17th International Conference on Greenhouse Gas Control Technologies, GHGT-17

20th -24th October 2024 Calgary, Canada

Lessons learned in the design and construction of the Brevik CCS facility

Andrew Burns*, Ytalo Davila Gomez

*Project Director Brevik CCS Project, Heidelberg 69120, Germany
*Engineering Manager Brevik CCS Project, Brevik, Norway

Abstract

This report is a summary of the lessons learned collected over four years of the Brevik CCS project (2021-2024). The project objectives have been achieved despite many challenges such as COVID, the war in Ukraine creating shortages in materials and an increase in the inflation rate.

The lessons learned during 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 identified are from Heidelberg Materials perspective and are unique to this CCS project and not just generic to all projects. CCS projects are complex (new technology, high visibility, multiple stakeholders, new contractors, multiple interphases, etc..) therefore the need to apply the standard lessons learned for projects of this nature is required.
Keywords: CCS; Lessons Learned; Amine; Cement;

---

1. Project Overview

Brevik CCS is a wholly owned by Heidelberg Materials Sement Norway, the only cement producer in Norway. In 2011, Heidelberg Materials received support from ECRA (European Cement Research Academy) for CC studies. From 2013 to 2017, Heidelberg Materials received funding from CLIMIT to test four different technologies on real flue gas at the cement plant in Brevik and in 2016, the Norwegian CCS Demonstration Project (NDC) was launched and Heidelberg Materials received support from Gassnova/Ministry of Petroleum and Energy to carry out concept and FEED studies. In December 2020, the Norwegian government gave final approval and support for the construction of the world's first full-scale carbon capture plant at a cement plant. Brevik CCS is part of the Longship CCS project which is Europe's first complete value chain for the capture, transport, and storage of industrial CO2 emissions. The project is under construction and is planned to be operational by 2025.

The CCS project is designed to capture and produce 400´000 tonnes of liquified CO2 per year, which represents half of the CO2 produced at the Brevik cement plant. The heat for amine regeneration is taken from the waste heat from the cement process and from excess heat within the CO2 capture facility.

The project has worked over 1 million construction man hours on site and had 2 LTI´s. The project faced a 10 month delay in the schedule due to material sourcing problems and late engineering.

A multiple contracting approach was used on the project which allowed for the necessary flexibility of installing the capture plant within the tight confines of a running cement factory.

2. General lessons learned

2.1. Project Complexity

To execute CCS projects in the cement industry is extremely complex. The complexity is higher than a conventional cement plant project due to;

- Unfamiliar construction methods (piping & insulation)
- Adopting new technology
- Cultural differences between cement and oil & gas industry
- High visibility to public
- Multiple stakeholders
- Multiple interfaces

Therefore, standard project management principals must be followed and established practices identified by the project management profession used. During project development project complexity should be reduced wherever possible.

2.2. Cultural Challenges

The staffing of CCS projects is challenging as few people have the necessary experience. However, a ready source of talent can be obtained from the oil & gas sector. In the Brevik CCS project a portion of the owners project team and all of the main contractor´s personnel came from the oil & gas industry in Norway. This difference in experience created significant misunderstandings, miscommunication, and frustrations. Simple issues became complex, complicated situations were underestimated. Both industries use similar terms but they convey different meanings. In addition, the oil & gas industry often has more expensive technical specifications due to the more dangerous chemicals they work with.

The project was not able to find an effective method to properly address this challenge, despite many attempts. The lesson learned is to create new terms and definitions for activities where similar words are used in both industries. For example snow to Calgarians has a different meaning to Indonesians. Commissioning in the oil and gas industry is that different to commissioning in the cement industry.

2.3. Piping

CCS projects are piping projects. A cement project has limited piping in it and getting experienced piping people on the owner´s team was overlooked. A considerable amount of the project delay was due to issues around piping and it takes time to find an expert and build the trust for them to become effective. The following knowledge would have helped greatly:

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

2.4. Design Experience and Standards

CCS is an emerging field and lacks accepted standards that have been tested over many projects. To fill this void in the project, the engineers relied on standards from other industries or they created standards. The project lost time and efficiency when there were disagreements between engineers as they could not draw from real world experience to help. This was further challenged by the strict NDA´s that are in place in the project, which limited discussion on many fronts.

Therefore, it is recommended that an engineering association for CCS be formed so that it can develop standards, and share knowledge rapidly across all CCS projects.

3. Lessons learned in design

3.1. Difference between offshore and land-based project design

The main contractor´s design team had significant offshore experience which became evident later in the design. The following issues were identified as carry over´s from design & execution methods from the offshore oil and gas projects that need to be reconsidered for land-based projects to save costs:

- Non process corrosion protection levels are much higher in offshore projects. Land based projects do not need the same design standards as the atmospheric corrosive conditions are much less severe and the replacement of parts is much easier. Design specialists are very reluctant to relax design standards as they have little incentive to change, and they do not have the historical knowledge of many land-based projects to draw from. In future projects it is recommended to accept the design standards (for non-process equipment) of the existing plant being converted.
- Design safety factors developed in offshore projects applied in land-based projects increase the cost of projects. It was not possible to compare the design safety factors used by suppliers coming from the offshore businesses to land based suppliers, however it was easy to see the differences between their equipment. In every case the equipment from the offshore supplier was more robust and of higher quality than the land-based supplier. It is unlikely that the offshore suppliers will change unless they hire people with land-based design experience. In addition, offshore engineering companies with ingrained offshore DNA should generally not make onshore installations. The mindset is totally different.
- It is believed that the design standards from the thermal power industry are the most similar to the CCS plant system due to the many similar components. This could be a starting point for change away from the offshore oil & gas standards that are clearly more costly.
- To keep costs down with suppliers the cement industry tends to accept the standard specification that prequalified suppliers have. The oil & gas industry´s tendency is to make suppliers change their standards to fit their specification. This should be explored more in future projects as workshop visits indicated that these standards can be somewhat relaxed.

General differences between offshore and land-based projects that may influence costs if not addressed in advance.

- Profit of the final project product is in a different scale than offshore. One lost month does not mean billions in lost profit.
- Consequences of technical failure is generally neglectable compared to offshore.
- Weather conditions are less aggressive on shore. Much less salty water ingress into installations and instrumentation.
- Maintenance costs are enormous offshore compared to onshore
- A CCS plant is not an EX-zone where everything is explosive or highly flammable
- Environmental consequence of leakage (of chemical in CCS plant) is neglectable compared to offshore leakages (oil into sea)
- Installation is generally much easier onshore and needs much less detail planning than offshore.

- Weights of the final construction is not critical onshore like it is onshore where every kilo has to be accounted for in design of the construction.

Below are some of the specific observations that have been made to the current design from an Oil & Gas company used to doing offshore projects:

- A lot of money and time has been spent on designing and installing stainless steel plates for pipe supports and gliding shoes. In comparison to the average requirements in the cement industry this requirement seems to be unnecessary and therefore only adding cost without adding a lot of value. In a future project such requirements could be avoided or relaxed.
- An extensive amount of, if not all, pipe supports, and gliding shoes are delivered in stainless steel. Stainless steel is very seldom used in the cement industry. In many, if not all cases, it would be possible to change the material used from stainless steel to galvanized steel to reduce cost.
- Generally tubing for compressed air have been supplied using stainless steel on equipment skids. For equipment not exposed to high temperature such as water treatment and similar it could be easily changed to plastic tubing as it is less expensive to purchase and install.
- Some condensate piping on the steam system have condensate traps which are drained directly onto the ground. This is a challenging concept as the condensate may freeze to ice on the ground creating slipping hazards for personnel in addition to a discussion reg. pureness of the condensate in relation to obtaining an emission permit as the condensate eventually will be drained directly to the sea. For future projects it will be more effective to have a closed system where all steam condensate is directed back to the feed water tank. In addition, this will also reduce the water consumption somewhat.

3.2. Liquid CO2 design considerations

The following design considerations are lessons learned;

- Sampling & analysis of liquid CO2 - How to obtain a representative sample of CO2? There is a need to avoid any boiling in the sample line as both water and O2 will boil off before the analysis which will give unstable readings. The flow rate of the sample is so low that take off point needs to be sized correctly so sample taken is recent enough and isn´t lingering in the line. It is recommended to install local evaporators next to sample point rather than attempt to transport liquid CO2 as only 3 Watts will cause liquid CO2 to boil.
- The pipelines for Liquid CO2 need to be designed such that they can be drained. Without such design consideration, it is more challenging to remove water after the hydro static test and when the system is not in operation, liquid CO2 left in the pipeline will evaporate and build up pressure in the pipeline.
- It is recommended that there is a specification for the amount of inert gases in the Liquid CO2. Currently the spec on vapor return is too general and a more detailed one is needed in future projects so that the inert stripper can sized correctly. This is a complex issue with multiple CO2 storage tanks / vessels and currently it is unknown where the CO2 ship will be loaded. Dynamic simulations by Northern Lights have been ongoing by more than a year, with no conclusion.
- Max. N2 content was specified as that corresponding to physical solubility of the gas in the liquid at given conditions (13-15 barg, but temperature not specified in design basis). If other capture facilities are expected to have other contaminants there is a possibility of cross contamination of facilities storage through vapor return, then the CO2 specification has to be better defined.
- A method for the disposal of off-spec liquid CO2 should be included during the pre FEED design. Currently it is not possible to dispose of off spec liquid CO2 locally as no evaporator and permit for venting large amounts has been included at the storage tanks and without this equipment the venting of CO2 from the tanks would require weeks to empty one tank.

3.3. 3D model coordination

The common 3D model has been an effective tool to reduce errors and keeps all parties informed of the latest status of the design work, however this is not achieved without considerable effort. Some of the challenges that were faced in using a common 3D model:

- Frequency of updates were not aligned, so that one contractor working offline on their scope would not upload the changes regularly
- Often the 3D model did not match the P&ID´s due to delays in updating the model.
- Responsibility to resolve clashes – due to the shared responsibilities within the model it was necessary to create a model interference alignment list to track the clashes to ensure timely resolution.
- Technical issues related to model conversions and transfers to BIM resulted in various
- interface alignment issues and challenges (model misalignments) Internal QA reviews did not discover all issues often leaving a significant amount of issues to be detected by Civil counterpart post frozen milestones.
- Color shading of equipment to reflect design stage (preliminary, final, etc..) was not followed similarly by all contractors such that there was no trust that the color showed the true design stage.
- A complete detailed 3D site scan should made and include permanent site markers. This needs to be done during the FEED and made available to all contractors.
- A 3D workshop for all contributors to the model is required to align on the above issues and agree on the rules to follow.
- For future projects, the use of augmented reality it is believed that more things could have been caught early in the project

4. Lessons learned in construction

4.1. 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

4.2. Insulation on liquid CO2 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 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.

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.

4.3. 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

4.4. 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 (touch-up 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. The benefit from this sequencing is minimal 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. Lessons learned in commissioning

5.1. Give process design team commissioning responsibilities.

The Brevik CCS process is the first of its kind and it is challenging to prepare commissioning procedures in the necessary detail to instruct an inexperienced operator. With the owner responsible for commissioning of the facility it is recommended to incentivize the contractor´s process dept in the preparation of the commissioning procedures. Give them clear responsibilities during the later plant commissioning, rather than requiring only providing a written description of the steps someone else will have to follow

5.2. Commissioning/Operation/Maintenance Requirements for CCS plant

The Brevik CCS project started over 6 years ago with the understanding that it was a proof of concept and that costs should be kept to a minimum. Therefore, the need of isolating adjacent systems / part systems from each other during commissioning and startup were not included within the design. Lack of isolation valves influences strongly on how the commissioning phase can be planned and executed. This will probably influence on future maintainability as well, as i.e large fluid filled systems will have to be drained completely in order to dismantle equipment for periodic maintenance or repairs.

Future projects should consider, in tender/contractual documents, describing commissioning and maintenance (design) requirements in more detail. As the cement industry is not familiar with the operational requirements of a chemical plant, training is required and more specific instructions from supplier/engineering company is needed.

Some issues to consider during commissioning and startup procedures early in design (priming of liquid CO2 service, sequencing during startup, venting lines, need for silencers

6. Lessons learned in operational planning

6.1. 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

6.2. 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 the variation in training is 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. The OTS is expected to play a very important role when it comes to practical and virtual reality training, and the learning curve is expected 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, the OTS is expected 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