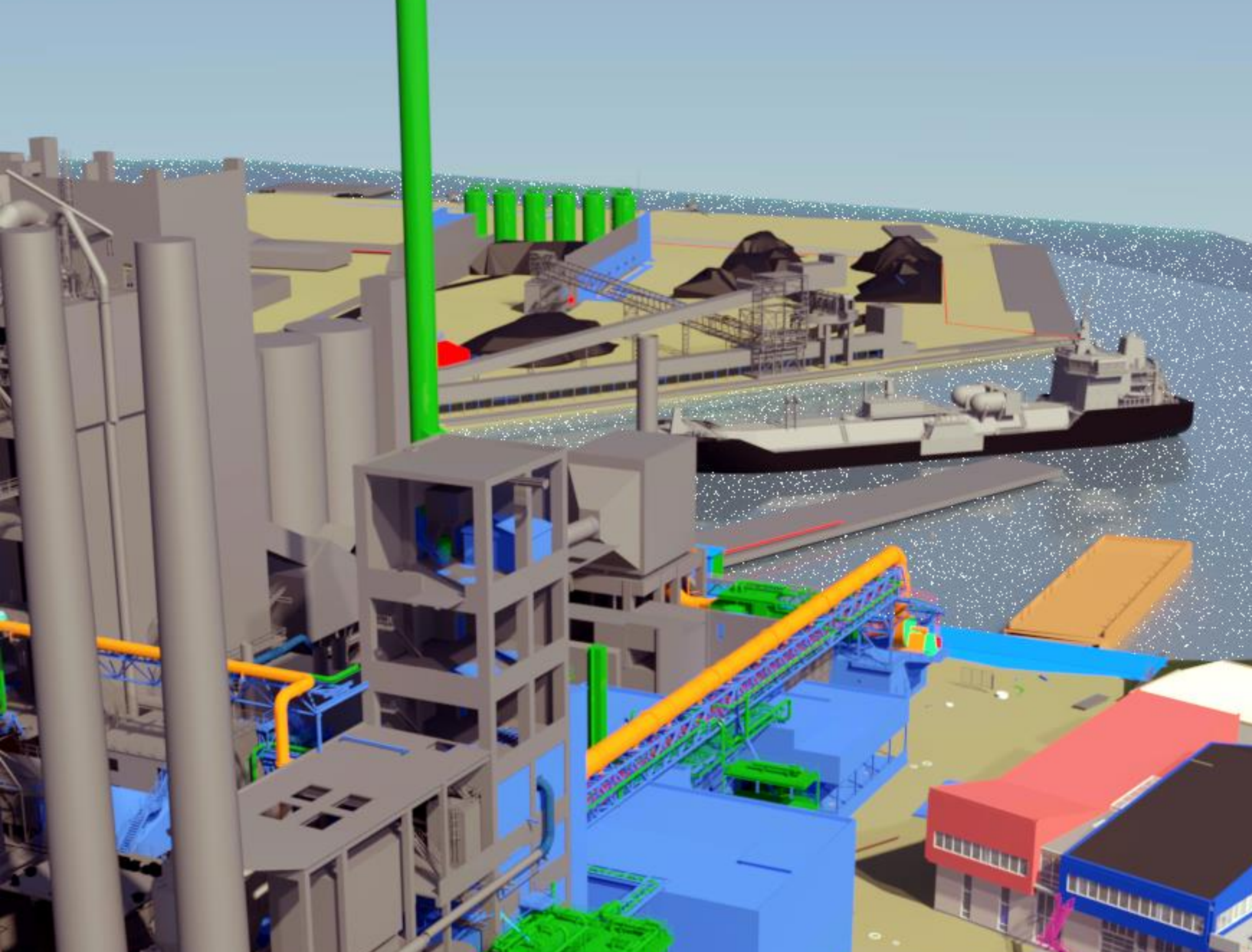
BREVIK CARBON CAPTURE & STORAGE

Heidelberg Materials



Document No.: NC04-NOCE-A-RA-0014				Rev.: 01	Page: 1 of 12	
Originator: NOCE		Tag.No.:		System No.:	Area Code:	
Classification Code: Open						
Rev.	Issue date	Description	Made by:	Checked by:	Disc. Appr.	Proj. Appr.
01	26.06.24	Issued for Information	AB	AP		AP
02						
03						
04						

Brevik CCS

Lessons Learned Report 2023 – Public Version

Contents

Executive Summary:

This report is a summary of the lessons learned collected from the third year (2023) of the Brevik CCS project. During the past year, the project objectives have been achieved despite the continued challenges of the war in Ukraine creating shortages in materials and an increase in the inflation rate.

The lessons learned during this period of the project execution have been collected from multiple stakeholders and contractual partners. The input was then reviewed and reduced to the lessons learned included in this report. In summary the lessons learned in 2023 cover the following:

- Piping Technical Expertise is required within the project team to address the many practical issues around the supply, fabrication, and installation of complex piping systems.
- Selection of piping standard ASME, ANSI, ASTM, EN can have an impact on the project and a full understanding of the differences between the standards and the contractors' experiences with the selected standard is important.
- Engineering Completion should include milestones and definitions of the steps to improve communication and expectations.
- Installation of cold insulation on Liquid C02 storage tank requires careful climate control during the installation process and is challenging to do in the winter.
- Owners field supervision of construction activities to be defined in advance to ensure appropriate staffing of site team.
- Extent of project delays are difficult to forecast when there is a constantly changing supply situation.
- Work sequencing with pressure testing should be fully understood to plan effectively.
- Training of Operational personnel takes time and resources to do effectively, and the Operator Training System (OTS) can be an effective tool in the process.
- First Heavy Lifts confirmed that the use of an experienced heavy lift contractor minimizes risks.
- Project Cost adjustments due to inflation is recommended to minimize the project budget overruns, as this is an known-unknown and out of the control of the project team.
- The permitting process for the project generated many lessons learned for future CCS projects.

1 Purpose

This report is a summary of the lessons learned during the third year of the Brevik CCS project (Jan to Dec 2023).

This report has collected the lessons learned from:

- Heidelberg Materials (HM) – Brevik CCS project team members
- Heidelberg Materials – Brevik Plant
- Heidelberg Materials – Competence Center Cement
- Project Partners; ACC
- Gassnova

The lessons learned have focused on the following areas of interest:

- Technical Setup and performance
- Costs (investment and operation)
- Project management and execution
- Business model (including project contract and execution)
- Environmental impact (emission reduction and other effects)
- Health and safety

The lessons learned have been collected through surveys and then evaluated and discussed separately by the project management team. The input was further refined down to the key lessons learned to be shared outside the project organization.

2 Results and Interpretation

On a high level, the following has been accomplished on the Brevik CCS project in the past year:

- The earned value progressed to 70% complete during the year.
- Completed the year with one lost time injury on site.
- Pre-fabrication of piping and outfitting of the modules in the nearby fabrication yard of Trosvik, were the main focus during the year.
- The CO2 capture plant engineering progressed to 100% complete.
- Two cost and one schedule risk analyses were performed, CBS-04 and 05
- Completed the first of two heavy lift campaigns.
- The second winter repair outage took place where the Gas Conditioning Tower (GCT2) was partially replaced along with one of the main process fans.
- Recruitment of CCS operators and other key personnel for CCS operations has been made and training started.

The following specific challenges and/or changes in the project scope were encountered during the past year:

- The war in Ukraine continued throughout the year and impacted the project budget and schedule substantially.
- Delay difficulty in sourcing pipe and fittings in general.
- There were no noticeable effects due to COVID and there were no travel or work restrictions.
- Union strike during spring 2023, concluded on 20.04.23 as parties came to agreement. Only minor effect on project performance.

3 Technical set-up and performance

3.1 Piping Technical Expertise

During 2023 much of the focus of the project team has been on managing challenges within the piping supply, prefabrication and installation. The lack of piping specialists in the project team that had the practical experience to address the many questions that the project team was faced with impacted the effectiveness of the owner´s project team overall. A clear recommendation for future CCS projects is to have sufficient piping expertise on the project team. This should include experience in the following:

- pipe suppliers
- pipe supply markets
- prefabrication methods
- prefabrication companies
- logistics tracking of pipe components
- productivity assessments in pipe fabrication and installation

3.2 Selection of piping standard ASME, ANSI, ASTM, EN

During the FEED study, the decision was made to design the piping according to the EN standard. There are many factors that should be evaluated when making this decision and it should be very carefully decided for each project.

However, it was observed that ASME pipe fittings are more readily available on the market than EN fittings during the critical time period in the project.

A lesson learned for future projects is for the main contractor/supplier to use the pipe specification with which they are most familiar to avoid unnecessary surprises.

The complexity of the piping supply was more than HM expected. When the supply chain was disrupted and the parts were not delivered as scheduled, the work to track and expedite the components that were late was considerable.

3.3 Engineering Completion

The milestone for engineering completion was months later than originally planned.

The following recommendations are proposed to help reduce the risks of delays in engineering:

- Require the submittal of a detailed heat and mass balance as a milestone.
- Define a milestone in the contract schedule for Design Review and allocate sufficient time for revision of PFD's, H&MB, Material Selection, Equipment Summary List and P&ID's
- Create a log with detailed technical information for each critical action arising from HAZOP and 90% 3D model review, to track all open actions from engineering phase, so that it is easier to resolve differences with Contractor when disagreement arises on completion of milestones.

4 Costs

4.1 Installation of insulation on Liquid C02 storage tanks

The CO2 tanks were supplied with insulation on approx. 80% of the tank surface, however due to the shipping supports of the 265-ton tanks, two bands were left uninsulated. The top band is shown in the photo below.

The field installation procedure for the missing insulation required that no moisture is on the steel surface when the insulation is applied to the tank and that the moisture barrier is airtight. In the case of Brevik, the contractor chose to install the insulation in the winter period, which required weather protecting and heating the work area to ensure that no condensation was on the steel. The photo below shows the scaffolding enclosure that was constructed to accomplish this task.

In contrast, at Northern Lights terminal in Øygarden, tanks delivered from same sub-supplier had only one non-insulated area for cradle per tank, vs. two at Brevik, as they used the skirt of the tanks to position the second cradle. In addition, insulation was installed on that area while the tanks where in horizontal position, and not during wintertime, thus minimizing the weather protection requirements.

The lesson learned for future cold insulation installation is to better understand the constraints weather may have on the installation procedures.

4.2 Insulation of compressed air piping

The contractor´s design specification for compressed air piping stipulates heat tracing and insulation to ensure that during shutdown´s and operation, water that condenses in the pipe does not freeze during the winter period. This specification was seen as excessive by HM given the many years of experience at the cement plant operating compressed air systems without insulation.

The lesson learned is - Carefully review the contractor´s standards against the existing plant´s experience. It should be noted that often compressed air and water systems in cement plant operations do not receive much attention as they rarely cause problems. However, this may be more due to the fact that they are not critical systems rather than they are correctly designed.

5 Project management and execution

5.1 Owners field supervision of construction activities

The owner's construction site team needs to identify in advance of the start of construction which construction activities require additional supervision. Due to the novelty of the equipment being installed there was insufficient knowledge on the owner's project team to know in advance which activities should be inspected during construction.

While the civil and electrical works are very much in line with typical cement plant construction projects, the following areas were identified for future CCS projects to have field checks during installation:

- Packing installation in the absorber
- Pressure testing of larger pipes
- Installation of cold insulation
- General piping and welding inspections prior to insulation

5.2 Scope take over– Liquid CO2 piping to Jetty

Due to the numerous changes of the CO2 loading point, HM decided to take over this scope due to the forecasted cost increase. The project team had received offers from contractors and it was believed to be much less expensive than the price forecasted.

In the end the costs were below the estimate but exceeded the forecasted cost and the work took months longer than planned. The root cause of these cost overruns, and delay was assigning an inexperienced contractor to the work. The lessons learned from this experience was when taking over scope of work within a CCS project, in which the scope is not related to the Cement Plant itself (i.e., Company has no experience), always look for references from other industries with similar applications to understand what solution can be applied and to select a suitable Contractor with required expertise. Specifically, the following actions should be taken:

- Verify the qualifications of the installation contractor and its sub-suppliers. Particularly, check references of execution of similar projects.
- Verify prior to contract signing that contractor understands all the critical quality control points and procedures, as required for the specific application.
- If a low-cost contractor with limited experience is the only alternative, then allocate additional resources within Project team or via outsourcing for supervision and quality control.

5.3 Winter Repair Preparation and Planning

After the problems encountered during the 2022 winter repair (WR) a more rigorous approach was taken to the planning and coordination of the 2023 winter repair. These steps paid off and the winter repair was successfully executed on time and with no safety issues. The following actions were felt to have been the most beneficial:

- Contractor was required to bring in a person with more competence with the Norwegian HSE regulations, as well as an understanding of the HM specific requirements.

- Prior to the WR Weekly meetings were held for planning purposes. The Contractor participated in all meetings. Not all technical disciplines participated in all meetings, but the necessary management was present to ensure ownership to the sequence & priorities of the activities.
- A detailed level 5 plan was communicated to the plant twice a week during the winter repair and Contractor participation in the plants daily WR meetings.
- Contractors provides input to the Integrated Detailed Schedule (IDS) (level 4).
- Structured review of the schedule with all parties. Line-by-line review.
- Detailed review with relevant parties on level 5 schedule.

5.4 Management of different contracts

The project has many different contract types, from reimbursable to lump sum. Each contract comes with pros and cons. The following contracts are executed on a reimbursable basis: Civil engineering, structural steel erection, Electrical construction and engineering, and the owners project team members that are hired through the three consulting firms. This approach has allowed for HM to quickly adapt. However, it has come with higher costs as the work cannot be executed efficiently. In addition, it is very difficult to control the manhours of the contractors as often the cost increases only become known after the work has been done. Therefore, the trust level between the owner and the contractors must be high.

The main contract with ACC for the overall process design, equipment supply and mechanical equipment installation is on a fixed price basis.

In retrospect, the selection of the different contracting structures was the correct decision to take. If all the contracts had been fixed price, it would have left no room for flexibility when one contractor didn´t meet their responsibilities. Alternatively, if the main contract had been reimbursable, it would have been very difficult to control the costs on the main scope.

The challenges and pros and cons in the management of different contract types is not unique to this CCS project and have been learned and relearned in the past. For “demonstration” projects it is often challenging to get a contractor to bid fixed price and accept the risks.

5.5 Project delays

The project has encountered approx. 10 months of delay at the writing of this report. As the delays were not presented in one single event but rather in a constant trickle of problems it was very difficult to quantify the problem and develop corrective actions. With each slip of the project schedule efforts were made to expedite work through detailed planning sessions. Several joint planning workshops were held, and the heavy lift campaign was rescheduled many times.
These problems are not unique to this CCS project but rather to projects in general. Perhaps in “demonstration” projects there should be more float built into the schedule to allow for some delays. However, the danger of building in float is that it removes the pressure to deliver the project as fast as possible. It is the author´s opinion that an aggressive schedule will yield better results than a conservative one.

5.6 Work sequencing with pressure testing

The Contractor proposed work methods to facilitate pressure testing have potential for optimization. Specifically, the Contractor requirement that no field painting (touchup painting) on field pipe welds can take place prior to pressure testing. This leads to inefficiencies in the erection sequence because the heat tracing can only be installed after the field welds are painted on piping. HM does not see the benefit from this sequencing as any leaks can be detected if the weld in question is painted or not.

It is recommended that new entries into the carbon capture projects receive training in the construction procedures around pressure testing of the installed piping.

5.7 Training of Operational personnel

The future CCS plant operators were hired in 2023 and as no CCS facilities like Brevik exist, the operators need to be trained in all aspects of the plant to be able to effectively operate it. The operators started work in October 2023, prior to the latest extension to the schedule which has added 6 months to their training period making it now a total of 12 months before they will be actively assisting in commissioning. The extra time has allowed for more flexibility in the training program and the involvement of the operators in supervising the construction works.

An essential part of the training has been to give all process operators special tasks and individual process units to specialize in. Each of the operators have special responsibility for 1 process unit each. They are currently studying all relevant information related to the unit and they are developing training material to teach the other operators. To prepare the training materials, prepare lesson plans and task assignments is a full-time job for the operations engineering manager and the CCS plant manager.

The first lesson learned is proper planning of the office space that is needed for training, for studying and for group work (with multiple offices, a meeting room large enough for everyone). In Brevik an entire existing office floor was refurbished to meet the needs at a lower cost than renting construction trailers until the new maintenance center is constructed. If possible, it is recommended in future CCS plants this office space is be constructed in the early stages of the project so that it can used prior to the start-up of the CCS facility.

iPads were selected as the IT tool to be used for the operators which is more convenient to bring outside in the plant compared to a PC. However, during the education it was found that the operators also need a PC, for making presentations and other training material. Hence, it was necessary to purchase laptops for everyone. They will still keep their iPads to bring outside, and they will also keep them for the future plant operation period.

5.8 Operator Training System (OTS)

The Operating Training Simulator (OTS) was not part of the original scope of the project but came up as an opportunity during second year of project execution. Initial motivation for the development of an OTS came from the risk management processes where several risks were related to lack of training, failure in PLC programming, lack of preparations for commissioning, risk of process not working as intended in full scale, risk of product quality issues, and more. As a very important mitigating action relevant for mentioned risks, development of an OTS was proposed.

The OTS is **expected** to provide several advantages and opportunities for the project are listed below, but it may be premature to claim these as lessons learned as the process is still underway.

- Optimization and tuning of PLC logic, controllers and timers
- Potential optimization of design details
- Identification of risks during commissioning and startup
- Preparation of all involved personnel in commissioning
- Design optimization of control room screen schematics
- Advanced training of process operators on specific scenarios and potential hazards
- Training of cement plant process operators (to understand the interface between cement plant and CCS)
- Improved efficiency of operator training.

Since development of the OTS started, a lot of learning is already made although the product is not yet finished. During the development, the process has been tested system by system, revealing several minor weaknesses in procedures, PLC-logic, regulators and timers. So, in parallel with the OTS development, the programming of process control system for the physical plant are also being tuned.

The main purpose of the OTS is training of process operators in order to prepare them for commissioning, startup, and operation of the CCS plant. Operator training is currently ongoing and we experience every day that variation in training is very important to keep attention and motivation high. Classroom training is necessary, but individual capability of absorbing large amounts of theory over long time is for sure limited, especially for people with DNA programmed more for the practical side than the theoretical. We expect the OTS to play a very important role when it comes to practical and virtual reality training, and we expect the learning curve to steepen significantly as soon as this stage of training is being unleashed.

An unplanned but significant benefit of the OTS is also the group of operator's ability to be self-managed when it comes to OTS training. 3-4 operators are selected as super users and instructors, and they will attend specific and professional training with Equinor to learn how to maximize training efficiency on OTS. One of these operators also have special competence related to this kind of technology, and he will have dedicated responsibility for systematic identification of any in-optimal performance of the model. The findings will be handed over to the specialists who can make the proper assessments and rectifications. Through this strategy, the operational staff does not have to follow up on the operators every hour or every day. This is increasingly important as the commissioning approaches since the staff key persons are already overloaded in preparing everything else necessary for next phase of the project execution.

Further down the road, we also expect the OTS to play an important role in engineering for optimization of the process. Before any rebuild proposal is being forwarded, the modification will be modelled and tested out in the OTS to support the decision process.

5.9 First Heavy Lifts – Lessons Learned

The first heavy lifts were completed in 2023, with the setting of the following equipment:

- CO2 tanks
- Absorber
- Pipe rack modules

The following lessons learned were noted by ACC during the heavy lifts:

- Subcontract the lifting to an experienced heavy lift company.
- Maintain high HSE standards and foster strong cooperation between involved parties.
- Agree on rates for necessary equipment for marine and lifting operations beforehand to avoid complications.
- Clarity in Insurance. Timely decision-making on the value of objects for insurance purposes to avoid uncertainties.
- Transport operations confined to weekends effectively reduced on-site personnel, ensuring smoother operations.
- Adopting a "Fast and Calm" attitude allowed the team to maintain momentum without compromising safety.
- Better evaluation of cost-benefit analyses, especially regarding the use of hardwood mats, could optimize future heavy lift campaign.
- Double check that everything is prepared. Despite all the planning some issues were missed. Discoveries such as a high amount of required gravel for levelling and the need to remove piping caused delays and extra work.
- Changing plans led to communication gaps among involved parties. Avoid reliance on emails for communication among stakeholders.

- Ensure availability of adequate technical resources in advance so that last minute technical questions do not cause delays.

6 Business model (including project contract and execution)

6.1 Project Cost adjustments due to inflation

There have been a considerable number of world events since the signing of the State support agreement. The inclusion of adjustments in costs due to inflation an index has been very helpful in minimizing the extent of the cost over run for the project. For projects that last many years it is important to include inflation adjustments into the budget as this is a very uncertain calculation to estimate at the beginning of the project.

7 Environmental impact

7.1 Permitting

In general, the permitting process for the CCS facility went very well. The main reason for this was the very collaborative and transparent approach that both HM and the National Environmental Authorities (NEA) maintained throughout the process.

The setting of emission limits (air, water) for the project was challenging. Due to the novelty of the technology, there are limited benchmarks that can be used, and the theoretical calculations are complex making it open to either errors or disagreements between parties.

In other CCS projects in development within HM, this is also an issue that has delayed the project development and also increased the CAPEX of the project due to the installation of additional equipment to ensure that theoretical emission limits can be met.

These experiences further reinforce the need for these "development" projects such as Brevik, so that both industry and government have a physical installation that can start to form the environmental benchmark for future CCS plants.

Based upon the experiences over the past 4 years, the following lessons learned should be noted for future projects:

- It is recommended to prepare a detailed Environmental Impact Assessment (EIA) report, even if it is not specifically required by the authorities. This document was very useful in addressing any questions that arose and gave the NEA confidence in the design of the project. It was also useful for the discussions with the local community stakeholders.
- It is important to have experienced and knowledgeable environmental support personnel on the project team throughout the process as well as having the support of the Plant environmental manager who will be needed to validate the application with the NEA.
- As there were no other reference plants to use the pilot unit that was operated for over 7000 hours was critical in confirming the emission assumptions for the future larger unit.
- In Brevik the emissions permit was only received in 2022, which was one year after the FID (financial investment decision). The many meetings in 2020 and 2021 with NEA were critical in giving the confidence to HM management to proceed without the permits. However, for future projects it is recommended to start the permitting process as soon as possible if the organization requires these permissions to be in place prior to FID.
- It is recommended to ensure that all the misc. project components are included in the EIA report. The Brevik missed one component that fell between large scope packages that had to be added later, which required considerable extra work and coordination between the parties.

- Due to the strict water emission regulations in Norway this component was the most challenging and required the most effort to achieve an acceptable solution. Particular attention should be paid to this component in the CCS plant design and a good understanding of the limits and how they can be achieved.
- The public hearing process is an important step in the process as all comments need to be considered fully. Having the NEA present during these meetings was very helpful and constructive in the process.
- Having a good relationship with the NEA was very constructive for the project. The NEA was very responsive and worked together with HM in looking for solutions to the challenges encountered along the way. A transparent respectful dialogue between the parties greatly assisted in maintaining the relationship.

8 Health and safety

8.1 Scaffolding

The scaffolding for the support of construction works in the project has been far more than expected and budgeted. This is a clear example of the different expectations between projects in the oil and gas industry vs the cement industry. However, at the core of the issue is what degree of scaffolding is needed for the safe and efficient construction of the CCS facility?

It is recommended for future projects that there is a more detailed investigation into the scaffolding requirements for construction. Specifically, the following areas should receive focus:

- Dimensions of walkways – how many people can walk side by side for example.
- Heights of stairways to prevent hitting your head.
- Weather enclosure requirements – where and when.
- Congestion of working area – when should mobile platforms be used vs fixed scaffolding.
- Duration of scaffolding installation.

9 Conclusions and Recommendations

Based upon the lessons learned during the third year of the project execution, a few of the key points are summarized here:

- It is important to staff the project team with people that have sound piping and insulation technical expertise, as well as people who have a good understanding of scaffolding and the necessary field inspection requirements.
- The taking over of scope from the contractor should not be entered into lightly as what can seem to be a relatively easy task can become quite complicated if the selected contractor is inexperienced.
- Having a sound and robust Environmental Impact Assessment report is an important back up document to the permitting process.