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Annual experience transfer report 2023 for Northern Lights Phase 1 Facilities

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1 Introduction

As per the Service Agreement (SA) Equinor is required to deliver an annual experience report to the Northern Lights Joint Venture as part of the State Support Agreement (SSA) requirements. This shall cover learning points on the topics listed in SSA appendix D 12.3.2:

- Technical solutions
- Experiences from the project implementation phase
- Project management
- Environmental impact
- Health, Safety and Environment (HSE)
- Business models
- Potential improvements

Equinor has its own governance process for collecting and sharing experiences internally (PDn85). The focus in this process is on sharing best practices and recommendations to avoid disadvantageous situations from reoccurring in the future. This process was used to collect experiences to fulfil the SSA requirement mentioned above, and to be reported to the Northern Lights Joint Venture (NL JV DA).

The period covered in this annual experience transfer spans from 1st of January 2023 until December 2023.

The main project activities for Northern Lights Phase 1 (facilities part) that were performed during previous year 2022 were:

- Project management
- Follow-up of contracts
- Finishing main civil work activities at Energiparken and handover of site from main civil contractor to onshore facilities Engineering, Procurement and Construction (EPC) contractor
- Drilling of Horizontal Direction Drilled (HDD) tunnel
- Fabrication of components by various contractors and suppliers
- Offshore installation campaign for: rock placement, well 2 template, umbilical and Direct Current/Fibre Optic (DCFO) cable
- Completion of primary injection well, drilling and completion of contingent well

During 2023 period the following activities were conducted:

- Project management
- Follow-up and close-out of contracts
- Fabrication and installation of components by various contractors and suppliers at site in Øygarden
- Completion of the HDD tunnel
- Offshore installation campaigns for installation and preparation of export pipeline, umbilical and DCFO cable.
- Start-up of commissioning activities at the onshore facility

The following list of experiences reflect the execution phase that the Northern Lights project is currently in. Many of the observations have been made as a result of having equipment on site and seeing the facility in its actual physical form rather than on paper. The items listed below cover Equinor internal experiences as well as experiences involving external stakeholders.

2 List of Acronyms

Acronym	Full description
ATEX	ATmosphère EXplosible
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
DCFO	Direct Current/Fibre Optic
EIGA	European Industrial Gases Association
EPC	Engineering, Procurement and Construction
ESA	EFTA Surveillance Authority
FCG	Flooding, Cleaning and Gauging
HDD	Horizontal Direction Drilled
HSE	Health, Safety and Environment
MPE	Ministry of Petroleum and Energy
NEA	Norwegian Environment Agency
NL JV	Northern Lights Joint Venture
NL JV DA	Northern Lights Joint Venture
OSA	Oseberg A
PDO	Plan for Development and Operation
PIO	Plan for Installation and Operation
RTJ	Ring Type Joint
SA	Service Agreement
SIS	Subsea Injection System
SRI	Subsea Rock Installation
SSA	State Support Agreement

3 Experiences

3.1 Modification on jetty with mooring point extension

Context

The civil design of the jetty on Northern Lights was performed approximately 2 years before detail design of the ships, with jetty design in 2018/19 and jetty construction start in the beginning of 2021. Therefore, the jetty design had to be based on preliminary assumptions for final ship length and location of the central manifold as well as other key interface facilities.

Initially, the jetty length was dimensioned to 50 meters to fit with an expected ship length of 125 meters and midship placement of the manifold plus a growth margin in case interface requirements from ship would change.

What happened

- The length of the jetty was reviewed in 2018 and considered longer than necessary, and a reduction from 50 to 38 meters length was decided.
- Ship length was revisited as part of detail design, resulting in an extension to 130 meters. Also, the manifold was placed behind the midship center point.
- A mooring analysis in 2023 identified that the actual spacing between the outer mooring points is too narrow. Hence, new additional and costly mooring points will have to be established as modifications to existing construction 8-9m further away from the center.

Lessons learned

- As the jetty design was concluded significantly earlier than the ship design, the jetty design should have been more flexible/conservative, allowing for changes to key parameters from the ship design.
- In the future the Northern Lights jetty may receive CO_2 from other ships of which we do not have any influence of the design of. A more conservative jetty design will also allow for more flexibility for these ships to moor.

Recommendations

As the jetty design and construction typically starts way before the ship design is concluded, the jetty must be designed and constructed with margins to cater for the uncertainty in ship design. The final ship design is pending on the contracted yards solutions and preferences, and their detail design of the ship.

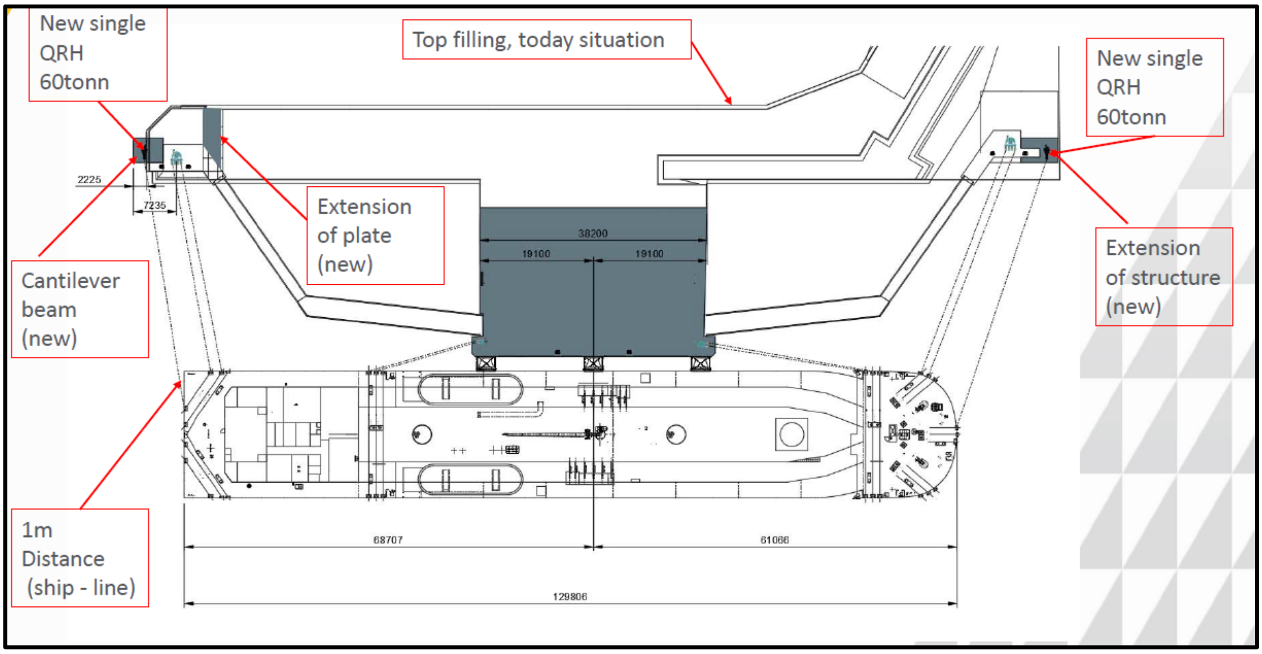

Figure 1 Changes required due to findings in the 2023 mooring analysis.

3.2 Flange management

Context

The high-pressure piping system on Northern Lights onshore facility is connected by Ring Type Joint (RTJ) carbon steel flanges according to ASME B16.5 standard. Before assembly, it is important to verify that flange surface finish of sealing surfaces on RTJ flanges is according to the applicable standard, the flange is clean and free from any contaminations and that there are no presence of corrosion or mechanical damage on sealing surfaces. Damaged seal surfaces may interfere with the integrity of the joint.

What happened

Observations were made at construction yard and at Energiparken causing concerns regarding the quality in flange management during construction activities.

- The project engaged third party inspectors to do inspections of flanges on pipe spools and valves. Results from these inspections showed that a substantial number of RTJ carbon steel flanges were not approved according to ASME B16.5 requirements. Main defect cause was corrosion on sealing surfaces, mechanical damage on sealing surfaces and wrong surface finish on the sealing surfaces. Based on inspections, the identified flanges with corrosion and damage were repaired by machining or grinding the surfaces smooth.
- The project also experienced recurring issues with incorrect tightening of flanges, by means of incorrect bolt tensioning (incorrect torque). Also lack of cleaning, lack of inspection of flanges before assembly and insufficient preservation was observed. Based on these observations Plant EPC Contractor performed a project assurance activity on flange management to identify actions for improving performance and to deliver quality in flange

management. As an outcome several improvement actions were identified and implemented. The most central elements were:

- Follow up of workers competencies at site, by introducing site test for pipe fitters executing bolt tensioning.
- Focus on workers knowledge and understanding of procedures, work instruction and checklists prior to the work.
- Testing of manual torque wrenches and establishment of better routines for handling torque wrenches before and after usage.

After implementation of the above-mentioned actions, bolt tensioning was no longer regarded as an issue in the project.

Lessons learned

- Have more focus on training of personnel.
- Have more focus on preservation of carbon steel pipe spools when stored outside.

Recommendations

- Close follow up of flange management, including handling of flanges before assembly, cleaning and preservation requirements.
- Ensure that workers at fabrication yard and at site have required competence by requiring site-test.

3.3 Fixed lights

Context

The Northern Lights facility is a normally unmanned plant, meaning that there will not be people present at the plant other than during offloading and maintenance activities. As CO_2 is not flammable, it is also not subject to ATEX regulation.
The Northern Lights onshore plant is designed in conformance with applicable standards, however, has a significant number of fixed lights to ensure i.e. adequate work lights, which are typical 200lux, for maintenance tasks. These fixed lights all come with dedicated supports, cable trays, cables, and switchboards.

What happened

The plant is designed according to normal oil and gas industry practice, but the design did not take into consideration that Northern Lights is normally unmanned. Further that Northern Lights is non-ATEX, and hence can utilize portable light solutions with extension cords or batteries.

Lessons learned

Ability to transfer project specific needs into design is limited when it deviates from established practice, hence design is compliant but not effective due to e.g. higher CAPEX and maintenance requirements.

Recommendations

Make specific and tangible requirements in scope of work and philosophies that are adequately placed in the contract with next contractor. These should allow for intermittent and portable work lights where applicable, which is most of plant except for the jetty.

3.4 Extent of insulation on piping

Context

The CO_2 that arrives at Energiparken has temperatures below -20˚C. This low temperature is maintained through much of the processing on the Northern Lights plant, meaning that the piping is insulated to avoid the formation of ice on the outside of the equipment. This ice formation can hinder operation and maintenance.

What happened

The piping at the Northern Lights plant was insulated in compliance with specifications and requirements to avoid ice formation. The insulation work is time consuming and drives cost and schedule. However, these specifications did not take into consideration that some of the insulated pipe segments and valves are not expected to have any issue with ice being formed during normal operation. The reason for no ice being formed is for example that the medium inside the piping is CO_2 vapour, which typically does not have heat transfer properties that would cause ice to form on the outside of the pipe and that for some of the segments downstream of the pump the liquid CO_2 will have a higher pressure and not as low a temperature as upstream in the facility.

Lessons learned

Improved evaluation and specifications are recommended to avoid insulation of segments and valves where ice formation is not expected to be a problem due to operating conditions during normal operation.

Recommendations

Challenge and improve evaluation of where insulation will be required, especially where the medium in the piping is CO_2 vapour and where the temperatures will not be low enough to cause ice formation.

3.5 Pipeline cleaned during FCG operation in June 2023

Context

When a newly constructed pipeline is installed on the seabed, it can contain pollutants and debris. To ensure efficient operation of the CO_2 pipeline, removal of the pollutants and debris is part of the preparations for operation. This is done through Flooding, Cleaning and Gauging (FCG), a well-established method for pipeline cleaning in the oil and gas industry. The method can consist of several processes, mainly flooding with fluids and sending pig trains through the pipeline. The cleaning of the CO_2 pipeline to remove debris is crucial, as the injectivity of the well can be reduced by the debris. This FCG operation was performed as planned in June of 2023.

What happened

- Despite that number of pigs in the FCG pig train was increased from 4 to 6 pigs and the first pig was equipped with bypass to keep debris suspended for easier removal, insufficient cleaning of the pipeline was concluded post FCG operation of pipeline from kp 52.3 – kp 108.9.
- The magnets on all 6 cleaning pigs were fully packed with ferrous debris. Expectation was that magnets on pig number 6 would have little or no ferrous debris compared to magnets on pig number 1. This would then indicate that the pipeline had been cleaned.
- Since the magnets on pig number 6 in the FCG pig train was just as packed with ferrous debris as the magnets on pig number 1 in the train, there was no evidence that the pipeline had been sufficiently cleaned during the FCG operation.

Lessons learned

- More ferrous debris than expected had been formed in the pipeline.
- Considering the service of the pipeline, CO_2 injection where good injectivity is critical, pipeline cleaning is important and should be planned for more extensively.

Recommendations

- Perform additional cleaning run to ensure the pipeline is sufficiently cleaned prior to start of CO_2 injection.
- Consider qualifying internal coating for pipeline for future CO_2 projects.

3.6 Installation of DCFO tails and nodes by lay-away method

Context

The Northern Lights Subsea Injection System (SIS) will be connected to the Oseberg A (OSA) platform for operations. This connection is through the Direct Current Fibre Optic (DCFO) cable and the umbilical. Northern Lights are amongst the first users of such a DCFO cable, meaning that there is no previous experience to build upon. The DCFO consists of the backbone DCFO cable with tails springing out of it to connect to the subsea structures at each well. These tails are connected by y-splices to the backbone cable and nodes with jumpers to the subsea structures.

The DCFO tails and nodes were installed in a separate campaign from installing the backbone DCFO cable. The tails and nodes were installed by "lay-away" method. This means that the nodes had to be landed on the subsea structure and then the tails were laid away from the subsea structures. The installation method required the already installed DCFO backbone to be retrieved onto the installation vessel for the connection of the nodes.

To make this method work, large bights (loops) of DCFO cable of between approximately 3.0 and 4.7 km length from the DCFO backbone to the template structures had to be established on the seabed to enable splicing of tails. See Figure 2 for the DCFO seabed layout.

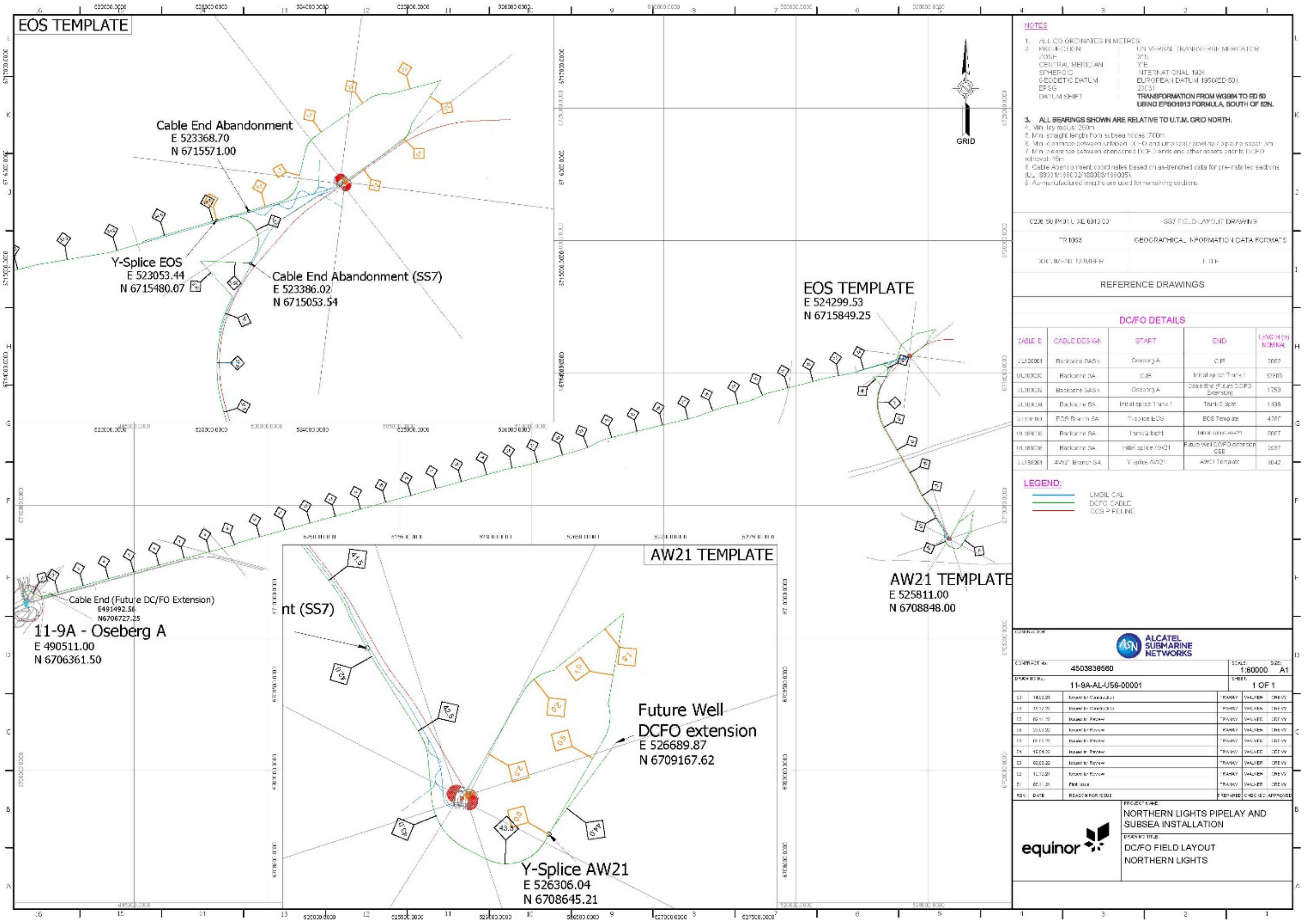

Figure 2 DCFO seabed layout

What happened

This installation method was time consuming as two tail ends had to be recovered to make the splice and resulted in extra lengths of tails between backbone cable and subsea structure. The campaign for installation of nodes and tails lasted for approximately 1 month, which is a long time for installing 2 nodes and splicing of tails.

The work was completed successfully but with additional cost for the length of installed product as well as offshore installation time. Following installation of the DCFO cable on the seabed, the scope of trenching is increased as well as additional Subsea Rock Installation (SRI) for those areas that cannot be trenched.

Lessons learned

The DCFO nodes and tails could have been more effectively installed by applying "lay-in" method.

- I.e. the majority of the tails will be installed together with the DCFO backbone. Then for installation of the nodes, the tail would be recovered to the installation vessel and spliced to a short tail on the node. The tail would then be installed towards the subsea structure and the node landed in the subsea structure.
- Node with short tails could then also be installed in the same campaign as the backbone DCFO cable.

- This would be a faster installation and the "looped" tails caused by "lay-away" method would not be necessary.
- Cost and time spent for installation would be significantly reduced compared to the "lay-away" method.

Recommendations

- Use "lay-in" method for installation of future DCFO tails and nodes.
- Challenge the DCFO contractor to justify its proposal for a lay-away method if proposed.
- Use Marine contractor for installation of both backbone and nodes.

3.7 Testing from OSA of DCFO cable during installation/lay

Context

Due to the installation method described in Chapter 3.6, where the “lay-away” method was used, multiple splices of the DCFO tails had to be conducted as part of the offshore construction activities. After each splice, extensive tests are conducted to ensure the joints made on deck for each of the fibre cables and the electrical conductors are within acceptance limits and to confirm the integrity of the overjacket. The overjacket is an outer sheath on the DCFO, used for protection against corrosion and mechanical damage.

What happened

The Project developed an installation sequence that required testing for each joint made to the subsea network on the installation vessel from both the host platform OSA and the Installation Vessel,. This required contractor personnel to be stationed on OSA and required dedicated support from OSA personnel providing 24-hour coverage. This working regime required specific derogation to established working practices whilst testing from two sites led to inefficiencies in the installation campaign.

Lessons learned

Testing from a single location, the installation vessel, would effectively decouple vessel and platform operations leading to a more efficient, safer, and less costly installation campaign. If it is not possible to implement such a regime, a minimum of 6 months should be allowed for the approval process when seeking 24 hours working from the platform.

Recommendations

Future projects should evaluate methods of test which allow testing during installation to be conducted from the installation vessel, limiting testing from the Platform to the final, post lay test.

3.8 Review of Northern Lights start-up plan across the whole project

Context

To get the Northern Lights facility up and running, a long list of activities must be performed both in parallel and consecutively. Some activities depend on other activities having been performed and others need to take place in the same areas, which means having a precise start-up plan describing these activities is crucial. The start-up plan was developed with the entire project’s scope in mind, meaning that input from project members across all scope areas is required. The end date in the start-up plan is the acceptance test, where the entire facility will be filled with CO_2, including the pipeline and the injection of CO_2 into the reservoir.

What happened

A full day workshop was held in September 2023 with the focus on going through all key activities completed and what is planned up to and including acceptance test across all scope areas. These activities depend on both internal and external parties to the project, for example customer ships, Sture, onshore facilities, subsea, wells, sub surface and OSA. The meeting participants covered all scope areas, OSA pre-ops personnel, Operations and NLJV.

- Focused presentations were held on topics where there are typically many interfaces.
- A similar workshop was also held in June 2022.

Lessons learned

The learning was very positive:

- All participants had the opportunity to learn what is going on across all scope areas in the project.
- Common understanding of key focus areas going forward towards acceptance test.
- Team building across TSP, Oseberg and NL JV.

Recommendations

Continue with the start-up workshops on a regular basis (minimum one per year) to ensure alignment in the team.

3.9 Fit for purpose specifications

Context

Northern Lights is developed under a company specific management system and uses corporate specifications and guidelines established with the oil and gas industry as basis. These are not always fit for purpose as CO_2 is not the same as hydrocarbons. For example, the properties of the CO_2 differs from hydrocarbons in that it is not a pollutant, neither flammable nor defined as toxic. However, it is heavier than air at atmospheric conditions and can cause suffocation if present at high concentrations. These properties make for a different risk picture than what is common for facilities with hydrocarbons, where the medium is both flammable and toxic. The operating conditions are also different from most oil and gas plants as the liquid CO_2 needs to be transported under moderate pressure and at low temperature. The value generated by handling of the CO_2 is also quite different from the hydrocarbon business, leading to different requirements for availability and regularity. The market for CO_2 is under development and has different drivers than the market for hydrocarbons.

What happened

During the design development, many engineering hours were spent to find acceptable solutions based on the existing corporate specifications and guidelines. This has led to solutions sometimes converging towards over-design.

Lessons learned

Lessons learned over the execution period of Northern Lights indicates a new explicit set of specifications is required that address the specific need of a low-cost business with a different product with vastly different risks.

Recommendations

- The specification set for CCS should start from zero and provide arguments for adding in requirements, rather than value engineering by subtracting from existing set of oil and gas requirements. Inspiration for the new set of specifications could use onshore industry standards such as European Industrial Gases Association (EIGA). EIGA is an organization for producers of industry, medicine, and food gases.
- A dedicated team should be given this task with appropriate framing from management to ensure team, technical ladder and subject matter experts are adequately motivated and equipped to deliver.
- This work will require strong focus on experience transfer to ensure that the improvements on specifications are available to and included in future projects.

3.10 Application for injection and storage of CO_2 to NEA and ESA

Context

To be allowed to inject and store the CO_2 that the Northern Lights facility receives, an injection and storage application according to the pollution regulation, must be submitted to the (NEA) for approval. NEA then has the obligation to send the application to EFTA Surveillance Authority (ESA) for information. NEA will process the application and make a draft permit, that will be sent to ESA for commenting. ESA then has four months to send comments back.

What happened

Due to ESA's involvement the content of the application had to include more information than expected from the already approved Plan for Development and Operation (PDO) and Plan for Installation and Operation (PIO). It also required to detail out activities as decommissioning, which is normally handled separately by NEA upfront of the activities.
ESA required all documentation in English as well, including Impact Assessment. This requires additional cost and increased timeline for preparation of the document and delivery of additional document. Application was submitted in December of 2022, with additional information being provided up until October 2023.

Lessons learned

The application for the Northern Lights project is the first Norwegian project to go through the ESA process. Processes involving ESA is new for all actors involved and led to additional work for project that was not expected. The consequence is that the application process to NEA and the Ministry of Petroleum and Energy (MPE) cannot be aligned and optimised as one single injection and storage application. As this application is crucial for the internal milestone for when the facility is to be ready to receive CO_2, this application must be sent early enough as to jeopardize the project's ability to reach this milestone.

Recommendations

- Streamline process and keep the process towards handling of draft permit and not application content.
- Optimize regulation process and seek to have one application for injection and storage to both NEA and ESA.