Ministry of Petroleum and Energy

Feasibility study for full-scale CCS in Norway

GASSNOVA

GASSCO

Contents

1 Summary

1.1 Introduction

This is an unofficial English version of the report "Feasibility study for full-scale CCS in Norway". In case of deviations between the Norwegian and English versions, the Norwegian version prevails.

In the Sundvolden Political platform, the Government states that it will "invest on a broad front to develop cost-effective technology for carbon capture and storage (CCS) and seek to build at least one full-scale carbon capture demonstration plant by 2020". The Government's CCS strategy was presented in Proposition 1 S to the Storting (2014-2015). The strategy covers a wide range of activities, including the assessment of potential full-scale CCS projects in Norway.

Gassnova's pre-feasibility “Study report on potential full-scale CCS projects in Norway” from May 2015 identified several emission sources and storage sites that may be technically feasible for a CCS project. It also identified industrial players that could be interested in participating in further studies. In the autumn of 2015, the Government decided to continue this work and initiated a feasibility study.

The Ministry of Petroleum and Energy (MPE) has had overall responsibility for the feasibility study. Gassnova SF has been project coordinator and responsible for the CO_2 capture and storage components of the study, while Gassco AS has been responsible for the CO_2 transport component.

Three companies have studied the feasibility of CO_2 capture at their industrial facilities. Norcem AS has assessed the feasibility of capturing CO_2 from the flue gas at its cement factory in Brevik; Yara Norge AS has assessed CO_2 capture from three different emission points at its ammonia plant at Herøya in Porsgrunn; the Waste-to-Energy Agency in Oslo municipality (EGE) has assessed CO_2 capture from the energy recovery plant at Klemetsrud (Klemetsrudanlegget AS). Gassco has carried out a ship transport study with assistance from Larvik Shipping AS and Knutsen OAS Shipping AS. Statoil ASA has assessed the feasibility CO_2 geological storage at three different sites on the Norwegian Continental Shelf.

The aim of this feasibility study was to identify at least one technically feasible CCS chain (capture, transport and storage) with corresponding cost estimates and this has been achieved.

The results of this study demonstrate that a flexible CCS chain is feasible that makes use of CO_2 transport by ship from multiple sources to a single storage hub. That would mean the initial investment in CO_2 infrastructure can benefit several CO_2 capture projects.

1.2 Technical feasibility and costs

CO_2 capture is technically feasible at all three emission locations. Given the project's objective, both Statoil and Gassnova consider a solution with an onshore facility and a pipeline to "Smeaheia" as the best solution for CO_2 storage. The "Smeaheia" area is located east of the "Troll" field, approximately 50 km from the coast. This solution has the lowest implementation risk, large storage capacity and it is relatively easy to increase the capacity of the infrastructure. Developing a CO_2 storage site is possible in many different ways, but other solutions than with an onshore facility will entail a higher technical risk.

Ship transport of CO_2 between locations for capture and storage has been assessed for three different pressure and temperature conditions. Gassco considers the solutions for all three studied transport conditions (low-pressure, medium-pressure and high-pressure) as technically feasible.

The cost for planning and investment for such a chain is estimated to be between 7.2 and 12.6 billion kroner (excluding VAT). The planning and investment cost will depend on how much CO_2 will be captured, where it will be captured from, and how many transport ships are needed. Operational costs vary between approximately 350 and 890 million kroner per annum for the different alternatives. The cost estimates are based on the reports from the industrial players and have an uncertainty of +/- 40% or better.

1.3 Assessments of benefit

In order for a full-scale project to gain a socio-economic benefit, it must contribute to the reduction of barriers and costs for the next CCS projects. In parallel with the feasibility study, the Ministry of Petroleum and Energy (MPE) has carried out a Concept Evaluation, which seeks to answer whether full-scale CCS is socio-economically profitable. The Concept Evaluation sets requirements for a project in order to achieve these effects. The following aspects from the Concept Evaluation form the basis for evaluating the benefit from a CCS project:

- Achieve knowledge that can be shared across countries and sectors.
- Provide a storage solution with sufficient capacity for economy of scale.
- Demonstrate that CCS is a safe and effective climate measure.
- Contribute to improvements of the market situation for CCS.

The assessment of benefits shows that all alternatives will contribute to significantly reducing barriers and costs for subsequent CCS projects. This is in particular valid for alternatives which establish and qualify storage sites and other infrastructure with capacity to store excess amounts of CO_2.

Important learning will be achieved through realisation of one of the alternatives; construction and operation of CO_2 capture facilities integrated with existing industry facilities, regulation of CCS chains, the establishment of a business model for capture, transport and storage, updated cost estimates and the further development of capture technology.

For CO_2 storage, an onshore facility will be well suited to provide economy of scale in the sense that it has capacity to receive volumes that are higher than are needed from an initial demonstration plant. If investing in more than one capture project, CCS will prove even to a greater extent that it is a safe and effective climate measure. This is because of lower risk of lack of CO_2 for the chain, and because cost per unit CO_2 reduced will be lowered with increasing CO_2 volumes in the chain.

All alternatives can contribute to improvements of the CCS market situation, and reinforced if capture from several CO_2 sources is realised. Stimulation of the market for CCS is important to achieve further technology development and cost reductions for other future projects.

1.4 Framework conditions and incentive structure

The State's starting point is a split of costs and risk between the State and the industry players that participate in the project. During the feasibility study phase, the State has informally explored possible incentives and principles for sharing costs and risk in the development and operating phase.

State support for a first CCS project will be a combination of several elements. State support rules prohibit covering more than the cost related to CCS. A combination of support for investment and operations could be a solution. Important parameters such as required rate of return, discount period, and length of state support period will also have to be determined before making an investment decision. An overarching objective of the State's effort to establish framework conditions and incentives for an initial CCS project is directed at the State and the industry players achieving maximum concurrence in the incentives for building and operating a cost effective CCS chain.

1.5 Next phase – the concept and FEED phase

The next phase will be used to optimise concepts for the identification of the best-suited solution for a CCS chain, clarify technical requirements in the chain, and develop a technical and commercial basis for an investment decision. Preparing for the construction phase is also part of the task. This work is necessary to provide a sufficient basis for an investment decision for both the State and the industry players.

According to the feasibility study report, the next step in the project should be a combined concept and Front End Engineering and Design (FEED) phase, which could be announced in the autumn of 2016 as a competitive tender process. Signed contracts for the concept and FEED phase could be obtained in the first quarter 2017 and the work finished early in the autumn of 2018. This work will form the basis for the State's quality assurance and decision processes for an investment decision (Decision Gate 3), a decision that can be taken, according to this plan, in the spring of 2019. If so, a full-scale CCS project can have its start-up in 2022. The industry players will have to make their own investment decisions, therefore they should carry out these studies according to their own project execution models and procedures.

Based on the result from the feasibility study, Gassnova recommends that several of the industry players should get the opportunity to continue to study CO_2 capture in the next phase. More participants will enhance competition and thereby contribute to assuring cost effective solutions in the project. Further assessment of multiple emission sources also reduces the risk of no completed project should one or more of the CO_2 emission sources failing to provide CO_2.

Gassnova will be responsible for managing the project through the concept and FEED phase. Gassco will be responsible for work related to transport. The Ministry of Petroleum and Energy will have overall responsibility for the development of framework conditions and incentives.

Before announcing the concept and FEED phase, a decision must be made as to how many players will receive support for the concept and FEED phase and, if relevant, at what point this selection should be made. Before commencing the concept and FEED phase, the overall design basis for the CCS chain, pressure and temperature conditions for ship transport and development solution for the CO_2 storage site must be clarified. These issues will have to be thoroughly discussed with the industry players, and decisions should be based on what is optimal and will give the best balance of cost and benefit for the total chain.

The CCS-project is subject to external quality assurance under the Norwegian state's quality assurance process for large public investments (the "KS scheme"). The quality assurance process includes two stages, KS1 and KS2, where KS1 is currently ongoing and expected to be complete by 31 August 2016. KS2 will need to be completed before any final investment decision by the Storting.

2 Introduction

In the Sundvolden Political platform, the Government states that it will "*invest on a broad front to develop cost-effective technology for carbon capture and storage (CCS) and seek to build at least one full-scale carbon capture demonstration plant by 2020*". During the processing of the 2014 national budget, Proposition 1 S (2013-2014), every party in the Storting (The Norwegian Parliament), except for the Norwegian Green Party, supported resolution XIX: "*The Storting approves the ambition to build at least one full-scale carbon capture plant by 2020*", cf. Recommendation 9 S (2013-2014) from the Standing Committee on Energy and the Environment. The Storting's endorsement of the ambition was expanded to also include CO_2 storage. The Government's strategy for the CCS work was presented in Proposition 1 S (2014-2015).

The Ministry of Petroleum and Energy (MPE) is responsible for following up the Government's CCS policy. The Government's CCS strategy covers a broad range of activities. The key elements of the strategy comprise research and technology development, investment in the technology centre for CO_2 capture at Mongstad (TCM), work on the realisation of a full-scale carbon capture, transport and storage (CCS) demonstration project as well as international cooperation.

Given this strategy, Gassnova, along with Gassco and the Norwegian Petroleum Directorate, was asked to map the feasibility of realising a full-scale CCS demonstration plant in Norway. The work was done as a pre-feasibility study. The "Study on potential full-scale CCS projects in Norway" was submitted in May 2015. The pre-feasibility study identified several emission sources and storage sites that could be technically feasible for a CCS project. It also identified industrial players that may be interested in participating in a further feasibility study. Furthermore, the pre-feasibility study demonstrated that the industrial players' interest in participating in a CCS project will be depend on what framework conditions are established by the Norwegian State. The industrial players provided their input on this in connection with the pre-feasibility study work.

Based on the pre-feasibility study, the Government decided to continue the project in a feasibility study phase in the autumn of 2015 (MPE, 2015). This report documents the findings of this latest study. The MPE has had overall responsibility for the project, while Gassnova has been responsible for managing individual studies within CO_2 capture and CO_2 storage and Gassco has been responsible for managing the CO_2 transport study. In addition Gassnova assisted the project manager in the MPE with necessary resources for coordination and management of the overall feasibility study project.

Any new CCS project development in Norway is subject to external quality assurance under the Norwegian state's quality assurance process for large public investments (KS scheme). The first of two rounds of quality assurance (KS1) is ongoing and will be finalised on 31 August 2016.

2.1 Purpose

This document summarises the results from the component feasibility studies and will draw general conclusions for the entire CCS chain. The document is an important part of the basis for the Government's decision on whether to continue the project in a concept and FEED phase.

The aim of the feasibility studies is to identify at least one technically feasible CCS chain (capture, transport and storage) with corresponding cost estimates within an uncertainty range of +/- 40%. The component feasibility studies also include work to identify and understand the industrial players' expectations and need for incentives and risk mitigation from the Norwegian state for planning, development and operation of a CCS project.

The need for technology development and potential for dissemination shall be documented as part of the feasibility study work.

3 Implementation of feasibility studies

Based on the pre-feasibility study, Gassnova signed feasibility study contracts for CO_2 capture with Norcem Brevik, Yara Porsgrunn and the Waste-to-Energy Authority in Oslo municipality (EGE) at the start of the current phase of work. The pre-feasibility study recommended ship transport of CO_2 from the Norwegian east coast to west coast and this formed the basis of the feasibility study for transport. Following an open tender process, Gassco entered into contracts with Larvik Shipping and Knutsen OAS Shipping for assistance with the ship transport study. For execution of the feasibility study on CO_2 storage, the MPE entered into a contract with Statoil following an open tender process, and MPE appointed Gassnova to follow up delivery.

Norcem has assessed the feasibility for capturing CO_2 from the flue gas at its cement plant in Brevik. Yara has assessed CO_2 capture from three different emission points at its ammonia plant at Herøya. EGE has assessed CO_2 capture from Klemetsrudanlegget AS, an energy recovery plant from waste incineration.

Statoil assessed the feasibility of CO_2 storage at the following three locations on the Norwegian Continental Shelf: 1) The “Smeaheia” area directly east of the Troll field, 2) the Heimdal field and 3) the Utsira South area near the Sleipner field. The locations were defined based on the request for tender and Statoil's tender. A number of different offloading solutions for CO_2 from ships were also assessed: offshore offloading to a platform, offshore offloading to a floating storage and injection ship (FSI), offshore offloading directly to an injection well and harbour offloading to an onshore buffer storage facility that would then be connected to an injection well by a pipeline link.

The feasibility of ship transport was assessed for three different pressure and temperature conditions; low, medium and high.

Figure 3.1 below provides an illustration of what the feasibility study assessed. Further details of capture, transport and storage of CO_2 is included in Chapters 5, 6 and 7.

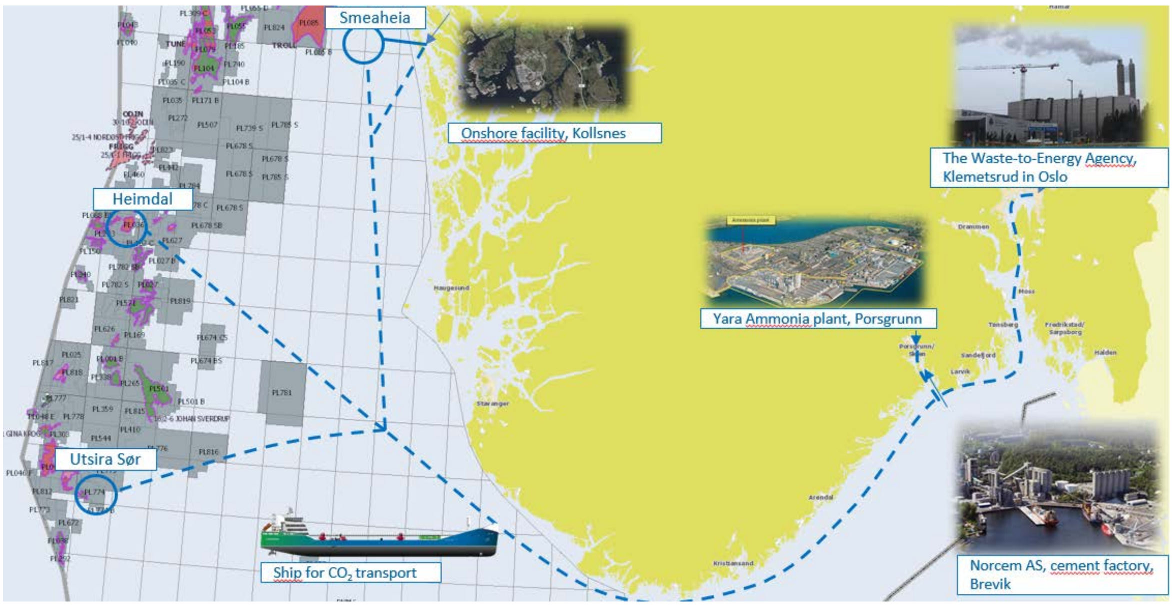

Figure 3.1 Illustration of CO_2 chains assessed in the feasibility study.

3.1 Basis for the feasibility study

This chapter describes framework and guidelines for this feasibility study and its components within CO_2 capture, transport and storage. The scope is consistent with that of the pre-feasibility study; land-based emission sources with annual emissions of 400,000 tonnes of CO_2 or more unless exceptional benefits from CCS application could be demonstrated.

The framework for the feasibility study was defined by an initial design basis for the CCS chain that was established by MPE (MPE, 2016c). The design basis was prepared with input from relevant stakeholders. The purpose of the design basis was to describe relevant parameters to clarify technical and organisational interfaces in the value chain. A primary objective of the design basis was to contribute to a comprehensive approach to the CCS chain and to optimise technical solutions within each sub-project with regard to the entire chain.

The current section describes the most important premises for implementation of the feasibility study.

It was important to clarify the definition of the interface between capture, transport and storage at an early stage in order to define the scope of work for the various sub-projects. The interfaces between capture, transport and storage are shown in the Figure 3.1.1 below. It was a key principle that any needs for interim storage before or after ship transport were included in the capture and storage studies, respectively.

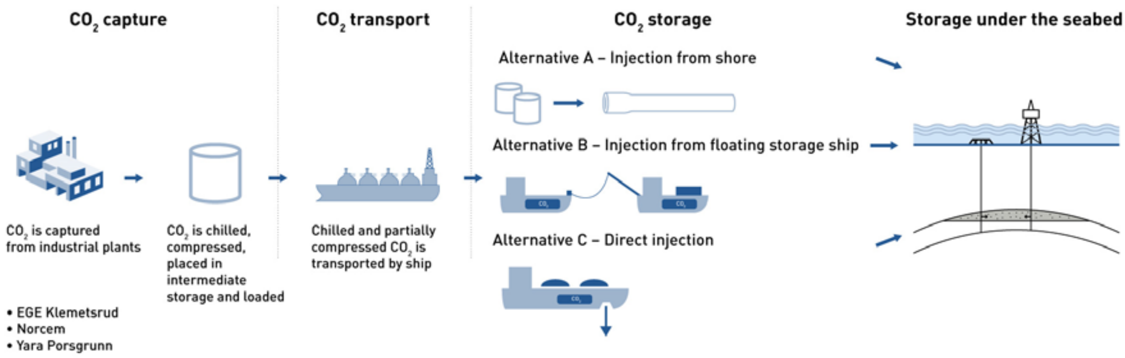

Figure 3.1.1 Schematic presentation of a CCS chain with interfaces.

Another key parameter was the size of the volumes to be transported and stored, as well as their source. The starting point in the design basis is that the CCS chain will be designed to allow for capture, transport and storage of CO_2 from all three industrial plants. The following volume alternatives were defined as the basis for this feasibility study:

- Reference alternative: 0.6 million tonnes CO_2 per year (CO_2 from two capture plants)
- Sensitivity 1: 1.3 million tonnes CO_2 per year (CO_2 from three capture plants)
- Sensitivity 2: 0.4 million tonnes CO_2 per year (CO_2 from one capture plant)

The volume alternatives represent a range of how much CO_2 will be captured, transported and stored, regardless of which capture plants, transport solutions and storage locations are chosen at a later stage in the project.

Yara, Norcem and EGE have evaluated solutions where their CO_2 can be placed in interim storage and be offloaded to transport ships according to set preconditions for shipping logistics. The storage study was based on storage of 1.3 million tonnes of CO_2 per year, with an option to scale the CO_2 volumes up or down.

The temperature and pressure conditions at which the CO_2 will be transported on the ships will influence the design of CO_2 conditioning equipment for the capture and storage studies. There are multiple references for suitable conditions for ship transport, but a decision was made for the feasibility study that the capture and storage studies must be based on the assumption that CO_2 is transported at a pressure of 15 bar and temperature of -25 °C (medium pressure). Low pressure (6-8 bar) and high pressure (45-60 bar) were also studied in order to determine the most optimal transport of CO_2.

Requirements related to maximum content of impurities for the CO_2 being transported and stored is also an essential parameter that will influence the design of the CCS chain. Specific requirements have been set for components that are assumed critical with regard to corrosion. Several parameters with a “non quantifiable” value have also been defined, which are expected to be present, but for which it is challenging to define critical values. The result of the feasibility study shows that a study should be carried out to assess the cost consequences of changing the CO_2 specification in different parts of the chain with the objective of establishing a CCS chain that is operationally optimised and has sufficient integrity.

An operational period of 25 years is used as a basis for technical design of the CCS chain.

4 Learning and dissemination effects

In the spring of 2015, the Ministry of Petroleum and Energy (MPE) conducted a concept evaluation (KVU) on full-scale demonstration of CCS (MPE, 2016d). A major goal of realising full-scale CCS in Norway is contributing to reducing barriers and costs for the next round of projects.

The concept evaluation stipulates requirements for CCS projects to ensure the goals of the measure be achieved. They are:

1. Achieve knowledge that can be shared and transferred across countries and sectors.
2. Provide a storage solution with sufficient capacity for economy of scale.
3. Provide positive learning effects in connection with:
    a. The investment and operating phase along all stages of the CCS chain, and the overall chain.
    b. Regulatory conditions.
    c. Providing up-to-date information on costs.
    d. Contributing to technology development.
4. Demonstrate that CCS is a safe and effective climate measure.
5. Contribute to improvements of the market situation for CCS.
6. Realisation as soon as possible.
7. Expedient distribution of costs and risks between the Norwegian state and industry.

The requirements will be operationalised as the project progresses to ensure that benefits are achieved through the project.

Learning through the project should be achieved both for the individual player, for the integrated CCS chain and for other involved players. The benefit of the learning will depend on how many future projects are initiated and the cost reduction potential that the learning can provide.

The largest cost reduction potential that the project can provide for future projects is expected to be the making available a storage site that can be used by several capture projects. Furthermore, there are significant commercial and regulatory barriers preventing CCS from becoming commercially relevant. Learning and sharing experiences related to this could be an important contribution for reducing barriers for future projects. CCS projects are capital-intensive. It is expected that increased faith in the technology and its commercial potential could reduce financing costs for projects in the future. Sharing experiences with relevant players can help reduce costs.

Learning effects related to capture technologies, including optimisation of integration towards primary production, could also contribute to significant cost reductions. Such learning effects primarily occur when technologies and solutions are utilised by commercial players. It is therefore important that the frameworks for future projects be clarified to generate commercial interest, so the gains can be realised.

Chapters 5, 6 and 7 will discuss learning and relevant dissemination effects for the capture, transport and storage part of the project. Chapter 8 provides a general summary of the learning and dissemination potential for the entire CCS chain. Chapter 9.1 discusses, among other items, further work that is in planning to obtain benefits from this project.

5 CO_2 capture

5.1 Summary

CO_2 capture has been studied at three land-based emission locations in Norway as part of the feasibility study; Norcem assessed the possibility of CO_2 capture from the flue gas at its cement plant in Brevik, Yara assessed CO_2 capture from three different emission points at its ammonia plant at Herøya and the Waste-to-Energy Agency in Oslo municipality (EGE) has assessed CO_2 capture from the energy recovery plant at Klemetsrud (Klemetsrudanlegget AS).

The feasibility study show that CO_2 capture is technically feasible at all three locations and that, in total, capture of up to 1.5 million tonnes of CO_2 per year could be possible. All industry players delivered feasibility studies with a satisfactory level of maturity and detail for a DG1 decision basis, including assessments of technical, economic and health, safety and environment consequences of implementing CO_2 capture plants in their existing facilities. The cost estimates were prepared within an uncertainty of +/- 40% or less.

This chapter discusses the owners of the emissions and their emission points, costs, plans, health, safety and the environment (HSE), learning and dissemination effects and recommendations for further work ahead. The regulatory plan for the entire CCS chain is discussed in Chapter 10.

5.2 Development of CO_2 capture technology

In 2005, the Ministry of Petroleum and Energy established the CLIMIT programme to provide financial support for the development of CCS technology. Over the past ten years, Norwegian research environments, industry and technology suppliers, have collaborated with international partners to carry out about 300 development projects with approx. NOK 1.7 billion in support from CLIMIT. This support triggered corresponding amounts from industry partners and has allowed Norwegian players to develop internationally recognised solutions and expertise within CCS.

CO_2 Technology Centre Mongstad (TCM), in operation since 2012, has facilities for testing both amine-based technologies and chilled ammonia process (CAP). The size of the capture plants at TCM, with a capacity of up to 100,000 tonnes of CO_2 per year, is highly relevant for scaling up capture technology from pilot scale (CLIMIT-financed projects) to full-scale projects. In addition to Aker Solutions and GE that constructed the two technology plants at TCM, three other technology suppliers have tested and optimised their solvents at TCM or have entered into agreements for future testing. There is also an established practice at TCM for evaluation of emissions and dispersion of trace elements from the solvents so that various CO_2 capture technologies can be compared. This work also formed the foundation for multiple countries' authorities' regulation of emissions from CO_2 capture plants.

Five suppliers of CO_2 capture technology underwent an extensive technology qualification programme in connection with the previous full-scale project at Mongstad. This process included documentation of safe environmental handling of solvent-based capture technology. Today, several of these technologies have achieved a maturity level that can be used in a full-scale capture plant, including Aker's amine technology and GE's chilled ammonia process (CAP) technology. Aker and GE were sub-suppliers for EGE (Aker and GE) and Norcem (Aker) in the feasibility studies.

Work in projects supported by the CLIMIT programme, and conducted at the CO_2 Technology Centre Mongstad (TCM) and in connection with the full-scale project at Mongstad, has contributed, over the past few years, with knowledge and experience that have reduced technological and HSE-related risk associated with establishment of full-scale CCS projects in Norway. Therefore, there are capture technology suppliers who can deliver facilities for a full-scale project in Norway on a commercial basis.

5.3 Norcem

In its feasibility study, Norcem assessed solutions to capture 400,000 tonnes of CO_2 per year from its cement plant in Brevik. Norcem has a vision to achieve zero CO_2 emissions from its concrete products in a lifecycle perspective by 2030. In this context, Norcem investigated the possibilities of CO_2 capture from the flue gases in the cement production. In 2010, Norcem started CLIMIT-supported projects to assess alternative capture technologies. Results from these projects were used as a basis for the work on the feasibility study. Norcem has found, before the feasibility study started, in a 2020 perspective, the amine technology the most suitable capture technology. They chose Aker Solutions as its technology supplier through a broad-based technology and supplier evaluation process. Aker Solutions conducted more than 8,000 hours of testing on Norcem's flue gas with its mobile test unit, and the technology was thus considered sufficiently qualified by Norcem to remove CO_2 from Norcem's flue gas. Aker Solutions has previously completed successful test programmes at both TCM and other pilot facilities. In the work on the feasibility study, Norcem used multiple sub-suppliers to find and assess the impacts from a CO_2 capture facility on the premises of the cement plant in Brevik. Norcem placed particular focus on how residual heat from the cement production can be taken into use for CO_2 capture. Available heat makes it possible to capture about 400,000 tonnes of CO_2, which corresponds to approximately half of the plant's total CO_2 emissions. This has been the key basis for the design of the CO_2 capture plant. Suitable solutions have also been found for interim storage and shipping of CO_2 on the quay in Norcem's area.

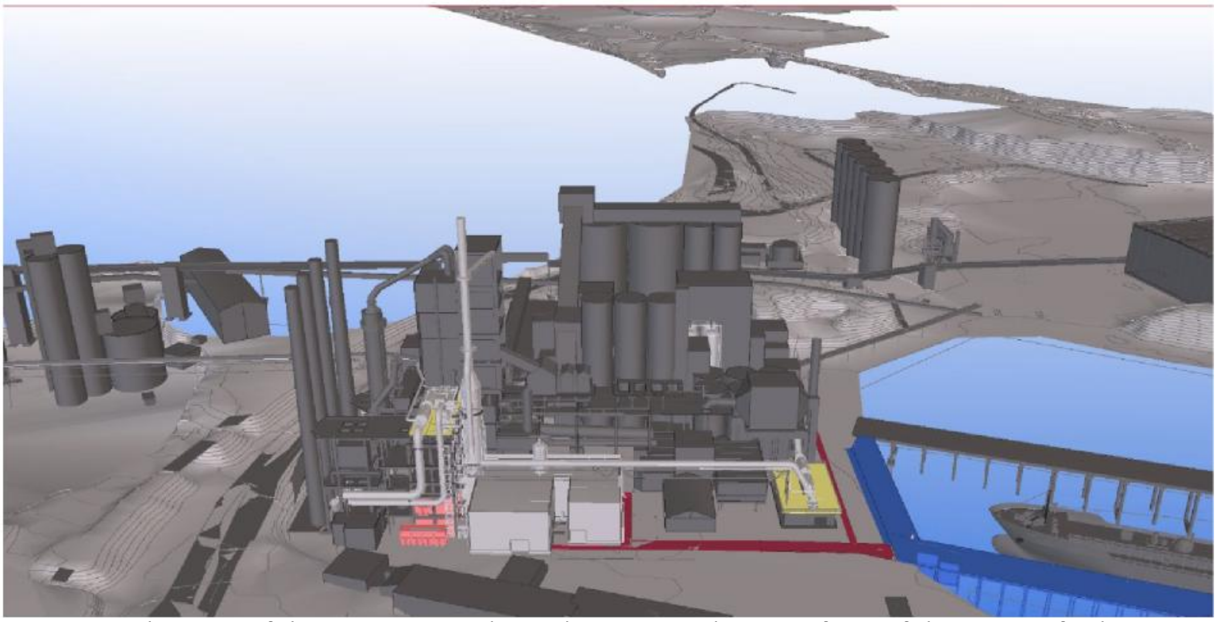

Figure 5.3.1 location of the CO_2 capture plant. The capture plant is in front of the cement facility. (The cement facility in dark grey).

No elements have been identified that would indicate that a CO_2 capture plant cannot be built. By capture of 400,000 tonnes of CO_2 per year, in combination with the use of CO_2-neutral energy (biofuel) in production, Norcem will be in position to achieve its goal for zero CO_2 emissions from its products in a lifecycle perspective.

5.4 Yara

Yara has assessed the possibility of capturing 805,000 tonnes of CO_2 per year from its total emissions of 895,000 tonnes from its ammonia plant in Porsgrunn. This would come on top of the 200,000 tonnes that they already capture and sell for use within food production today. Overall then, they will capture about 90 per cent of the plant's total CO_2 emissions. Yara has for many years prioritised to reduce greenhouse gas emissions from its production.

Yara's has been dedicated to reduction of the nitrous oxide emissions, and major reductions are obtained. Nitrous oxide is a greenhouse gas with a high CO_2 equivalent. In the CO_2 capture feasibility study, Yara has, for the first time, looked into the possibility of building a CO_2 capture facility for their ammonia production. The making of ammonia is the start of the production chain for fertilizer. It is also the most CO_2-intensive step in the production chain. Ammonia is a commercial product in a global market. The ammonia plant in Porsgrunn is thus in a competitive situation where the cost of producing ammonia for fertilizer production must be cheaper than purchasing ammonia (including transport costs).

Figure 5.4.1 Ammonia plant N2 in Porsgrunn. In the four water wash towers in the foreground, CO_2 is removed from the process gas.

There are three primary sources of CO_2 emissions from the ammonia plant.

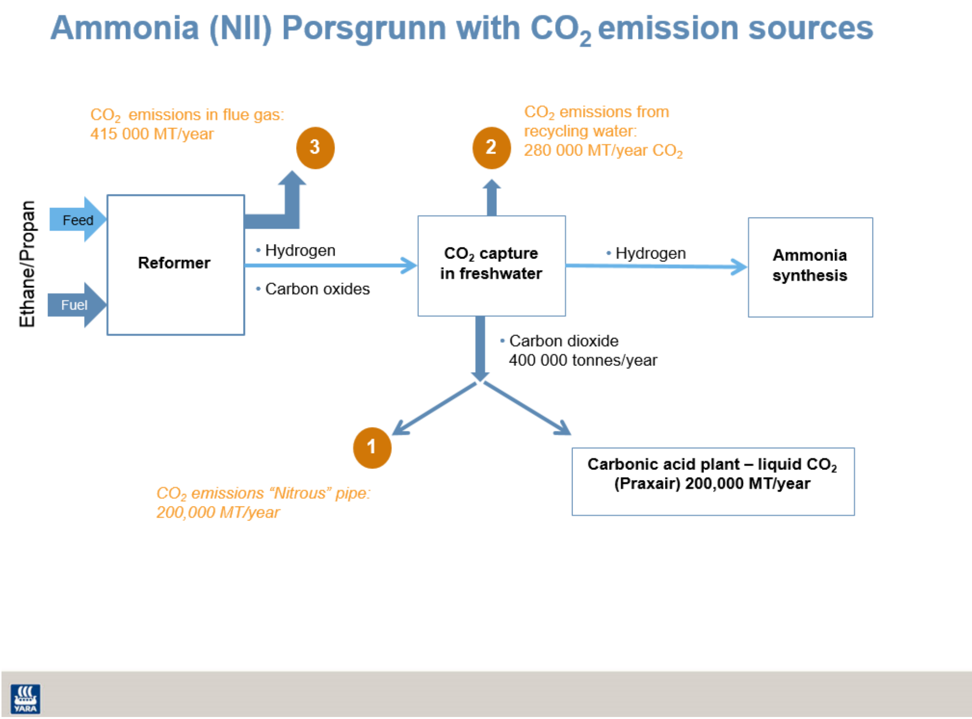

Figure 5.4.2 Ammonia plant N2 in Porsgrunn with three CO_2 emission sources.

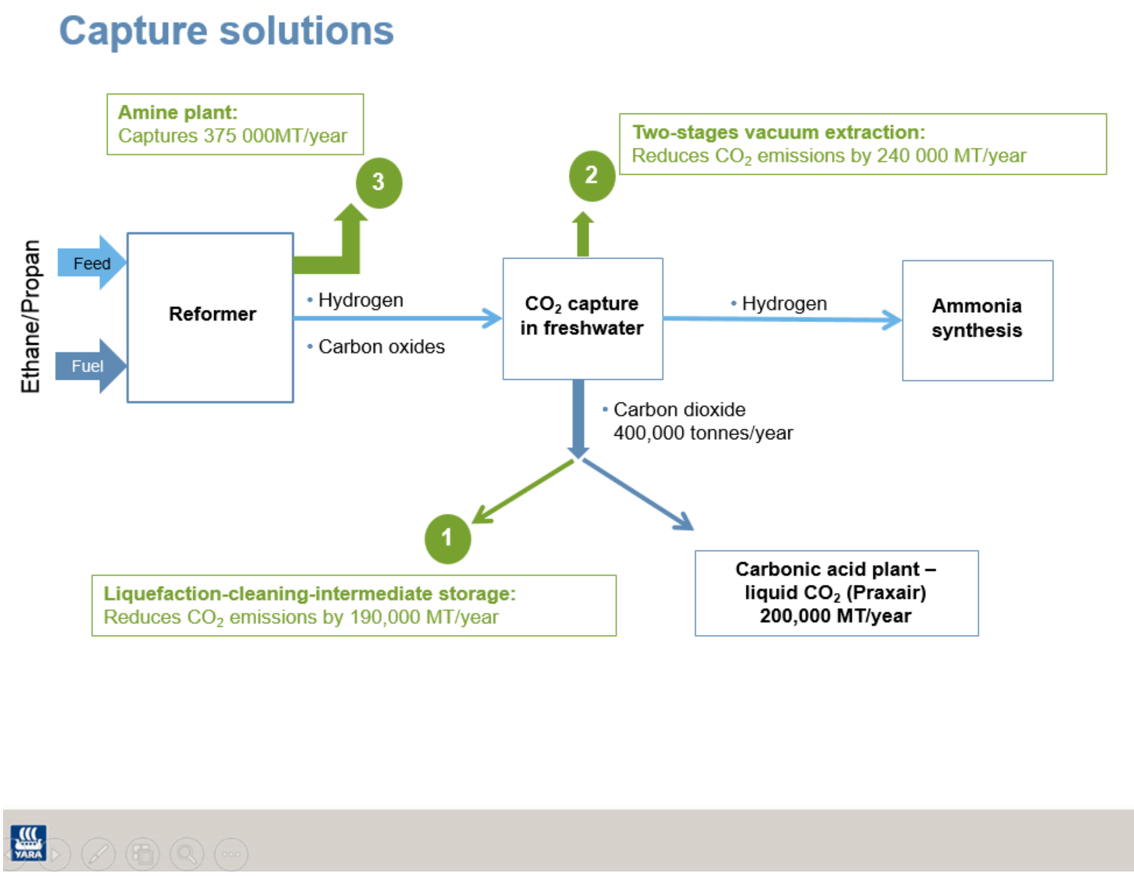

Figure 5.4.3 Capture solutions for the three CO_2 emission sources.

Sources 1 and 2 come from the process of cleaning CO_2 from the production stream (through absorption of CO_2 in water, so-called water wash). The third emission is flue gas from a gas-fired reformer. Source 3 will require a CO_2 capture plant with secondary combustion technology. Yara chose not to commit to one technology supplier in the feasibility study, but rather used an independent study supplier who designed and calculated the costs for an amine-based plant based on freely accessible information about the commercially available amine, monoethanol-amine (MEA). In the next phase, Yara anticipates a need to qualify a technical solution for sources 2 and 3 to reduce risk. Yara sells approx. 200,000 tonnes CO_2 per year, the CO_2 that is removed from emission point 1, to the food production industry. Their knowledge about CCS has been useful in the work performed in connection with this study, as well as beyond Yara's own studies.

The feasibility study shows that it will be technically feasible for CO_2 capture from the ammonia plant, and that the Herøya industrial park location is suitable for capture, intermediate storage and shipment of CO_2.

5.5 Oslo municipality represented by the Waste-to-Energy Agency

Oslo municipality, represented by the Waste-to-Energy Agency (EGE), has assessed the possibility of capturing 315,000 tonnes of CO_2 per year from the energy recovery plant at Klemetsrud. This constitutes about 90 per cent of the total CO_2 emissions from the Klemetsrud plant.

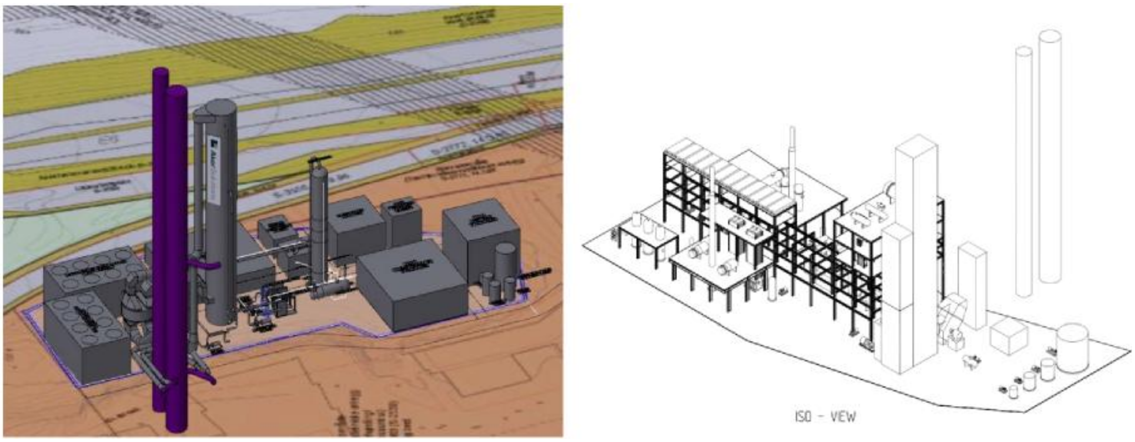

Figure 5.5.1 Sketch of Aker's amine plant (left) and GE's CAP plant (right) at Klemetsrud.

EGE's plant at Klemetsrud has lower annual CO_2 emissions than stipulated in the mandate for the feasibility study. However, EGE is included in the study as the plant at Klemetsrud is planning to ramp up production, thereby also increasing CO_2 emissions from the plant. The learning potential from the plant has also been deemed to meet the terms of the mandate.

EGE has assessed two different capture technologies, and chose Aker Solutions and GE as sub-suppliers in an open competitive tender process. Both GE's and Aker Solutions' capture technologies are based on absorption technology, but use different types of solvents. Aker Solutions' technical solution is based on their proprietary amine, while GE's technology is based on chilled ammonia. Both technologies have completed successful test programmes at both TCM and in other pilot plants. Both technologies are using heat pumps and steam turbines to recover and return sufficient thermal energy. This will allow the energy recovery plant to maintain the same thermal energy balance and thus allowing it to maintain its deliveries to the district heating grid in Oslo. Both technologies will use electricity produced at the energy recovery plant. Efficient energy integration and the use of air coolers have removed the need for establishing a cooling water system or reinforcing the electricity supply for the plant.

As EGE's plant at Klemetsrud does not have nearby access to a quay, extensive work was carried out to assess various transport options for CO_2 from the capture plant to Oslo harbour for intermediate storage and further shipment. Transport by pipeline with different routes (over land and along the seabed), tanker trucks and train have been considered. The assessment in the feasibility study concludes that transport by tanker trucks still appears to be the best solution. The next phase of the project will involve determining whether other driving fuels for the tanker trucks can be used to keep greenhouse gas emissions at a minimum (biofuel/electric/hydrogen). Ormsundkaia has been proposed as the location for intermediate storage due to the available area and the possibility for ship arrival.

The study shows that it will be technically feasible to implement CO_2 capture for 315,000 tonnes of CO_2 per year (capture rate of 90 per cent) from the energy recovery plant at Klemetsrud. A test of Aker's mobile test unit was carried out in parallel with the feasibility study. This test used real flue gas from the plant, and showed that CO_2 can be captured from the flue gas using solvent technology. The CO_2 capture plant will not have a negative impact on the energy recovery plant, which can still fully maintain its primary function, which is recovering energy from waste and energy deliveries to both the district heating grid and the electricity grid.

5.6 Joint intermediate storage site for CO_2 in Grenland

The point of departure in the design basis (ref. Chapter 3.1), is that the CCS chain shall be designed to include CO_2 from all three industrial plants to be captured, transported and stored. In this context, it is considered to establish a joint interim storage site for CO_2 at Herøya Industripark in Grenland. The assessment was conducted as a pre-feasibility study with unclassified cost estimates to determine whether there are synergy effects that could reduce the investment and operating costs for the players in the component feasibility studies. Potential positive effects with regard to the technical solution, logistics and HSE were also considered.

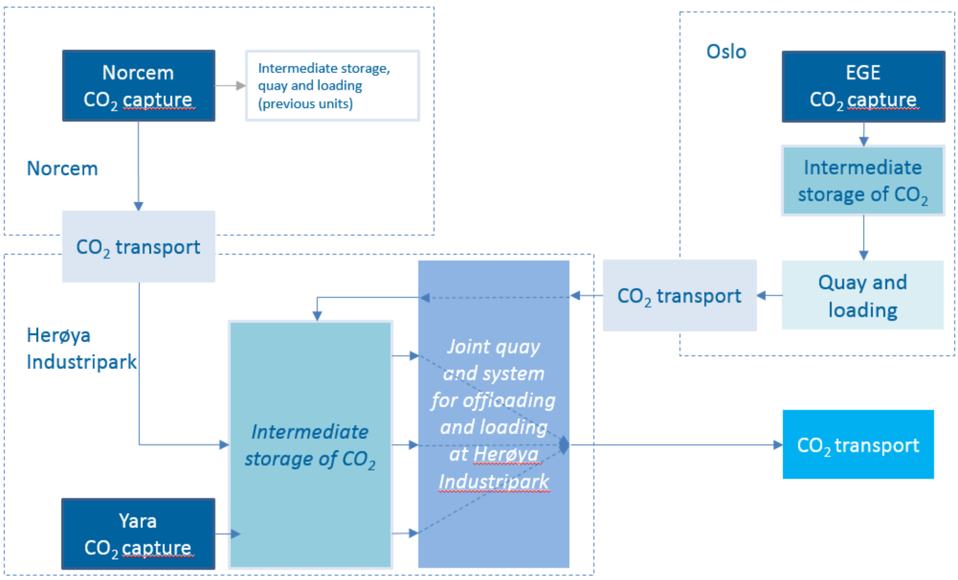

Figure 5.6.1 Joint CO_2 intermediate storage site in Grenland.

Potential positive synergy effects from a joint intermediate storage site for multiple CO_2 capture sources were identified in this work. A potential solution with a joint intermediate storage site for Yara, EGE and/or Norcem at Herøya Industripark should therefore be evaluated further if it becomes relevant to realise CO_2 capture from more than one emission source.

5.7 Health, safety and the environment (HSE)

Every CO_2 capture feasibility study also included assessments of health, safety and the environment (HSE), primarily for the operating phase of the capture plants. No HSE aspects have been identified that would prevent construction and operation of CO_2 capture plants, nor HSE requirements that would cause significant expenses.

Both ammonia and amine-based CO_2 capture processes will have issues relating to emissions, waste and use of chemicals. The understanding relating to the properties and handling of amines and their degradation products has increased substantially through research and studies, particularly in connection with planning of full-scale capture at Mongstad and the construction of TCM (Gassnova 2012, 2013) (Helgesen, 2016), (TCM DA, 2012). This means that both ammonia and amine-based CO_2 capture can now take place in a manner that is safe for both people and the environment. Since Norcem chose a technology supplier, they also considered specific HSE aspects such as spread of emissions to air and water. Yara and EGE will focus on this in the next phase of the project, after selecting their technology supplier.

New installations in existing industrial areas are normally subject to more stringent noise requirements to ensure that the entire area can comply with noise requirements in relation to the closest neighbour. Noise will be a challenge for all three locations and compliance with the current noise requirements will undergo further assessment in the next phase.

Norcem is the only party that studied accidental CO_2 spills, but Yara and EGE have also flagged this as one of the greatest HSE risks, as an incident of this nature could have a high hazard potential. However, the estimated risk of full pipe rupture in a CO_2 storage tank is far below the acceptance criteria used by the Norwegian Directorate for Civil Protection for such incidents.

All issues relating to the external environment and safety will be addressed further in a potential next phase. Impact assessment processes will also be completed for all facilities. All affected parties will be able to provide input to the impact assessment programmes.

5.8 Risk

Gassnova, Yara, EGE and Norcem have conducted risk analyses as part of the feasibility studies. No unmanageable risk elements have been identified. Risks can be both opportunities and threats. Joint risks identified by one or multiple players include:

1. Entire chain – If the company that captures CO_2 is shut down because the preconditions for primary production are no longer satisfactory, the CO_2 volumes in the chain will decline or disappear.
2. HSE – Possible local resistance towards CO_2 capture plants due to fear of emission of new components or increased strain on the local environment.
3. Production – Disruption of primary production during construction or operation of the capture plant, which could affect the player’s position in the market and create cost consequences.
4. Technology – The technical solutions for capture plants or heat integration are untested and require technical qualification in the next phase.
5. Realisation phase – Cost overruns for the owner of the plant and delays.

6. Production – Strengthening competitiveness for primary production as establishment of CCS support the transition to the low emission society.

5.9 Costs

The capture players used their own systems for cost estimation and quality assurance in the feasibility studies. Gassnova has reviewed the estimates, e.g. through a systematic presentation of the cost estimates in order to make comparisons between blocks of costs between the players and previous CO_2 projects.

The cost estimates were delivered as "first classified estimates" within a range of uncertainty of +/- 40 per cent (Class 4 estimate) (AACE, 2005). Norcem's cost estimate is within a range of uncertainty of +/- 30 per cent to balance requirements for internal decision-making processes.

The estimates are the expected costs of constructing and operating the CO_2 capture plant, including expected contingencies. The estimates do not include back-up or heavier obligations (such as performance guarantees). The players have delivered cost statements in accordance with the agreed structure, which has allowed Gassnova to compare the various estimates. An assessment was also made as to whether the estimates cover a complete work scope or whether elements are missing. These assessments were e.g. made with a basis in Gassnova's previous experience from CCS projects.

CO_2 costs from Yara's sources 1 and 2 are expected to be lower than the costs of capture from flue gas sources, as the existing process stage is exploited, where CO_2 is already captured and the existing plant is adapted to take advantage of this. These sources therefore do not require the cost elements related to a CO_2 capture plant from a flue gas source.

The costs of the capture process at EGE, Norcem and Yara's source 3, which are all CO_2 capture from a flue gas source, are largely comparable. The differences in total costs for these projects are mainly caused by local conditions related to preparation work at the existing site and varying degrees of heat integration with the existing plant.

5.10 Plans

The next step of the planning process for the capture projects is a combined concept and FEED phase (FEED). Norcem, Yara and EGE have presented plans for further maturing of their CO_2 capture concepts that will enable them to present the basis for an investment decision (DG3) in 2018. The most suitable CO_2 capture technologies and suppliers will be chosen during the concept and FEED phase and the final solution for integration of the capture plant with the existing plant will be designed. A cost estimate within an uncertainty of +/- 20 per cent will be developed and detailed plans for engineering and construction will be prepared.

The schedule for the construction phase was roughly estimated during this phase. The players have estimated somewhat varying schedules for constructing a CO_2 capture plant following an investment decision. The realisation period varies from 26 to 42 months. The variations are mainly caused by different needs for local preparation and adaptations to implement the capture plant.

5.11 Learning and dissemination effects

CO_2 capture at Yara, Norcem and EGE's emission sources hold a substantial potential for technology development and knowledge dissemination, both within and beyond the sectors in question. This includes:

- Learning related to technical integration and establishment of a "standard" design basis and CO_2 specification

- Regulatory conditions related to implementation of CCS in an industrial plant
- Commercial integration of CO_2 activities in existing business model
- Technical integration of CCS in existing plant
- Implementation and optimisation of CO_2 capture technology

The capture players have studied solvent-based capture technology for flue gas cleaning. However, there is a possibility that the players will choose different technologies and technology suppliers for further studies. One criterion is that the capture technology is considered sufficiently mature for full-scale. Through realisation, relevant capture technologies will be qualified for new industries. Furthermore, all of the concepts contain important qualification elements, including connection and heat integration with the existing plants.

The capture sources studied in the feasibility studies represent different sectors. The capture projects contribute complimentary learning and have different dissemination potentials as they come from different industries and could have different solutions for CO_2 capture on their facilities. The degree of learning and technology development will increase with the number of CO_2 capture projects that are built. They represent all industries that generally do not have any other alternatives than CO_2 capture and storage if they want to significantly reduce their CO_2 emissions, and a CO_2 capture project could thus contribute to a new environmental standard for the respective industries. Through further maturing of the projects during the concept and pre-project phase, the implementation should be optimised to harvest experience across the projects.

The cement industry represents about five per cent of the world's total CO_2 emissions, and CO_2 capture in Brevik could contribute to the global spread of CCS technology. A specific learning element from Norcem is how they will design the capture plant to capture an optimal volume through exploiting surplus heat from the cement production. This alternative is highly relevant for the process industry in general, as this industry often has surplus heat (thermal energy) that is not fully exploited. Norcem and Aker Solutions have developed new technical solutions to allow CO_2 capture to use existing energy from cement production without a negative impact on the operation of the cement plant. The solutions are based on use of smoke pipe heat exchangers, as well as heat recovery from compression of the captured CO_2 for further transport.

Energy recovery has a major growth potential as restrictions are being imposed at landfills in Europe and more new energy recovery plants will be built to combust this waste. CO_2 capture in an energy recovery plant could demonstrate so-called bioCCS (which is CO_2 capture from combustion of organic waste, which removes CO_2 from the natural flow). This is how CCS at Klemetsrudanlegget can contribute to important knowledge for a future-oriented industry. EGE has placed a major focus on integrating the capture plant with the energy flows in their facility. They use e.g. heat pumps for energy optimisation and integrate residual heat from the capture plant for delivery of heat to Oslo district heating system, among other things. This means that heat production from the energy recovery plant is not affected by the introduction of CO_2 capture. This contrasts with the preconceived notion that CO_2 capture from power plants will cause considerable losses in their primary production (power production) when they are capturing CO_2.

The ammonia industry represents somewhat limited of the total CO_2 emissions in a global perspective, but the industry has a significant potential for more reasonable CO_2 capture. Ammonia production could thus become an important industry in the first CCS rollout. CO_2 cleaning from Yara's reformer could generate significant knowledge extending beyond their own industry, to the chemical process industry in general, and hydrogen production based on natural gas in particular, as Yara's reformer is a standard process unit for splitting natural gas into hydrogen.

5.12 Gassnova's assessments

Based on the completed feasibility studies, Gassnova believes it is technically feasible to carry out CO_2 capture at all three emission locations. All players have delivered satisfactory cost estimates that reflect proposed technical solutions. The feasibility studies were not intended to rank the various capture projects, but to determine whether the various projects can be executed. This has been sufficiently clarified, and Gassnova recommends that the industry players be given an opportunity to further assess CO_2 capture. More participants in the concept and potential FEED phase will also encourage competition and will most likely have a positive effect with regard to minimising the Norwegian state's costs in subsequent phases. Further assessment of multiple sources also makes the project less vulnerable if one or more of the capture players fail to complete the process.

EGE, Norcem and Yara represent three different industries that all have significant CO_2 emissions, and generally have no better alternatives than CO_2 capture and storage to substantially reduce their CO_2 emissions. The players represent different industries and will need different technical solutions, and are therefore largely complementary as regards knowledge and dissemination potential. A common denominator for them all is that CO_2 capture is secondary to their primary production of cement, ammonia and energy recovery, respectively, and none of them will maintain CO_2 deliveries to a CCS chain if the basis for their primary production is lost. To ensure the CCS chain is robust, facilitation for realisation of more than one source of CO_2 is necessary.

Gassnova recommends establishing business models for upcoming CCS projects in parallel with the further project implementation process. The CO_2 storage site that will be established as a part of this project will have excess capacity that should be utilised by allowing more capture sources to store their CO_2 at the site. A higher overall stored volume will reduce the unit costs related to storage. This makes it possible to add, cost-efficiently, capture projects both those with a considerable technology development potential and those with smaller sources having reasonable and easily accessible CO_2 volumes. The limit of 400,000 tonnes CO_2 which this initial project has, should be removed in this connection, as the measures do not need to carry an investment in a storage site, and can rather be considered as ordinary climate measures. Establishment of a business model for upcoming projects will also be important for following up industry players that are potentially unable to build their CO_2 capture plant through this project, as well as generally maintain the significant Norwegian commitment to research and development and exploit the learning potential that the first CCS project will yield.

The choice of technical solution and design of a capture plant are closely correlated to commercial conditions and the requirements stipulated for the owners of the emissions during the planning, development and operating phase. Examples of this include regularity requirements, the volume of the captured CO_2 emissions, compensation format and financing model. Determining the design at an early stage in the next phase will be crucial in order to complete the project in accordance with the planned budget, schedule and quality. Gassnova therefore believes it is important to maintain the ongoing dialogue with the players to clarify framework terms, so that commercial conditions can be completed well before continuation to the concept and FEED phase. This will also be important for maintaining the industrial players' interest in participating in a CCS chain. For additional information about the topics described in Chapter 5, reference is made to Gassnova's CO_2 capture report that summarises the three completed feasibility studies (Gassnova, 2016 F).

6 CO_2 transport

6.1 Summary

The feasibility study for ship-based CO_2 transport was performed in accordance with Gassco's governing documentation for project management. The feasibility study emphasised maintaining the feasibility of ship transport of CO_2 that was identified in Gassco's pre-feasibility study from 2015.

The scope of work in the feasibility study covered relevant elements for ship-based transport of CO_2 between the capture location and storage location, such as ship, technical equipment, processes, logistics, operations, regulations, investment and operating costs and schedules.

Results and evaluations are based in part on studies conducted by Larvik Shipping and Knutsen OAS Shipping. Interface clarification vis-à-vis the capture plants and vis-à-vis the storage solutions has been key in the feasibility study and should be subject to special attention in the continuation of the project.

Ship solutions have been designed for the defined transport terms, low, medium and high pressure, respectively for the feasibility level, cost estimates were established within an uncertainty range of +/- 40 per cent and implementation plans that support feasibility. Gassco now considers all the evaluated solutions for ship transport of CO_2 as feasible, and ship transport is not considered to be a critical factor in the realisation of the full-scale project.

6.2 Technical assessments

The transport study has assessed three different transport terms for ship transport of CO_2, that each represent different technologies for transport of CO_2 in equilibrium between the gas and liquid phase. Operationally, it is important to prevent CO_2 from switching to solid form. At atmospheric pressure, CO_2 is exclusively in the gas phase and as dry ice.

The three evaluated solutions are briefly described in the below table.

	Low pressure	Medium pressure	High pressure
Condition	6 -8 bar at -50°C	15 bar at -25°C	45 bar at +10°C
Advantages	High density of CO_2. Known technology based on LPG ships. Scalable tank size and ships.	Experience from transport of CO_2 with food grade quality. Mature concept.	Least energy-intensive. Scalable tank capacity. Lowest energy demand with direct injection.
Challenges	Small operational margin against freezing to dry ice for CO_2. Energy-intensive process. High insulation requirements.	Relatively high volume of steel in the tank system. Technically challenging tank structure.	The tank system requires a lot of space, high steel weight and challenging piping. Less mature concept. Lowest CO_2 density.

Table 6.2.1: General assessment of alternative transport terms for ship transport of CO_2.

6.2.1 Ship design

The below figures illustrate the ship design for the three evaluated transport terms. Ships for transport of CO_2 at low pressure would have a comparable design as typical LPG boats, with large, cylindrical tanks. These ships will transport CO_2 with the highest density in liquid form, and would therefore be the smallest size.

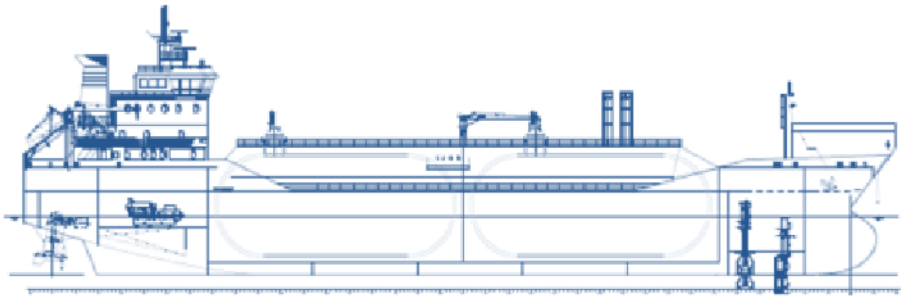

Figure 6.2.1.1 Low pressure, transport volume 6 000 m^3–7 700 m^3, ship length 114 m–150 m.

The ships studied for transport of CO_2 at medium pressure have the same tank design as the ships used for commercial transport of CO_2. The ships that currently operate only have one tank on board, while those that were studied in the project have four tanks.

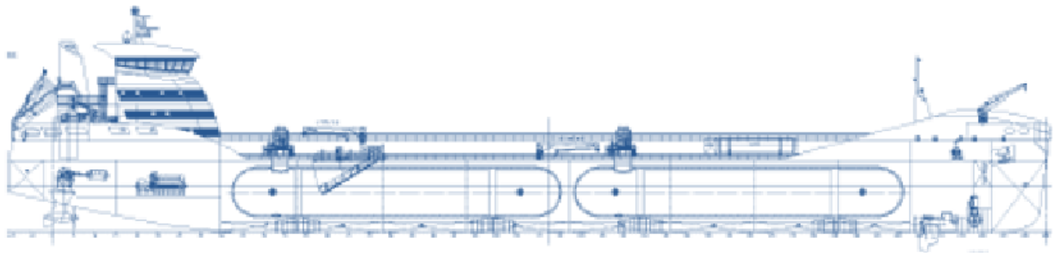

Figure 6.2.1.2: Medium pressure, 7 400 m^3–7 770 m^3, ~160 m.

Ships for transporting CO_2 at high pressure would have the same tank design as CNG ships, and would have cylindrical bottles, made of pipes with an end cap. These pipes are comparable with the pipes used for pipe transport of natural gas. The ship would typically have 700 – 900 bottles on board.

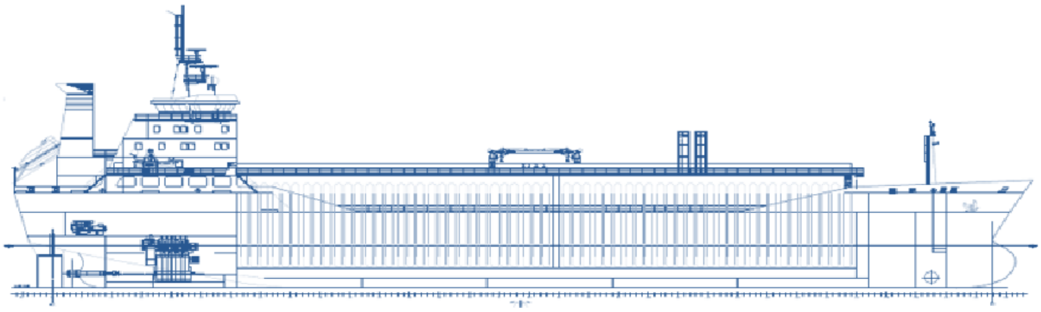

Figure 6.2.1.3: High pressure, 7000 m^3 –12000 m^3, 140 m–160 m.

6.2.2 Transport routes

The need for transport capacity has been assessed with a basis in the development alternatives described in the design basis for storage in Smeaheia. The development alternatives studied in the transport study are based on transport to quay, to a floating intermediate storage site or direct injection from transport ship via a buoy solution. If Heimdal or Utsira are subsequently chosen as the storage location, this could result in a somewhat shorter transport distance and somewhat higher regularity in the transport stage compared with Smeaheia.

The below table shows how many ships are required in the various transport alternatives and the time between each ship arrival. As the number of ships will increase when the capture volumes are scaled up, the ship arrivals in harbours will increase, while the time between each ship arrival will be shorter. The ship arrival frequency is important for the design of potential intermediate storage sites at the capture location and storage location, respectively.

	Offloading solution	Low pressure	Medium pressure	High pressure
Reference alternative **600 000 tonnes/year**	No. of ships	1	1	1
	Quay to quay or to floating storage	3.3 days	3.6 days	3.3 days
	Direct injection	4.7 days	4.6 days	4.7 days
Sensitivities				
Three sources **1 300 000 tonnes/year**	No. of ships	3	2/3 (with DI)	3
	Quay to quay or to floating storage	1.4 days	1.9 days	1.4 days
	Direct injection (DI)	1.7 days	1.4 days	1.7 days

Table 6.2.2.1: Overview of the number of ships and frequency of ship arrivals in the evaluated transport alternatives.

6.2.3 Offloading alternatives at storage site

6.2.3.1 Offloading to buoy for direct injection in well

Upon direct injection, it is presumed that the transport ship will be connected to an offloading buoy (STL buoy). In this case, conditioning, pressurisation and heating of CO_2 will take place on the transport ship prior to injection in the well. CO_2 is pumped out of the ship's tanks for further pressure build-up in the injection pump, up to an injection pressure from 80 to 150 bar. The CO_2 flow is heated to injection temperature, 5°C to 10°C before it is offloaded from the ship via an offloading buoy. To the extent possible, seawater will be used as the heat source for heating CO_2, but an additional heat source may be required depending on the transport condition, time of year and temperature of the seawater. The energy demand beyond heat from seawater will increase substantially in line with how cold the CO_2 is during transport.

The pressurisation and heating processes will be quite similar for medium pressure and low pressure, but significantly more energy will be required for heating CO_2 from -50 °C at low pressure and the energy required to increase the pressure will also be higher.

No heating is required before injection for high-pressure CO_2, just pressurisation. The Norwegian Continental Shelf holds a wealth of experience with offloading buoys that will be useful in the work going forward. The offloading buoy experience does not cover the higher frequency of connection and disconnection that would be the case for direct injection from transport ships. The expected offloading rate for direct injection is 200 tonnes of CO_2 per hour.

6.2.3.2 Offloading to a floating intermediate storage site

Offloading to a floating intermediate storage site would not require conditioning of CO_2 on board the transport ship. The process equipment for compression, heat exchange and injection will be located on the floating intermediate storage site, which would not be included in the transport interface, and is part of the storage sub-project.

The transport ships will contain pumps to transfer CO_2 through the offloading system and on to the floating intermediate storage site. There is little relevant experience from this type of offloading system. The expected offloading rate for a floating intermediate storage site is 600 tonnes of CO_2 per hour.

6.2.3.3 Offloading to an onshore intermediate storage site

Offloading to an onshore intermediate storage site will not require conditioning of the CO_2 on board the transport ship. The process equipment for compression and heating will be located on shore and will be covered in the scope of work for the CO_2 storage. The storage site operator will also be responsible for transport of CO_2 by pipeline to the injection well.

The transport ships will have pumps to transfer CO_2 through the offloading system to an onshore intermediate storage site. These types of offloading systems are available today. The expected offloading rate to an onshore intermediate storage site is 600 tonnes of CO_2 per hour. This storage solution is technically the simplest solution with regard to ship transport, as the ship does not need to be dimensioned/equipped for offshore offloading, which would require dynamic positioning (DP), among other things. This could provide easier third party access to volumes from future CCS.

6.3 Cost estimates for ship transport of CO_2

Cost estimates have been prepared for each solution, within an uncertainty of +/- 40 per cent. Estimates for the investment cost for main systems on the ships such as engines, generators and the like are based on budget or reference prices from recognised market-leading suppliers.

The estimates are comparable per tonne of CO_2 transported for the three evaluated transport conditions. Seen in isolation, the costs associated with offloading to an offshore floating intermediate storage site or offloading to direct injection are higher than for quay-to-quay solutions.

The ship solutions presume use of LNG as fuel.

Benchmarking of cost estimates was performed for all three transport conditions and the associated proposed ship solutions.

6.4 Plan for ship transport of CO_2

The plan for the transport sub-project will be adapted to the general plan for the full-scale project. The next phase of the transport study will cover the following main activities:

<u>Concept selection</u> for the transport study should, as a minimum, include selection of a storage solution and transport conditions. The benefit from further maturing shipping alternatives will be limited until this is clarified. In order to optimise shipping logistics/ship size, the number/which capture locations and annual transport volume must be defined as early as possible in the process described under Item 3 below. Continuation of multiple capture locations and combinations of these into the FEED phase will likely result in having to define a non-optimised ship size before FEED.

<u>Procurement activities:</u>

1. Technical maturing of chosen concept as foundation for inquiry regarding ship transport of CO_2

2. Establishment of commercial foundation/terms for inquiry regarding ship transport of CO_2
3. Invitation to tender and establishment of contract proposal for ship transport of CO_2. These will cover realisation (construction of ships) and operation of these for an agreed period

The above activities will start after concept selection and have an expected duration of 19 to 23 months. Detailed engineering and ship construction are expected to take 24 to 30 months from the date the contract is signed. Ship transport is no longer considered a critical element for realisation of the full-scale project.

6.5 Risks associated with ship transport of CO_2

The uncertainties and possibilities associated with ship transport of CO_2 have been assessed. Resources from DNV GL, the Norwegian Maritime Authority, Sintef, Gassnova and Gassco have participated in these risk assessments. The following paragraphs have taken a basis in uncertainties on the "top 10 list" for risks in the project and were evaluated with regard to different exposure depending on the transport conditions.

The direct injection solution is associated with uncertainties with regard to investment costs because it could result in an increased demand for process equipment on board the ship and potential regulatory requirements from the PSA in addition to maritime regulations. All three transport alternatives are subject to these risks.

Maritime regulations are, relatively speaking, considered most challenging for the high-pressure alternative, as few or no ships have been constructed under corresponding regulations. Operation of a CO_2 transport ship based on LNG as fuel will require a regulatory clarification to prevent classification as an LNG transport ship. The advantage of the medium pressure alternative is that this solution already exists.

Ship dimensioning (flexibility) appears to be most challenging for the evaluated medium pressure alternative, as there will be limited options to scale tank size, and thereby optimise transport capacity. There will be a general challenge for high pressure in connection with high steel weight per transported unit of CO_2. The low-pressure concept, relatively speaking, has the least risk associated with flexible ship dimensioning.

Interface vis-à-vis capture/storage – these challenges were partially explained under the earlier section on direct injection, and low pressure in particular will require extensive processes and energy consumption; first for cooling for intermediate storage at the capture location, and then heating before injection to the storage site. High pressure will be the least challenging alternative in this context.

Project plan – There is not yet an exact schedule and process for the concept selection (at what date decisions will be made); these must be prepared in a comprehensive chain perspective. Coordination of the schedules for the different sub-projects is difficult, and there is also an extensive KS2 and decision-making process preceding the investment decision.

None of the listed risks are probable stoppers for the project.

6.6 Learning and dissemination potential

Ships for transporting low-pressure CO_2 have not yet been constructed. There will be learning elements relating to operations near the triple junction, pressure control and potential re-use of ship for LPG transport.

There is also no existing transport of CO_2 at high pressure today. There will be learning elements relating to ship classification and tank production.

There will be learning elements relating to buoy solutions, transfer of chilled product between ships, as well as metering equipment and process equipment on ships in connection with offshore offloading, both to a floating intermediate storage site as well as direct injection. This could also provide valuable lessons with regard to future CO_2 injection for enhanced oil recovery (EOR).

Establishment of a transport and storage chain based on ship transport of CO_2 will allow for potential storage from other sources and to new future storage locations.

6.7 Health, safety and the environment (HSE)

A hazard identification process (HAZID) performed during the transport study revealed no major risks with a potential for stopping the project. The clearest recommendation was the need for a new hazard identification process across the value chain in the next phase where capture, transport and storage are all represented.

If there will be special environmental requirements imposed on the transport solution, such as emissions from the propulsion system, this should be defined before invitation to tender of work in the next phase.

The requirements relating to noise and use of the best available technology ("BAT") will also set guidelines for the ship design. Power from shore should be facilitated to reduce noise and pollution when at quay.

The propulsion system is based on use of LNG as fuel, potentially in combination with battery operation. CO_2 emissions from the transport stage are estimated at about 1.3 to 2.9 per cent of the transported volume of CO_2. The emissions will be lowest for transport from quay to quay, and highest for direct injection, in part due to higher fuel consumption when using dynamic positioning during offloading and for potential heating of CO_2.

6.8 Gassco's assessment

Gassco finds that the three evaluated transport conditions, low pressure, medium pressure and high pressure, respectively, are all technically feasible. The most important advantages and challenges associated with the different transport conditions are outlined in Chapter 6.2.

Transport from quay to quay will be the least complex transport solution, with the highest expected regularity and lowest cost, when only taking the transport stage into account.

Before announcing further work on ship transport of CO_2, the next phase should include a concept selection that, as a minimum, includes selecting the storage solution and transport conditions (pressure/temperature).

The conceptual decisions should be made in a chain perspective that also includes capture and storage.

Special requirements for the transport solution, such as emissions from ship propulsion, should be defined before announcing work in the next phase.

A hazard identification process that covers the entire chain should be completed in the next phase in order to cover the many uncertainties in the interfaces between the sub-projects.

7 CO_2 storage

7.1 Summary

Gassnova was responsible for the CO_2 storage component of the feasibility study and Statoil was contracted to perform this work following a process of public tender. Statoil has evaluated three locations and different development solutions based on the available data and previous studies. The study corresponds to at least DG1 level according to the practices in the petroleum industry. The CO_2 storage work is based on the results of the pre-feasibility study, the Norwegian Petroleum Directorate's storage atlas and CO_2 storage studies conducted by the NPD, Gassnova and Statoil.

Gassnova conducted much of the previous work. Statoil also conducted technical work, interpreted geological data and assessed potential movement of the CO_2 volumes in the subsurface. Flow analyses have been completed, concepts have been developed and described, and costs and schedules have been prepared. Risks and additional possibilities were identified and evaluated. Statoil has evaluated the locations in this study based on a storage capacity of 1.3 million tonnes of CO_2 per year for 25 years, leading to a total storage capacity of 32.5 million tonnes of CO_2.

From the candidate storage locations examined, Statoil recommends Gassnova to select the Smeaheia location in combination with a sub-sea pipeline link to a harbour facility as the most promising solution for further development. Statoil's assessment concludes that this solution carries the least risk, the greatest operational flexibility and greatest potential for future capacity expansion. For the two direct injection alternatives at Smeaheia and Heimdal (CO_2 injection directly from a transport ship connected to an offshore well), Statoil presumes that process facilities will be established on board three ships, which (according to their estimates) would entail a significant added cost and technical and operational risk. Expanding the capacity of these solutions would also come at a relatively high cost. Statoil points out that use of floating storage and injection ships is contingent on the development of offloading systems that are not yet commercially available, which will take time and involve technical and operational (e.g. regularity) risk. Statoil does not consider the evaluated geological structure in the unlicenced area in Utsira South to be suitable for the storage of the volumes in question.

Gassnova agrees with Statoil's general assessment of the storage solutions and supports the recommendation to continue working with Smeaheia in the next project phase, though the dimension of the pipeline from the harbour facility to the offshore field should potentially be increased to 12 inches to take advantage of the large storage potential that is available. The direct injection solution from a ship to a well is expected to be more cost efficient for low volumes of CO_2, but Gassnova agrees that this will entail a higher implementation risk.

In conclusion, Gassnova believes that the Smeaheia storage site in combination with a harbour facility and sub-sea pipeline is well-suited for demonstrating CO_2 storage as a safe climate change mitigation measure as part of a future full-scale CCS project.

Looking ahead to future development of the Smeaheia site, Statoil predicts that a site developer will require a period of 30 months from the start of a concept-select phase until an investment decision, and 36 months for construction of the project. It is assumed that the plans can be somewhat optimised through coordination with the rest of the CCS chain.

7.2 Description of the different storage alternatives

This chapter summarises the assessments in the feasibility study for CO_2 storage.

7.2.1 Smeaheia

CO_2 may be stored in the Alpha structure in the large fault block located east of Troll. At original reservoir pressure, this structure could store approx. 100 million tonnes of CO_2 before there will be a risk of migration to the nearby Beta structure, which Statoil also evaluated. Figure 7.2.1.1 shows the location of these structures in a map of the top of the Sognefjord formation. Statoil has assessed injection in both the Sognefjord formation and in the deeper Fensfjord formation. Reservoir simulations show that rates far exceeding what was used as a basis in the development solutions of 200 tonnes/hour are possible in both formations and one injection well is therefore sufficient. The primary seal in Draupne is very good and is overlain by a number of shallower, tight shale layers. The data basis is good, with two exploration wells and both 2D and 3D seismic. Statoil also sees an opportunity for storing substantial volumes in the deep Lunde formation, but this would need to be proved by drilling.

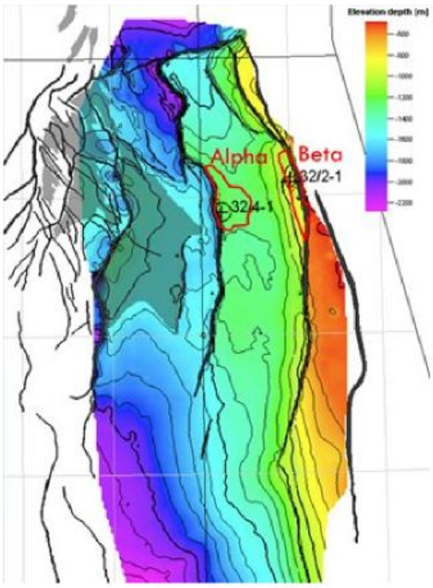

Figure 7.2.1.1: Smeaheia; the map shows the location of the Alpha and Beta structures in the large fault block located east of Troll.

One uncertainty in the evaluation is the magnitude of the pressure drop in the storage reservoir caused by gas production at the Troll field. If the storage reservoir is, or becomes, significantly depleted as a result of Troll production then the injected CO_2 will take up considerably more volume. Injection at greater depths (Fensfjord Fm.) might alleviate this effect, though the conclusion from the current study is that the Alpha and Beta structures together will cover the storage need in this project. Assessment of additional capacity should be included in the scope of future work if this location is selected.

7.2.2 Utsira South

Statoil narrowed down this work to areas in block 16/7, which are located outside areas in which production licences for petroleum activity have been awarded. A large structure has been identified in this location, called Sæter, which does not have direct contact with old wells and shows few disturbances in the seal. The Utsira formation has excellent storage properties, which have been demonstrated through 20 years of storage at Sleipner.

The Utsira formation is covered by a 50-150 metre thick marine shale with good sealing properties. Utsira has a number of legacy wells in the evaluated area that constitute a leakage and cross-flow risk because they are plugged and abandoned with respect to deeper formations, below Utsira.

Statoil has calculated a storage capacity of 15-18 million tonnes for the Sæter structure. It therefore must be expected that CO_2 will migrate in a north-easterly direction into an area that is currently licenCed, and it could come into contact with at least one old exploration well. There are some smaller structures in the licenCed area that could help catch migrated volumes.

7.2.3 Heimdal

The Heimdal structure is documented well and analysed through a long history of gas production. The formation properties and injectivity are good. The integrity is demonstrated through the fact that a substantial gas column has been trapped here for millions of years. The capacity in the structure is estimated at 150 million tonnes.

Statoil proposes injecting CO_2 into the water zone underneath the gas reservoir through a sidetrack from the new gas producer, A-5. It is proposed that the platform at Heimdal is used as a pure wellhead platform and CO_2 can be injected directly from the transport ship. When gas processing on the platform is completed, a subsea facility is established and a new well is drilled from there. Alternatively, a subsea facility with a new injection well connected to an offloading system from the start could be established (same as for Smeaheia direct injection).

7.3 Development solutions

Statoil assessed different development solutions for the storage site: pipeline to shore, floating storage and injection ship (FSI), as well as direct injection from the transport ship. Statoil's conclusions are summarised in this section

All of the development concepts use a subsea facility with independent satellite wells. It is possible to expand the facility with new satellites as needed. The exception to this is Heimdal, where one platform well is used in the primary scenario. Wells and facilities are controlled with a control line from shore or nearby fields. The wells will be completed with gas-tight cement and corrosion resistant steel in the lower sections.

7.3.1 Flow calculations

Statoil conducted thorough flow calculations for each storage solution. These calculations show that the CO_2 volumes will generally remain in one phase, and the risk of hydrate formation is minimal. The scenario with significantly reduced formation pressure at Smeaheia may require flow constriction within the well to maintain single phase flow. This scenario should be assessed in more detail in the next phase.

Gassnova has conducted analyses that support Statoil's conclusions (Gassnova, 2016L).

7.3.2 Smeaheia with harbour facility

The concept involving a pipeline to shore is exemplified in the feasibility study with landfall at Kollsnes in Øygarden municipality. The final location will be determined upon concept selection if this location is developed further. A facility with interim storage, quay, offloading equipment, injection pumps and heating of CO_2 can be built so that the ships will be able to offload in sheltered waters.

Statoil has taken a basis in a pipeline with a pipe diameter of eight inches in this study. The pipe diameter can be increased to 12 inches at a cost of NOK 50 – 70 million, and this would significantly increase capacity.

The onshore facility solution is considered to be robust, with low execution risk and good preconditions for handling additional volumes without involving considerable added costs. This solution is largely based on the experience from Snøhvit.

7.3.3 Floating storage and injection ship (FSI)

The floating storage ship concept has been assessed for the Smeaheia and Utsira South locations and is based on a modified CO_2 transport ship that is permanently moored above the storage location and fitted with injection facilities. Statoil proposes using a Submerged Turret Loading (STL) buoy for offloading, which is lowered down into the sea in standby mode and hoisted onto the ship when in use. The STL buoy would be connected to the subsea wellhead, or back to the platform in the case of Heimdal, with a flexible riser to transfer the CO_2 volumes from the ship. The buoy could be disconnected in critical situations. The ship would also need to be equipped with a swivel and other connection equipment for the offloading buoy. Use of flexible hoses to connect the transport ships to the storage ship was studied and the ships would need to be dynamically positioned.

One potential challenge that was identified in this study is the use of relatively small ships and the considerable movement they may experience in bad weather compared to the larger shuttle tankers used for oil. This is outside the industry's current experience base. Alternative solutions for transferring CO_2 between the different parts of the concept can be assessed in subsequent phases. This solution will require development of new technology, which will take time and entail increased project risk. As an example, there is an experience gap in connection with use of flexible hoses for underwater CO_2 transfer.

Utsira will have a lower need for delivery pressure, and will thus have lower requirements for injection pump capacity. However, a shallower water depth will entail a more complex riser configuration than on Smeaheia.

7.3.4 Direct injection from transport ship

Direct injection from CO_2 transport ships has been assessed for the Smeaheia and Heimdal locations. This concept uses the transport ships as a basis, each of which would be equipped with an injection facility and connection equipment for an STL buoy.

The number of connections and disconnections between ships and the STL buoy for this concept is considerably higher than the current industry has experience with and the system pressure would also need to be higher than is normal today. This could result in significant wear on the buoy and reduced regularity.

Another challenge with this solution would be the frequent thermal and pressure cycling of the injection well shutdown of the well, with a risk of formation back-flow in the lower part of the well.

This solution could offer scalability by increasing the number of transport ships since Smeaheia and Heimdal would both have sufficient well capacity to accept greater volumes of CO_2, but costs will increase in line with the number of ships and on-board injection facilities.

At Heimdal, the injection wellhead would be located on the field's main platform and a transport ship would connect via an STL buoy, flexible riser to the seabed and a pipeline and riser to the platform.

Alternative offloading systems could potentially be assessed in a future project phase for both storage locations.

7.3.5 Risks and opportunities

The following risks are highlighted for the different storage alternatives:

- Pressure depletion at Smeaheia caused by gas production at the Troll field that would increase the volume of injected CO_2, decrease the available storage capacity, and accelerate CO_2 migration beyond the Alpha structure.
- The storage capacity in the evaluated structure in Utsira South, Sæter, is limited and CO_2 migration out of this structure and into an area with petroleum licences must be expected.
- Legacy wells in the Utsira South area and close to the Sæter structure are not plugged across the Utsira formation and represent a high leakage risk.
- Legacy wells are present at all three storage locations studied, but the leakage risk associated with them varies from location to location.

Statoil has not identified any particular geological risk at Heimdal.

The most significant risk elements identified by Statoil for the different technical solutions can be summarised as follows:

- Ship-to-ship CO_2 transfer systems for the FSI alternative;
- Reduced regularity from all offshore offloading solutions;
- Threat to flexible riser integrity from CO_2 stream for all offshore offloading solutions;
- High connection frequency for offloading buoy in the event of direct injection could result in increased wear and reduced regularity.

This means that the implementation risk will be higher for offshore offloading solutions than for harbour based offloading.

The most important opportunities for improving the concepts, according to Statoil, are:

- Optimisation of the transport condition for CO_2 in the transport ships;
- Potential alternative offloading systems;
- Optimisation of pipeline dimension;
- Optimisation of operations.

With respect to monitoring of CO_2 storage, Statoil makes reference to successful application of 4D seismic Sleipner and Snøhvit and also provides an overview of additional or alternative monitoring technologies

7.4 Statoil's recommendation

7.4.1 Choice of development solution

The following text is translated from the feasibility report prepared by Statoil: "For the next phase of work, Statoil recommends to continue development of the Smeaheia storage location based on a pipeline link to a harbour facility for offloading of CO_2 from transport ships. This solution involves the least risk, greatest operational flexibility and greatest potential for future capacity expansion.

The Utsira South location is not considered appropriate for storage of the intended volumes due to limited structural capacity and the CO_2 leakage risk associated with legacy wells.

As regards the two direct injection alternatives at Smeaheia and Heimdal, Statoil presumes that process facilities will be established on board up to three transport ships, which will entail an added cost, as well as technical and operational risk. Capacity expansion could come at a relatively high cost, as it would involve investment in additional vessels and subsea facilities.

Use of a floating storage and injection ship is contingent upon the development of offloading systems that are not commercial available as of today's date. This would take time and involve technical and operational risk. Furthermore, capacity expansion would require a major investment, as it would require the procurement of a new floating storage and injection facility."

Statoil evaluated the different storage alternatives based on the work in the feasibility study. The assessment criteria were prepared in cooperation with Gassnova. Important criteria include geology, feasibility, environmental impact, cost, commercial complexity, potential for further development and learning. Statoil has concluded that the learning potential for every alternative is the same. The Smeaheia alternative with pipeline link to a harbour is considered best with regard to feasibility and potential for further development. Smeaheia combined with the concept of storage ship and direct injection is not considered to be optimal.

Statoil used a storage rate of 1.3 million tonnes/year as a basis for the assessment of every solution.

7.4.2 Proposed plan

Statoil has described examples of project implementation plans in its report. The example plans were prepared in line with Statoil's management system and decision points. They have estimated a duration of 30 months from the start of the concept phase and up to an investment decision, and 36 months for the construction phase of the project. It is presumed that the plans can be optimised to some extent through coordination with the rest of the CCS chain.

7.5 Gassnova's assessment of the alternatives

Gassnova has monitored Statoil's work closely and has received continuous access to Statoil's studies. The quality and robustness of the work appear to be excellent, and Gassnova agrees with the technical assessments.

The following section refers to Gassnova's comments concerning Statoil's assessments of the various storage and development solutions. These remarks form the basis for Gassnova's own comprehensive assessment of the storage alternatives based on aligned criteria (Chapter 7.5.8). The criteria governed the following assessments.

7.5.1 Alternative storage and development solutions

Gassnova's assessment of Smeaheia as a storage site largely corresponds with Statoil's assessment. The storage reservoir at Smeaheia offers a high degree of storage integrity and Gassnova does not consider that storage capacity will be materially reduced by pressure depletion caused by gas production at the Troll field. This conclusion is based on earlier work carried out by Gassnova in 2011/2012 that estimated the capacity of the reservoir to be about 500 million tonnes of CO_2 at original pressure.

The risk of leakage from legacy wells or via the Øygarden fault zone is considered to be low, though a detailed risk assessment of the legacy wells should be performed if this storage location is to be developed further. Alternative locations for the harbour facility should also be assessed in the next phase.

The Utsira formation is a regional aquifer with a very significant storage capacity, but Gassnova supports Statoil's assessment that the actual Sæter structure does not have sufficient storage capacity for this project development.

Gassnova agrees with Statoil's assessment of the storage capacity in the Heimdal reservoir, but Gassnova believes there is a possibility for optimisation in the development solution that could save costs. On the well side in particular, the current well, A-5, has an ideal location for injection of CO_2 in Gassnova's opinion. This option should be evaluated if a decision is made to proceed with Heimdal in the next phase.

7.5.2 Costs

Statoil estimated the costs of the various storage alternatives in accordance with their internal system. The costs include expected contingencies, and are within an uncertainty range of +/- 40 per cent. Tariffs and lease of area are not included. Gassnova has established storage costs for entire chains with different capacities and scenarios based on Statoil's and Gassco's (injection facility on transport ship) cost estimates.

For low annual CO_2 rates (400,000 – 600,000 tonnes of CO_2 per year), direct injection has lower investment costs than a harbour facility at Smeaheia with pipeline link. For rates around Statoil's design basis of 1.3 million tonnes of CO_2 per year, the investment costs for these two solutions are about the same. It could be an option here to optimise the number of ships, which would make direct injection somewhat cheaper. For additional volumes, the harbour facility with pipeline link would clearly be more reasonable. Heimdal is expected to have a higher cost than the other alternatives, as a modification will be necessary in the event the Heimdal platform is shut down.

The operating costs for direct injection may be somewhat lower than for an onshore facility or a floating storage ship, if successful integration between injection and maritime activity could be achieved.

7.5.3 Plans

Gassnova believes that the plan outlined in the feasibility study could be optimised to enable an earlier concept selection (DG2) for storage that would then be more in line with DG2 for the other components of the project. The ordering of long-lead items prior to a final investment decision could also be considered in order to accelerate the plan later in the project.

Criteria for selecting bidders for future phases of work should be established as soon as possible in order to facilitate timely project development.

7.5.4 Possibilities for economies of scale and additional volumes

The Smeaheia storage location with a pipeline link to a harbour will have significant potential for receiving and storing additional CO_2 volumes. The onshore facility could be expanded at low incremental cost and the injection well is expected to have a higher capacity than needed for an initial project (see Chapter 7.2.1). In this case, the limiting factor for expansion would be the pipeline dimension. A diameter of eight inches would yield a maximum throughput of 1.9 million tonnes of CO_2 per year, whereas a twelve-inch diameter would yield a throughput of 3 million tonnes of CO_2 per year for an additional investment of NOK 50 – 70 million. Such a capacity increase could potentially reduce the unit cost of stored CO_2 by half.

The harbour facilities can be constructed to receive CO_2 from ships of varying sizes during all types of weather conditions. This would make it possible to develop the Smeaheia harbour facility into a hub with the potential to store CO_2 from other sources beyond those evaluated in the feasibility study.

7.5.5 HSE

Statoil uses the ALARP principle (As Low As Reasonably Practicable) in its assessments, and identified no critical risks that could not be resolved with respect to health, safety and the environment.

A number of findings and actions resulted from a hazard identification exercise (HAZID) that covered pressure conditions, depressurisation, ship-installation-shore interface, regularity, sea conditions and risk of high CO_2 concentrations. Actions not closed during this phase should be included in the scope for the next phase of the project.

A Working Environment Health Risk Assessment (WEHRA) was conducted in the feasibility study. Different working environment factors were assessed for all alternatives where human activity would take place.

One general finding was potential noise exposure, and all evaluated alternatives had challenges relating to the interface between ship-ship, ship-platform and ship-shore, respectively. A general risk relating to CO_2 and chemicals handling was also identified.

The study included a number of functional requirements related to safety for CO_2 systems, such as CO_2 detection, emergency shutdown, depressurisation, well integrity and prevention of vessel collisions. Functional requirements relating to the environment include estimated energy consumption, emissions to air, wastewater and chemical consumption for those alternatives where this is relevant.

A CO_2 emissions footprint was estimated for annual operations related to the following storage alternatives (excluding ship transport):

- Smeaheia location with a storage ship (FSI) – 10,000 tonnes CO_2 per year
- Smeaheia location with harbour facility and pipeline link – 100 tonnes CO_2 per year
- Smeaheia location with direct injection from a transport ship – in between the 100 and 10,000 tonnes CO_2 per year

7.5.6 Risks

According to Gassnova’s assessment, the most important risks are as follows:

- Insufficient capacity in the Sæter structure, Utsira South
- Legacy wells near the Sæter structure that are not plugged with respect to the Utsira formation
- Shorter field lifetime and commercial complexity on Heimdal
- Threat to flexible riser integrity from CO_2 stream for all offshore offloading solutions;

Gassnova has assessed that Smeaheia has a low risk when it comes to geology, project implementation, environmental impact, cost and commercial complexity. The risk of capacity limitation due to the Troll production, as indicated by Statoil, is considered smaller by Gassnova. The importance of early clarification of the exact placement and acquisition of acreage is emphasised for the onshore facility. Gassnova shares Statoil’s perception that the implementation risk will be higher for ship-based solutions than for an onshore facility. The ship solutions are new, complex concepts with new or modified technology and with extensive operations at sea. The onshore facility, on the other hand, is based on tested solutions, such as the Snøhvit development.

7.5.7 Learning

Technology development would be most comprehensive for direct injection. This would be a completely new concept, which could prove flexible and attractive in the future, but would require extensive testing. The injection equipment would be placed on the transport ship, which can go to any storage site with a well and offloading buoy, and the storage does not need a large facility for injection and interim storage. Furthermore, the offloading buoy concept and use of flexible hoses/risers can be tested. There are several empty fields and aquifers in the North Sea Basin that could be suitable for this concept and there is a potential for multiple local storage sites and a considerable total capacity.

The learning potential from developing the Smeaheia location with a harbour facility and pipeline link comes from the ability to demonstrate reliable storage as part of an overall CCS chain that can be expanded at a later date to exploit economies of scale.

Heimdal will provide considerable knowledge concerning use of empty petroleum fields for CO_2 storage. Sæter at Utsira South will largely be a copy of Sleipner in terms of technology deployment.

7.5.8 Gassnova's assessment of the alternatives for further CCS project development

Gassnova conducted its own assessment of the storage alternatives in parallel with Statoil and making use of the same criteria. Gassnova also conclude that the Smeaheia storage location - based on a pipeline link to a harbour facility for offloading of CO_2 from transport ships – ranks highest. Nest highest is the Smeaheia storage location with direct injection via an STL buoy from transport ships.

These conclusions are based on the following findings for each of the criteria used in the assessment:

Geology; The Smeaheia and Heimdal storage alternatives were found to have good integrity in relation to leakage risk and sufficient capacity. It was determined that the Sæter structure in Utsira South will not have sufficient capacity within the area that formed the basis for the feasibility study.

Technical solution; Smeaheia with a pipeline link to a harbour facility has the lowest implementation risk and environmental emissions/discharges. The storage ship alternatives were found to have the greatest implementation risk and environmental emissions/discharges. The grounds for this are provided in Chapter 7.5.6.

Discounted cost; Smeaheia with direct injection via an STL buoy from transport ships was found to be the most cost efficient option, particularly at lower rates of CO_2 supply (such as 400,000 – 600,000 tonnes of CO_2 per year). Heimdal would be most expensive due to the required re-engineering of the injection facility after approximately 10 years when the Heimdal platform is expected to be de-commissioned.

Commercial complexity; With the exception of Heimdal, there is little difference between the different solutions. Heimdal would be more challenging as the platform is owned by a partnership that also holds a production licence for petroleum activity and will require a new development solution in order to achieve a lifetime of 25 years.

Potential for further development: The most reasonable and largest additional capacity can be achieved with at Smeaheia with a pipeline link to a harbour facility. The potential from direct injection is also significant, as more ships can be added to expand capacity, and it can be used on other shutdown fields and storage sites in the North Sea. However, this could be more costly.

Learning and dissemination potential: The potential technology learnings from developing and testing a direct injection solution are greater than developing a harbour facility with pipeline link. However, the potential learnings from successful deployment of a total CCS project on time and on budget with low technology risk are deemed to outweigh this. See also Chapter 7.5.7.

Gassnova supports Statoil's recommendation to continue working on the Smeaheia alternative with a pipeline link to a harbour facility in the next phase of project development. If there is a desire to also assess a smaller, cheaper or more short-term alternative in addition to this then Gassnova recommend Smeaheia direct injection or the Heimdal alternative. It should be noted, however, that these alternatives would increase implementation risk because due to untested elements and they are also more vulnerable to poor weather conditions. According to Statoil, this would not affect the storage plan, but could result in some additional costs, depending on when the final decision is made. The implementation plan for the entire chain will most likely depend on whether continuation of one or more storage solutions is pursued, cf. Chapter 12.3.

Reference is made to Gassnova's CO_2 storage report, which summarises Statoil's feasibility study and Gassnova's assessments (Gassnova, 2016).

8 Assessment of full-scale CCS in Norway – entire chain

The feasibility studies have assessed CO_2 capture from three industrial plants in Norway. CO_2 storage was assessed for three locations with different development solutions. Ship transport was assessed for three different pressure and temperature conditions. This chapter will describe and assess relevant CCS chains based on the completed feasibility studies for capture, transport and storage, respectively. Furthermore, the chapter will provide an assessment of what framework should apply for a next phase, if the project is continued.

With multiple capture locations, transport alternatives and storage concepts/locations, there are a number of alternatives for how a CCS chain could potentially be composed. Table 8.1 below describes four alternatives that can represent the possibility of how much CO_2 should be captured, transported and stored, regardless of what capture plants are chosen at a later stage in the project. The described storage solutions were those considered most relevant for continuation, cf. Chapter 7. The transport study did not include an assessment of what transport solution should be chosen, but has taken a basis in the medium pressure alternative for the assessment of costs.

Alternative	Capture	Transport	Storage	CO_2/year ktonne
One source, onshore facility	CO_2 from one plant	One ship	Smeaheia, onshore facility	400
Three sources, onshore facility	CO_2 from three plants	Two ships	Smeaheia, onshore facility	1 300
One source, direct injection	CO_2 from one plant	One ship	Smeaheia, direct injection	400
Three sources, direct injection	CO_2 from three plants	Three ships	Smeaheia, direct injection	1 300

Table 8.1: Description of different alternatives for the project scope.

8.1 Costs

The planning and investment costs for a CCS chain are expected to be between NOK 7.2 and 12.6 billion, depending on how many CO_2 capture sources will be developed, how much CO_2 will be captured and how many transport ships are required. The estimates are based on CO_2 storage in Smeaheia with an onshore facility. Expected operating expenses vary between NOK 350 and 890 million per year for the various alternatives.

Tables 8.1.1 and 8.1.2 below show estimated expected costs for selected alternatives for a full-scale CCS chain in Norway. All costs are excluding value added tax. Planning and investment costs include costs for completing concept and FEED studies and will be distributed between the years from 2017 to 2021. Operating and maintenance expenses are expected to incur from 2022 for all alternatives. The abatement cost is based on costs for planning, construction and operation, discounted with a four per cent interest rate (at 2016 values). Discounted costs are then divided among discounted CO_2 volumes. The abatement cost is based on 25 years of operation.

	One source, onshore facility	Three sources, onshore facility
Planning and investment costs (NOK million)	7 200	12 600
Operating and maintenance expenses (NOK million/year)	350	890
Abatement cost (NOK/t)	2 000	1 290

Table 8.1.1.1 Presentation of costs according to flue gas sources. Estimated project costs in NOK million (ex. VAT), 2016 values.

Table 8.1.1 above shows the costs for different CCS chains based on storing CO_2 in Smeaheia with an onshore facility solution. A CCS chain with CO_2 from one facility will have expected planning and investment costs amounting to NOK 7.2 billion. If the CO_2 volumes in the chain are increased as a result of CO_2 from three plants being connected to the CCS chain, expected planning and investment costs will amount to NOK 12.6 billion. The operating expenses for three sources with an onshore facility will be higher than for one source as a result of more CO_2 capture plants, while the abatement cost will be lower because the CO_2 volumes are higher and the cost is lower for this alternative, relatively speaking.

Table 8.1.2 below shows costs for alternatives with an onshore solution compared with direct injection solution alternatives. With low CO_2 volumes, the investment costs for a direct injection solution will be about NOK 1 billion lower than an onshore solution. If the volumes are increased as a result of the connection of CO_2 from three plants to the CCS chain, the costs of the two storage development solutions are more even. However, the direct injection solution is associated with technical risks and limitations that are not reflected in the costs. This is described in the next chapter, benefit assessments. The costs should also be considered more uncertain than for the onshore facility solution as direct injection is not a tested technology for this purpose.

	One source, onshore facility	One source, direct injection	Three sources onshore facility	Three sources, direct injection
Planning and investment costs (NOK million)	7 200	6 100	12 600	12 900
Operating and maintenance expenses (NOK million/year)	350	250	890	820
Abatement cost (NOK/t)	2 000	1 600	1 300	1 250

Table 8.1.2 Presentation of costs according to Storage concept. Estimated project costs in NOK million (ex. VAT), 2016 values.

The abatement costs show the cost per tonne of CO_2 that is reduced. This helps illustrate whether the measure is an effective climate measure. The purpose of the measure is to reduce the barriers and costs for future projects. This means that the abatement cost is not the most crucial parameter in this project, but will indicate whether CCS can be an efficient climate measure. The costs include elements such as investment in storage with excess capacity that can yield lower costs for future projects.

The next phase of the project will entail work on optimising solutions that can somewhat reduce expected costs in the project. Using transport as an example, the size and number of ships can be optimised in the next phase. On the other hand, costs may also increase, e.g. due to the discovery of complex elements or additional charges as a result of the players having to assume greater responsibility and/or risk than expected. However, these cost reductions or increases are expected to remain within the uncertainty of +/- 40 per cent.

Developing and testing technology is expensive, and it is challenging to establish necessary framework terms and incentive structure. The costs of establishing a storage site and infrastructure, along with capture from emission sources, will constitute a major development project. On the other hand, a potential next project is expected to have a lower cost as the storage and infrastructure will already be in place. CO_2 from multiple sources can be stored at the same site.

The cost estimates are based on the following assumptions:

- Costs associated with capture, transport and storage come from Gassnova and Gassco's summary reports. The cost estimates were delivered as classified estimates within an uncertainty of +/- 40 per cent or better. The estimates are the expected costs of constructing and operating the CO_2 plant, including expected contingency.
- The Norwegian state's follow-up costs are included for capture, transport and storage in the planning and realisation (investment) phases. The Norwegian state's follow-up costs are not included for the operating phase. The Norwegian state's follow-up costs also include an expected contingency.
- There was no uncertainty analysis of the costs at a full chain level. The estimates are based on expected costs from the industry players, as well as an assessment of the Norwegian state's expected follow-up costs.
- Upside values have not been included in the calculations. The value of direct emission reductions as quota gains or the value of excess capacity that a storage solution will include were therefore not taken into consideration. Furthermore, the feasibility studies show that the alternative where CO_2 is captured from three sources can entail capture, transport and storage of a larger volume (about 1.5 million tonnes of CO_2 per year) than what was assumed when the studies were initiated (1.3 million tonnes CO_2 per year). The costs of these additional volumes have been included in the capture part, but not in the transport and storage parts.
- Other elements that were not covered in the estimates for this phase include performance and process guarantees, compensation for costs relating to operational interruptions, as well as taxes and depreciation. This will be included in the further clarification of framework terms for players.

8.2 Benefit

Realisation of a Norwegian full-scale CCS project should facilitate the achievement of benefits as described in the Ministry of Petroleum and Energy's concept selection report (KVU) on demonstration of full-scale CCS, cf. Ch. 4.

The project is expected to reduce the barriers and costs for realisation of the next batch of CCS projects. It is furthermore pointed out that a Norwegian CCS project should be beneficial for future CCS projects. To support the achievement of this benefit, the KVU document defines "should" requirements for a potential CCS project. Beyond the requirements related to costs (cf. Ch. 8.1) and time (cf. Ch. 9.1), the requirements can be categorised as follows:

- Achieve knowledge that can be spread to other countries and industries
- Provide a storage solution with enough capacity for economies of scale
- Demonstrate that CCS is a safe and efficient climate measure
- Contribute to improving the market situation for CCS

The learning and dissemination potential related to capture, transport and storage in the realisation and operating phases are described in more detail in Chapters 5, 6, and 7, respectively. The establishment of a CCS chain alone is expected to provide vital technological, regulatory and commercial knowledge. This would make significant contributions towards reducing barriers and costs for future CCS projects. The below table contains an assessment of the various alternatives shown in Table 8.1 in relation to the KVU requirements. The table first provides a description of the benefit for the alternative with one source and Smeaheia onshore solution. For the other alternatives, only changes compared with the one source alternative are described.

	Learning and dissemination	Economies of scale storage	Safe and efficient climate measure	Market situation
One source - onshore	- Realisation and operation can provide knowledge from the capture source and industry this represents. - Regulatory learning related to full chain CCS, for example quota system, storage permit, HSE and environment. - Establishment of commercial CCS model for involved commercial players in the chain. - Updated costs for CCS – full chain - Full-scale demonstration of capture provides possibilities for further development of technology. - Establishment of infrastructure that can handle more CO_2 in the future, represents an option value.	- Establishment of storage with excess capacity and storage operator will reduce a significant barrier and costs for upcoming projects. - Establishment of standard conditions for transport and storage of CO_2 will enable further utilisation of storage. - Harbour facilities can be constructed as flexible to receive CO_2 from ships of varying sizes. - The harbour facilities will be more robust for different weather conditions than direct injection. - Storage and storage solution can be developed as a hub for more CO_2 volumes.	- Realisation and operation of chain with one source will provide possibility for increased confidence and a stronger reputation for CCS. - A chain based on one source will create a major dependence on the availability and performance of one industrial plant and capture project. - The solutions are based on technology that is ready to be built at an industrial scale. - Storage solution is based on known technology, and possibility to use standardised transport solutions. - Abatement cost for the alternative will be approx. NOK 2,000/tonne CO_2, but will vary depending on the volume captured in the chain. - In this case, the transport ship can be scaled down to accommodate actual need and contribute to reduced operating and investment costs.	- Establishment of a full CCS chain will increase commercial interest in CCS and further development of CCS-related technology. This is expected to stimulate the supplier markets and increase the research and development efforts in this field. - Construction/ modification of ships for CO_2 transport will increase expertise in the market for these types of ships. - Establishment of CO_2 infrastructure will facilitate a market for CO_2 storage for other emission owners
Three sources - onshore	- Going from one to three sources will increase learning, and establish CCS within more industries. - Much of the regulatory learning will be similar, but will be relevant for more types of CO_2	- The alternative will use more of the storage capacity, but still considerable upside in storage solution. - The alternative can actualise the establishment of joint infrastructure for intermediate storage on the capture side.	- Three capture players will somewhat increase the complexity of the CCS chain, but will reduce the risk of interruptions in the chain as the captured CO_2 will come from multiple sources. - The abatement costs for this alternative will	- Same as for the one source alternative, but this alternative will have an increased market stimulation, as it can stimulate suppliers of different capture

	emissions in this alternative. - Establishes reference cost for capture solutions and integration in three industrial plants and three industries with associated transport and storage costs.	- The alternative will provide a robust chain with a substantial volume that provides good documentation of the storage site's capacity to receive additional volumes, as well as even lower storage costs for new volumes, based on better utilised economies of scale.	be approx. NOK 1,250–1,100/tonne CO2[1].	technologies, provide increased competition and provide suppliers with reference projects within different industries.
One source – direct injection	- Direct injection can be relevant for chains with small volumes.	- It will be more expensive to use the storage site's excess capacity for direct injection compared with an onshore facility. - Direct injection will require more specially adapted ship solutions, which could reduce the possibility for third party volumes without major additional investments.	- Increased implementation risk due to technical elements that are currently not fully available technology. - Challenges with frequent connection and disconnection, and reduced regularity due to inclement weather conditions. - The abatement cost for this alternative is approx. NOK 1,600/tonne CO_2.	- No change in relation to the alternative with one source.

Table 8.2.1 – Benefit assessments for various alternatives.

The benefit assessment shows that all alternatives will lead to significant reductions of barriers and costs for subsequent projects. Not least, this applies for alternatives that establish and qualify storage and other infrastructure with the capacity to handle additional CO_2 volumes. Realisation of one of the alternatives will allow learning to be achieved in several areas; realisation and operation of capture facilities integrated with existing industrial plants, regulating the CCS chain, establishing a business model for capture, transport and storage, updated information about costs for CCS, as well as contribute to further development of capture technology.

The capture sources studied in the feasibility studies represent different industries and will therefore provide a certain degree of complimentary learning. The degree of learning will increase along with the number of CO_2 capture projects that are built, particularly flue gas sources. The onshore facility alternative for storage will better facilitate economies of scale than the direct injection alternative. Onshore facilities also have a lower implementation risk. The onshore solution makes use of conventional offloading solutions that better facilitate receiving volumes from third parties.

Investment in more than one capture source will to a greater extent document that CCS is a safe and effective climate measure. It may yield a lower risk of losing CO_2 in the chain, and the abatement cost can be reduced with increasing CO_2 volumes in the chain.

[1] The measure cost is indicated as a range, as the feasibility studies show that about 1.5 million tonnes of CO_2 can be captured per year, which is 200,000 tonnes more per year than what was assumed when the studies were initiated.

All alternatives may contribute to improvements in the market situation for CCS, but this effect will increase as a result of realisation of multiple sources of CO_2. Stimulation of the market for CCS will be important for further technology development and cost reductions for future projects.

8.3 Risk

Realisation of a full-scale CCS project will entail risk. In addition to risk elements described for capture, transport and storage in Chapters 5, 6 and 7, there will be elements that must be considered in an overall perspective and which deal with the integration in an entire chain. Risk elements can be defined as either a threat or an opportunity for the project. Below we list the most important risk elements that have been identified and which must be handled in the next phases:

Threats:

- Loss of CO_2 volume for the CCS chain because the factory/enterprise which is the source of the CO_2, is shut down. This can e.g. be due to the fact that profitability in the primary production is no longer satisfactory.
- Limited follow-up and detailing of interfaces in the chain may lead to sub-optimal solutions due to dependencies in the chain not being adequately considered.
- Ship-based offloading solutions for storage entail limitations for minimum ship size, which in turn may limit the opportunity to have cost-effective transport solutions.
- Ship-based offloading solutions vis-à-vis storage are vulnerable to adverse weather conditions and may cause reduced regularity in the CCS chain.
- It is challenging to coordinate the sub-projects' progress schedules. A comprehensive quality-assurance and decision process on the hand of the State prior to the investment decision will be implemented in the project implementation plan.
- If framework conditions and/or incentive structure are too unclear, this may result in limited interest from industry players regarding continuation of the project.
- The CCS chain becomes exorbitantly costly or demanding to operate due to strict requirements e.g. for CO_2 specification.
- Dissemination of information and knowledge from the project is not achieved and only limited learning is therefore attained.

Opportunities:

- Strengthening of competitiveness for primary production because the establishment of CCS facilitates the low-emission society.
- Storage with overcapacity combined with flexible transport solution facilitates the realization of new CO_2 capture projects
- A CCS chain in Norway with development potential may provide a basis for new industry and jobs.

The threats and opportunities are described in more detail and categorised in the project's risk register. Measures to limit the threats or contribute toward realization of the opportunities are also described in the register.

8.4 Assessments

If the Government wants to continue the work on full-scale CCS in Norway, this should be done through a combined concept and FEED phase with completion in the autumn of 2018. This work will then form the basis for the State's quality-assurance and decision processes before a potential investment decision.

In connection with a continuation of the project, one should consider facilitation of studying additional capture projects in the next phase. This must be weighed against the increased planning costs of planning multiple facilities. The three plants have all demonstrated that CO_2 capture at their facilities is technically feasible with associated cost estimates. The three facilities represent different industries and contribute complimentary learning for CO_2 capture from industry.

Based on Statoil's and Gassnova's recommendations, it will be logical to continue a single storage location and a single development solution in the next phase. Smeaheia is deemed to be the most suitable location. In addition to the fact that the relevant storage formations in Smeaheia have the capacity to store CO_2 volumes beyond the volumes in the feasibility study, the reservoir's seal is considered to be secure. The onshore facility at Smeaheia and the pipeline to the storage location will be based on familiar technology and can be built with significant overcapacity. This development solution best facilitates utilisation of economies of scale in the transport and storage part of the project. A development solution with direct injection entails a greater risk and this solution is therefore less attractive than an onshore solution. The direct injection solution will be more exposed to reduced regularity due to adverse weather conditions and frequent connections and disconnections to/from the loading buoy. It will require extra equipment and special adaptations of the transport ships, and will also have a reduced potential for providing economies of scale without additional investments, compared with an onshore solution.

As regards the transport part, transport conditions for further maturation should be chosen early in a potential next phase. This choice should be based on the chosen storage location and development solution and should be based on what is optimal for the entire CCS chain.

9 Project implementation

9.1 Project goals

In the Sundvolden Political platform, the Government states that it will "invest on a broad front to develop cost-effective technology for carbon capture and storage (CCS) and seek to build at least one full-scale carbon capture demonstration plant by 2020". The Government's strategy for the work on CCS was presented in the MPE's Prop. 1S (2014-2015). The measures addressed in the strategy have the following purpose: "To provide an independent and measureable contribution toward developing and demonstrating technology for capture and storage of CO_2 with a potential for dissemination".

The Ministry of Petroleum and Energy prepared a concept choice study (KVU) to assess whether or not realisation of full-scale CCS is socio-economically profitable.

The project has operationalised the goals in the KVU to make them more measure-specific. This work has defined goals that should be followed up within the project, in addition to goals for gains realisation. Gains realisation means processes and activities designed to facilitate realisation of the gains enabled by the project, so that the project actually contributes to cost reductions and reduced barriers for future CCS projects.

The project's overall goal is the same as for the KVU:

"Demonstration of CCS shall provide the necessary development of CCS, so that the long-term climate goals in Norway and the EU can be achieved at the lowest possible cost"

The project has operationalised the KVU's purpose as follows:
"Several upcoming European CCS projects will have reduced barriers and costs by 2030 through implementation of this project, by:

- Potential access to established storage
- Benefit from learning and development provided by this CCS project"

The project has furthermore identified the following project goals:

The project shall deliver a complete CCS chain that:

- Documents and shares technical, regulatory and commercial learning in the realisation and operating phase
- Captures, transports and stores a considerable volume of CO_2 in the first three operating years to:
    - Demonstrate that the CCS chain is safe
    - Show that CCS can be an effective climate measure
    - Achieve documented storage with very low risk of leaks
- Avoids harm to personnel, equipment and the environment in engineering, investment and operation
- Has a total State investment cost in line with the State's investment decision, and within other frameworks provided by the State and involved players
- Makes an investment decision (DG3) and is commissioned (DG 4) in line with agreed project plans, along with the relevant industrial players, for phases after DG1

In order to facilitate gains realisation, the project has identified a need for establishing work and goals that should be followed up outside, but coordinated with, the project. Further work will be carried out to specify this. Important elements may include strategies for knowledge sharing and technology collaboration, establishing a commercial framework for future projects and other measures to exploit the storage potential afforded by realisation of the project. This work must be viewed in context with the range of policy instruments for CCS.

9.2 Project implementation plan

Overall timeline with the most important milestones and phases for a conceivable lifecycle for the project is shown in Figure 9.2.1 below.

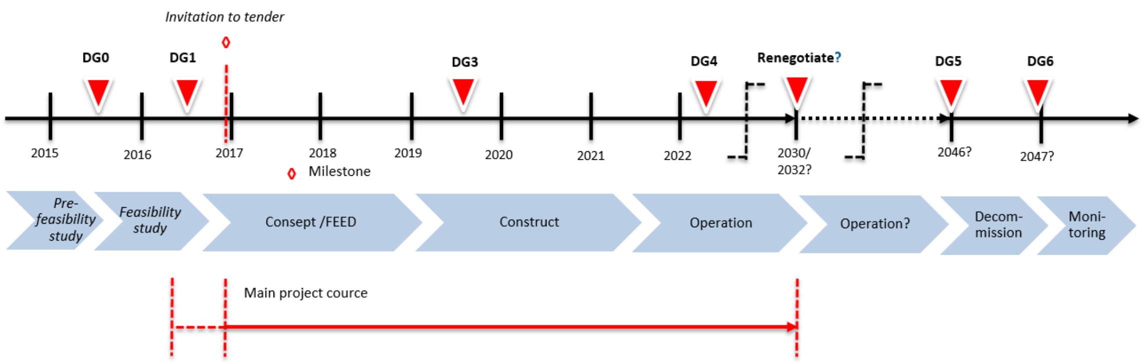

Figure 9.2.1 Timeline with overall milestones and phases.

The project's main milestones are:

- Completion of feasibility study and decision to continue in connection with processing of the National Budget for 2017 (DG1)
- Announcement of main project course in autumn 2016 with start of concept and FEED studies
- A possible coordinating milestone during the concept and FEED phase
- Fully negotiated agreements based on FEED studies, and a potential investment decision no later than summer 2019 (DG3)
- Completion and decision to start operation in 2022, based on necessary adaptations to follow the industry players' own project courses (DG4)
- Operating support period as agreed with industry players, with renegotiation or further operation without state support.
- A decision to decommission when operation shall cease; the feasibility study presumes a 25-year technical lifespan (DG5)
- Following decommissioning, an administrative closing, as well as continuation of necessary monitoring of storage (DG6)

The plan is to combine concept and FEED studies to shorten the planning time in the project. This entails that the individual industry players in the project will have to make concept choices for their parts of the project according to more detailed agreement. These concept choices will not necessarily be coordinated. It is nevertheless possible that a coordinated milestone will take place in the next phase, where the project will e.g. have the opportunity to restrict the number of concepts/players and where it is possible to make an assessment of expected costs.

9.3 Tendering process for future phases of the full-scale CCS project

If the full-scale CCS project develops beyond the current feasibility phase, then pre-qualification, tendering, negotiation and contracting for concept and FEED studies may commence in the autumn of 2016. Illustration 9.2 below shows the planned process from pre-qualification to fully negotiated support agreement for investment and operation with the involved stakeholders.

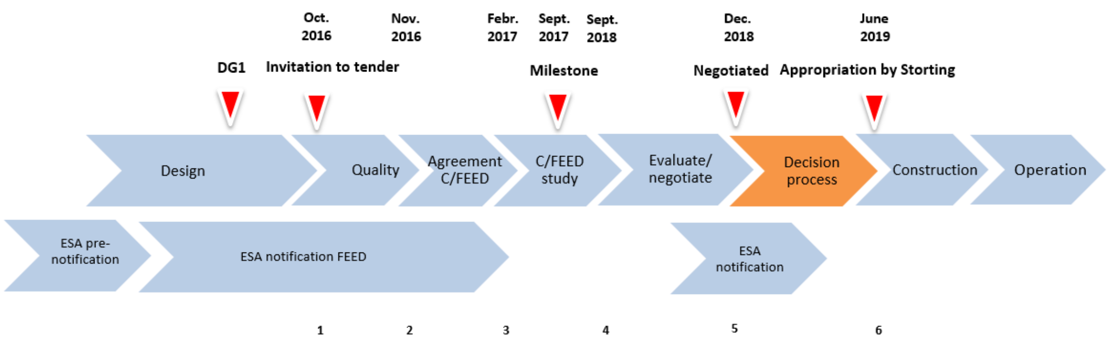

Figure 9.3.1 Process for invitation to tender, negotiation and entering into agreements in the project.

A brief description of the different milestones follows (based on the figure's numbering from 1 to 6):

1. Pre-qualification: brief description of objective and process for the entire project's life, as well as qualification criteria.
2. Invitation to Tender (ITT): issued to pre-qualified bidders for concept and FEED studies (with award and selection criteria, as well as agreement basis and enclosures such as scope of work, compensation, time and administrative provisions).
3. Start concept and FEED studies. Performed according to agreed milestone deliveries and final deliveries. Presumes completed notification to the EFTA Surveillance Authority (ESA) of the concept and FEED phase.
4. Start final evaluation and final negotiation, based on FEED studies. Studies with their milestone deliveries and final deliveries are complete. Largely based on negotiated support agreements concerning investment and operation.
5. Negotiation complete. Agreements for realisation and operation are signed, given ESA and Storting approval.
6. Final investment decision by Storting. Decision process including KS2 quality-assurance and ESA notification are complete.

Negotiations with the remaining suppliers on the final support agreement for investment and operation will take place during the concept and FEED phase. The final study results will be based on the support agreement and include the suppliers' final tender on a few key elements. Contracts will then be awarded, which will form the basis for an investment decision by the Government and Storting. The individual industry players must also make their own investment decisions based on the concept and FEED studies and the negotiated agreements with the State.

The tendering process timeline described above will be relevant for the capture and storage part of the project. Transport will follow a somewhat different course. This is described in Gassco's sub-project report.

9.3.1 Criteria for choosing concepts and project participants
All ITT's will incorporate requirements for financial commitment, knowledge sharing, technical qualifications and professional qualifications.

ITT criteria may differ for the concept/FEED phase and the construction/operation phases, but will cover cost, schedule, risk, learning potential, experience, and demonstrated ability to execute relevant projects.

More information about procurement processes and criteria can be found in the Project Implementation and Procurement Strategy (MPE, 2016a).

10 Incentive structure and framework conditions

10.1 Framework conditions

The different parts of a CCS project will have to deal with a number of authorities and will have to apply for necessary permits to conduct their activity. This is covered in Chapter 12 Authority plan. This chapter will address preconditions and assumptions regarding the framework that will affect the entire chain.

10.1.1 Ownership of CO_2 throughout the chain

It is presumed that the capture players will have ownership of the CO_2 up to the shipping point. Ownership of CO_2 during transport will depend on how the transport is organized. If the storage operator also organizes the transport, it would be logical for the storage operator to take over responsibility at the shipping point. If the transport of CO_2 is organized by a State player, the ownership of the CO_2 will have to be studied further. At the offloading point on the storage side, the ownership of the CO_2 will be transferred to the storage operator. As a starting point, responsibility for the stored CO_2 will be determined by the CO_2 Storage Regulations.

10.1.2 CO_2 subject to emission allowances throughout the chain

The EU Emissions Trading System (EU ETS) was established in 2005 and is one of the EU's most important instruments for reaching its overall climate goal to reduce greenhouse gas emissions by 40 per cent in 2030, compared with 1990. The sector subject to emission allowances contributes toward this goal in that a joint ceiling has been established for emissions from nearly 12 000 industrial enterprises and power producers in Europe. Emission goals are reached by gradually reducing the number of emission allowances available on the market. Each year, enterprises that are covered by the emission allowance system must report their emissions subject to emission allowances the year before, and then acquire emission allowances for these emissions. One emission allowance corresponds to one ton of CO_2.

Emissions of CO_2 from capture, transport in pipeline to storage and from storage are all activities subject to emission allowances included in the emission allowance system in the third emission allowance period (2013-2020).

Norway currently has two enterprises with permits that also include CCS activities subject to emission allowances. Both Sleipner and Hammerfest LNG acquire emission allowances for CO_2 vented in connection with the capture and diffuse emissions. There have not been any leaks from these storage sites, and no leaks are expected, but the enterprises' permits for emissions subject to emission allowances stipulate requirements for how a leak must be measured and reported, should one occur.

The emission allowance system gives enterprises increased production costs both in that direct emissions are subject to allowances and because the power price increases as a result of the power producers having to acquire allowances for their emissions (indirect emission costs). Compensation for direct costs is awarded through the allocation of free allowances. Enterprises in sectors that are exposed to carbon leakage are awarded a higher share of free allowances than the other enterprises covered by the emission allowance system. The rules define carbon leakage as increased CO_2 emissions due to enterprises moving production to areas outside the EU because they cannot price the extra costs caused by the emission allowance system into their products without losing market shares to competitors in countries outside the emission allowance system.

CO_2 from an enterprise subject to emission allowances that is captured for transport and storage in a geological formation is not subject to emission allowances. The allocation of free allowances to the enterprise will remain unchanged. However, no additional allowances will be awarded for CCS activities. Both Norcem and Yara are subject to emission allowances and belong to sectors defined as exposed to carbon leakage as of today. As regards EGE's facility at Klemetsrud, this is not currently subject to emission allowances. Only incineration plants defined as co-incineration plants are subject to emission allowances.

An incinerator plant is defined as a co-incineration plant if the incineration plant primarily produces steam for industry (more than 50 per cent); cf. guidelines for Annex I of the Emission Trading Directive. EGE's plant at Klemetsrud currently produces primarily district heating which is not delivered to industry and is therefore defined as a waste incineration plant and is thereby not subject to emission allowances. If the definition of waste incineration/co-incineration is changed or if Norway chooses to "opt in" waste facilities, EGE's waste plants may become subject to emission allowances. Article 24 of the EU Emission Trading Directive allows for "opting in" activities and gases beyond what is listed in Annex I, presuming that the criteria in Article 24 are met.

A new issue that could be relevant for Norcem, but particularly if EGE should become subject to emission allowances, is the handling of negative emissions. The emission allowance rules as they appear today provide no incentive for combining biomass with CCS, as negative emissions are not possible. The rules also currently do not cover transport of CO_2 by ship, rail or lorry. Now that CCS from industrial sources actualises transport other than pipeline transport, there will be a need to close this gap in the chain leading up to the storage. This can be done by "opting in" other transport solutions, but there will also be a need to develop guidelines for monitoring and calculating emissions from all relevant transport solutions.

The current emission allowance period lasts until 2020, and the allowance rules will be changed before the next allowance period, starting in 2021. In connection with revision of the rules, it will also be logical to address new issues that the current rules do not have guidelines for solving.

10.1.3 State support rules

The starting point of the EEA Agreement with Norway is that any award of state support that distorts or threatens to distort competition within the EEA area by favoring certain enterprises is not allowed. The EFTA Surveillance Authority (ESA) can approve state support if it conforms with the EEA Agreement. ESA's environmental guidelines provide an indication of what is needed for ESA to approve the support.

<table>
<tr><th></th><th>General conditions</th><th>State support for CCS</th></tr>
<tr><td>1</td><td>Defined purposes of shared interests</td><td>Support for CCS contributes to shared purposes</td></tr>
<tr><td>2</td><td>Need for State intervention</td><td>Need for support for CCS</td></tr>
<tr><td>3</td><td>Appropriateness</td><td>Both investment and operating support is appropriate</td></tr>
<tr><td>4</td><td>Incentive effect</td><td rowspan="2">Costs entitled to support: Financing need, i.e. net funding gap compared with a counterfactual scenario:
• All income and savings must be taken into consideration
• Support up to 100% of the costs entitled to support
• No more than necessary</td></tr>
<tr><td>5</td><td>Proportionality</td></tr>
<tr><td>6</td><td>Limited impact on competition and trade between member states</td><td>Balance test</td></tr>
<tr><td>7</td><td>Transparency</td><td>The support scheme must be published on the Internet</td></tr>
</table>

Table 10.1.3.1 Conditions for legal state support for CCS.

Table 10.1.3.1 shows the relationship between ESA's general conditions for approving state support and how CCS corresponds with them. The need for support must be notified to ESA, and cannot be awarded until a final approval is issued. A process has therefore been initiated to notify support for potential further planning of a CCS project. The state support rules limit the support that can be awarded to up to 100 per cent of the costs entitled to support. In a CCS project, this will entail support for up to 100 per cent of costs linked to CCS.

10.2 Incentive structure for CO_2 capture, transport and storage

The State's starting point is that there must be a sharing of costs and risk between the State and the industry players participating in the project. Over the course of the feasibility study, informal talks have taken place with the capture and storage players regarding incentives and sharing costs and risk in the development and operating phase of an eventual fullscale CCS project. The results of this work will be found in draft support agreements for capture and storage, respectively, that will be part of the tender documentation for the concept and FEED phase. This draft will then form the basis for further negotiation with stakeholders awarded contracts to conduct concept and FEED studies. Different alternatives are being considered for organisation of the transport part, which is largely a service that can be purchased in a commercial marketplace. The agreements to be entered into for transport, and who will be party to such agreements, depends on how CO_2 transport is organised.

The State's support for a first CCS project will be composed of multiple elements. The state support rules prohibit covering more than the costs related to CCS. It will be logical to envision a combination of investment support and operating support. Important parameters such as return on investment, discounting period and support period must also be established before an investment decision is made. One overall goal for the State's work on framework and incentives in a first CCS project is that the State and industry stakeholders' incentives for building and operating a good, cost-effective CO_2 chain must coincide as much as possible. The State's need for control and management of the project will depend on the extent to which the State and the industry have coinciding incentives in the development and operating phase. As a basis, the State will have the same approach to support for both the capture and storage part of the CCS chain, but adaptions for storage will be needed.

11 Authorities and regulations

11.1 Introduction

Different agencies will act as regulating and responsible authorities in the different parts of a CCS chain. It will therefore not be logical to carry out application processes and impact assessments jointly for the entire chain, but rather let each facility owner, developer and proposer carry this out pursuant to the applicable regulations. For a more detailed overview of authorities and associated regulations, please see (MPE, 2016b).

Some coordination of the authority processes will be beneficial and, to a certain degree, necessary as regards interface clarifications and descriptions of systems of a joint nature. The Greenhouse Gas Emission Trading Act and its associated regulations are the only overarching regulations for the entire chain. Coordination vis-à-vis the Norwegian Environment Agency, which administers these regulations, will be handled by Gassnova.

The Regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO_2 and relating to transport of CO_2 on the continental shelf do not currently cover shipping of CO_2. The Greenhouse Gas Emission Trading Regulations currently do not cover any transport other than pipeline transport, but as described in Chapter 10.1.2, this may change in the future.

An impact assessment (IA) may be needed for capture and storage, while it is presumed that this will not be needed for transport. Key topics that are to be included in an IA are presented in the feasibility study reports from the industry players. Proposed study programmes must be in place early in the next phase of the project. An IA must be included as a basis for an investment decision and an emissions permit must be granted before a capture facility can be started up. Both the study programme and IA are subject to public consultation and must be processed by the coordinating agency.

11.2 Capture

All industry players have assessed applicable regulations and elucidated the authority process that will be needed in connection with construction and operation of a CO_2 capture facility.

One important part of the process vis-à-vis the authorities will be an IA. Such an assessment will comprise studies of emissions to air and discharges to water and ground, as well as the handling of chemicals and waste, the risk of accidental emissions and hazardous conditions in general. In line with the Regulations relating to impact assessments, societal consequences of a positive and negative nature must be mapped. An IA must have been carried out when a permit for polluting activity is sought from the Norwegian Environment Agency and before an investment decision is made. It is presumed that the Norwegian Environment Agency will be the coordinating authority for processing the IA. A new zoning plan may also be needed and this must be investigated vis-à-vis the relevant municipality in each individual instance.

A CO_2 capture facility will also need an emissions permit or an amendment of an existing emissions permit for an enterprise. The developer must prepare an emission application and an emissions permit must have been granted before the facility can start up. A number of other consents and permits from the Norwegian Directorate for Civil Protection, the Norwegian Labour Inspection Authority, the Norwegian Coastal Administration and municipality must also have been granted before construction starts and before the facility for capture and intermediate storage is commissioned.

If the capture player is subject to an allowance obligation, it will have new activity with an allowance obligation in connection with establishing capture of greenhouse gases from enterprises subject to allowances to be transported and stored in a geological formation approved by competent authorities. An amended permit for emissions subject to an allowance obligation, which includes emission sources linked to the new activity subject to allowance obligations must be in place before the capture facility starts up.

11.3 Transport

Shipping of CO_2 will primarily be subject to maritime regulations, i.e. the regulations that apply for maritime transport in general. Ships used to transport CO_2 will not be treated differently than other transport of gas under pressure on ships.

The maritime regime is characterised by the fact that the ships must have valid maritime certificates from a national maritime authority (flag state) and class certificates from a recognised classification society in order to operate.

Flag certificates document that the ship satisfies requirements from the UN's International Maritime Organisation (IMO) as regards safety and pollution, while the class certificates document compliance with detailed technical requirements in class rules and standards.

The Norwegian Maritime Authority is the regulatory authority for ships registered in Norway, but ships are not dependent on Norwegian certificates to operate in Norwegian waters.

Norwegian continental shelf legislation distinguishes between activity from vessels or facilities, depending on whether or not the unit is in contact with the wellstream and whether its function is considered to be an integrated part of an offshore field operation.

As regards the alternative with direct injection of CO_2 from transport ships, there is a need for a clarification as to whether or not the ship will have direct control over the well. A ship that loads or offloads cargo offshore is defined as a cargo ship. A mobile facility is a floating, mobile offshore unit that is used for activities within subsea petroleum activity. A mobile facility is covered by the Petroleum Safety Authority Norway's (PSA's) regulations, which will also reference the Norwegian Maritime Authority's regulations for mobile facilities.

Units categorised as mobile facilities must also be granted special approval from the PSA, a so-called Acknowledgement of Compliance (AoC). An AoC documents that the technical condition and management systems are in conformance with the requirements of the petroleum regulations.

A detailed design specification for ships to be used to transport CO_2 will have to be prepared for the next phase, where one includes all relevant regulatory requirements, certificates and standards that are important for a new build.

The Maritime Traffic Regulations and Pilot Requirement Regulations will also be relevant for CO_2 transport on vessels and vessels of a certain size will be subject to a pilot requirement.

A requirement for an impact assessment of the actual CO_2 ship transport is not expected.

Emissions in connection with transport of greenhouse gases in pipelines for storage in a geological formation approved by competent authorities are currently subject to an emission allowance obligation. If emissions in connection with transport of greenhouse gases using transport other than pipeline transport is also subject to a duty to surrender allowances, the transport player will have to apply for a permit for emissions of greenhouse gases subject to a duty to surrender allowances.

11.4 Storage

The Storage Regulations with reference to the Framework Regulations and the PSA's regulations will be relevant for all considered storage alternatives. Maritime regulations will apply for the ship alternatives (floating storage vessels), while it is presumed that regulations administered by DSB will apply for onshore facilities. The Heimdal alternative will be governed by relevant regulations for oil and gas facilities as long as petroleum activity is conducted there.

The Storage Regulations also list the requirements for process and content of the study programme and IA for development and operation of subsea reservoirs for injection and storage of CO_2. The alternative involving intermediate storage on land may also require an amendment of the zoning plan pursuant to the Planning and Building Act.

The municipality will be the responsible authority for plans pursuant to the Planning and Building Act, while the MPE will receive an application for a permit for exploitation of subsea reservoirs for injection and storage of CO_2, as well as a proposed study programme and the actual IA. The latter will also be taken into consideration in the approval of the Plan for Development and Operation (PDO/PIO). The EU's Directive on Geological Storage requires the application for CO_2 storage to be made available to be ESA with a deadline for comments set at 4 months.

An application must be submitted to the Norwegian Environment Agency for a storage permit pursuant to Chapter 35 of the Pollution Regulations and a permit for emissions subject to a duty to surrender allowances, cf. Section 11(2) of the Pollution Control Act, cf. Section 16. Chapter 35 of the Pollution Regulations sets requirements for the content of the application and what requirements the permit shall stipulate to achieve environmentally safe storage of CO_2. The terms of a permit will e.g. comprise injection conditions, a monitoring programme and financial security for stored CO_2. The emission trading regulations set requirements for calculation, measurement and reporting of emissions subject to a duty to surrender allowances. CO_2 leaked from a CO_2 storage site will be subject to a duty to surrender allowances.

12 Next phase - concept and FEED study

If the full-scale project is continued, a combined concept and FEED phase is planned. According to Chapter 9 of the project execution plan, the concept and FEED studies are planned to start in the first quarter of 2017, and will conclude in the third quarter of 2018. It is furthermore presumed that the project will be quality-assured before the investment decision in accordance with the State's system of external quality-assurance (QA2). Formal notification of the project will also be made to the ESA.

12.1 Organisation

The outlined schedule for the full-scale project is demanding, and it is therefore decisive for progress that organisation of the work, including roles and responsibilities, is clarified. The MPE has decided that Gassnova will be responsible for managing the project, and thereby coordinate the entire chain through the concept and FEED phase. Gassco will be responsible for managing the transport part of the work.

The conclusion from the feasibility study is that the work be organised as a project with a project manager who has overall responsibility for ensuring that the work on the full-scale CO_2 project is implemented according to the mandate and plan, and that the project achieves its goals as regards quality, cost, plan and HSE. The project organisation will also include separate follow-up teams for the sub-projects capture, transport and storage. There will also be a need for resources within HSE, authority contact, quality-assurance, coordination of technical interfaces in the chain, as well as various support functions in line with common industrial project implementation practice (project management, risk management, cost estimation, commercial negotiations, procurement, document management, etc.).

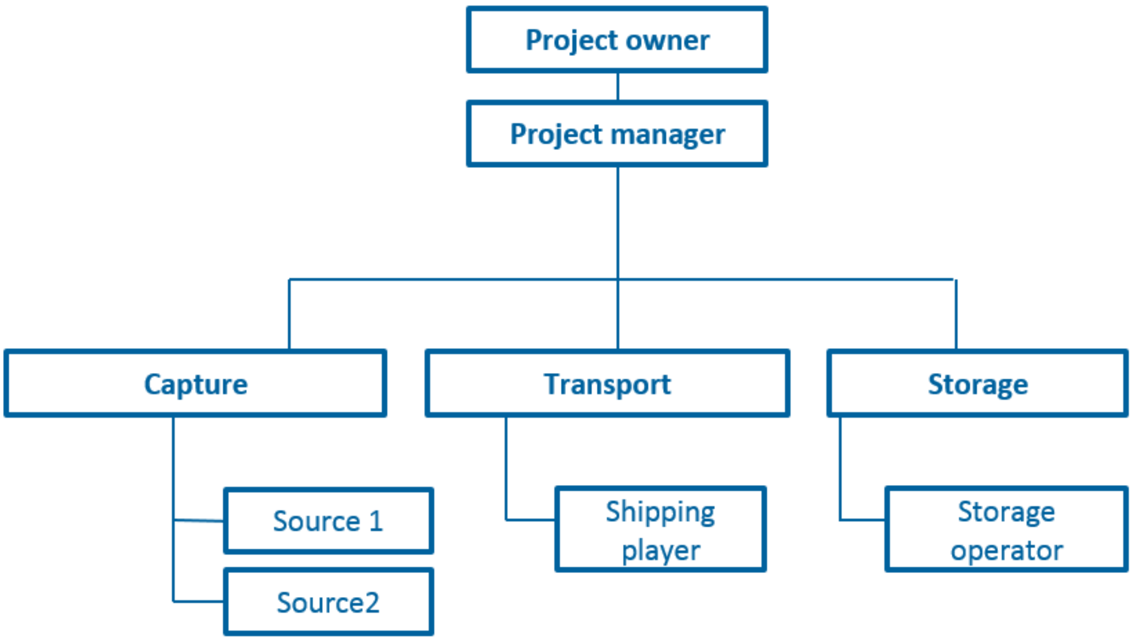

Figure 12.1.1.1 Overall organisation of the concept and FEED phase.

The planning work for CO_2 capture, transport and storage should be performed by the players that will have a role in the operating phase if the CCS chain is built. However, there will be different needs for follow-up, involvement and organisation by the State in the various phases of the full-scale project. The following should be emphasised for the organisation of the development and operating phase:

- The goal of learning and dissemination of knowledge from all parts of the CCS chain
- "Feedback" from full-scale demonstration to R&D institutions and the technology centre for CO_2 capture at Mongstad (TCM). This is key in order to promote technology development and the goal of cost reductions
- The need for technical advice and follow-up of the capture, transport and storage part of the chain
- Optimal utilisation of the State's expertise and cooperation between players
- Establishing an appropriate and comprehensive contract structure for the CCS chain

The organisation should also allow the State to take a less central role if a functioning market should develop over the long term, as well as the establishment of future infrastructure for transport and storage of new CO_2 volumes.

Experience shows that the choice of technical solutions is closely related to commercial matters and the requirements set for the industrial players in the planning, development and operating phase. The MPE will have overall responsibility for the further work on framework conditions and incentive structures, but the work will be carried out in close collaboration with Gassnova and Gassco so that this mutual dependence is taken into consideration. Necessary clarifications concerning framework conditions and commercial matters should take place to an appropriate extent before the next phase starts.

12.2 Scope of work

The combined concept and FEED phase aims to find the most appropriate conceptual solution for the CCS chain, as well as prepare a unified basis for the investment decision. The concept and FEED studies will also act as a basis for the various industrial players' investment decisions, and it is therefore deemed appropriate that the studies be conducted in line with their project implementation models and procedures. In this context, the State will set requirements for deliveries from the concept and pre-engineering studies, while the industry players will propose the necessary work and scope of work in order to deliver them at an adequate level of maturity.

The decision basis will, according to normal industry practice, comprise cost estimates within an uncertainty of +/- 20 per cent. The scope of work for the industry players in the concept and FEED studies will include technical descriptions of capture, transport and storage, respectively, including intermediate storage, conditioning and interfaces to any surrounding facilities. The need for technology qualification should be clarified and carried out as early as possible in the concept and FEED phase. The cost estimates shall comprise both the investment and operating phase, as well as an uncertainty analysis e.g. for establishing the expected contingency and a confirmation that the range of uncertainty is within the precision requirements. One important part of the industry players' work in the concept and FEED phase will also be a mapping of important HSE aspects and circumstances, as well as the establishment of a programme for and subsequent implementation of an impact assessment (IA). A coordinated work programme for the next project phase, detailed engineering, realisation and operation, including a budget and schedule, will be established based on input from the various players in the CCS chain.

It is presumed that all players will contribute to find good solutions (incl. concept choices) across the entire CCS chain, and both through the work on concept and FEED studies and in the operating phase contribute to support the State’s goal of dissemination of knowledge and the spread of technology.

Before the concept and FEED phase is announced, we must consider whether additional interested parties and qualified industry players will be given the opportunity to complete the studies and whether a process will be established for selection during the study phase. The time of clarification of the technical framework conditions and functional requirements for the CCS chain is an important risk factor in the concept and FEED phase. In this context, it will be particularly important to establish the CCS chain’s overall design basis. This e.g. applies to CO_2 specification, pressure and temperature conditions, total CO_2 volume in the chain, as well as the overall choice of technical solutions in the different parts of the CCS chain. These issues should be thoroughly discussed with the industry players, and decisions should be made on the basis of an optimisation and cost/benefit assessments along the CCS chain.

12.3 Schedule

An overall schedule has been established for implementation of the project. The autumn of 2016 will comprise various preparations, such as work on optimisation of the design basis and the announcement of a competitive process to support a combined concept and FEED phase immediately following presentation of the National Budget for 2017. This competitive process will also select the players that have the opportunity to enter into agreements on investment and operation. Based on start-up of concept and FEED studies in February 2017, the FEED studies are scheduled for completion in September 2018.

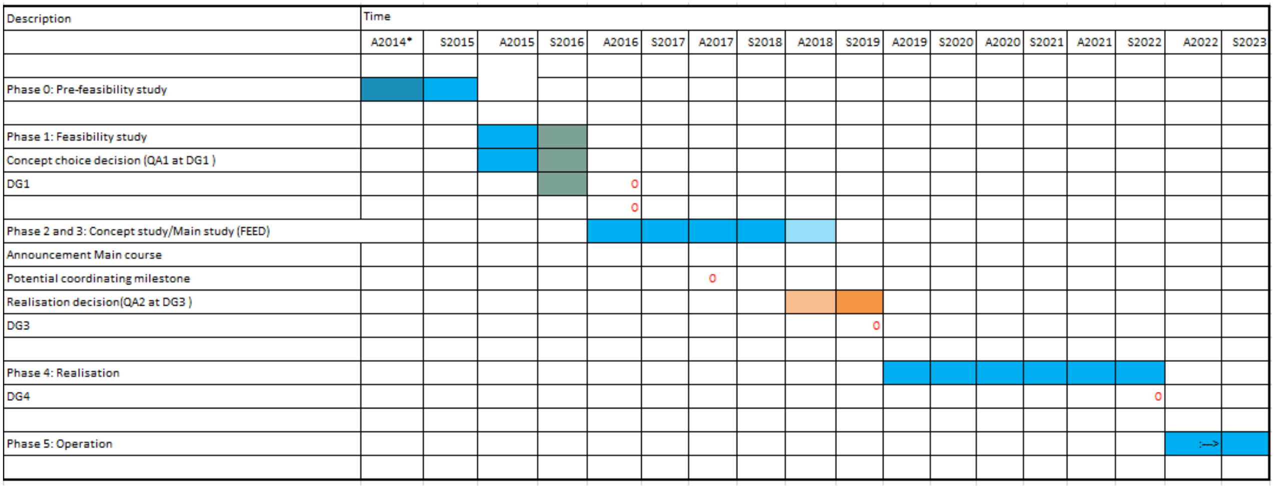

Figure 12.3.1 Overall schedule.

As part of the feasibility study work, the different industry players have prepared proposed plans for continuing the work in concept and FEED studies, as well as realisation. The plans vary somewhat in scope and duration, and comprise the activities and areas for which the individual industry player is responsible, regardless of the rest of the CCS chain. The overall and coordinated schedule for the further work on the project is based on input from the industry players. Mutual dependencies between CO_2 capture, transport and storage, as well as the need to establish a unified decision basis for the investment decision has been taken into consideration in this schedule. The schedule also includes preparation of the basis for and implementation of external quality assurance in accordance with the KS scheme, ESA notification of the project, as well as the Storting’s approval of the investment decision.

This schedule must be further processed in the concept and FEED phase.

It is presumed that there may be a need for a coordinating milestone for the entire chain during the concept and FEED phase, most likely in the autumn of 2017. The content of this milestone may include coordination of the CCS chain and a form of reporting on the technical status and costs, a potential reduction of the number of parallel studies, more detailed framework conditions and incentive structure. Delivery requirements for this coordinating milestone must be specified before the announcement and potentially adjusted following the start-up of the concept and FEED studies based on input from the industry players.

13 References

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