1 Introduction and summary

1.1 Background

1.1.1 The Implementation Agreement and mandate

In 2006, the Norwegian government granted permission for the building of a combined heat and power plant at Mongstad (EVM). At the same time, an Implementation Agreement was entered into between Statoil ASA and the Norwegian government, represented by the Ministry of Petroleum and Energy. The Implementation Agreement is available in its entirety on the following website: http://www.regjeringen.no/upload/kilde/oed/prm/2006/0143/ddd/pdfv/293147-avtale_mellom_staten_og_statoil_mongstad_12_okt_06.pdf.

In the Implementation Agreement, Statoil undertook to develop a master plan for future CO_2 capture at Mongstad (the "Master Plan"). Pursuant to the agreement, the master plan shall include the following elements:

- Conceptual studies of relevant technical and commercial solutions for CO_2 capture. Clarifications of area requirements, energy requirements, the need for operating and maintenance services, HSE solutions and the need for dialogue with, and permits from, the authorities.
- Identification of relevant CO_2 capture sources in the existing oil refinery, the combined heat and power plant and any future projects.

This has formed the basis for StatoilHydro's (SH) work on this master plan.

At the same time as the Implementation Agreement was signed, the Norwegian government, represented by the Ministry of the Environment (ME), granted the combined heat and power plant an emission permit for carbon dioxide. In doing so, ME endorsed SFT's recommendation that a CO_2 capture solution be estabished for the combined heat and power plant in accordance with the Implementation Agreement.

The Implementation Agreement describes a stage-wise development towards full-scale CO_2 capture. The agreement describes the test centre as Stage 1 and the planning and implementation of full-scale capture as Stage 2. The master plan is an important step towards an investment decision. It confirms that CO_2 capture is possible, and it describes two main alternatives for realising this at Mongstad.

The master plan is part of the basis for the Stage 2 agreement to be entered into by the Norwegian authorities and SH on full-scale CO_2 capture at Mongstad. The master plan and the Stage 2 agreement will be the basis for the decisions required to establish a full-scale CO_2 capture facility at Mongstad. A number of studies and clarifications will be required before an investment decision is made. The master plan as such consists of early-phase assessments, and the concept and capture sources have not been finally decided. The master plan describes central areas and important challenges relating to the establishment of full-scale capture. Technical and industrial solutions will be further developed and optimised in the period leading up to an investment decision in order to reduce risk. This could influence both the estimated costs and plans.

1.1.2 Work on the master plan

The master plan is an overall plan for future CO_2 capture at Mongstad. The work includes a number of external studies that were combined with extensive internal work, assessments and experience transfer. The report describes relevant technical and commercial solutions for full-scale CO_2 capture at Mongstad integrated with the combined heat and power plant and the refinery. Assessments of area and energy requirements, the need for operating and maintenance services, HSE (health, safety and the environment) solutions etc. are covered in the report. The potential CO_2 sources in the existing oil refinery, the combined heat and power plant as well as any future projects at Mongstad are identified.

CO_2 capture on a scale of millions of tonnes per year from exhaust and flue gases is unique in the global context. Quality assurance of the technical requirements and solutions in the project has therefore been a particular priority. Key areas have been the size of the facility, including the dimensioning of equipment, HSE challenges related to open amine systems and carbon dioxide under pressure, the need for utilities and integration with other facilities at Mongstad. The descriptions and assessments are based on industry practice for project development at an early stage.

The work has also utilised experience from relevant projects, including Halten CO_2, Snøhvit and Kårstø [1], and the transfer of experience from these projects is part of the quality assurance of solutions, technological evaluations, the identification of critical equipment and attention to special issues.

The project has included the following interfaces and stakeholders, among others:

- Authorities (OED, MD, SFT, local authorities etc.)
- The Mongstad refinery (MRDA)
- The Mongstad Energy Plant project (EVM)
- The European CO_2 Test Centre Mongstad project (TCM)
- Gassnova, including their CO_2 transport and storage project

The capture facilities are part of a larger overall project, which also includes transport and storage. It is important that the entire chain of CO_2 handling is implemented as a whole in terms of planning, safety, design and technology. In further project development, it is important that time schedules, interfaces and requirements are coordinated for the whole chain. Start-up of a full-scale capture plant requires a transport and storage solution in place.

CO_2 transport and storage will be implemented as a separate project managed by Gassnova SF on behalf of OED. The transport and storage project is studying storage locations for the storage of carbon dioxide volumes from Kårstø and Mongstad.

Although they are relevant for realising the total carbon dioxide chain from source to final storage, the following projects, activities and interfaces are not part of this work:

- TCM (TCM owners are responsible)
- Transport and storage of CO_2 (the authorities represented by Gassnova are responsible)
- Roles, responsibilities, organisation, implementation etc. in connection with further project development (covered by the Stage 2 agreement)

The purpose of this master plan is to provide the best possible basis for decisions relating to the time schedule, implementation, possibilities and uncertainties relating to full-scale CO_2 capture from the combined heat and power plant and the refinery.

1.1.3 Organisation of the work

StatoilHydro (SH) established a project for the master plan work called CO_2 Master Plan Mongstad (CMM). Work on the project has been ongoing for roughly one and half years. More than 30 internal man-years have been spent on the project within the budget of NOK 60 million, including a number of external studies. SH's governing documents, principles, early-phase requirements and quality assurance have been used during the study work, which has been organised and carried out in the ordinary industry practice for an early-phase project.

There has been good contact with Gassnova SF, the authority's technical advisor in matters relating to CO_2 capture, transport and storage during 2008.

Due to the size of the project and its use of technology on a scale not utilised before, there has been a particular need for quality assurance of the technical assumptions and solutions in this project. SH's project model with decision gates (DG) has been followed, and a so-called DG1 was passed in April 2008. Relevant discipline entities in SH have been involved in reviews of the work.

1.1.4 The industrial area at Mongstad

The capture facilities described in the master plan will be established in an existing industrial area at Mongstad containing several different sub-plants, which will all be operational when the capture facilities are established. Mongstad is located approximately sixty kilometres north of Bergen, and the industrial area contains a refinery, a crude oil terminal, a technical development centre (PTC) and a facility for processing natural gas liquids (Vestprosess). In addition, a combined heat and power plant (EVM) is under development. There are nearly 650 SH employees and about 250 other workers on site. There are different ownership structures and different partners present; Shell, for example, is part-owner of the refinery (MRDA), Petoro is part-owner of the crude oil terminal, and Vestprosess is a joint venture consisting of SH, Petoro, ExxonMobil, Shell, Total and ConocoPhillips. The area is near the large oil fields in the North Sea, where daily production of oil in the Norwegian sector is approx. 1.5 million barrels.

A highly upgraded refinery
The refinery is a modern, highly upgraded oil refinery for North Sea oil with the capacity to process 10 million tonnes of crude oil per year. In the European context, it is a medium-sized refinery. The main products are petrol, diesel, LPG and aviation fuel. The heaviest fractions of the crude oil are used, among other things, to produce petroleum coke, which is a raw material in the manufacture of anodes for the aluminium industry. The production of petrol corresponds to nearly twice the Norwegian consumption, and large volumes are exported to the European market. The refinery also has a road tanker facility at which 25-30 road tankers call each day and take out 1-1.5% of the produced volume.

A crude oil terminal for customers all over the world
The crude oil terminal is at a strategic location, only a short distance from the oil installations in the North Sea. Six large caverns provide temporary storage for nearly 10 million barrels of crude oil (1.5

million cubic metres). The oil is transported to the storage facility on shuttle tankers from fields including Statfjord, Gullfaks, Norne and Heidrun, and through pipelines from Troll B and Troll C. Approximately one third of all North Sea oil produced by SH, including the state's share, is stored here intermediately. The oil is exported to the USA, Canada, the Mediterranean countries and the Far East, among other places.

The second-largest oil port in Europe
Mongstad is the second-largest port in Norway in terms of tonnage, with about 2,000 ships calling every year. The plant can accommodate crude oil tankers of up to 450,000 tonnes and product tankers of up to 90,000 tonnes and it is the second-biggest oil port in Europe, second only to Rotterdam. In order to be able to handle the extensive shipping traffic in a safe and satisfactory manner, Mongstad port has four tugboats, three of which are custom-built for escort duty. The tugboats are also an important part of emergency oil spill response.

Vestprosess refines condensate
Vestprosess connects the onshore plants at Kollsnes, Sture and Mongstad in order to increase the value of wet natural gas from the Troll, Oseberg, Tune, Kvitebjørn, Visund and Fram fields in the North Sea. The plant uses wet gas and condensate as raw materials, which come by pipeline from the gas processing plant at Kollsnes and from the terminal and processing plant at Sture in Øygarden. Wet gas and condensate are stabilised and fractionated into naphtha, propane and butane at Vestprosess. The annual production of propane and butane is approx. one million tonnes, and two new caverns of 60,000 cubic metres each and a new quay have been built, among other things.

Energiverk Mongstad (EVM)
EVM is the most recent major expansion at the refinery. EVM consists of a new natural gas pipeline between Kollsnes and Mongstad, modifications and alterations to the Mongstad refinery, and a new combined heat and power plant that will produce electrical power for export to the grid (including to Troll A and Gjøa) and heat for the refinery processes. The project will be in operation from 2010. The Danish energy company Dong Energy is building and will own and operate the combined heat and power plant, while MRDA will own the production (electricity and heat). The natural gas pipeline is part of the production and landing system for Troll. MRDA has overall responsibility for the Mongstad facility, and, as operator, SH is responsible for compliance with emission permits and licences.

Mongstad's total energy requirement for the operation of the refinery area was approximately 60 MW of power and approximately 800 MW of heat in 2007. The combined heat and power plant will enable future development of the refinery and will provide opportunities for energy efficiency measures in the future. The building of a combined heat and power plant is an energy improvement measure in itself that will result in better overall energy efficiency. For more information, visit the following website: http://www.statoilhydro.com/Mongstad.

1.2 Recommended capture sources and technology

Mongstad industrial area has several emission points of varying size. The catalytic cracker plant is the largest single CO_2 emission point in Norway today, and it is a key part of the refinery in which the heavier components of the crude oil are upgraded to fuel components. All sources have been evaluated, and the following recommendations made for CO_2 capture sources:

- The combined heat and power plant and the catalytic cracker plant are recommended as the basis for CO_2 capture. These two sources will emit approximately 80% of the refinery's CO_2 emissions when the combined heat and power plant is in full operation. Capture from the combined heat and power plant will amount to approximately 1.2 million tonnes of CO_2 per year, and approximately 0.8 million tonnes per year from the catalytic cracker plant.
- The remaining 20% of CO_2 emissions stem from eleven other flue gas sources. The cost per unit of removing carbon dioxide from these sources has been estimated to be significantly higher than for the combined heat and power plant and the catalyst cracker plant.
- The refinery area's total CO_2 emissions, including from the capture facilities, should be further minimised by means of energy optimisation.
- Capture from potential future projects that produce large CO_2 emissions must be considered as the need arises.

Reformer 2 is specifically mentioned in the Implementation Agreement as a possible source for CO_2 capture. These heaters were modified in autumn 2008, which has reduced CO_2 emissions. In addition, the heat in the flue gas from Reformer 2 can be utilised to pre-heat the combustion air, which would result in a further reduction of CO_2 emissions. This and other possible energy efficiency measures are therefore recommended for Reformer 2 instead of capture.

The exhaust gases from the combined heat and power plant and the flue gas from the catalytic cracker plant have different properties. The catalytic cracker plant produces flue gas that can be compared, in many ways, to coal power. Compared with the combined heat and power plant, the flue gas from the catalytic cracker plant has a higher concentration of carbon dioxide, a lower concentration of oxygen and a smaller volume rate of gas. In addition, the flue gas contains catalyst particles, sulphur dioxide, entrained seawater and a higher concentration of nitrogen oxides, which means there is greater technical uncertainty in relation to the implementation of CO_2 capture. Independent capture plants are therefore recommended for these two sources. This will also make it possible to choose different capture technologies and to have different time schedules for the two capture plants.

Since CO_2 is to be captured from existing sources, only post-combustion capture is relevant for the refinery and the combined heat and power plant. Other technologies, such as pre-combustion capture or oxyfuel (fuel combustion with pure oxygen to produce carbon dioxide and water), would imply major modifications and disturbance of the combined heat and power plant and refinery than post-combustion capture, and are therefore not recommended.

The most promising post-combustion technologies, selected on the basis of HSE, energy efficiency, cost, maturity and complexity criteria, are the following:

- Improved amine processes
- Carbonate processes

Amine technology is considered to be known, through the studies carried out in connection with the master plan and previous SH projects, but there are a few risks that need to be clarified in the following phases. The primary risk is deemed to be potential negative health and environmental effects of emissions to air (amines may form reaction and degradation products that can be hazardous to health). Another risk is in scaling up of the process, particularly in relation to the absorption tower, stripping tower and large rotating mechanical equipment. There is no post-combustion capture plant of similar dimensions, with capture in the order of million tonnes of CO_2 per year. The facility will require some of the biggest absorption towers and mechanical components that have ever been built. Fluor's facility in Bellingham, USA, for example, is among the biggest ever built, with a capture capacity of approximately 120,000 tonnes of carbon dioxide per year from the gas turbine exhausts.

It is not considered realistic for carbonate processes to be mature enough for an investment decision for full-scale capture within the next few years. In a long-term perspective, however, carbonate processes may rival amine-based technology and have the potential for better energy consumption and HSE performance. So far, their potential has not been completely documented in pilot units and laboratory experiments.

Exhaust gas recycling in the combined heat and power plant is not a capture technology in itself, but can be combined with capture processes to improve performance. Exhaust gas recycling is a promising technology that can result in improvements in HSE characteristics and energy requirements with a potential cost reduction, and further studies of EGR for both alternatives are recommended in future phases of the project. If exhaust gas recycling is to be applied, then it should be implemented at the same time as the capture plant.

Two alternative routes have been outlined for the choice of technology for the combined heat and power plant: 1) A capture facility based on currently available amine technology, provided that the health and environmental risk associated with the amine process is deemed to be acceptable at the time of the investment decision, 2) The choice of technology and concept for the capture facility will be based on stage-wise technology development through technology qualification, test facilities etc., as is proposed for the catalytic cracker plant. This could result in improvements in the amine process (cost reduction), the possibility of other technologies becoming qualified (e.g. carbonate technology), more competition in the market (more suppliers to choose from) and reduced technical risk etc., before an investment decision is made.

For the catalytic cracker plant, it is recommended that the capture technology be selected following technology qualification and extensive testing through TCM, among others, including testing the effects of the chloride content and catalyst particles on operations and design. The possibility of removing particles should be tested and the consequences of this assessed, before a full-scale facility can be built for the catalytic cracker plant. It is expected that separate tests will answer many questions before a final decision on the design of the facility and flue gas pre-treatment is made.

In this report, available amine technology has been used in the technical description of capture from the catalytic cracker plant as the basis for dimensioning support and auxiliary systems and the CO_2 export system. The final choice of technology will be based on the results of tests and the technology available at the time of the investment decision. Flue gas from the catalytic cracker plant has many similarities with flue gas from coal-fired power plants. The capture technology used for the cracker plant therefore has potential for application to coal-fired power plants.

The energy requirement identified for capture from the two sources is 40-45 MW of electricity and 170-230 MW of heat in the form of low-pressure steam (including the CO_2 export system). In addition, a proposed recovery unit for heat in the combined heat and power plant exhaust gas will require approximately 10 MW. The mass and energy balance of the facility is shown in figure 1.1.

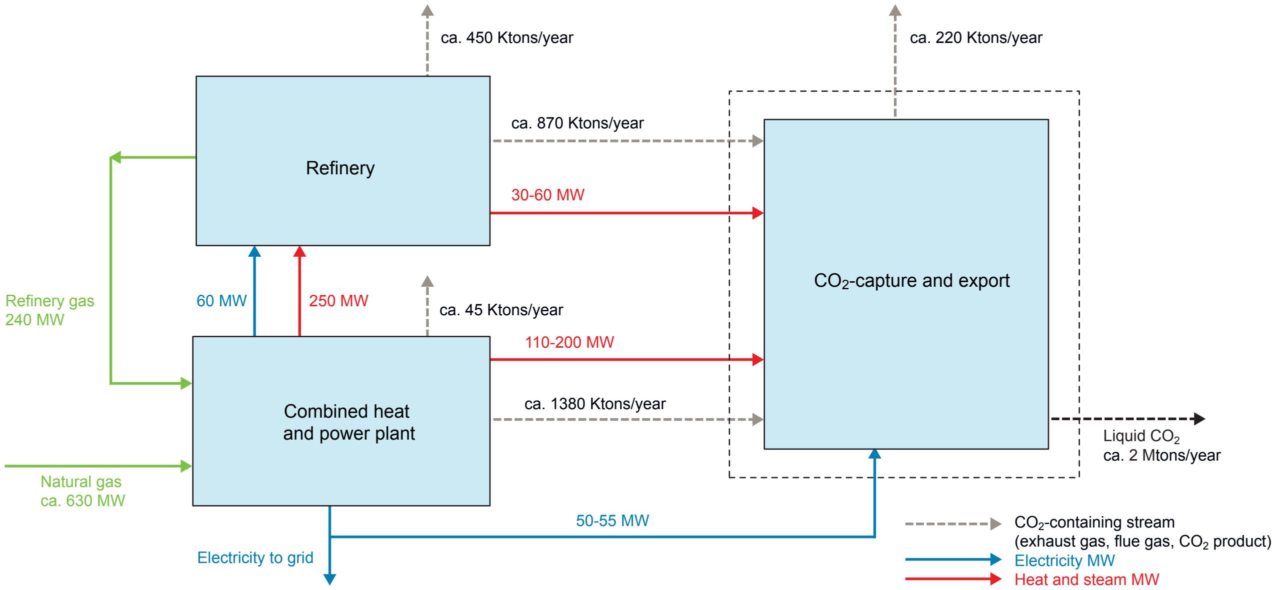

Figure 1.1 The mass and energy balance of the facility.

In many cases, energy optimisation will be a more cost-efficient way of reducing CO_2 emissions than large facilities for CO_2 capture. Improvement measures in existing refineries and reduced energy consumption in capture plants with good design solutions have also been studied. Heat in the exhaust gas from the combined heat and power plant would provide a significant proportion of the capture facility's energy demand. The combined heat and power plant will also enable more efficient energy production, since fuel gas from the refinery can be combusted in the combined heat and power plant. Other measures identified are pre-heating air for heaters and heat recycling in the catalytic cracker plant. This will result in a reduction of fuel gas of two tonnes per hour, corresponding to 40,000 tonnes of carbon dioxide per year.

1.3 Execution plan

The refinery is a very complex industrial facility where many processing plants and utility systems are highly integrated. Any new investment will have consequences for the rest of the facility, and interruptions to individual plants will affect the total value creation at the facility. It is therefore important to assess the capture facilities as effectively as possible, also in order to prevent reduced regularity of the plants. Two main alternatives have been defined for full-scale CO_2 capture at Mongstad, based on the Implementation Agreement and work carried out in connection with the master plan. Both alternatives describe capture from both sources and involve total capture of approximately 2 million tonnes of carbon dioxide per year. The master plan forms part of the the basis for the Stage 2 agreement to be entered into between the Norwegian authorities and SH. SH has therefore not decided on an alternative, but has described the time schedule, implementation, possibilities and uncertainties relating to the two main alternatives.

Alternative 1:
CO_2 capture from the combined heat and power plant utilising currently available amine technology, normal industry practice for safe and efficient implementation of the project and acceptable health and environmental risk with the aim of starting up as soon as possible. CO_2 capture from the catalytic cracker facility as phase 2 based on stage-wise technological development.

Characteristics of alternative 1:

- Soonest possible capture from the combined heat and power plant.
- Stage-wise technological development based on TCM for the catalytic cracker plant.
- Limited or no experience from TCM for the combined heat and power plant.
- A facility where the size and certain pieces of equipment are without reference in the industry.
- Health and environmental risks associated with the use of amines and a relatively short period for risk mitigation before the investment decision must be clarified.
- Requires a relatively rapid decision-making process, and it could be challenging to establish the necessary framework conditions.

Alternative 2:
Simultaneous development of CO_2 capture from both the combined heat and power plant and the catalytic cracker plant, based on stage-wise technology development.

Characteristics of alternative 2:

- Stage-wise technology development based on TCM can be used for both facilities.
- Facilities where the size and certain pieces of equipment are without reference in the industry.
- Two large, parallel projects.
- Health and environmental risks associated with the use of amines, but more time to map and reduce the risk.
- Longer decision-making process.

Figure 1.2 provides an overview of the two alternatives in terms of captures source, technology and start-up time.

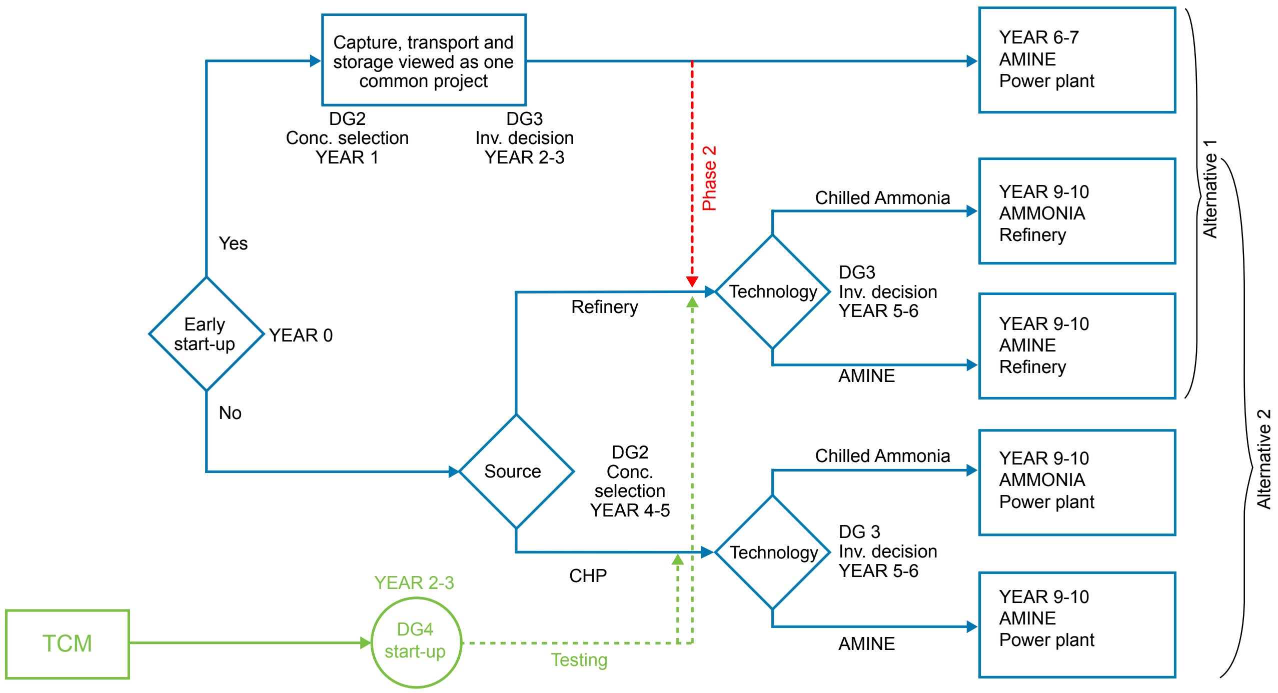

Figure 1.2 Implementation alternatives.

Amine technology is considered to be known, based on studies carried out in connection with the master plan and previous SH projects, but it has never been applied on the scale required for the combined heat and power plant. It is a requirement that the health and environmental risks associated with amines and the amine process are acceptable at the time of the investment decision. Factors that remain unclarified in this connection can result in a postponement of the investment decision and change the choice of technology. Naturally, this risk is greater for alternative 1, since it is based on a relatively short period until the investment decision.

For the catalytic cracker plant, technology qualification and development is recommended before an investment decision is made, since today's amine technology has never been used on flue gas of this type. The technology qualification and development can, for example, be achieved through test facilities.

The implementation plans for both alternatives have been established on the basis that two independent capture facilities are recommended for the combined heat and power plant and the catalytic cracker plant. Connection to, and adaptation of, existing installations at Mongstad is challenging, and this is deemed to be a critical success factor for the implementation plans.

SH's practice for safe and efficient implementation of projects and planning work indicates that it will take approximately four years from the investment decision to the operation of the capture facilities. As of today, this is uncertain and only a rough estimate, and certainty with respect to the implementation period will increase as the investment decision approaches. No conceptual choices have been made yet, for example, and this will have a bearing on the implementation period.

A project development phase must be completed before an investment decision can be made. This phase includes conceptual studies (including choice of concept), qualification activities, choice of suppliers, impact assessment, detailing phase (FEED phase), authority approval etc. Based on the current project status, the duration of the project development phase is estimated to be two to three years for an amine-based solution for the combined heat and power plant. The duration of the project development phase will be decided in particular by the complexity of the project (including integration with existing activities), the use of new technology, knowledge about the health and environmental effects of amines and the size of the facility.

Alternative 1 has been established with the purpose of achieving capture from the combined heat and power plant as soon as possible. However, the Implementation Agreement's goal of establishing CO_2 solutions by the end of 2014 appears demanding in light of normal industry practice for safe and efficient implementation of projects of this kind. The immediate commencement of required activities is critical in order to allow capture from the combined heat and power plant as soon as possible. This means that the division of roles, the project framework and financing must be clarified during the first six months of 2009. A tender procedure will be crucial in order to qualify more suppliers with respect to technology and HSE. This will entail extensive evaluation work. The final schedule will be clarified in the phase preceding an investment decision.

Both alternatives are based on an investment decision for capture from the catalytic cracker plant being made in 2014 at the earliest. This schedule is based on benefiting from experience from TCM.

The implementation plans are in an early project development phase and capture technology, the choice of sources and the technological design of the capture facilities must all be developed further before a final choice of concept is made. In addition, research and technology development studies and competitive tendering between potential suppliers will be carried out in order to find optimal solutions, which may include reduced investment and operating costs. The next phase and further technology development will also shed light on, and quantify, the gains that can be achieved through stage-wise technology development.

1.4 Cost estimates

The cost assessments carried out so far are based on results from external studies and SH's experience basis. They indicate a rough division between the combined heat and power plant and the catalytic cracker plant, as well as joint systems to be used by both capture facilities. The cost estimate for both sources is based on the available amine technology. This is due to the immaturity of alternative technologies.

There is great uncertainty attached to the technical basis for the cost assessments. The typical uncertainty margin for projects in this early phase is -30%/+40 % given an 80% confidence interval (the probability of falling within the given interval). The risk in this project has been deemed to be even greater due to the extensive use of new technology and because this is a type of project with which the industry has no relevant experience. The project also involves extensive construction activity within an existing and complex operational industrial facility, which creates special demands in terms of design and safe implementation. The uncertainty relating to the cost assessments is also large because the implementation plan, procurement strategy etc. have not been decided and the final investment decision is at least two to three years in the future. Therefore, no detailed assessments of cost differences between alternative 1 and alternative 2 have been carried out at this stage.

On this basis, SH has estimated the total investments for both capture facilities and their joint systems to be around NOK 25 billion (nominal NOK), but with the uncertainty as described above. A rough estimate is that 50% relates to the capture facility for the combined heat and power plant, 20% to the capture facility for the catalytic cracker plant, and 30% to joint systems for both capture sources. In the coming project phases leading up the investment decision, possibilities for optimisation will be looked into with a view to reducing the costs. The cost estimate for the support and utility systems relates primarily to the requirements of the capture plants. The degree to which excess capacity will be installed and how the costs of these support and utility systems will be allocated will be clarified in the next phase of the project.

In addition to the above investments, there will also be annual operating expenses relating to the operation of the two capture facilities. These expenses are assumed to be of the magnitude of NOK 1.0 billion to 1.7 billion per year (for 2020 with both facilities in operation). Since annual operating expenses are largely variable costs relating to energy requirements, both electricity and steam, future energy prices will be decisive for the level of annual operating expenses.

On the basis of the above investments and operating expenses, the cost of capture per tonne of carbon dioxide will be approximately NOK 1,300-1,800 (2008 NOK with a required return of 7%).

Even though the capture plants are based on known technology, no plant on this scale has ever been built before. SH has experience of carbon dioxide removal on Sleipner, but there, the partial pressure of carbon dioxide is approximately 200 times that in the exhaust gas from the combined heat and power plant. There are two factors that contribute significantly to the cost level and uncertainty. Developments in the supplier industry will also be decisive in relation to the cost level. Costs will also be decided by the division of risk chosen in contracts between suppliers and owner and the guarantees required of suppliers, including the degree of capture, energy consumption, emissions etc.

The uncertainty in the cost level is also due to the uncertainty relating to the market conditions for materials, equipment and personnel at the time at which the investment decision is made and during the implementation period. General cyclical fluctuations will be critical to the final cost level. In the same way, general macroeconomic factors such as the exchange rate will have a decisive effect on the final cost level.

The above investment estimate includes costs relating to the planning phase up until the final investment decision. These are primarily costs relating to staffing, external technical studies (pre-engineering), technology qualification and, finally, detailed engineering. Seen from the present project perspective, this period will last for two to three years. Approximately 5-10% of the investment costs can be incurred during this period. This will depend, among other things, on how many supplier studies are performed.

1.5 The scale and risks of the project

SH has been responsible for, or has participated in, the development of three of the four major carbon dioxide gas chains developed with CO_2 storage worldwide. They are Sleipner and Snøhvit, where SH was the developer, and In Salah in Algeria, where SH is a partner together with Sonatrach and BP. Each of these three projects captures 0.5-1.0 million tonnes of CO_2 per year, transports it to an injection well and injects it into a suitable geological structure.

So far, no large and complete carbon dioxide chain has been developed using exhaust gas or flue gas as a source. The master plan deals with full-scale capture plants for more than two million tonnes of CO_2 captured per year. The total project will also include transport to an injection well and injection of carbon dioxide into a suitable geological structure.

The transport and storage parts of the CO_2 chain have many similarities with the carbon dioxide chains that SH has participated in, while the capture part differs significantly from previous experience. Capture from exhaust gas/flue gas at low pressure and with a low concentration of carbon dioxide differs from, and is more challenging than, capture from natural gas at high pressure. Thus, it is the source (exhaust and flue gas) for which we lack references since CO_2 capture from atmospheric-pressure sources on such a large scale is new. The capture of CO_2 from natural gas under pressure is carried out at similar scales.

When the Implementation Agreement was signed, Statoil and Shell were collaborating on the Halten CO_2 project. This was a value chain project involving an approximately 860 MW gas-fired power plant at Tjeldbergodden with CO_2 capture and transport to Draugen (later also Heidrun) for pressure support and improved oil recovery using the CO_2. Later, it was concluded in the Halten CO_2 study phase that the increase in recoverable oil volumes did not justify the required investments under the given framework conditions.

CO_2 capture feasibility studies at Mongstad were also carried out in 2006, but they were not detailed enough to produce authoritative estimates for costs, risks and the concept for full-scale capture. Work on the master plan, the TCM project and other experience have increased the certainty relating to the feasibility of CO_2 capture from the large sources. Moreover, several studies and projects are being carried out outside SH, for example full-scale capture studies carried out by Gassnova at Kårstø. There is, therefore, greater understanding of the risks, costs, processing and technology involved in full-scale capture at Mongstad than there was two years ago. Altogether, this has contributed to SH outlining a full-scale capture facility for the combined heat and power plant in alternative 1, even though an early investment decision will only have the benefit of limited experience from TCM.

Health and environmental risks from amine systems

Emissions of degradation products and reaction products from the amine process to air are the biggest risk. It is necessary to carry out more in-depth studies and experiments in future project phases before the potential risks at Mongstad are sufficiently understood. The health and environmental risks must be reduced sufficiently before an investment decision can be made, and this could cause a postponement.

A mega-project

IPA (Independent Project Analysis Ltd) classifies projects with an investment budget of more than USD 1 billion as mega-projects. Mega-projects are generally described as demanding to plan and implement. This project is considered a mega-project because of its size and the investments, new technology and complexity involved. Full-scale capture entails a high degree of integration with existing operational facilities and the use of technology with which we only have limited experience. The following examples illustrate the size of the project:

- The combined heat and power plant's absorption towers could have a diameter of 15-20 metres and be up to 60 metres in height.
- Exhaust gas ducts of 8.8 m x 6.6 m (almost 60 square metres), with a throughflow of 3,100 tonnes per hour.
- Cooling water requirement in the region of 20,000-40,000 cubic metres per hour.
- The facilities' electricity requirement will be around 55 MW (corresponding to the consumption of approximately 17,000 detached houses).
- Approximately 300,000 cubic metres of surplus uncompacted materials.
- Approximately 1,000 metres of intake and outlet tunnels for seawater with a cross sectional area of 25 square metres.
- Area requirement of 150,000 square metres (corresponding to approximately 20 football pitches), including areas for capture facilities, auxiliary systems and temporary storage.

Close integration with the refinery
The project will be carried out in close integration with a refinery in full operation. This is a complicating factor in terms of safety during the construction phase. Moreover, this is a type of facility and technology with which the industry has limited design and construction experience.

Complete value chain from capture to reservoir
It is also a complicating factor that the capture facilities are only part of an overall chain intended to handle CO_2 from capture to underground storage. This will mean more interfaces and require good coordination between different projects and actors.

The risks discussed later in this report are primarily related to technology, HSE and implementation. A risk register has been established, and measures and actions to reduce the risks in future project phases have been planned.

Framework conditions
The division of roles, the project framework and financing of the project are critical activities. Several of these activities will require clarification from the authorities, both Norwegian and international. The timing of clarification of these activities, including the process vis-à-vis ESA to clarify the issue of required government subsidies, will be crucial in terms of the progress of the project.