Pilot Plant and initiate a test campaign to document that the technology was fit for purpose and would meet the stringent emission requirements when exposed to the specific flue gas at Klemetsrud WtE plant. Another purpose of the pilot was for Fortum to gain competence about CO_2 capture technology and plant operation. With FOVs experience from the pilot plant operation, the project has gained invaluable experience on operation of such a process which benefits both FOV and Fortum greatly in the work with multiple carbon capture projects in the corporation. The same level of knowledge and experience would not be possible without pilot plant testing. The importance of analysing dust and fine particles/ aerosols in the flue gas from the WtE plant, both during stable operation and upset conditions, has been established. Awareness of source of flue gas has been achieved due to this. Some of this knowledge will be fully understood during full scale operation, but awareness is already in place and parameters to investigate are established. As with all process industry, stable operation is of high importance. This affects all important parameters of the plant, especially energy requirement, amine emissions and CO_2 capture efficiency. Prior to starting the pilot plant, the plant was initially planned to be used to optimize the process design of the full-scale plant, but it was also acknowledged the need to prove that amine emissions can be controlled and understood as part of the technology qualification.	Pilot testing should be considered unless the technology performance parameters and emission data have been documented thoroughly through other relevant full-scale plants or pilot tests. It should be noted that a pilot plant has many advantages related to building knowledge and competence, understanding correlations between process parameters, verifying simulation models for optimisation of a future full-scale plant, etc. The pilot test results from Klemetsrud will most likely be relevant for future CC projects retrofit to WtE plants provided that the flue gas composition and selected capture technology is similar to Klemetsrud (note: similar, not necessarily identical). The time period for pilot testing should be no less than 6 months of operation period to get sufficient data and variations in source (waste/ fuel), seasons and upset conditions. Moreover, the longer the testing, the more information is gained about solvent degradation. The value of a pilot plant in regard to public awareness and acceptability both towards politicians, stakeholders, regulatory agencies, industry and the public should be recognized. A pilot plant draws attention and adds focus to the importance of CCS. The experience gained by having operated a carbon capture pilot plant on actual flue gas is considered valuable and is a good investment for future improvement of design of a full-scale plant and training of personnel. It also significantly decreases some of the technical and economic risks involved in designing a carbon capture plant.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.3	Expected Reliability, Availability and Maintainability level for a full-scale CC plant	Two RAM (Reliability, Availability, Maintainability) Analyses have been performed during FEED Phase of the LOOCR project. One was performed by TechnipFMC, and one internally in the project. The studies have concluded with an availability between 90 and 96 % of production of CO_2, based on the set of assumptions as defined in the analyses. The RAM analyses have been done based on one specific equipment configuration, i.e. no sensitivities have been done. The studies covered the whole chain from flue gas entering the capture plant to the point at which CO_2 is loaded to Ship. The WtE plant has periodically planned maintenance stops (yearly) on three individual incinerator lines. CC plant maintenance is aligned with the stop on the line with largest capacity, giving the least loss of captured CO_2.	The main components in the CC plant are basically a single line setup, i.e. without redundancy in the design. Sparing might in some cases be economically feasible. However, further sensitivity analyses should be done to document this. An availability between 90 and 96 % is feasible for a single equipment/ train solution. If higher availability is necessary, this could be achieved with buffer tanks in the design, but this would over time reduce the maximum output from the process. Detailed analysis to be performed in detail engineering investigating which small/ low-cost components are critical for availability in large trains, e.g. pumps, sensors etc. It will be necessary to prepare for standby/ spares of low-cost components, and/or easy access to quickly replace more costly components. The planned maintenance for CC plant should be aligned with: • Main plant maintenance program, • Transport chain (ship) docking plan • Storage requirement for stand-still/ or continuous operation.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.4	How to impact the RAM level	The RAM level is dependent on a number of conditions and data, primarily: • Plant configuration • Component reliability and failure data • Corrective and preventive maintenance • Operation.	Single train or equipment configuration is very vulnerable to single equipment failures. RAM levels could be improved by sparing of specific equipment of parts of the process. To calculate a representative RAM level, relevant data has to be used. If no such data exists, FMECA or other studies can be used to estimate data. Downtime can be reduced by having good routines for preventive but also for corrective maintenance. Capital spares should be procured to reduce the risk of long downtime. Operation of the plant according to user manual and within design limits is essential to keep high availability.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.5	CO_2 Capture efficiency and CO_2 losses	The pilot plant operation has shown that a CO_2 capture efficiency between 90 % and 95 % in the absorber is achievable. The maximum achieved capture rate in the pilot plant campaign was 99 %. Pilot testing has provided good knowledge about CO_2 capture efficiency. Capture efficiency was of high importance at the early stage of the test program, but as this proved not to be an issue, this a secondary issue later in the test program. During Pilot testing, many variables and factors have been investigated. This is documented in separate reports: • NC03-KEA-P-RA-0016 rev 01 Pilot Plant Final Test Report • NC03-KEA-P-RA-0017 rev 02 Pilot Plant Test Report - Extended Phase • NC03-KEA-Z-TB-2001 rev 03 Pilot Plant Test Program. There is an estimation of approximately 1%-point loss in the overall carbon capture process due to truck transport and ship loading.	By using the same technology on similar type of flue gas, a capture efficiency of 95 % in the absorber will be feasible. The actual CO_2 capture efficiency will depend on how the plant is designed and operated and the energy/ steam consumption. Capturing a high percentage (95%+) of the CO_2 in the flue gas is not technically difficult, but it requires a high amount of energy, retention time and contact area between solvent and flue gas. Solvent losses due to degradation are known and manageable due to the existing high standards in flue gas cleaning upstream of the CO_2 capture plant. In order to achieve 1 % fugitive loss of CO_2 or less in the process outside the absorber, all potential loss contributors must be identified and followed up towards the supplier(s). Especially, the gas-gas heat exchanger will need additional systems to limit the losses. Other systems to be aware of in regard to CO_2 losses are liquefaction package vent, CO_2 compressor seals, truck loading, truck unloading and ship loading. Mitigation of the aforementioned losses can be recycling of liquefaction package vent to absorber, CO_2 compressor seals to be evaluated or recirculated back to absorber, rigid arms instead of hoses for ship truck loading and unloading, purging with vapour CO_2 before disconnecting ship loading arms. All these possible mitigations and others have to be reviewed with suppliers and a cost-benefit analysis should be done.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.6	Solvent mass balance	Although the solvent is contained in a closed system, there will be some losses from the system, which must be replenished. There are mainly three loss areas/ locations: 1. Traces of solvent in the treated flue gas, 2. Traces of solvent in the CO_2 product 3. The solvent regeneration loop (Thermal Reclaiming Unit, TRU).	For both full-scale plants and pilot plant testing, it is essential to have control of the solvent mass balance and how it is closed. Necessary measurements analyses have to be done to validate the mass balance. Gas flow measurements and solvent concentration analysers (e.g. PTR-TOF-MS) are most essential in addition to keeping track of liquid samples and possible spillage that might occur during sampling, reclaiming and maintenance. Having control over volume in the columns, ducts and tanks during steady state operation and as amine concentration in the solvent is known, one can have control over the amount of solvent in the system. This is a quite easy and quick way to get a good figure regarding solvent mass balance to keep within the specified range of amine concentration. Solvent leaving the system can also be measured to keep track of the solvent mass balance as described below. This does not include any possible losses as described in ID 1.5. 1. Online measurement with PTR-TOF-MS is possible. PTR-TOF-MS together with flow measurement downstream of gas-gas heat exchanger on the treated flue gas side will provide amount of solvent lost due to traces in the treated flue gas 2. Traces of solvent on the CO_2 product side can be measured downstream the liquefaction package and together with flow measurement on both on-spec and off-spec CO_2 flow meters amount of amine lost can be established. LC-MS analysis of waste from TRU can be done regularly if needed to have correct value of amines being sent for destruction together with the waste.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.7	Solvent degradation and consumption	The pilot plant operation has shown a consumption of amine through degradation to be 0,078 kg per ton CO_2 captured. Full scale summer operation, based on these results, is estimated to be 0,11 kg per ton CO_2 capture. Compared to the Boundary Dam CO_2 capture plant, the degradation rate at Klemetsrud WtE will very likely be significantly lower. The main reasons have been much lower dust and acids content in the Klemetsrud flue gas. It is acknowledged that NO_2 has a strong impact on the degradation rate. Hence, separate NO_2 analysers have been installed on the pilot plant and will also be included in the full-scale plant. Degradation rate remained constant up to around 3 wt% (wet) degradation concentration. Above 3%, data indicate a possible acceleration of degradation. For the full-scale carbon capture plant, the degradation concentration will typically be in the range between 1 and 2 wt% (wet). Based on pilot plant operation, a lower degradation rate than anticipated has been observed, thus one TRU has been removed from design of the full-scale plant.	Knowledge about the potential degradation of the solvent when exposed to the site-specific flue gas should be gained before starting a full-scale CC project. Solvent consumption is caused by degradation, emissions and losses in the process or during maintenance or other spillages and leakages. Degradation rates may be simulated, but pilot testing on specific flue gas is highly recommended as validation of the simulations. Composition (contaminants) of the flue gas need to be well known prior to designing a carbon capture plant, especially NO_2, SO_2, a few heavy metals, aerosols and sub-micron particles. Average values over extensive periods and possible fluctuation and upset conditions need to be taken into consideration. Extended sampling/ test program on the actual flue gas should be established to gain necessary data on the mentioned critical parameters prior to pilot testing. Degradation rate will be an important design parameter for the solvent reclaiming unit(s). NO_2 and SO_x should be measured upstream of the absorber (acid gases concentration will be lowered in pre-scrubber). Thermal and oxidative degradation can also occur, and temperatures in the process needs to be controlled – especially during regeneration/ stripping of the CO_2. Degradation concentration above a certain level, indicates possible acceleration of degradation. Thus, concentration of degradation products should be kept at a lower limit by limiting the appearance of impurities in the flue gas or removing degradation product or both.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.8	Quality of captured CO_2	The pilot plant tests have demonstrated a quality of CO_2 (i.e. contaminants, type and level) within expected and designed levels. However, to fulfil Longship specification for the CO_2 product, post treatment (conditioning) of the captured CO_2 will be necessary. Pilot plant confirms very low levels of amine in CO_2 product stream. Amine average has been measured to below 5 ppbv. Oxygen (incl. Ar) level has been analysed to be 25ppmv on a dry basis in pilot plant testing versus ~37 ppmv (dry) assumed during operation. Water content is around the same level in CO_2 product as expected for inlet to 1st CO_2 compressor (4.2 vs 4.1 vol%). All of these mentioned values have provided us with the information that the CO_2 product is at expected or better quality than anticipated.	The purity/ quality of the captured CO_2 can be demonstrated through specific tests prior to detailed design of the full-scale plant in order to prepare the design basis for the conditioning plant (compression, dehydration, O_2 removal and liquefaction). However, the tests performed by FOV have not shown any unforeseen values of impurities in the CO_2 product, so the extent of the testing should be considered and can be considered not needed based on requirement. CO_2 purity has proven to be 99.9+ vol% (dry). Based on CO_2 specifications requirements, post treatment of the captured CO_2 by removal of O_2 and H_2O is necessary.
1.9	Energy demand per ton captured CO_2	The pilot plant is not representative of a full-scale plant with respect to energy consumption per ton captured CO_2. However, energy consumption for a future full-scale plant has been discussed in the DNVGL Technology Qualification Report. It is acknowledged that the pilot tests give only a partial input to this parameter. This is because several utility systems or energy saving options have not been included in the pilot plant. Hence, the energy consumption (steam) has been measured during the pilot tests and combined with an estimation of the energy saving by, e.g., the Mechanical Vapor Recompression (MVR) compressor to obtain a number for the total plant.	Energy demand (GJ/ ton captured CO_2) is an essential parameter directly impacting the OPEX for the plant. To get a good understanding of this parameter, both testing and simulations/ estimations should be conducted. Optimise reheat of flue gas before outlet from stack. Minimum temperature to ensure lift and dispersion of cleaned flue gas should be calculated. It is important to optimize steam parameters to reduce overall cost.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.10	Heat integration with WtE plant (flue gas source). Energy optimisation	Steam is supplied to the CC plant and condensate is returned to the WtE plant. The net heat transfer is about 40 MW. During summer, this heat is not needed for district heating purposes and can be regarded as "supplied at no cost". However, during winter all heat produced by the WtE plant is needed for district heating. To compensate for the heat used by the CC plant, a heat pump will be installed to transfer heat from the CC plant cooling system to the WtE plant District Heating system.	Depending on the nature of the flue gas source, energy optimisation studies should be undertaken to utilise the surplus heat/energy in an efficient way. Energy costs are a major OPEX cost. Due to large amounts of water with a relatively high temperature (40°C) in the CC plant, the electricity consumption to generate hot water to the District Heating system is quite low. Thus, CO_2 emissions from the use of heat pump are also limited
1.11	Design basis covers the full emission permit	From the start of the project, FOV wanted to have a CC plant designed according to the amounts of the full emission permit of the flue gas. Operational experience at Klemetsrud showed that the actual emissions are significantly lower than the permit for most of the substances. Later it was assessed that such stringent requirements might not be necessary. If the CC plant was designed based on actual values instead of maximum values, cost could be saved for instance by having a simpler solvent reclaiming unit.	Future projects should thoroughly consider the most representative flue gas as the basis for CC plant design. Awareness should be gained about which constituents that are cost-driving and which are not.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.12	Amine emissions	Amine emissions can be controlled and maintained at a low level by adjusting operational parameters. Keeping a sufficient temperature difference (around 5°C sufficient for most cases) over the water wash has proven to be most crucial. Amine emissions were possible to keep at a very low level and well below defined level during FOV pilot plant campaign, with steady state operation and when no upset conditions occurred. Mitigation devices have not been required to be in operation to be able to meet requirements. Acetaldehyde emissions did not increase with increased levels of degradation. The level of other contaminants (incl. NH_3) in the flue gas is effectively reduced (both by the pre-scrubber and the absorber) FOV has not experienced increase in amine emissions due to increase in degradation. Upset/disturbance in upstream process that influences the flue gas and dust content in the flue gas has big impact on amine	Certain self-induced upset conditions, for example a rapid large decrease or increase in flow, will cause amine emissions to increase for a brief period. This can be controlled by decreasing and increasing flow in a controlled matter. In case a sudden large change in flow occurs without having control, an Aerosol Mitigation Device can help reduce the possible peak in amine emissions. It is suspected that submicron particles can cause amine emissions, thus during disturbances that might create such particles, it is recommended to take samples of dust during upset condition which causes amine emission and compare with analysis of dust from stable operation. Both chemical and physical tests should be performed to be able to find the root cause for the submicron particles. Procedures for sampling should be prepared prior to test start. A temperature difference over the water wash section of around 5°C is recommended to have sufficient condensation to reduce amine emissions. Amine emissions to air are not significantly affected by an increase in degradation level.
1.13	Flue gas blower	A side channel blower was selected for the pilot plant. It was the only type of machine that complied with the required duty point (pressure at a given flow rate). This machine is very sensitive to moisture and particles in the flue gas and has failed and been repaired several times during the pilot operating period. The challenge in selecting a suitable machine is the relatively high pressure (20.000Pa), which is often too high even for HP radial fans.	Alternative blower/ fan configurations should be evaluated for future pilot plants. Side channel blowers should be avoided for similar flue gases. This issue is only relevant for pilot plants since side channel blower design will not be used for full-scale plants.

ID	Learning items	Achievements	Learnings and recommendation for future projects
1.14	Description of the flue gas	The flue gas at Klemetsrud WtE plant is continuously monitored and well understood, both in terms of flow, properties, composition and constituents as well as transients and variations. This information is essential for heat- and mass balance calculations and for preparing an optimised design of the CC plant. For instance, flow, temperature and CO_2 concentration are essential.	Long term monitoring of the relevant flue gas is required to prepare a suitable design basis for the CC plant. Good understanding about how the respective parameters affect the actual CC plant design is also critical. This should be discussed with technology provider as early as possible in the process to measure necessary impurities required.
1.15	Key input-, output and design parameters Input: flue gas amount, composition, temperature and pressure at CC plant boundary, waste incineration amount Output: Flue gas composition after treatment, produced CO_2 quality and quantity, number of transports by truck	Further sampling on flue gas (line 3) verified previous measurements of aerosols being low. Analysis performed during pilot plant operation confirms very low levels of amine in CO_2 product stream. Disturbance in WtE plant affects the flue gas which may affect emissions for shorter periods	Verification of CO_2 specification after testing and tuning in of CC plant. Defined programs for logging and sampling of previously not focused/ measured components. Start sampling early to collect good basis knowledge of the flue gas and variations over time. Challenges due to process upset/disturbance should be analysed.

4.2 Operation

FOV has gained valuable experience from operating the CC pilot plant, and already has extensive experience in running WtE plants. There is also experience in the project operating CC plants via main EPC contractor and other collaborators. This chapter covers items that have been discussed during FEED phase, which are assumed to be important during operational phase.

ID	Learning items	Achievements	Learnings and recommendation for future projects
2.1	Interaction between flue gas source and capture plant	At Klemetsrud, the WtE and the CC plant will be two separate plants operated separately to as large extent as possible. Ideally, the WtE plant should not notice that a CC plant is connected downstream the flue gas treatment. However, the flue gas path will inevitably cause interface issues which have to be investigated. Typical issues are pressure and temperature conditions, flow control, emission monitoring, start-ups, shutdowns and emergency situations. FOV has started a process with EPC contractor to obtain a common understanding of the actual thermodynamic interface conditions and challenges of the current technical solution. Operations in FOV are included in the project, to anchor the new operation in the existing operation. Details design will be done in EPC Phase.	Since the flue gas interface is complex from a process point of view, it is urgent to address the topic early. Also, both personnel from existing plant and from the CC plant project should be involved.
2.2	Logistics	During operation, solvent and chemicals will be consumed and waste will be produced. Solvent is supplied through a large storage tank. Other chemicals are supplied through dedicated tanks or tote tanks. Truck transport has been secured to all filling points. Sludge from the wastewater treatment plant as well as from the solvent reclaimer will be removed by truck (current solution, may be changed later).	Utility consumption (incl. chemicals) and the main waste/ effluent streams should be identified early since the selected solution will impact the plant layout and thereby the plant CAPEX.

ID	Learning items	Achievements	Learnings and recommendation for future projects
2.3	Manning Number of personnel required to operate the plant	Necessary manning has been evaluated and OPEX estimate has been prepared. Tentative manning is 1-2 additional persons in the existing 24/7 shift cycle of the WtE plant. Additional staffing up of personnel in CC plant will be discussed in detail and evaluated as a part of FOV overall Operation and Maintenance optimization.	After optimizing the control system for the Pilot plant, one operator was able to run the pilot plant, only working daytime on weekdays. The full-scale plant will be more a more complex system, which also includes liquefaction and conditioning of the CO_2. Based on the experience an estimate of 1-2 extra manning in the 24/7 cycle seems reasonable.
2.4	Competence level The need for employee training	Several employees have been trained to operate the Pilot plant.	Running a pilot plant gives a deeper understanding of the process and reveals challenges which may occur during full scale operation. This experience is difficult to gain from other sources.

4.3 Cost

ID	Learning items	Achievements	Learnings and recommendation for future projects
3.1	Aggregated total CAPEX and OPEX	CAPEX and OPEX have been established based on AACE 18R 97 Class 2 estimates. The estimates were refined from Class 3 to Class 2 during FEED phase. All changes and revisions from Concept phase were included in the updated cost estimates. Main equipment was based on supplier information and cost estimates based on tender from EPC contractor TechnipFMC and Civil contractor. Cost estimates were initially based on large elements of fixed price cost. This was changed late in the FEED phase and the change to a larger portion of the cost as reimbursable cost gave a significant reduction in the EPC contract pricing.	Accuracy of cost estimates is closely linked to the maturity of the design of the capture plant. It is useful to apply recognised cost estimating tools and standards to document maturity and select the levels of accuracy for the cost estimates. It is advisable to select contract terms that limit the risk additions and are thus cost driving. Finding a balancing mechanism between fixed price and reimbursable elements is important to identify at an early stage. Cost-cut sessions and workshops are necessary and should be done repeatedly several times during the project to optimize design and cost estimates.

ID	Learning items	Achievements	Learnings and recommendation for future projects
3.2	Transport solution	Transport from Klemetsrud to Port of Oslo will be performed by zero emission truck transport. Pipeline transport was evaluated in previous phase but was discarded due to high investment cost and higher risk for regulatory and performance of project	Transport solution should be evaluated. LOOCR project has documented the applicability of both pipeline and truck transport. Selection of transport solution will depend on: • Distance to port • Routing and pipeline • Above or below ground pipeline • Cluster possibilities • Flexibility. Regulation for a CO_2 pipeline is challenging in highly populated areas and need to be clarified in an early stage. Above ground pipeline is a cost-effective solution but may not be applicable in all locations Truck transport is safe and scalable but adds cost and a complicating logistics element. Truck transport is favourable for smaller distributed sources.
3.3	Cost per ton CO_2 delivered by different monthly levels of CO_2 Cost of CO_2 avoided vs. captured	Most of the costs relating to capturing and supplying CO_2 at the harbour are fixed both in the short and long run. Cost per delivered CO_2 is closely related to availability of flue gas and the plant. The costs of CO_2 vs captured will be closely linked to the ETS pricing or other CO_2 pricing systems.	The majority of costs of capturing and supplying CO_2 are fixed. Availability of flue gas and stable operation is important for cost per unit. Pricing of CO_2 is an important input to the evaluation of the business model.

4.4 Environmental impact

ID	Learning items	Achievements	Learnings and recommendation for future projects
4.1	Other environmental impacts from CO_2 capture during normal operation Results from ENVID report Corresponding operating results (as defined in ENVID report)	During operation of the full-scale plants, the following potential environmental impacts have been identified: 1. Emissions to air 2. Discharges to water 3. Leaks, spills and accidental releases 4. Diffuse leaks 5. Waste disposal (e.g. TRU sludge) 6. Noise 7. Light pollution. During the FEED, potential emissions to air has had high focus, particularly emissions of entrained solvent. During the EPC project, environmental management system will be implemented according to ISO 14001 or similar. This will involve systematic identification of all potential environmental impacts as well as control and monitoring of these to ensure regulatory compliance and ALARP. Noise is always an issue but found manageable at this point with mitigating efforts.	It is vital to be in control of all potential environmental impacts from the CC plant. This work should start at day one in order to establish a good management plan throughout all project phases. Such a plan is necessary to ensure minimal environmental impacts and compliance with regulatory requirements. Some of the equipment in the CC plant such as pumps and fans generate noise and noise reducing measures must be taken. The CO_2 compressor skids also makes a lot of noise. Noise measurement must be included in the cost estimates.

ID	Learning items	Achievements	Learnings and recommendation for future projects
4.2	Atmospheric dispersion of emissions to air	It is acknowledged that for CC plants where amines are used as solvents, amine entrainment will occur in the absorber and small amounts of amine will be emitted from the stack. The risk to the public is however related to the deposits of amine-based reaction products (nitrosamines and nitramines in particular) in drinking water sources as well as in the air. For this facility, products in the water is most critical. To analyse such environmental impact, LOOCR has ordered two such dispersion simulations, one by NILU and one by Norsk Energi/ CERC. The results (water and air concentrations) as well as the description of the dispersion physics and chemistry were different for these two simulations. Based on experience from the pilot, both models yielded values that were lower than the recommended limits from the Norwegian Institute of Public Health (FHI). The model used by Norsk Energi/ CERC s considered to be based on more conservative assumptions and this also gave higher emission levels. As the calculated levels for deposition to water were close to the guideline values, NIVA is engaged to do more detailed calculations to look at the deposition to water.	Atmospheric dispersion simulations are in general based on rough models and the results may vary significantly depending on the applied model. Running two separate simulations with two different models may not clarify the matter, since different models may produce divergent results and show that there is some uncertainty associated with the results. A study for comparison of different models and to gain more experience to reduce uncertainty and increase knowledge about the effect of emissions should be considered.

ID	Learning items	Achievements	Learnings and recommendation for future projects
4.3	Regulatory zoning work	A zoning plan has been prepared and sent to political handling. This included an EIA and a process with public hearing and public meetings.	Regulatory planning work takes time and allocating enough time is important. An open process where neighbours and stakeholders are informed at an early stage and along the way is essential. Having a good dialogue with politicians and various stakeholders is key to avoiding unexpected conflicts and progress problems. The handling of a zoning plan and EIA is strictly regulated through separate national regulations. These may vary in different countries. Removing CO_2 must be considered as an environmental project. This was probably also a reason why there was little local and political resistance to the necessary regulation and use of the area. An open dialogue with different stakeholders as NGOs, NHO, LO; Industry associations, local area and others has been valuable for the project. It is recommended to establish this dialogue early and maintain this throughout the project execution.

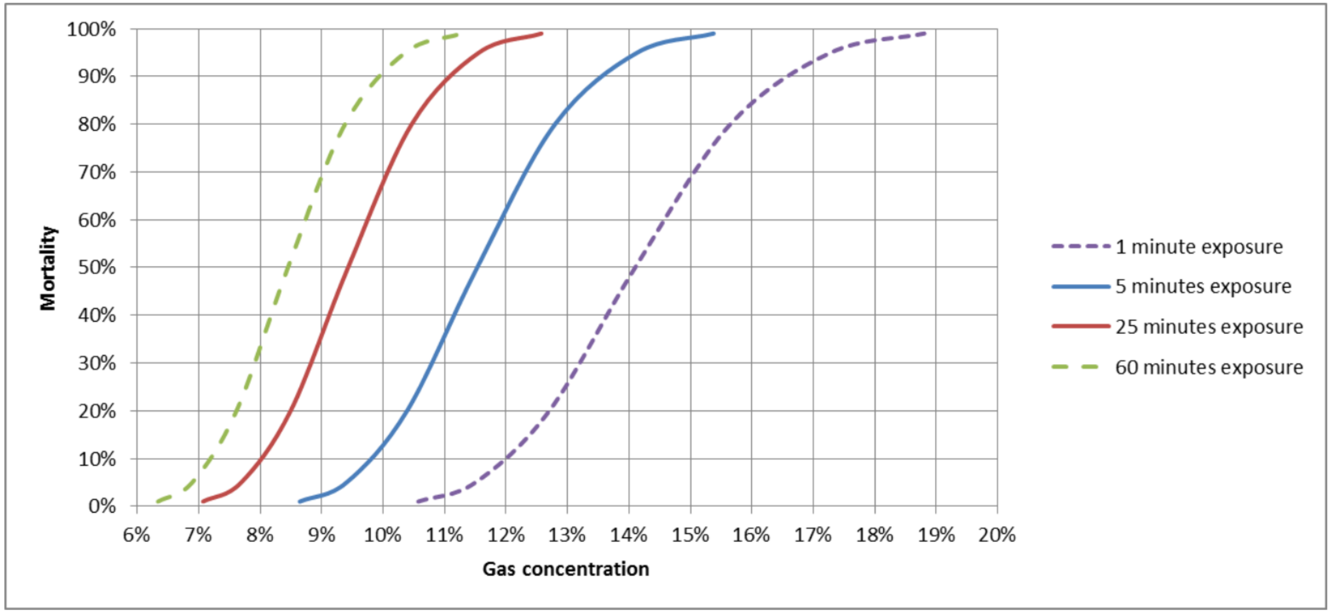
ID	Learning items	Achievements	Learnings and recommendation for future projects
4.4	Regulatory applications	A preliminary application for an emission permit was sent to the Norwegian Environmental Agency (NEA). This has been a baseline for meetings to clarify missing information and a discussion of progress in the project and act a preparation for a more detailed application. A dialogue with DSB has clarified the need to apply for a DSB consent Clarified possible progress and what documentation must be prepared to apply for a building permit	The application process for a discharge permit will not be started before the application is complete. This includes that the regulatory matters must be clarified. The need for quite detailed information, means that the project must be relatively complete before the application and processing can start. (In the CCS plant there is a need to apply for a discharge permit and a building permit. In addition, there is a need to apply for permission) To store large amounts of CO_2, the risks that this may entail must be analysed, and the regulatory consequences of this shall be incorporated. National regulatory bodies have different rules in processes in different countries, but the national regulations will be more or less the same in EU-countries since harmonized EU regulations must be implemented. As for the discharge permit, there is a need for detailed information about the project before the building permit application will be processed. This means that the project must be relatively complete before the application and processing of this can start. If the area needs a new zoning plan, the case processing time can be long, and it is important to allow enough time for this in the progress plans.
4.5	CO_2 footprint Footprint calculations	The basis for calculating the CO_2 footprint from the various phases of the establishment, operation and disposal of the planned CO_2 capture and the intermediate storage facility was obtained. The energy consumption is high and alternative use of the energy seems to be dominant in calculating the CO_2 footprint.	Energy consumption and emissions are fundamental and require an overall assessment. It is important to optimize the use of energy and reduce the use of energy that could otherwise be utilized e.g. in a district heating network. It is important to consider CO_2 footprint from the entire cycle, not just the CC plant itself.

ID	Learning items	Achievements	Learnings and recommendation for future projects
4.6	Pre-scrubber/ Cooler as a scrubber for sulphur removal	The CO_2 capture process is vulnerable to certain constituents in the flue gas from the WtE plant. For most WtE plants, the flue gas will be treated to comply with the stringent local emission permits. The flue gas treatment in the CC plant will be designed based on the actual flue gas treatment at the WtE plant. For the CC plant at Klemetsrud, injection of caustic will be included for sulphur removal and pH control, but no other flue gas treatment upstream the absorber has been included.	System for injection of caustic has to be designed based on the WtE plant specific flue gas. Hence, good quality flue gas information (SO_2, SO_3 and HCl in particular) is vital for a fit for purpose design. Based on pilot plant results without caustic injection in the pre-scrubber it seems that the pre-scrubber is not able to remove aerosols if formed upstream due to e.g. upset conditions at the electrostatic precipitator. However, operating under the same conditions with caustic injection has not been tested and therefore remains an option (until otherwise proven) for aerosol reduction in the pre-scrubber.
4.7	The CC plant needs considerable amounts of thermal energy (for desorption of amine) throughout the year	Energy balance has been developed which shows thermal heat (steam) demand and cooling demand during summer and winter. During summer, excess heat must be rejected (not used) at the WtE plant. However, since the CC plant will utilise considerable amounts of the excess heat, the WtE cooling demand will be reduced accordingly. Instead, this heat will have to be cooled off through the CC plant cooling system. The summer case will be dimensioned for the cooling water system. During winter, cooling is not a problem since the heat is needed for District Heating production and/or in the CC plant. For cooling water system, water cooling (to the sea, a lake, a river or to ground water) is preferred. However, since water cooling was not feasible at Klemetsrud, a hybrid air cooling concept was selected.	WtE plants with surplus heat during summer (and winter) can utilise such heat in the CC plant to reduce the amount of air coolers. However, the WtE plant should be self-sufficient with cooling capacity in case of CC plant being shut down. For air cooling systems, the design ambient temperature is a vital cost driving factor. Hence, it is recommended to use local weather data to specify a more moderate temperature than the maximum temperature. It should be noted that mitigating actions may be needed during the limited annual hours with very warm weather and high ambient temperatures.

4.5 Health and Safety

ID	Learning items	Achievements	Learnings and recommendation for future projects
5.1	Handling of CO_2	Since CO_2 has other mechanical, chemical and thermodynamically properties than other fluids, this may demand other and more expensive equipment and technical solutions. Some examples are system integrity requirements (CO_2 has lower viscosity than air and water and more likely to leak) and dry ice formation. LOOCR contractor TechnipFMC has made a process design and included "CO_2 service" in all relevant equipment mechanical datasheets.	A good process understanding of the particularities of CO_2 as well as ensuring CO_2 service is implemented in all aspects of the design, is essential to have a good confidence about the selected technical solutions and the costs.
5.2	Safety systems, pressure relief	Since the risk picture for a CC plant and CO_2 terminal will be quite different from a petroleum terminal, the type of and performance of the safety systems may also be quite different.	As a part of the Quantitative Risk Analysis or as a separate exercise, an early design review of the safety systems should be performed to be sure the safety systems will be fit for purpose for a CC plant.
5.3	Safety for 3rd party persons neighbouring CC plant	Several safety studies have been performed during the concept and FEED Phase. This includes HAZID, HAZOP, ENVID, WEHRA and Quantitative Risk Assessment (QRA). The Safety for 3rd party persons neighbouring the CC Plant will be insignificantly impacted. There is relatively little flow of CO_2, and a leakage would therefore not give large hazard distances.	A CC plant could be located inside most industrial areas, due to the relative low hazard distances. A reliable shutdown system should be in place, so that leaks would not escalate and have a long duration. Focus should be on areas with high pressure, and areas where large amounts of CO_2 is stored.
5.4	Safety for 3rd party persons neighbouring CO_2 storage areas	All calculations and analysis have shown that the risk is neglectable at Klemetsrud and Port of Oslo with respect to 3rd party. It is however a risk present, when large amounts of CO_2 are collected at the same location. Studies have shown that the use of several smaller tanks is preferred over fewer larger tanks. The probability for a leak is still low, but the consequence is reduced substantially.	From a safety perspective, the tank size should be reduced as much as possible, and large tanks (above 2000 m^2) should be avoided if 3rd party is present.

ID	Learning items	Achievements	Learnings and recommendation for future projects
5.5	CO_2 dispersion simulations	As part of the QRA, LOOCR has performed extensive CFD simulation of large-scale CO_2 dispersion. Due to the high density of CO_2 compared to air, a release of CO_2 will be affected by the terrain. It has also been discussed with Northern Lights, Norcem and Aker Solutions, to establish a common ground on how consequence simulations should be treated in the project. Hazard distances can be longer than for hydrocarbon gases, but the possibility to escape is much higher, since it is not ignitable. The longest hazard distances are related to low concentrations, and long exposures times.	CO_2 plants and storages should be in a location where the terrains are favourable to lead the CO_2 towards the safest direction. The plume will not be very high, so even though it can travel long distances on water, it will not travel inland again after some distance. Walls will have an effect and can be used to guide the plume. However, this is dependent on the local conditions, and effects should be verified through detailed CFD studies.
5.6	Lethality of CO_2	It has been several discussions in the project, on how to treat the lethality of CO_2 in risk analyses, since many factors come into play. The primary issues are concentration and exposure time. The project has decided to use a Probit-function to evaluate this, and for various concentrations this is shown in the figure below. Probit-functions are commonly used in quantitative risk analyses.	For exposure times of one hour or less, 6% CO_2 concentration should be used as the lower concentration that could pose risk for fatal accidents. This should also be used as the lower concentration in the plots from CFD simulations.

ID	Learning items	Achievements	Learnings and recommendation for future projects
			
5.7	Regulatory	LOOCR has applied for a consent from DSB (Directorate for Civil Protection). Even though CO_2 is not classified as a dangerous substance in the guidelines, DSB has requested a normal permit application process. Hence, DSB needs to give its consent to establish the CC Plant due to amount of pressurised CO_2 and the location of the storage facilities in accordance to the regulations for handling of flammable, reactive and pressurised substances and the equipment used for operation (Forskrift om håndtering av brannfarlig, reaksjonsfarlig og trykksatt stoff samt utstyr og anlegg som benyttes ved håndteringen - FOR-2009-06-08-602).	It is important to include the regulatory body early in the process, even at Concept level. They value being involved and can give good guidance on how to proceed and who to involve at certain stages. DSB will also have a larger picture on what is going on in certain industrial areas and could assist in avoiding potential conflicts before the appear.

ID	Learning items	Achievements	Learnings and recommendation for future projects
5.8	Waste management	During operation of the CC plant, there will be several products that are regarded as waste. The main type waste from the CC plant is identified to be: • TRU waste (degraded amine) • Sludge from Wastewater Treatment plant • Oil/ grease/ lubricants from preventive maintenance • Dust/ contaminated water etc. from cleaning as part of system prior to maintenance stop • Packaging waste etc. • Wastewater. A philosophy for handling the waste has been developed, but the actual methods will be decided at a later stage. Possible benefits with aligning this with waste management/ incinerate at the WtE plant is being considered.	Handling the waste from a CC plant is manageable, but the method will differ from site to site, depending on available resources. Waste management should be considered during FEED phase.

ID	Learning items	Achievements	Learnings and recommendation for future projects
5.9	Safety analysis used	LOOCR has based the safety work on risk-based approach, using the Quantitative Risk Analysis (QRA) as the cornerstone of the major hazard work. This was based on a HAZID that involved the entire plant. To perform the consequence simulations, LOOCR used the software tool KamelonFireEx, and its CO_2 module. This is able to incorporate the 3D terrain model, and simulate the CO_2 phase change from liquid, via ice to gas. This gave valuable information on choosing locations, and possible risk reducing measures. The project also investigated using calculation tools, like Phast, but this was not regarded as suitable, due to the high impact from the terrain, and this is not reflected sufficiently in these tools. It has been a challenge to identify relevant leak frequency tools. This is because there is limited experience with CO_2 accidents, so more standard and multisector tools were applied. It is questioned if this is totally relevant, but it was the best available information.	It is important to start the safety work as soon as possible in the project, to be able to include the obtained learning. If calculation tools limited to only a 2-dimensional representation of the site are used, this may not provide a reliable risk picture if terrain is not relatively flat and featureless. CO_2 dispersion simulations are sensitive to terrain and buildings. A realistic 3-D model of the plant and the surroundings should therefore be used. Effort should be made to identify more relevant leak frequency sources from CO_2 specific plants and operations. This is especially important when more projects come into operation. A common source like the HSE database would be a huge
5.10	SIL Analysis (IEC 61508/ 61511)	LOOCR has performed a Layer of Protection (LOPA) Study to evaluate the Safety Integrity Level (SIL) on the CC plant. The LOPA identified several safety functions that should be subject to further investigation and could potentially be part of a SIL Loop. It is particularly the dampers connecting the WtE plant to the CC plant that are critical.	When the design is sufficiently mature, a SIL Allocation study should be performed. There are several potential hazards that could be a safety concern. Even though there are few safety functions, comparing to i.e. a petroleum plant, the system should still be in place. When the Longship project is more matured, an alignment between the various operators/ parties should be performed. For future projects, a Safety Requirement Specification on ship loading/ unloading should be available during FEED.

ID	Learning items	Achievements	Learnings and recommendation for future projects
5.11	Quality Management System	LOOCR has developed a Quality Management System (QMS) that is based on ISO:9001, FOV and Fortum Corporation procedures. The QMS has helped the project to keep focus on quality issues and avoid unnecessary loss. During the execution, the project has conducted several Quality Audits on the suppliers. Gassnova and FOV has also done separate audits on LOOCR QMS to ensure compliance to the standard and propose improvements. LOOCR project has also performed internal audits on specific topics.	Projects should consider developing a unique project specific QMS, to be applicable to the dedicated project. This is especially important with respect to communication and documentation procedures. The project has benefited from both internal and external audits, and this should be prepared for in future phases and projects.

4.6 Business model

ID	Learning items	Achievements	Learnings and recommendation for future projects
6.1	Business model assessment Positive and negative consequences of the chosen business model	The Business model of LOOCR gives FOV a strong incentive to a cost-effective establishment and operation of the plant. FOV's cost contribution will kick-in sufficiently early in the establishment period to ensure a continuous incentive to keep the costs down. FOV has the opportunity to recover their cost contribution. This is however dependent on an efficient operation of the plant and supply of CO_2 to the CO_2 chain. Uncertainties regarding the cost savings of avoided CO_2 emissions present a risk to the business model. Negotiations with MPE are ongoing and will be concluded within the timeframe of the Interim phase.	Business models should involve value evaluation of the captured CO_2 from the WtE plant to potentially achieve negative emissions from incineration of biogenic waste. Future business models will benefit from more predictable costs saving of not emitting CO_2. The WtE business should cooperate to find realistic and accurate business models that stimulates the establishing of new capture projects. As coming projects will most likely be cheaper than the first ones and the emitting of CO_2 will be more expensive in the future, it will be easier to establish a business model for CCS.
6.2	Suggestions for business model improvements Any recommended changes to future business models	FOV's WtE plant is currently outside EU Emission Trading System (ETS). The Norwegian government have proposed that a national CO_2 tax regime will be implied on the WtE business from 2021.	FOV WtE plant is not included in the EU ETS system. CO_2 capture outside the ETS system will contribute significantly to emission cuts and should benefit from this. National CO_2 is proposed to be introduced in Norway. Increase in cost of household waste and industrial waste treatment, possibly in the form of higher gate fee on waste incineration, may also contribute to a commercially viable business model. However, it must be feasible to route the cost back to where the waste originates for the cost to have the intended effect.

ID	Learning items	Achievements	Learnings and recommendation for future projects
6.3	Rationale and motivation for the establishment of CC plants (economy vs. environment) Description of economic and environmental benefits and how this has been emphasized in decision-making of the project	Fortum is aiming at providing environmentally friendly products and services. Decarbonizing the Waste management and energy production is one of four pillars in Fortum Group's roadmap of future utilities and an important part of the business model	Carbon capture is an important tool to reduce emissions from waste management. Negative emissions can be achieved as waste materials are biogenic. Heat energy used in the capture process can be re-used as district heating through installed heat pumps, thus decreasing the load on electric grids in cities.

4.7 Project execution

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.1	Emissions permits	Revised dispersion analyses of flue gas are performed as part of the emission permit. It is apparent that the knowledge of dispersion analyses of amine is limited and recommended practice for dispersion analyses is missing CC plant emission permit is linked to the emission permit for the incineration plant	Dispersion analyses are important especially for amine-based CC plants. A recommended practice or recommended tools for dispersion analyses would be beneficial, and with the learnings from this project FOV could contribute to establishing common guidelines on this topic for future projects.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.2	Dialogue with stakeholders, including interaction with government agencies Process with the Environmental Directorate for emission permits for full scale CO_2 plants in densely populated areas Stakeholder analysis and communication plan for dialogue with stakeholders Experience from dialogue with stakeholders	LOOCR project has developed a Zoning plan and issued it for public hearing. All comments are incorporated, and zoning plan was issued for political handling in August 2019. Final approval by the City Council in February 2020. Documents for Application for consent from DSB is prepared and ready to be issued. Meetings with DSB has concluded that a consent is required due to storing of large quantities of CO_2. Meetings with PBE (Plan and Building Authorities) to clarify requirements and information required for the building application. Emission Permit application including required dispersion analyses is prepared and will be issued to NEA (Norwegian Environmental Agency). Two neighbour meetings have been held in order to keep neighbours informed and present the zoning plan.	A continuous follow-up of the zoning plan process is important. The time span for administrative and political handling may be long even if all parties agree to the zoning plan, as in our case. It is important to allow sufficient time for the approval processes in order to align the different phases of the project The other permits such as building permit, emission permit and application for consent will not be handled by the authorities before the zoning plan is finally approved. The final lay-out of the plant needs to be agreed prior to issuing the building permit application. The application for emission permit must include dispersion analyses for defining deposits of amine-based reaction products (nitrosamines and nitramines in particular) in drinking water source as well as in the air. These analyses are time consuming, so sufficient time should be included in planning. The LOOCR project is presented as an environmentally friendly and green project. Communication with neighbours and relevant NGO's is an important part of the external stakeholder dialogue.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.3	Summary of planned items that contributed positively to the implementation Summary of planned items that contributed negatively to the implementation Overall project plan and actual completion time Experience with a political process around planning and construction	Preparation of procedures for the FEED phase took longer than anticipated and needs to be planned properly for the execution phase. Insufficient time planned in the beginning for pilot commissioning, winter conditions were not fully considered. Initial schedule agreed with Gassnova assumed DG3 report submission in main holiday period. Because there is a waiting period between FEED delivery and final investment decision, it is a challenge to motivate contractors to submit offers and get enough competition in procurement processes. In addition, submitted offers most probably include a substantial risk margin by the contractors due to long waiting time and changing market conditions.	It is important to have plans and procedures sufficiently advanced when starting the project. Allow for sufficient time including political handling. The project phases from Feasibility/ Concept/ FEED and project realisation should preferably follow directly after each other. Time from sub-contractor pricing until actual contract should be kept as short as possible.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.4	Construction, commissioning and operation Experience with contract model and cooperation in the various phases Experiences with logistic, construction and model construction Experiences and challenges with respect to commissioning and start-up	For the pilot, LOOCR had an active role clarifying issues between contractors with different responsibilities. This implies for both commissioning and operation. Many of these clarifications could have been done more directly between the contractors. Winter conditions could be a real challenge, both for construction, commissioning and start-up.	Clear communication lines towards main contractor and technology provider is important. Penalties for not meeting the project obligations should be clarified It is important to include climate conditions when scheduling projects in harsh environments. Critical actions should be executed during summer, to allow for a better weather window.
7.5	Selected model for implementation in terms of division of labour between different contractors	Only one contractor for CC technology was selected for the FEED phase. TechnipFMC as main contractor will be responsible for interfaces towards other minor contractors at site during the next phase.	Main contractor may have the responsibility to coordinate all work and interfaces towards other subcontractors, and the existing plant. It is therefore important to clarify the interface roles of the Owner and the main contractor early.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.6	Advantages and disadvantages of the chosen interface and incentive mechanisms between project parties	Technology provider and main contractor were selected before start of FEED. LOOCR wanted to continue FEED with two potential technology providers, but this was not possible due to the criteria of the National full-scale CCS project. Technology selection criteria was set with a highly commercial focus. Selected companies were asked to accept both fixed price contracts and detailed performance guarantees. TechnipFMC and Apply were the only ones accepting this, while other very capable suppliers with substantial technical experience and capacity did not accept and were hence ruled out. CC technology is still novel and TechnipFMC had a license agreement with Shell (Cansolv) to use their technology for the LOOCR project. Commercially the LOOCR team focused on risk reducing measures in the pricing from main contractor, with high degree of fixed price elements and high level of performance guarantees. The positive aspect about selecting contractor is that the focus can be increased. It can become more developed with a mature technical concept. This means less technical risk. The negative aspect is that there is a risk for higher cost, due to lack of competition and negotiation possibilities.	Selection of technology and main EPC contractor should be done as late in the FEED phase as possible. If possible, the selection of technology and main contractor should be left to the EPC phase. Technology selection should primarily be based on technical performance issues with a short-list of candidate capture technologies. Commercial requirements should be included for the short-listed companies and should be kept at a level which is reasonable and acceptable to most of the technology providers. With more experience gained for the capture technologies, it should be possible to engage an EPC contractor without any binding to a technology provider. The CC technology can then be decided at a late stage together with the selection of other major process equipment The need for fixed pricing from technology/main contractor should be evaluated and be limited for relatively new technology. Excessive performance guarantees should also be evaluated carefully as they can be significant cost drivers in project utilising new technology.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.7	Risk-based approach in project	The LOOCR project has used a risk-based approach through all project phases. This has been documented in a risk register and reported to Gassnova on a monthly basis. The risk register has guided the project to have focus on the items that are regarded as most critical. The LOOCR project has adjusted the criticality and likelihood categories in the risk matrix according to the various phases of the project. At one stage, the categories where not adjusted correctly, so no risks were identified in the critical part of the risk matrix.	A risk management process is a valuable tool in all phases of a project. It is important to adjust the criticality and likelihood categories according to the phase and size of the project. This will ensure focus on the risks with the highest total risk score and the corresponding mitigating actions It is important to have both regular updates of the register and brainstorming session to ensure that all relevant risks are covered. When a new phase begins, it should be considered to close the old risk register but transfer all relevant risks to the next phase.
7.8	Technical competence in Company team	The LOOCR team had strong technical competence from the concept phase and continued, with a few replacements, into the FEED and Interim phase. A CO_2 capture plant is an advanced industrial process plant and strong technical competence in Company's team is indeed required in order to follow-up suppliers and sub-contractors as well as to make the best technical decisions and evaluations.	During concept phase, technical competence about CO_2 capture technologies, environmental impact, integration with WtE plant etc. is essential. During FEED phase, the company's team should be strengthened with additional competence within the main engineering disciplines that are not CO_2 technology specific, such as process, mechanical, structural, piping, layout, electrical, instrumentation and control. LOOCR's team setup for the Concept, FEED and Interim phases has proved effective, and this set-up may serve as a good starting point for future projects.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.9	Value of knowledge sharing and participation in networks and consortiums	Participation in networks and consortiums that focus on CC(U)S has contributed greatly to that LOOCR is being able to share experience and knowledge to both industry, organizations and politicians. By participating in other projects such as a CCS cluster, i.e. Borg CO_2 and discussing with research facilities and relevant knowledge communities such as Gassnova, University of Oslo and Test Centre Mongstad, LOOCR has gained learning and improved knowledge of what focus points should be, and the understanding of certain topics has increased. Within Fortum, LOOCR have had a great deal of contact and information sharing with Stockholm Exergi in addition to LOOCR personnel leading and providing insight to the feasibility studies performed in Poland (Zabrze) and Lithuania (Klaipeda). LOOCR has had interactions with many Companies and Project that are EU Innovation Fund first call applicants/feasibility studies for retrofitting WtE with CO_2 capture. FOV has two papers that have been or are being prepared for publication in the scientific community: • Paper 1: Full-length paper submitted to the International Journal of Greenhouse Gas Control (IJGGC), 5 October 2020; • Paper 2: Abstract accepted for oral presentation at the Greenhouse Gas Control Technologies (GHGT) conference to be held in March 2021. Spending resources on participating in CCS networks is well worth the time.	Participation in Norwegian and European networks, organizations and consortiums is highly valued. Participation in networks and alliances should be initiated at an early stage to ensure mutual learning, accelerate development, increase awareness of important topics and to share own experiences and concerns within technical, regulative, political or commercial matters. Organizations and companies in these networks commonly share their experience and communicate and participate in knowledge sharing to keep each other mutually updated.

ID	Learning items	Achievements	Learnings and recommendation for future projects
7.10	Organising work with main contractor	The contract with TechnipFMC in Concept and FEED phase has been based on a buyer/ supplier relationship and focusing on delivering according to contract obligations. Bi-weekly skype meetings and limited number of physical meetings were held. LOOCR's commercial and technical follow-up processes of TechnipFMC were too separated in the FEED phase. The schedule for the TechnipFMC delivery was not fully considered and the technical solutions were frozen earlier than anticipated by FOV. The contact between FOV and TechnipFMC was on project management/ commercial management level with limited contact with the project owner in the TechnipFMC organisation. At the closing of the FEED, the project was transferred to TechnipFMC EPC contract entity in Lyon, France from the engineering organisation in Milton Keynes in UK.	It is important to establish an open and honest dialogue with the main contractor. Frequent meetings should be arranged and with sufficient physical meeting venues in order to have a close cooperation. It is advisable to have an integrated commercial/ technical team working together with the main contractor. It is important to fully understand the contractors schedule and the required time for quality assurance activities, so that any changes/ optimisations could be considered. It would be advisable to establish a high-level contact between the two organisations in order to ensure continuity through the project phases. It is normal that projects are transferred from one organisation to the next when moving into the EPC phase. It is advisable that this is clarified prior to start of the FEED phase. It is also advisable to establish contact at a high level in the contractor organisation, preferably as project owner continuing into the EPC phase

4.8 EU Innovation Fund Application.

FOVs participation in the Longship project as presented by the Norwegian Government in September rely on conditional financing, and FOV is hence seeking external financing of the LOOCR project. Application to the EU Innovation Fund is deemed to be one important source for the total financing of the project. LOOCR has focused on submitting a full and thorough proposal to the first stage (Expression of Interest) of the EU Innovation Funds first call. LOOCR has strengthened the team working with the application with EU-application specialist PNO Consultants. The lessons learned from this process is addressed in this chapter.

At the end of the chapter some specific learning points addressed by PNO are included. They are numbered with a number starting with P. This is done to include their learning points as well.

ID	Learning items	Achievements	Learnings and recommendation for future projects
8.1	Planning	PNO had a good plan with milestones that was issued early in the project. The plan was never assessed in detail by FOV. In hindsight, the milestones were not realistic from a FOV point of view, and this should have been commented. As an example, most of the documents to be produced from FOV should have been in final status three weeks prior to due date of application and the necessary time for internal review of documents was not accounted for. FOV underestimated the extent of the requirements and level of details from EU application, and the amount of work and resources this would require from FOV. In the beginning of the process, it was assumed that many of the documents could be reused from other documents that FOV had prepared. This showed up not to be true	A more specific plan should have been prepared on how the application process would be performed by FOV. This should be aligned and confirmed with PNO. The plan must also include sufficient time for review from other FOV contributors outside the core project team. They must comment within fixed due dates. The commenting from FOV resources could be performed in workshops, rather than document review. This could be more effective, if performed at the correct time. FOV management and FOV personnel that has an ownership to the project should be closer to the process, to reduce time for reviews. The entire process should ideally have been 14 days longer.

ID	Learning items	Achievements	Learnings and recommendation for future projects
8.2	Planning	The FOV project team had to high expectations to how much PNO would manage and lead the application process. This was not followed up at the expected level. This was especially true for the process of asking questions from FOV towards INEA.	An expectation clarification should have been performed together with PNO at Kick-off, so that FOV and PNO expectations had been aligned. This should also include a role definition and unique contact points.
8.3	Organization	Early in the process, the application team and the different roles were not clear. The application team and the different roles were not clearly defined nor at the start nor throughout the project.	Organization of the Application Team should be clarified prior to the application process. A dedicated application manager with the overall responsibility for the application should be appointed early in the process. This should ensure that all the work and underlying documents are aligned.
8.4	Organization	To identify, find and understand EU directives and call documents takes a lot of time and is rather difficult.	A dedicated person should be responsible to identify and download all relevant EU directives. A summary of all directives and call documents should be prepared. It should be an expectation to project personnel that they familiarize themselves with the relevant documents for their area of responsibility.
8.5	Execution	This was the first application towards EU for many of the participants in the project. And the requirements to adaption of existing documentation to EU requirements and formats were more time consuming than anticipated.	EU is a special organization, with specific procedures and requirements. This must be accounted for in the planning. For the next phase of the application, the same personnel should be used to reduce the necessary learning and adaption.
8.6	Execution	Decision of Category was difficult and took a long time. A lot of documents could not be completed before the Category was selected, and this caused delays. There was also a lot of time spent in meetings to clarify the sectors.	A lot of the application is depending on the selection of correct Category. It should therefore be a top priority to decide this early in the process. Dedicated meetings should be booked to address certain topics. Too many of the status meetings where used to discuss the Category selection in this project.

ID	Learning items	Achievements	Learnings and recommendation for future projects
8.7	Execution	FOV expected all questions to be published online by EU IF, but late in the process it was discovered that there was a possibility to ask questions outside this process as well. If this had been known, more questions could have been raised. It also took longer time than anticipated to get answers from EU IF.	Better knowledge of the question process, could have lowered the threshold to ask questions/ clarifications.
8.8	Execution	The FOV project team used more time and effort to get response/ feedback/ assistance from FOV/ Fortum resources outside the project team than anticipated.	It is important that FOV/ Fortum resources outside the project are mobilized, available and participating in the process of establishing and aligning requirements and limitations. This is especially true for commercial issues. FOV resources must also have the time to review documents within the given timeframe.
8.9	Execution	The application team used SharePoint for coediting and commenting the documents, enabling several people to work in the document at the same time. This worked out well.	Consider locking the document based on agreed due dates for commenting. Since the documents were possible to edit at all time, this became an issue at the end of the project.
8.10	Execution	EU application requirements towards the business plan was very different with respect to what was expected by FOV. The EU-IF business plan was based on increased income from the investment while the CO_2 capture plant increases cost and reduces emissions with limited income benefits.	See 8.5: Since EU is a special organization, with specific procedures and requirements, this must be accounted for in the planning. For the next phase of the application. The same personnel should be used to reduce the necessary learning and adaption.

ID	Learning items	Achievements	Learnings and recommendation for future projects
8.11	Organization	FOV project team had an unclear decision matrix. Who had the formal decision authority on economy issues etc? It took a lot of time to clarify this in the process. An example was to decide the applicable exchange rate.	A clear authority/ responsibility matrix should be decided early in the project. See also 8.3
8.12	Planning	There was no formal budget for internal work on the application. The only budget was from PNO, and there was an overrun of 10%.	A formal budget would be preferable for all activities. This requires better understanding of the process
8.13	Organization	It was vital for the success of the application, to establish contact with an EU Application specialist (PNO) early. It was a very specialized process, and the assistance from PNO was required It is also an impression in the project team that the assistance from PNO improved the end result of the application.	Involve PNO early in the next phase as well.
8.14	Planning	In only a couple of months, a similar process will be performed to the next phase of the application, if the project is approved for the next phase. The due date for this application is 23rd of June. The PNO and FOV teams for next phase will be similar to the ones for the current phase, so a lot of the learning should be implemented.	It is expected that the next phase can start approximately on the 1st of April. It is expected that PNO takes more responsibility to propose different aspects and guide on the contracts. They could for instance guide more actively on how the project should handle different issues from EU that the project doesn't pick up themselves. If some of the information that is needed for the next phase is already available, it should be considered to start the work on those issues already.

ID	Learning items	Achievements	Learnings and recommendation for future projects
8.15	Planning	It was an expectation from FOV that PNO would have a template that could be used. But this template was not uniform through the project. This cause extra work on formatting etc.	Rules for documents and formats should be agreed upon. This will avoid unnecessary extra work later in the project.
		PNO Lessons Learned	
P.01	Planning	Avoid last minute changes, especially on numbers and most important information. When the grant requested amount was changed on the day the proposal is due and 2 hours before deadline, FOV took a big risk. After the last change was made, PNO had to re-run consistency checks and fortunately spotted the change in part A at last minute, but it could have been gone wrong. We should fix a deadline when changes on main claims and numbers, budget, GHGs and important information are not allowed anymore. Because those numbers needed to be triple checked with Part B, checked against implementation, biz plan, feasibility, etc	Close main claims and numbers at least 10 days before deadline.
P.02	Planning	Planning and process management: Good at the beginning but got 'messy' towards the last 2-3 weeks. PNO should have had much more control of the process, being stricter on pre-agreed planning, deadlines, main decisions to be taken, etc. FOV should have discussed the planning internally much more in details to align and make sure that the actions and deadlines proposed by PNO would have been met in due time.	PNO and FOV to discuss planning in detail and make sure they're all aligned on actions and deadlines

ID	Learning items	Achievements	Learnings and recommendation for future projects
P.03	Planning	The use of a single joint repository and collaborative editing of shared documents were extremely helpful BUT it can't be a continuous flow, i.e. having set periods of review (like we did last 2 weeks) is necessary. To this end, PNO should lock the documents for review and addressing main comments and release the new version for everybody to work on. This needs some time, so it needs to be planned beforehand	PNO should be include in the planning from the beginning to fix more precise deadlines for incremental versions of the documents, agreed beforehand, so everybody is liable to those from both sides (PNO and FOV). Next time PNO will be more in control of document management from day 1. PNO will also manage deadlines more strictly.
P.04	Organization	Process managers vs. specific owners (in FOV and PNO): PNO consultants believe it worked well having set "go to" people for each section in FOV, rather than having it all feed through a single PM. But we should also determine with FOV a decision-making hierarchy. There must be different persons for the documents but one reference to ensure consistency.	FOV and PNO to appoint an overall process manager on both sides from the beginning, that will have an overview of the process internally, ensure progression and consistency, act as main ref person to the other side in case of process monitoring and main decisions. FOV to appoint 'go to' people for specific parts of the proposal/documents that will be responsible to collect info, hold specific meetings (both internally and with PNO)
P.05	Organization	Comments and integration of information: At a certain point comments were too many and kept unresolved for a long time. Also, it was not clear if the comments were internal or who should take action to solve them (both at FOV or PNO).	Have a pre-defined 'comment writing etiquette: We should make explicit in the comment who we expect an answer from (Internal or from the other party?). Try as much as possible not to ask open questions. And also write an action in the comment. Decide beforehand who should close the comment (FOV or PNO?). This can be done better when the roles are defined. It comes back to the organization of the roles mentioned above.

ID	Learning items	Achievements	Learnings and recommendation for future projects
P.06	Planning	External reviews very useful and important to have (also because they come from FOV's management, investors and experts in the field). Fortum was expecting more control from PNO also for the external reviews, but PNO has not been informed before about this. This part needs to be included in the planning from the beginning, to allow integration of changes. PNO did not know how to prioritize comments from externa reviewers.	Include managing of external reviews in the planning since the beginning to allow proper integration into the incremental versions. FOV to read first the comments from external reviewers and decide on priorities and who should address them (internally? PNO?) Use same 'comments etiquette' as above
P.07	Planning	Too many meetings in the last two weeks. Is good and useful to have weekly meetings + specific meetings on specific parts, but not too many.	Last two weeks should be less meetings, as we need to re-write, ensure consistency checks, etc.
P.08	Planning	Connections with INEA: FOV was expecting that PNO was very well connected with INEA and could facilitate relatively quick answers. PNO should have clarified at the beginning that indeed we have connections with INEA, but with other units, not directly dealing with IF. Also, it is PNO perception that INEA officers would be more sensitive to answer to direct questions during the proposal preparation process, as they want to avoid critics.	See 8.1.

ID	Learning items	Achievements	Learnings and recommendation for future projects
P.09	Planning	General learning issues from planning phase	Allow as much time as possible for application process. Planning should start when FOV is invited to submit full applications, and the application process should start including required milestones. Include in the planning: - A thorough discussion of actions needed and deadlines - Clear definitions of roles and responsibilities from both sides - External reviews - Close main parts at least 10 days before deadline, to allow consistency checks - Include buffer times before intermediate and final deadlines to manage contingencies. Once the planning is discussed and everybody is aligned, be much stricter with its execution, to avoid accumulation of delays and confusion