KÅRSTØ INTEGRATION PRE-FEASIBILITY STUDY

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0	Merethe Bjelland Sten Arve Eide Per Aanestad Bjørn T. Hauge Svein Solvang Stein Espen Bøe Steinar Lervik Hans Jørgen Vinje Kjetil Emhjellen Kjetil Gjerde Bjarne Aarset	Ola Nestaas Tove Dahl Mustad	Thor Otto Lohne Bjørn Erik Haugan	22.03.2010

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1 INTRODUCTION

1.1 Purpose

The purpose of this report is to describe possible integration scenarios between Naturkraft's combined cycle gas power plant, Gassnova's planned carbon capture plant and the processing plant at Kårstø.

The report will with attachments and appendices, form the decision support package for the gatekeeper(s) to decide to initiate a feasibility study.

1.2 Background

Gassco presented a mapping study report (the "Naturkraft Integration Mapping Study") to the Ministry of Petroleum and Energy 6 March 2009.

Based on the Naturkraft Integration Mapping Study, the Government notified in a parliamentary bill (St.prp. nr. 67 2008-2009) to study the technical and commercial issues related to an integration at Kårstø to further reduce CO_2 emissions.

The Ministry of Petroleum and Energy requested by letters dated 15 September 2009, ref. [1] and [2] both Gassco and Gassnova to perform a pre-feasibility study of an integration between the processing plant at Kårstø and Naturkraft's gas power plant with adjacent carbon capture facilities. The results are expected to be presented to both the Ministry of Environment and the Ministry of Petroleum and Energy by the end of February 2010.

This pre-feasibility study report is prepared by Gassco and Gassnova with involvement from Gassled and Naturkraft owners. The study also covers a commercial mapping of challenges and opportunities to which all owners of the relevant facilities at Kårstø have contributed.

Gassco's responsibilities include system design of the integrated systems at Kårstø, all technical definitions of the Kårstø processing plant facilities, cost estimation and overall economical evaluations and modeling. Gassnova's responsibility for the technical definitions, quality and cost estimation is related to the carbon capture and compression facilities as well as CO_2 transportation and storage facilities. With reference to table of contents, Gassnova is responsible for sections 3.3, 4.2, 6.3, 9.2, 11.2 and 12.2.3. The responsibilities are further described in the above mentioned letters.

This report is intended to meet the requirements described in the above mentioned letters, dated 15 September 2009 and outline various integration scenarios between the Naturkraft gas power plant, the Kårstø processing plant and a future carbon capture and compression plant.

1.3 Objectives

The objective of this Kårstø Integration Pre-feasibility Study is to describe potential integration opportunities at Kårstø including technical, environmental, safety, commercial issues and arrangements. Integration scenarios between the Kårstø processing plant and a future carbon capture and compression plant have been evaluated in addition to integration concepts of the Kårstø processing plant with Naturkraft's gas power plant.

1.4 Definitions and Abbreviations

ATR	Auto Thermal Reforming
CCC	Carbon Capture and Compression
CCP	Combined Cycle Power
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CRAIER	CO_2 Removal and Increased Ethane Recovery
EIA	Environmental impact assessment
GE	General Electric (frame 6 gas turbine)
HRSG	Heat Recovery Steam Generator
HSE	Health Safety and Environment
MPC	Model based Predictive steam pressure Control system
NCV	Net calorific value
NIVA	Norsk institutt for vannforskning
NO_x	Nitrogen oxide
Oxyfuel	Combustion of hydrocarbon fuel with oxygen
SCR	Selective Catalytic Reduction
SMR	Steam reforming

2 SUMMARY

This study is based on the Naturkraft Integration Mapping Study as presented to the Ministry of Petroleum and Energy 6 March 2009.

Approach

The Naturkraft Integration Mapping Study described various technical integration scenarios; a) supplying heat and power from the Naturkraft gas power plant to the processing plant at Kårstø, by a limited steam supply from Naturkraft to the Kårstø processing plant and, b) by electrification of compressors, until all existing CO_2 emissions from boilers and gas turbines at the processing plant are either captured or replaced by steam generated at the Naturkraft gas power plant.

Scenario 0, 1 and 2 of the Naturkraft Integration Mapping Study have been updated, while scenario 3, 4 and 5 have been further matured and modified in this Kårstø Integration Pre-feasibility Study to improve emission capture capability, energy balance and operational flexibility of the integrated system. The original scenarios 3, 4, and 5 from the Naturkraft Integration Mapping Study are not repeated this report.

All integration scenarios are possible to mature individually and with the potential to be followed by any of the successive integration scenarios, except for the design capacity of some of the main components of the carbon capture plant which have to be designed for one of three potential capacity levels.

Description of the scenarios

The following is a short description of the scenarios studied, followed by table 2.1 which indicates remaining emissions per scenario at Kårstø. All scenarios below are defined as additional changes from the previous scenario;

- <u>As is;</u> describes the current situation at Kårstø where the Naturkraft gas power plant and the Kårstø processing plant are operated independently by separate organisations.
- <u>Scenario 0</u>; carbon capture facilities including transportation and storage facilities to capture and store CO_2 emissions from the Naturkraft gas power plant. Naturkraft will supply a limited amount of low pressure steam to the carbon capture plant.
- <u>Scenario 1;</u> limited amount of high pressure steam deliveries from Naturkraft gas power plant to the Kårstø processing plant and subsequently decommissioning of the existing GE / Moss boiler.
- <u>Scenario 2</u>; fuelling of the Naturkraft gas power plant with CO_2-rich CRAIER gas from the Kårstø processing plant and subsequently capturing the CO_2 at the carbon capture plant.
- <u>Scenario 3;</u> new gas fired exhaust boilers utilising the remaining oxygen and heat in the exhaust from the Naturkraft gas power plant before entering into the carbon capture plant. One new low pressure steam boiler supplying the carbon capture facilities with steam and one new high pressure steam boiler as replacement of some of the existing steam production facilities.
- <u>Scenario 4;</u> electrification of the three existing Statpipe compressors at the Kårstø processing plant. Two electrical compressors will replace the existing three gas driven Statpipe compressors.
- <u>Scenario 5;</u> electrification of all existing gas driven compressors at the Kårstø processing plant. Scenario 5 is based on additional high pressure steam boilers, CO_2 neutral or with CO_2 capture. Four alternative technologies to meet the steam demand at Kårstø have been studied;

- Scenario 5a; Oxyfuel technology, consisting of an air separation unit and two high pressure steam boilers fuelled with natural gas and oxygen. The exhaust gas from the boilers are mainly H_2O (water) and CO_2.
- Scenario 5b; a new biomass plant at Kårstø producing high pressure steam based on solid wood and chips. CO_2 neutral exhaust will be dispersed to air.
- Scenario 5c; hydrogen fuelled boilers producing high pressure steam.
- Scenario 5d; additional exhaust boilers producing high pressure steam.

Existing CO_2 emissions at the Kårstø processing plant are in these scenarios either captured or omitted.

The CO_2 will be treated to the requirements of the transportation and storage system and delivered into the CO_2 transportation system.

Resulting emissions

The CO_2 reductions at Kårstø are achieved by operating the Naturkraft gas power plant as a steam source for the Kårstø processing plant. The electrical power output and the load on the gas turbine are results of the balancing of the steam demand. By reducing the load on the Naturkraft gas turbine in scenario 1 to 5 down to between 62% and 80%, the natural gas combusted in the power plant is similarly reduced and hence the amount of CO_2 captured is also reduced. The remaining CO_2 emissions at Kårstø as a result of implementing the various scenarios are indicated in table 2-1. The figures are based on continuous operation of Naturkraft's gas power plant and 600 tonnes per hour steam demand at the Kårstø processing plant for the "as-is" scenario.

Table 2-1 Remaining CO_2 , CO_2 injection and NO_x emissions

Scenario	As is	0	1	2	3	4	5a	5b	5c [1]	5d
Remaining CO_2 emissions (mill tonnes pa)	2.5	1.4	1.1	1.0	0.8	0.6	0.2	0.2	0.2	0.2
Resulting CO_2 injection[2] (mill tonnes pa)	0	1.1	0.7	0.8	0.9	1.1	1.5	1.1	1.6	1.5
Remaining NO_x emissions (tonnes pa)	780	780	630	600	430	230	40	200	51/200	30

Electrical power balance at Kårstø

The electricity production and consumption at Kårstø varies significantly in the different scenarios as shown in table 2-2 below.

Table 2-2 Overview of power balance per scenario, all figures in MW

Scenario	As is	0	1	2	3	4	5a	5b	5c	5d
Naturkraft el production	420	397	174	174	174	174	224	224	224	224
Kårstø processing plant consumption	-65	-65	-105	-105	-105	-141	-197	-197	-197	-197
Carbon capture and compression plant	0	-37	-29	-30	-36	-38	-40	-40	-40	-48
Additional steam facilities	0	0	0	0	0	0	-28	-6	-20	0
Net el. power to grid	355	295	40	39	33	-5	-41	-19	-33	-21

The overall energy balance taking into account all energy input and output for the various facilities at Kårstø, shows a positive effect on the net energy efficiency as a result of steam integration between the gas power plant and the processing plant at Kårstø, primarily caused by reduced condenser losses at the gas power plant (sea water cooling).

[1] Depending on combustion based on air or oxygen
[2] Capacities; 1.1 mill tonnes for scenario 0 to 2, 1.5 mill tonnes for scenario 3, 4 and 5a/b/c and 1.8 mill tonnes for scenario 5d

Key findings

1. Technical integration scenarios significantly reducing the CO_2 emissions at Kårstø have been identified
2. Such integration scenarios will impose additional investments over and above the investments of the carbon capture for the gas power plant
3. The integration scenarios do however reduce the unit costs per CO_2 reduction relative to the carbon capture from the gas power plant alone
4. The unit cost calculations are uncertain and dependent on the expected operations and utilisation of both the gas power plant and the processing plant and the maturity level of the study
5. The integration scenario 3 is the most flexible and robust solution with respect to such uncertainties

The integration scenarios require regular steam supply from the gas power plant to the processing plant and hence continuous operation of the gas power plant is assumed. Operating the power plant at base load will result in losing the opportunity stop generating power when the value of the power is below the value of the gas. Such lost opportunity is not quantified in this report.

Total investment costs per scenario are indicated in Figure 2-1.

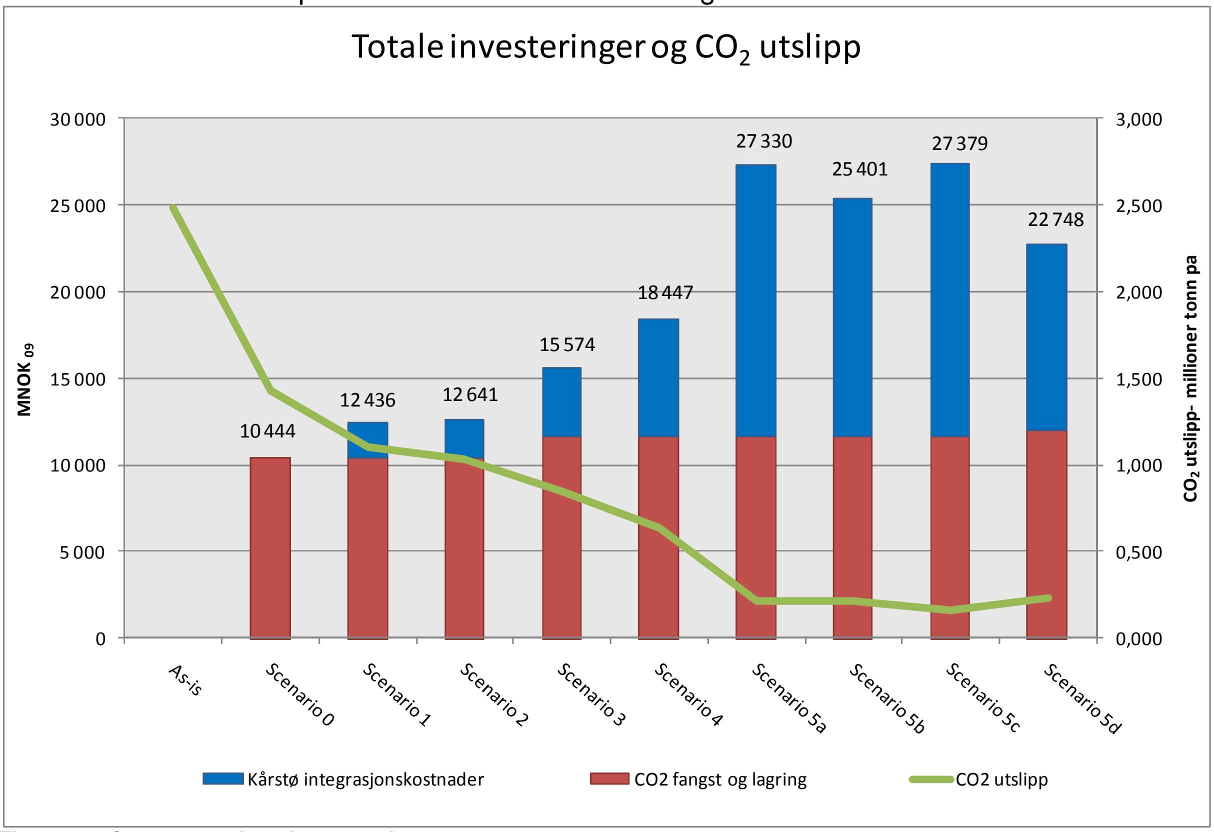

Figure 2-1 Cost comparison by scenarios

Unit costs of CO_2 reductions are dependent on modus of operation of the gas power plant and future utilisation of the Kårstø processing plant. Unit costs per tonne of reduced CO_2 emissions for the Naturkraft gas power plant (scenario 0) are estimated to 1,600 NOK based on a 15 years period and full utilisation of the gas power plant, which would correspond to CO_2 quota costs around 200 € per tonne. The unit cost in scenario 0 would be doubled if the assumed utilisation of the gas power plant is reduced from eight to four thousand hours per year. Figure 2-2 illustrates the range of unit costs based on full utilisation of the gas power plant and the processing plant at Kårstø assuming economical lifetime of 10, 15 and 25 years. The marginal costs for all integration scenarios (except for scenario 5a - Oxyfuel and

5c - Hydrogen fuelled) are below scenario 0 unit costs and hence reduces the overall unit costs. Assumptions for the unit cost estimates are described in section 11.3.1.

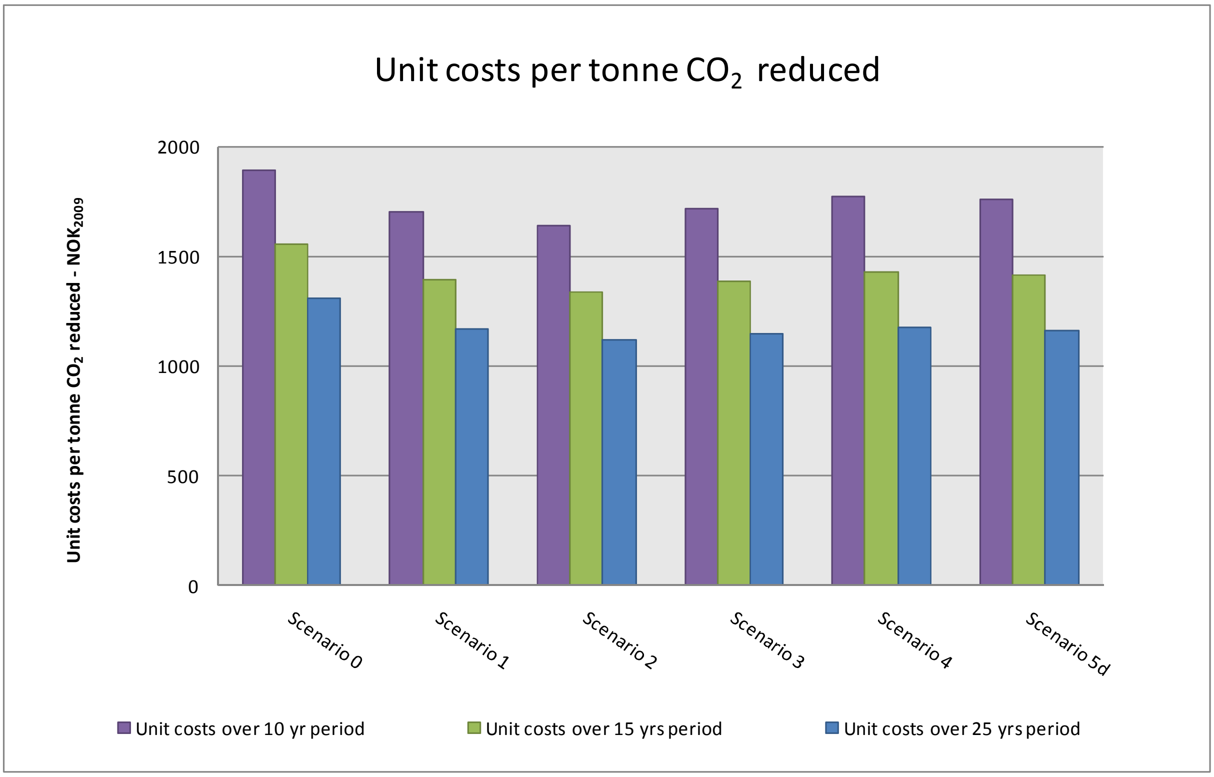

Figure 2-2 Total unit cost per tonne CO_2 reduction over 10, 15 and 25 years exclusive of CO_2 quotas.

There is no commercial basis for realising any of the scenarios, taking into account all relevant costs, expected CO_2 quotas and other benefits and savings.

Uncertainties and risks

A major concern related to operations of the Kårstø processing plant are the regularity and availability issues related to securing the gas and NGL exports. The value of the petroleum transported over Kårstø on any day is above 200 million NOK. In addition also significant oil production will be shut down if the Kårstø gas processing plant is not operating. Hence the availability and regularity of energy supply including steam is of utmost importance. The investment costs reflects the requirements to maintain availability and regularity.

The Naturkraft Integration Mapping Study was based on continuous operation of the Naturkraft gas power plant and thereby limiting the commercial use of the gas power plant. Maturing of scenario 3, 4 and 5 has, however, revealed a possibility for unconstrained operation of the gas power plant; Kårstø processing plant and the gas power plant may operate independently and the CO_2 will be captured. Such operations have not been matured and further engineering will be necessary to demonstrate feasibility. The carbon capture concept may have to be revised to handle the potential load variations in such independent operation scenario.

Any investment to avoid CO_2 emissions at Kårstø by integration with the Naturkraft gas power plant includes risks related to investing for an unknown future demand. The design basis for this pre-feasibility study is based on high utilisation of the Kårstø processing plant and assumes the current operational services and steam demand. The future utilisation is uncertain beyond 2020. Scenario 3 is flexible regarding future development of the Kårstø processing plant.

Scenarios 4 and 5 represent significant restructuring of the steam supply chain at Kårstø. Four different technologies for supplying the additional steam in scenario 5 are matured. In this report the alternative technologies represents a possible implementation at Kårstø based on integration with the Naturkraft gas power plant. These technologies also represent building blocks that could be implemented as standalone alternatives.

Organisation of the work

Gassco and Gassnova have matured all technical solutions in cooperation with expertise from Naturkraft and Statoil. Gassled and Naturkraft owners have been involved in the preparation of this pre-feasibility study report.

The scenarios studied in this report are all considered sufficient matured to a pre-feasibility level.

3 PLANT DESCRIPTIONS

3.1 Naturkraft gas power plant

Naturkraft's gas power plant at Kårstø is a combined cycle power plant, designed to maximize electrical power production. Naturkraft's capacity is 420 MW with an efficiency rate of 58% to 60% (NCV).

At continuous operation, the CO_2 emissions from the Naturkraft gas power plant without CO_2 removal are approximately 1.3 mill tonnes annually and close to zero NO_x emissions. The annual fuel consumption is approximately 0.6 GSm^3.

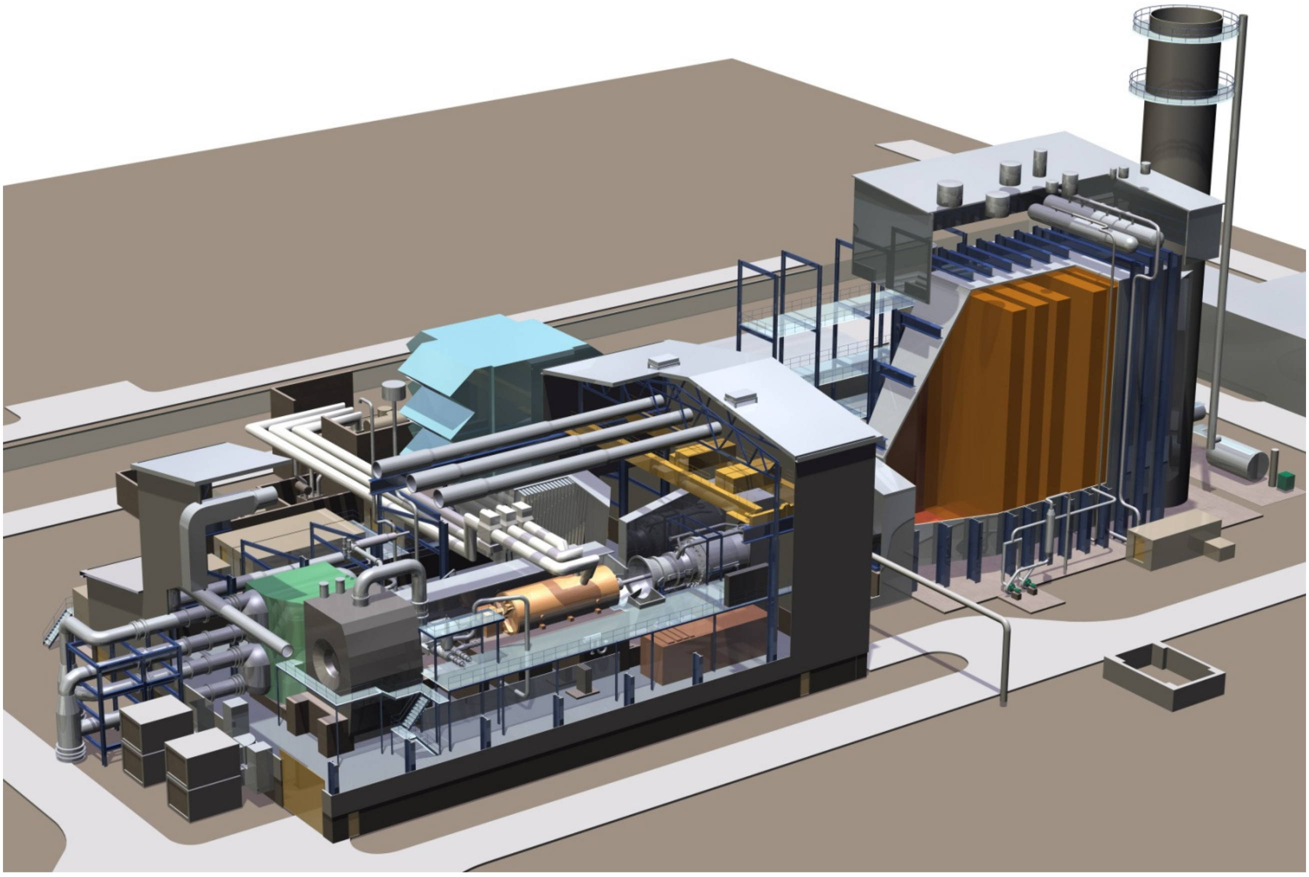

Figure 3-1 Overview of Naturkraft's Combined Cycle Power plant at Kårstø

The plant configuration is a single shaft, with a 3 pressure level steam boiler. The gas turbine delivers approximately 2/3 of the total electrical power and the waste heat go into the heat recovery steam generator where the remaining 1/3 of the electricity is generated. The steam boiler pressures are 120, 30, and 4 bar(a) respectively.

The low pressure steam turbine is connected to a seawater cooled condenser. The water condensing process generates as much as 33 % of loss as heat energy.

3.2 Kårstø processing plant

Kårstø processing plant processes rich gas from oil and gas producing fields in the Statfjord and Haltenbanken areas and delivers a daily rich gas capacity of up to 88 million Sm^3.

The Kårstø condensate facility receives un-stabilised condensate from the Sleipner field. The condensate is stabilised by separating out the lightest components for further fractionation.

The processing facilities at Kårstø comprise four extraction/fractionation trains for methane, ethane, propane, butanes, and naphtha, plus a fractionation train for stabilising condensate.

Ethane, iso-butane and normal butane are stored in refrigerated tanks, while naphtha and condensate are held in tanks at ambient temperature. Propane is stored in large refrigerated rock caverns. These products accumulate to some 7.5 million tonnes of Natural Gas Liquids (NGL) annually and are exported from Kårstø by ship. The dry gas is exported from Kårstø by pipelines.

Annual CO_2 emission from the Kårstø processing plant is between 1.1 and 1.2 million tonnes. The NOx emissions are around 750 tonnes per year.

The Kårstø processing plant currently utilises around 100 MW electrical power and approximately 600 tonnes/hour of high pressure steam for extraction, fractionation and compression. Kårstø processing plant has a production capacity of 40 MW electricity and 795 tonnes high pressure steam. Total energy utilisation at the Kårstø processing plant is as high as 77 % due to an efficient heat and power integration.

Figure 3-2 Kårstø processing plant

3.3 Carbon capture, compression, transportation and storage

The planned carbon capture and compression plant will handle the CO_2 in the exhaust gas from Naturkraft's gas power plant and other potential sources of CO_2 tied into the exhaust gas stream from the gas power plant as further described in this report.

Exhaust gas treatment will most likely be based on amine absorption. The carbon capture process shall remove as minimum 85% of the CO_2 from the exhaust gas stream and deliver the recovered CO_2 into the CO_2 compression and drying system.

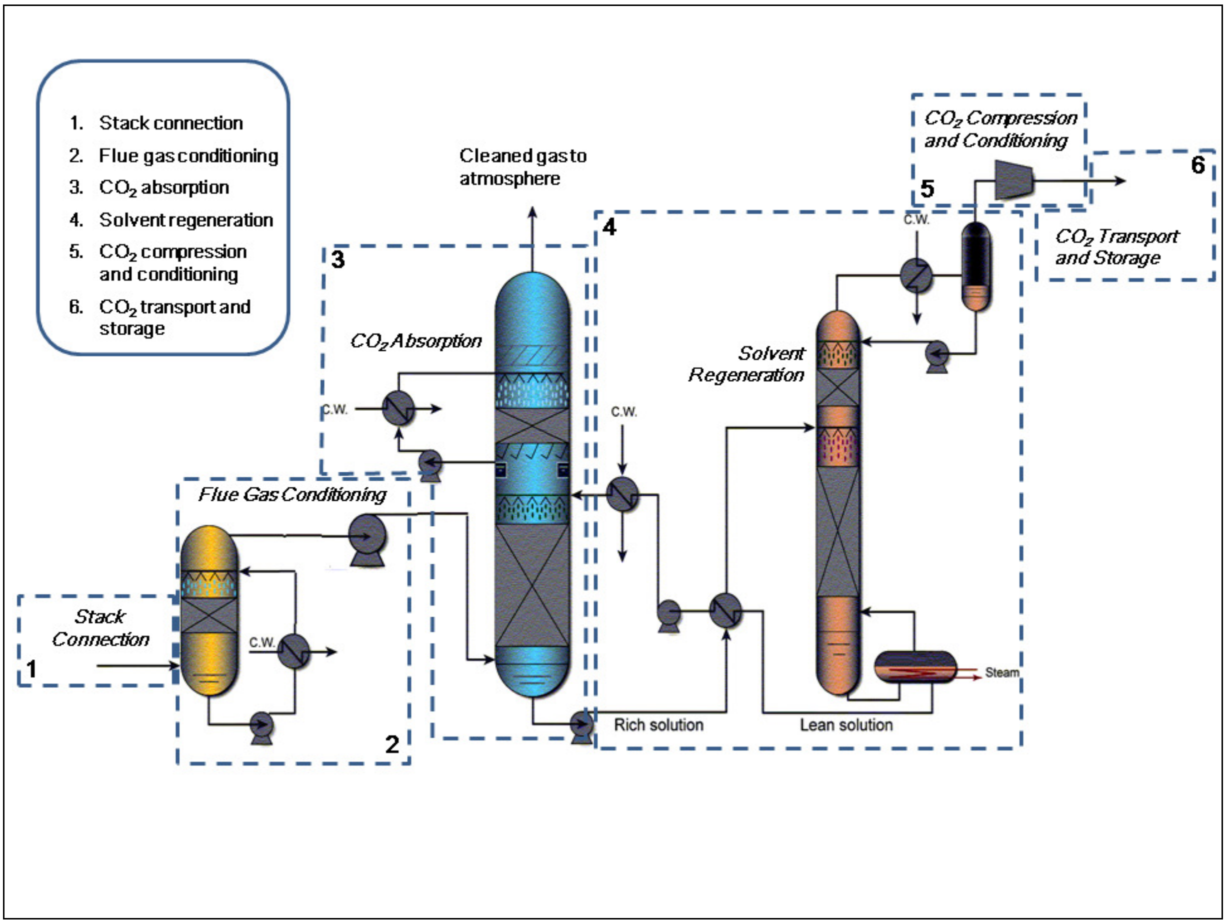

Figure 3-3 Typical amine based carbon capture and compression plant (Source: SINTEF)

The Carbon capture and storage (CCS) process consists of 1) stack connection and exhaust ducting, 2) flue gas conditioning 3) CO_2 absorber, 4) solvent regeneration, 5) CO_2 compression and conditioning and 6) CO_2 transportation and storage facilities.

Reference is made to section 6.3 for a detailed description of the carbon capture and compression plant.

3.4 Alternative steam generation facilities

Waste heat from gas driven export compressors at Kårstø is utilised to produce high pressure steam. As part of this study, various levels of electrification of the export compression system have been assessed. This requires new steam generation to be established at Kårstø.

The use of alternative technologies are considered as scenario 5a (Oxyfuel), 5b (biomass) and 5c (pre-combustion) in this study. The relevant technologies for the alternatives are described below. For more details about the alternative technologies, reference is made to Appendix C.

In this report the alternative technologies represents possible implementation at Kårstø based on integration with the Naturkraft gas power plant. However, the technologies also represent building blocks that could be implemented as standalone alternatives.

3.4.1 Oxyfuel

In Oxyfuel combustion, 97% pure oxygen is used in combustion instead of air, resulting in a flue gas that consists mainly of CO_2 and H_2O. The CO_2 can be captured by condensing the steam in a cooling process. Since unused oxygen, unburned gas and any other inert gaseous components in the fuel and oxygen feed streams (including most of the NO_x) will follow the CO_2 stream, additional purification of the CO_2 is required. The cooled flue gas is sent to a raw gas compression system where it will be compressed to minimum 25 bar. The compression system consists of multi-staged, centrifugal, electric motor driven unit with intercoolers between stages and phase separators to remove any condensate and compressed to 80 bar(a), sufficient for transportation to the CO_2 export pumping station where it is connected to a manifold through a non return valve.

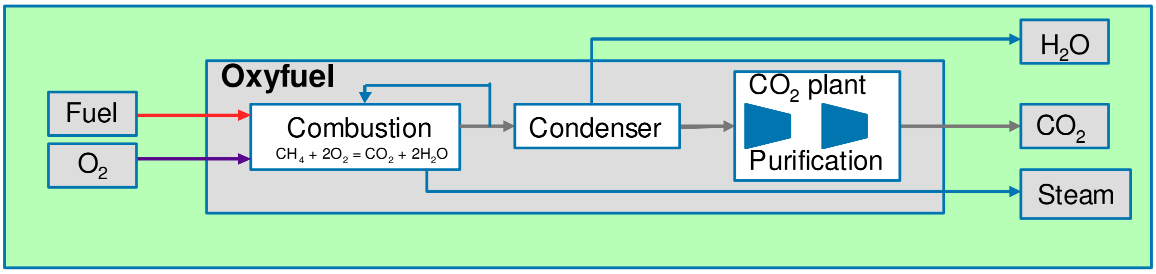

Figure 3-4 Oxyfuel steam production

Oxygen is normally produced by cryogenic air separation technology. Generation of 400 t/h steam will require about 2,400 tonnes oxygen per day.

3.4.2 Biomass

Biomass represents matured technology and commonly used for heat generation worldwide. In principle, biomass is sun energy captured by photosynthesis. Biomass combustion is regarded as CO_2 neutral.

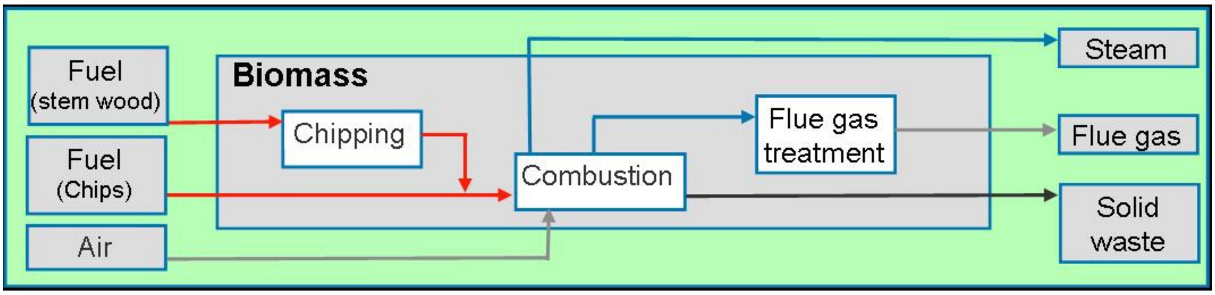

Figure 3-5 Biomass steam production

Forests are the most important feedstock for energy applications worldwide due to its large volumes and potential for efficient harvesting. Wood as energy is mainly handled along two different paths:

- whole stem handling system
- chips handling system

This technology is more area and manpower demanding than comparable systems using gas or oil as fuel. This is due to storage and handling of a solid fuel compared to gaseous and liquid fuels.

Technology for conversion to heat will normally give about 90-91% conversion efficiency from the effective heating value in fuel.

3.4.3 Pre-combustion

Pre-combustion capture involves reacting a fuel with oxygen and/or steam to produce high concentration of carbon monoxide and hydrogen (known as synthesis gas). The carbon monoxide is further reacted with steam in a catalytic reactor, called a shift converter, to give CO_2 and more hydrogen. CO_2 is separated either by a physical adsorption or a chemical absorption process, resulting in a hydrogen-rich gas, which can be used as fuel.

Hydrogen production technology is proven and commercial at the size required for Kårstø. Commercial bulk hydrogen is usually produced by steam reforming (SMR) of natural gas.

Hydrogen can alternatively be produced by auto thermal reforming (ATR) where natural gas is partial combusted with oxygen at high pressure followed by steam reforming in a catalyst containing reactor.

Pure oxygen, air or combinations of air and oxygen can be used as oxidant in the ATR reactor. All nitrogen as well as other inert components in the oxidant and fuel will end up in the hydrogen product when CO_2 is removed. The CO_2 is separated and compressed to about 80 bar. Due to increased product rate additional CO_2 pumps are required at the CCS booster pump area.

The oxygen based ATR concept requires about 750 tonnes O_2 per day, i.e. 1/3 of the Oxyfuel plant requirements.

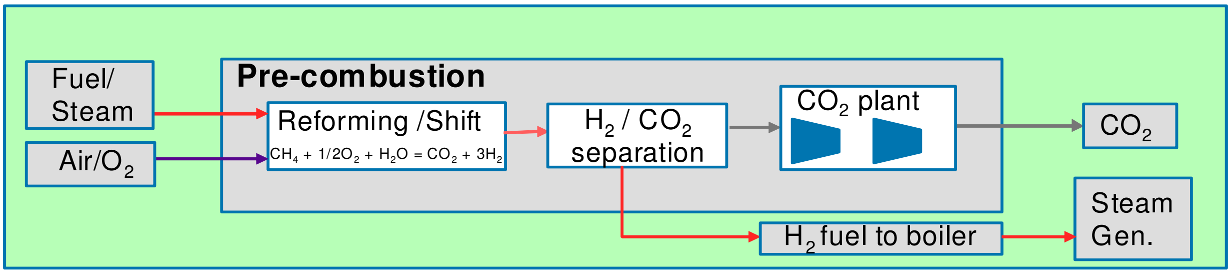

Figure 3-6 Pre-combustion steam generation

The combustion of hydrogen will produce no additional CO_2 emissions, and the main by-product is water. Hydrogen fired boilers are commercially available technology but up to 10% natural gas (heat input) will be needed for stable combustion.

4 DESIGN BASIS AND FUNCTIONAL REQUIREMENTS

A separate design basis document has been prepared for the study.

The following assumptions have been used:

- The scenarios shall not reduce the current safety or regularity levels at the Kårstø processing plant.
- Steady-state continuous demand of 600 t/h steam demand at the Kårstø gas processing plant. A sensitivity of 500 t/hr has also been considered with regards to robustness, including a 30 t/h margin.
- Continuous operation of Naturkraft's gas power plant as extended Kårstø steam provider, except for planned maintenance.
- All tie-ins to be installed during planned maintenance periods and will not require additional processing plant shut downs.
- The carbon capture and compression plant will have an on-stream factor of minimum 97% relative to the continuous operation of the gas power plant and to be capable of a minimum of two years continuous operation without requiring a shutdown for maintenance.
- Load factor of the Naturkraft gas turbine at 62% for scenario 1 and 2 and 80% for scenarios 3 to 5.
- 337 days or 8082 hours annual operations of the capture plant and the gas power plant.
- The minimum required capture rate of CO_2 is 85% of the yearly emitted CO_2 in the exhaust gas from the Naturkraft gas power plant and/ or the new boiler(s) located in the vicinity of the carbon capture and compression plant.
- Exhaust gas treatment based on amine absorption.
- A model based predictive steam pressure control system (MPC) to manage the required regularity level at the Kårstø processing plant.
- CO_2 dehydration and compression / pumping facilities shall be designed to provide the required product CO_2 composition and conditions to be transported and stored.

Control of water and oxygen content is of critical importance for transportation of CO_2, as well as the effect of water in connection with trace elements.

Table 4-1 CO_2 transportation and storage specifications

Fluid Composition	Units	Specification
Carbon Dioxide Purity	mol %	> 99.6
Nitrogen	mol %	< 0.04
Water contents	ppm (wt)	< 50
H_2S	ppm (wt)	< 100
Oxygen	ppm (wt)	< 10
NH_3		trace
Amine		trace

5 OPERATIONAL AND CONTROL PHILOSOPHY

The Kårstø integrated system will in this context consist of the following units:

- The Kårstø processing plant with inlet, export and utility facilities
- The Naturkraft gas power plant with utilities
- The Gassnova carbon capture and compression plant with utilities
- The CO_2 transport and storage facilities
- All defined interface and infrastructure facilities

Some of the scenarios do not connect Naturkraft's gas power plant with utilities from the Kårstø processing plant. In such scenarios Naturkraft's gas power plant is integrated with the carbon capture and compression plant.

The operational philosophy will be as follows:

- The Kårstø processing plant will be the governing unit
- All units shall be operated to ensure required regularity, product capacity and quality from the Kårstø processing plant
- In case of operational problems, all system units shall adjust their operation within their defined range to ensure optimal process production at any time
- All planned maintenance activities will be coordinated in accordance with the processing plant requirements

Control philosophy:

- The Kårstø processing plant main control room shall have the overall control of the system units
- Naturkraft's gas power plant and the Gassnova carbon capture and compression plant will require local control rooms
- A model based predictive steam pressure control system (MPC) shall govern all steam producers

6 DEFINITION OF THE INTEGRATION SCENARIOS

Scenario 0, 1 and 2 of the Naturkraft Integration Mapping Study have been updated, while scenario 3, 4 and 5 have been further matured and modified in this Kårstø Integration Pre-feasibility Study, to improve emission capture capability, energy balance and operational flexibility of the integrated system. The original scenarios 3, 4, and 5 from the Naturkraft Integration Mapping Study are not repeated this report.

6.1 Building blocks

The integration of Naturkraft's gas power plant and the Kårstø processing plant is described and cost estimated based on building blocks, (ref. Appendix B) defined as specific elements of modification as described in each scenario, ref. Figure 6-1.

Scenario 3 includes the building blocks from scenario 1 and 2, and may be further developed to scenario 4 and/or 5.

For the carbon capture and compression plant, the flexibility is limited. The flue gas conditioning and the CO_2 absorption must be built to handle maximum CO_2 from the Naturkraft gas power plant and any additional exhaust gas boilers from the start to benefit from the economies of scale. The most cost effective development of CCS will be to build for final demand initially. The CCS will have 3 different design configurations to cover the different operational scenarios. Required design for scenario 0 will cover scenarios 0/1/2, required design for scenario 3 will cover scenarios 0/1/2/3/4/5a/b/c, and finally the required design configuration for scenario 5d will cover all scenarios.

The CCS design and cost estimates are not based on staged development. The governing parameter for a stepwise development is the amount of CO_2 to be captured, mainly affecting the solvent regeneration and CO_2 compression part of the CCS. A stepwise approach could be further evaluated in a potential next study phase.

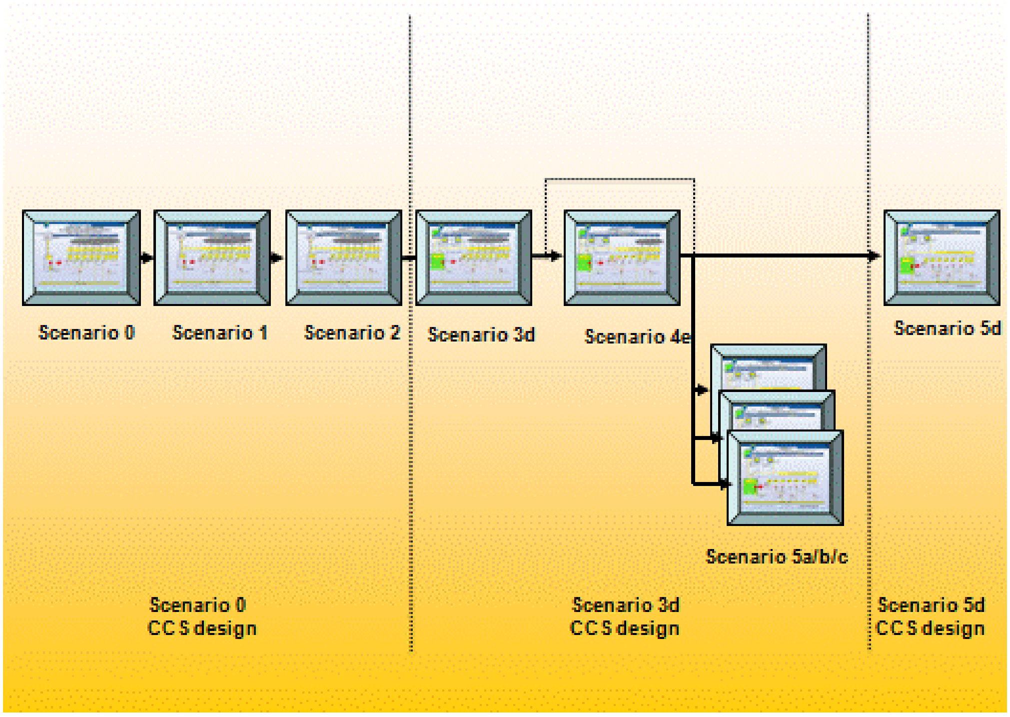

Figure 6-1 Scenario development

6.2 Descriptions of Kårstø processing plant for different scenarios

6.2.1 General

All scenarios are based on continuous operation of Naturkraft's gas power plant. Some of the scenarios also prepare for integration of the Kårstø processing plant with the carbon capture and compression plant.

The scenarios are illustrated as building blocks of various degree of integration, from the limited steam integration in scenario 1 through to the fully integrated scenario 5. The existing steam generation at the Kårstø processing plant turbine exhaust gas and boilers are gradually reduced.

The principle behind the new exhaust gas boilers in scenario 3, 4 and 5, is to use the remaining oxygen and run the boilers on natural gas in the exhaust gas stream and thereby increase the CO_2 concentration with limited increase of the volume of the exhaust gas stream. The design of the largest component in the CO_2 capture plant is directly related to the volume of the exhaust gas. Maintaining the volume flow and increasing the CO_2 content increases the efficiency of the carbon capture and compression facilities.

As a supplement to the conventional steam producing concepts, alternative technologies for steam production are described in scenario 5a (Oxyfuel), scenario 5b (Biomass) and 5c (Pre-combustion).

6.2.2 As is

The Kårstø processing plant as described in section 3.2 and the Naturkraft gas power plant as described in section 3.1 are currently in operation at Kårstø, operating independent and by separate organisations and owners.

Figure 6-4 gives a schematic overview of the existing facilities ("as is").

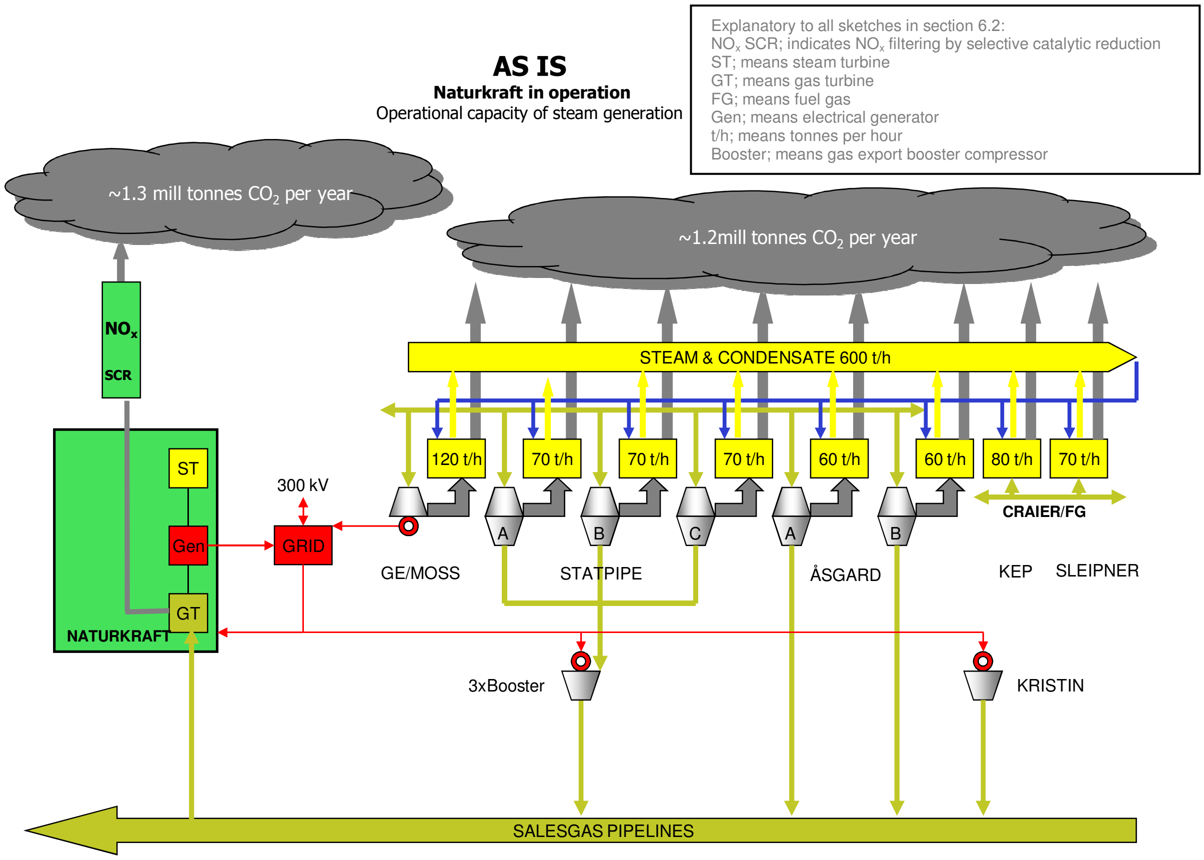

Figure 6-2 Schematic overview of existing facilities (As-is)

6.2.3 Scenario 0

Figure 6-4 gives a schematic overview of the scenario 0.

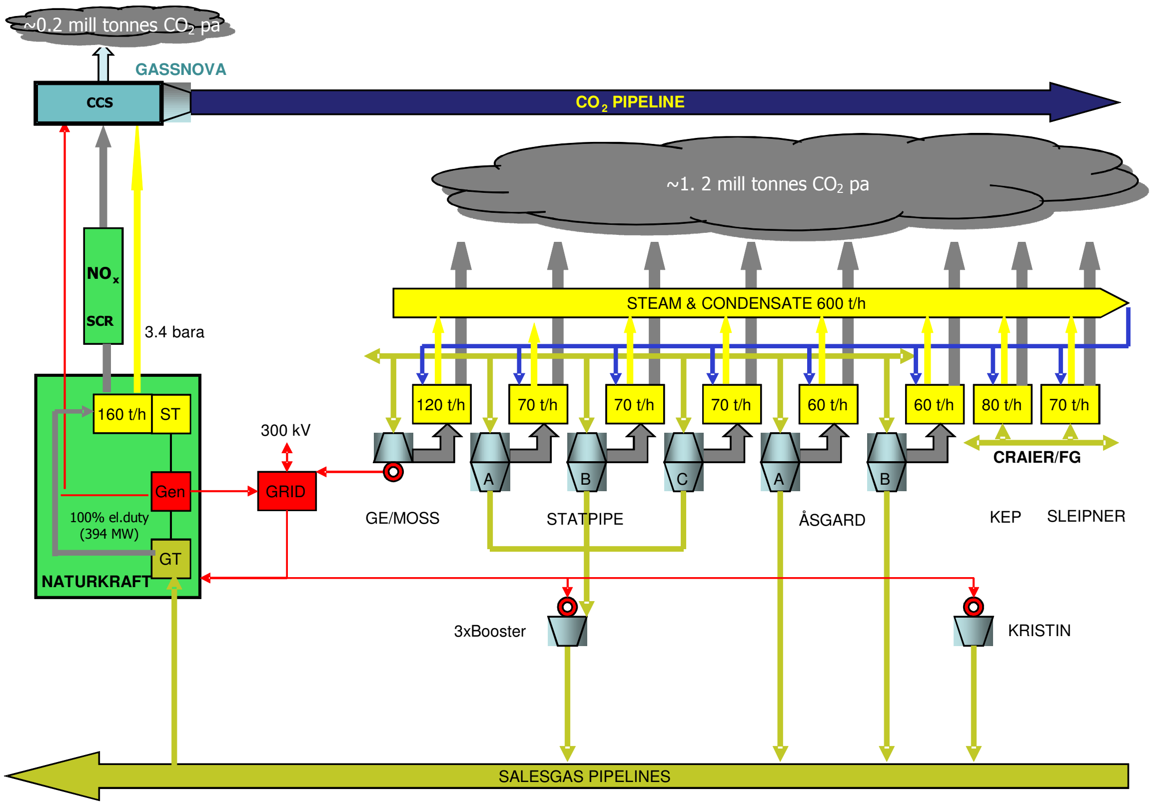

Figure 6-4 Schematic overview of scenario 0

Scenario 0 represents a scenario with no integration between the Kårstø processing plant and Naturkraft's gas power plant. The planned carbon capture and compression plant and the CO_2 transport and storage system are installed as defined in Gassnova's plans early 2009 [5].

The carbon capture and compression plant is supplied with low pressure steam from Naturkraft, reducing the gas power plants capacity by approximately 35 MW. The carbon transportation and storage system is designed for 3.5 million tonnes of CO_2 annual capacity, sufficient to handle future CO_2 from both Naturkraft's gas power plant and the Kårstø processing plant.

6.2.4 Scenario 1

Figure 6-4 gives a schematic overview of the scenario 1.

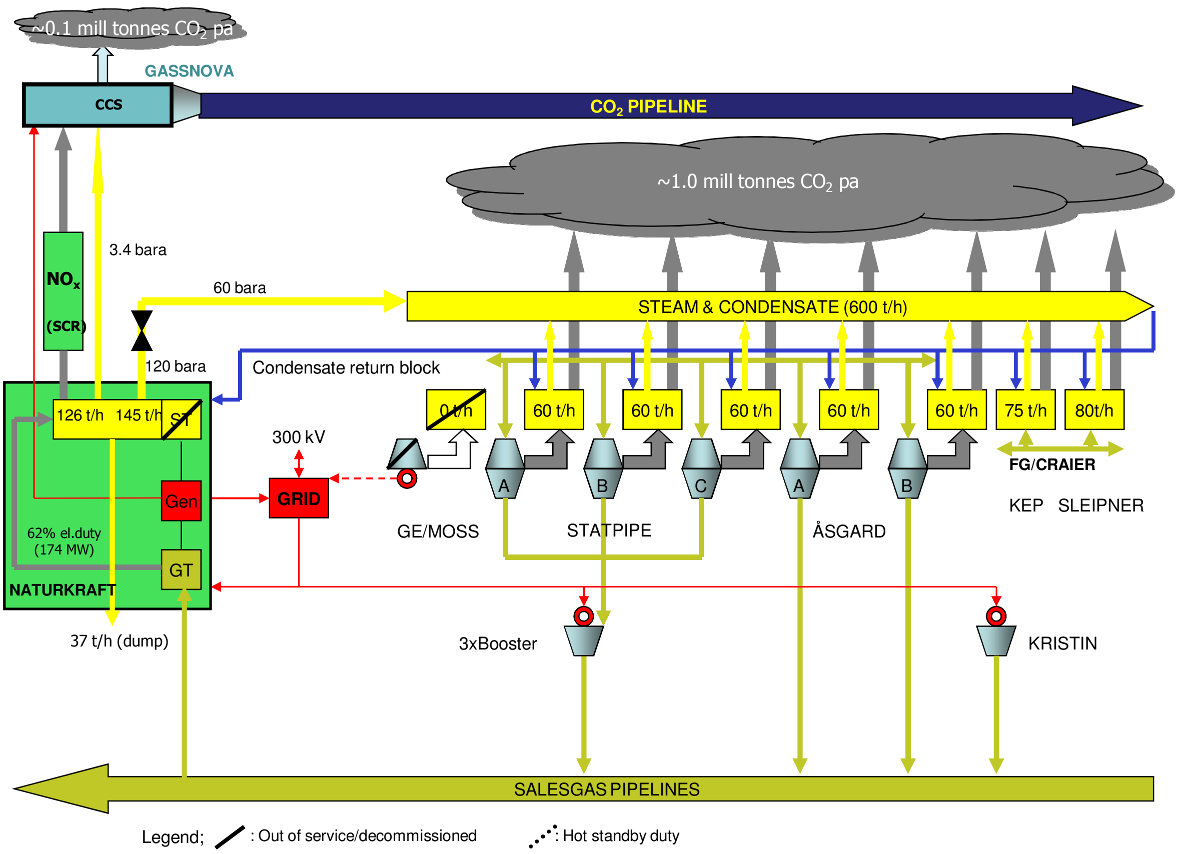

Figure 6-4 Schematic overview of scenario 1

Scenario 1 represents a limited degree of integration between the Kårstø processing plant and the Naturkraft gas power plant and no integration between the carbon capture and compression plant and the Kårstø processing plant.

The GE/Moss boiler is assumed to be decommissioned and removed and the high pressure steam capacity is replaced by steam from Naturkraft. The Naturkraft gas turbine will operate on part load of approximately 62% (minimum load) to ensure internal steam balance and meet the required steam demand to the Kårstø processing plant and the carbon capture and compression plant.

The other boilers at the Kårstø processing plant steam system will be operated at reduced load. Existing high pressure steam boilers will provide swing capacity during interruptions at the Naturkraft gas power plant. The Naturkraft steam generator may also provide swing capacity for the Kårstø processing plant steam system.

Changes compared to scenario 0:

- Steam supply from Naturkraft's gas power plant to the Kårstø processing plant
- Reduced CO_2 and NO_x emission from the Kårstø processing plant
- Reduced heat loss at the Naturkraft gas power plant
- Reduced power production at the Naturkraft gas power plant
- Reduced operational flexibility at the Naturkraft gas power plant

6.2.5 Scenario 2

Figure 6-5 is a schematic overview of integration scenario 2, which includes mixing of the CRAIER CO_2-rich gas with the fuel gas to the Naturkraft gas power plant as an additional building block to scenario 1. The CO_2 content is limited to 10% before combustion in the Naturkraft gas turbine in order to meet documented reference parameters for the gas turbine. The gas turbine will not be able to consume all of the CRAIER gas volumes in such operational scenario.

Changes compared to scenario 1:

- Reduced CO_2 and NO_x emission from Kårstø
- CO_2-rich CRAIER gas routed to Naturkraft's gas power plant
- Installation of mixing drum and control system for fuel gas system for the gas turbine

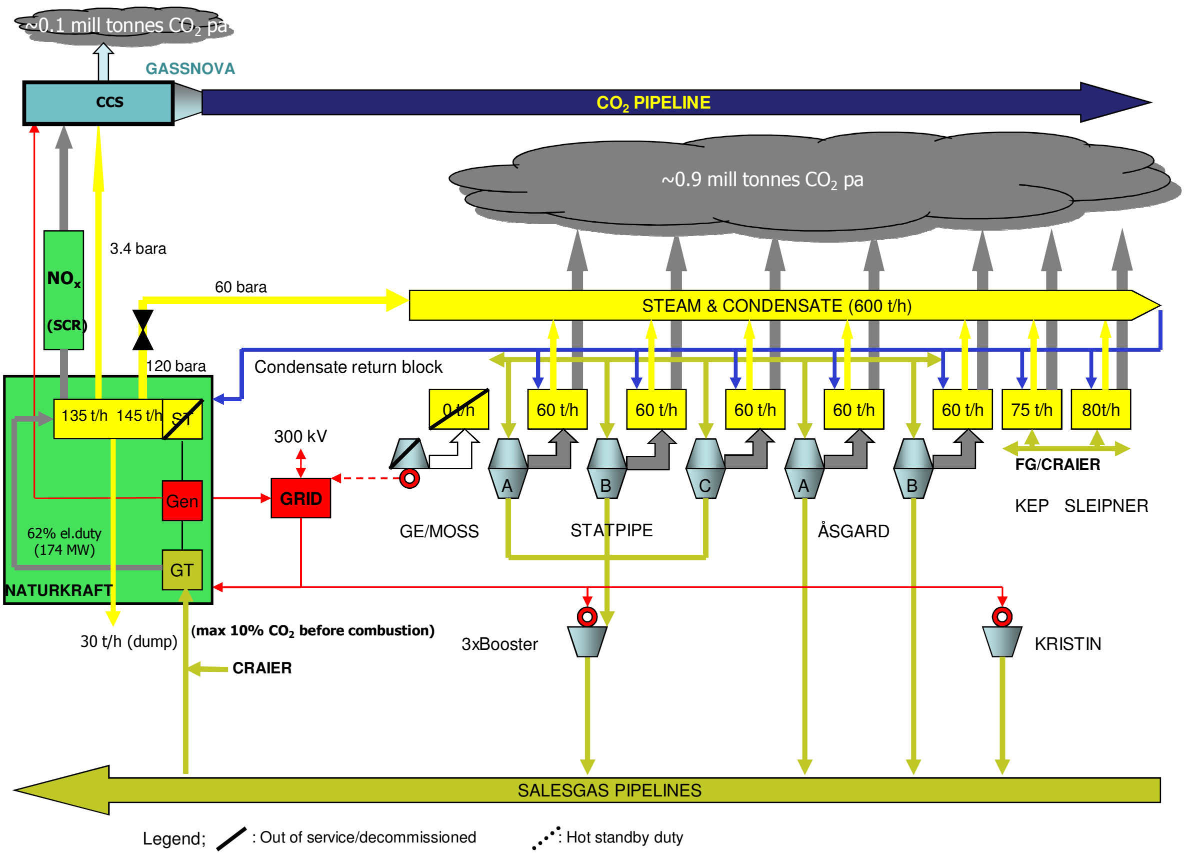

Figure 6-5 Schematic overview of scenario 2

6.2.6 Scenario 3

Figure 6-6 gives a schematic overview of the design scenario 3. Two new gas fired exhaust boilers are included in this scenario as new building blocks, one generating low pressure steam to the carbon capture and compression plant and one generating high pressure steam to the Kårstø processing plant. The new boilers will be located in the vicinity of the carbon capture and compression plant. The exhaust from the Naturkraft gas power plant contains approximately 13 % oxygen which will be used as combustion air for the new exhaust boilers. By utilising the remaining heat and oxygen content in the exhaust gas, the CO_2 content will be increased, which improves the efficiency of the carbon capture plant. The new exhaust boilers can also use fresh air and is equipped with a separate exhaust stack, hence enabling independent operation of both the Naturkraft gas power plant and the carbon capture and compression plant.

This scenario has a capacity of up to 250 t/h of new high pressure steam supply to the Kårstø processing plant. The combination of the Naturkraft gas power plant and the new boilers will be able to consume the total CRAIER gas volumes.

The increased steam capacity from the new exhaust boilers provides sufficient capacity for the Kårstø processing plant and may therefore prepare for a solution where the Naturkraft gas power plant and the Kårstø processing plant can be operated independently.

Changes compared to integration scenario 2:

- New high and low pressure exhaust boilers
- Reduced CO_2 and NO_x emission from Kårstø
- Potential for independent operation of Naturkraft's gas power plant and the Kårstø processing plant

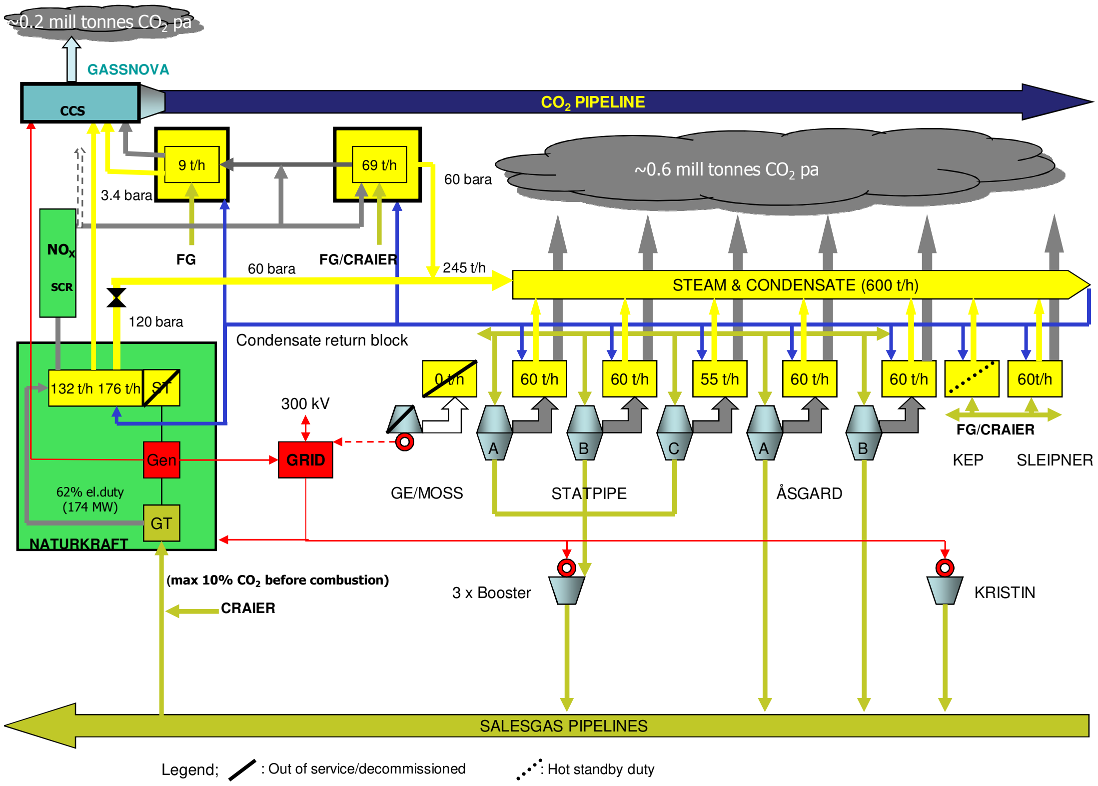

Figure 6-6 Schematic overview of scenario 3

6.2.7 Scenario 4

Figure 6-7 is a schematic overview of scenario 4. The main difference from scenario 3 is the replacement of the current gas turbine driven Statpipe export compressors by two new electrical driven compressors at a new location. The Statpipe compressor trains including the waste heat boilers are assumed to be decommissioned and removed. This scenario may also be further developed for independent operation.

Changes compared to integration scenario 3:

- 2 new electrical driven compressor trains
- Decommissioning and removal of Statpipe compressor trains
- Reduced CO_2 and NO_x emission from Kårstø

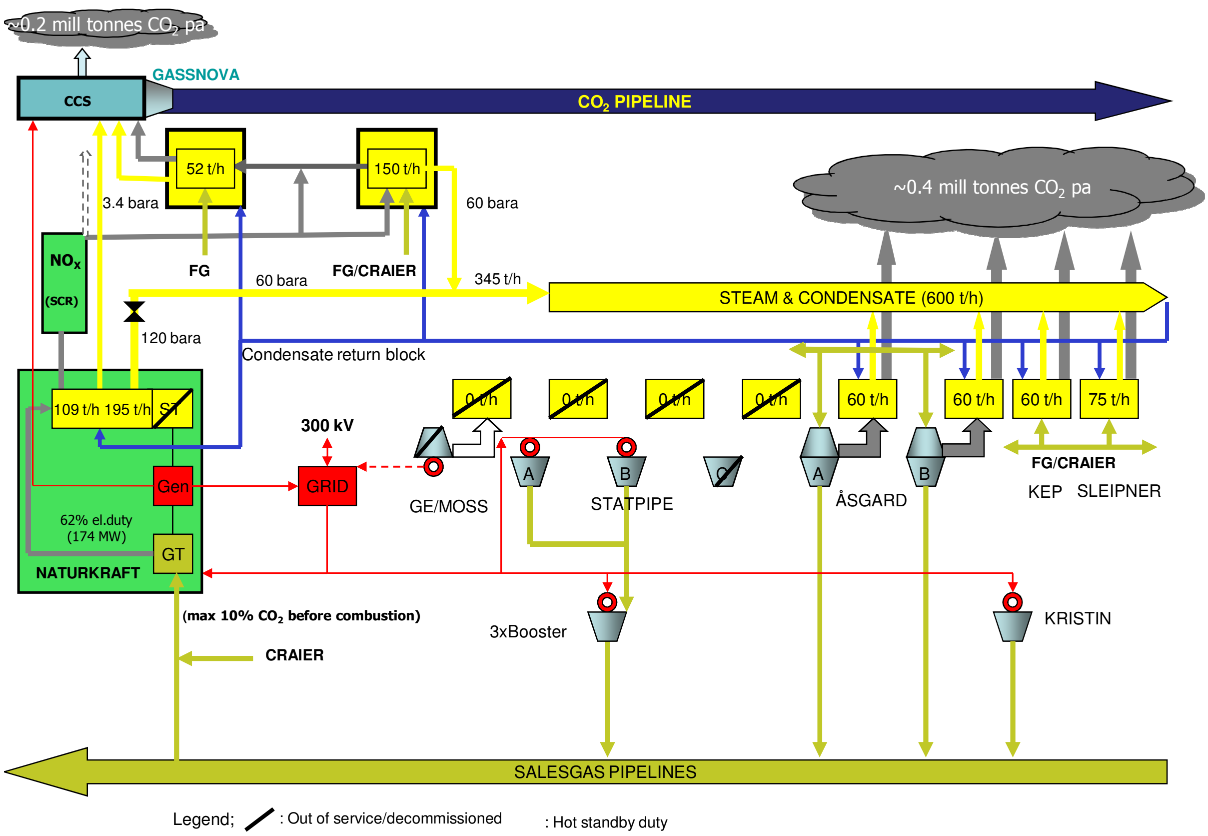

Figure 6-7 Schematic overview of scenario 4

6.2.8 Scenario 5

Scenario 5 represents a full electrification of the compressors at the Kårstø processing plant and includes the following new building blocks:

- Electrical drivers for the Åsgard export compressors
- A new flexibility compressor to maintain compressor capacity during the revamp of the Åsgard compressor trains
- Additional high pressure steam boiler capacity, supplied either by two new gas fired boilers in the vicinity of the carbon capture and compression plant (scenario 5d ref figure 6-8) or by new boiler facilities based on alternative technologies (scenario 5a,b,c)

All steam boilers at the Kårstø processing plant are removed except the two direct gas fired high pressure steam boiler that are kept in hot standby. This scenario may also be prepared for independent operation.

Changes compared to the scenario 4:

- Electrification of Åsgard compressor trains
- Decommissioning and removal of Åsgard gas turbine drives and exhaust boilers
- Reduced CO_2 and NO_x emission from Kårstø

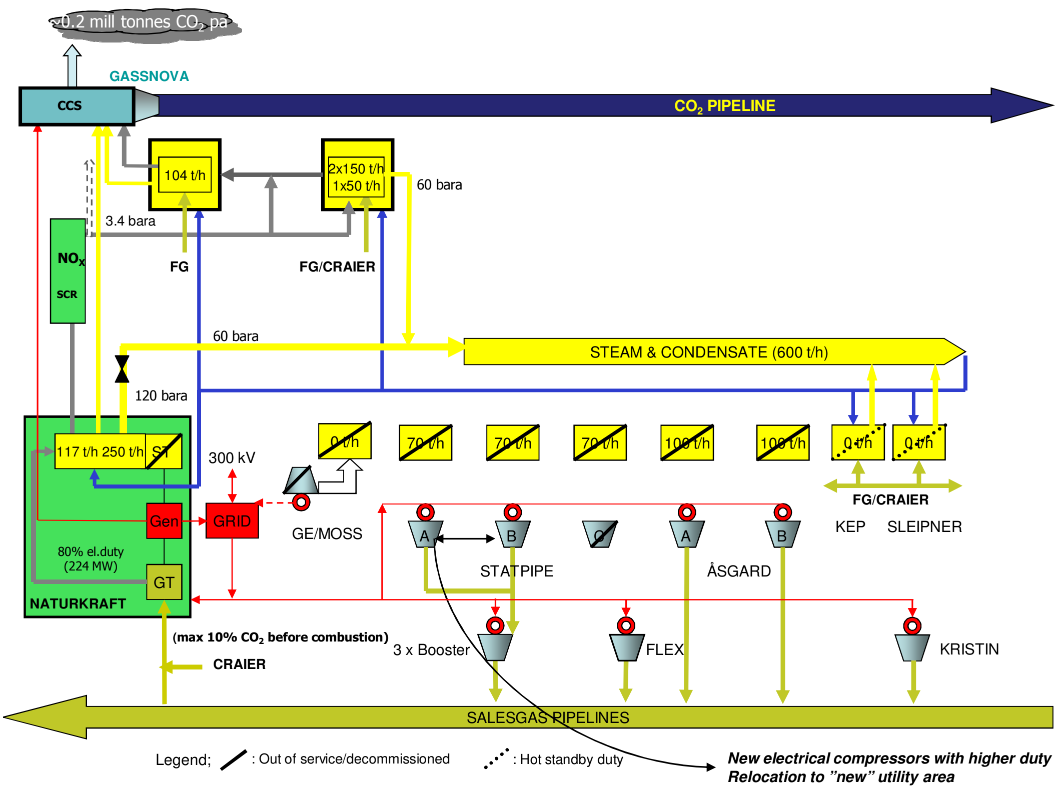

Figure 6-8 Schematic overview of scenario 5d

6.2.9 Scenario 5a (Oxyfuel)

Figure 6-9 is a schematic overview of scenario 5a.

In this scenario two 200 tonnes per hour Oxyfuel boilers are installed in parallel. These boilers are based on natural gas and oxygen combustion (nitrogen void atmosphere), thus enabling CO_2 separation by water condensation followed by compression and cryogenic purification of dried CO_2. The oxygen will be produced in an air separation unit.

The CRAIER fuel gas may be feasible in the Oxyfuel fired boiler as the boiler will be designed for operating in a CO_2 rich environment. Using CRAIER gas may reduce the need for flue gas recycle, which may slightly improve efficiency. To maintain high regularity level, the combustion will also be prepared for fresh air combustion.

The CO_2 will be transferred to the CO_2 transportation and storage system.

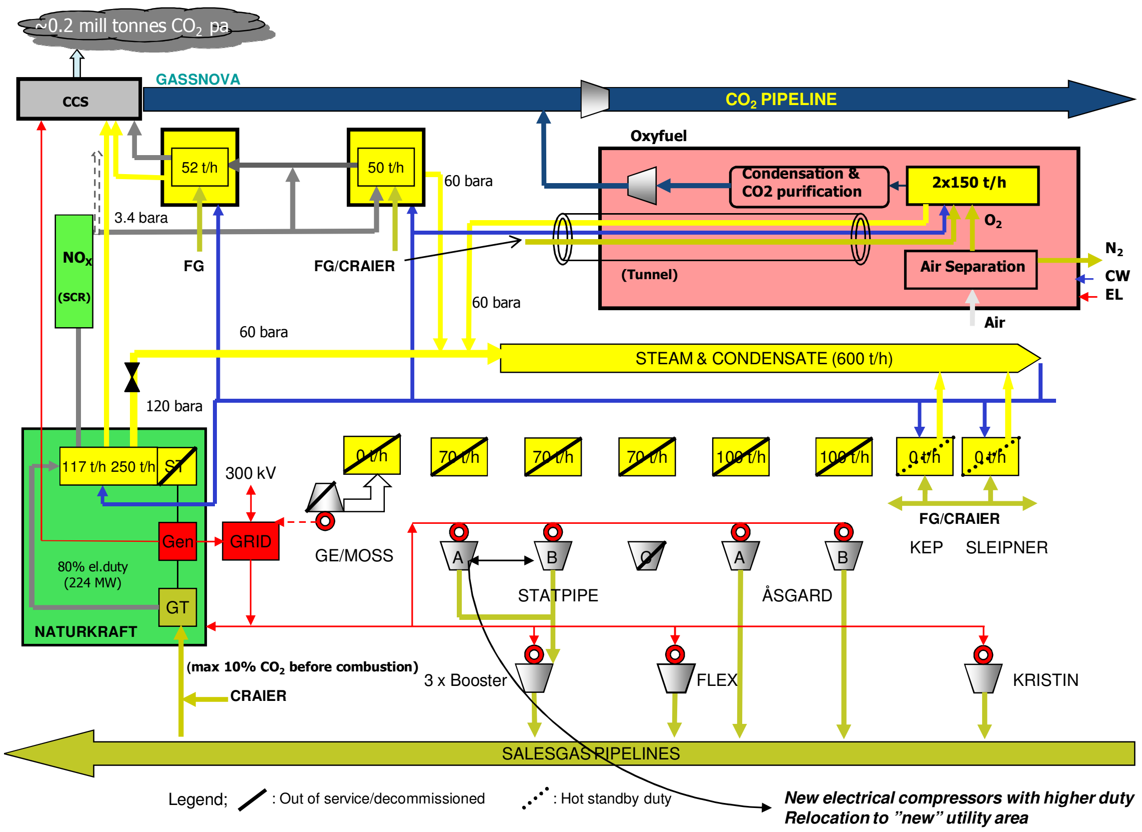

Figure 6-9 Scenario 5a - Oxyfuel

6.2.10 Scenario 5b (Biomass)

Figure 6-10 is a schematic overview of scenario 5b.

In this scenario two 200 tonnes per hour biomass based boilers are installed in parallel. These boilers burn biomass in air, and are per definition CO_2 neutral. In order to maintain regularity demand an additional conventional 200 tonnes per hour boiler is needed.

Biomass fuel has high fixed carbon content, large particle sizes and relative long residence time in combustion chamber. This may cause slower response than comparable fuel gas systems. Consequences of this have to be investigated further.

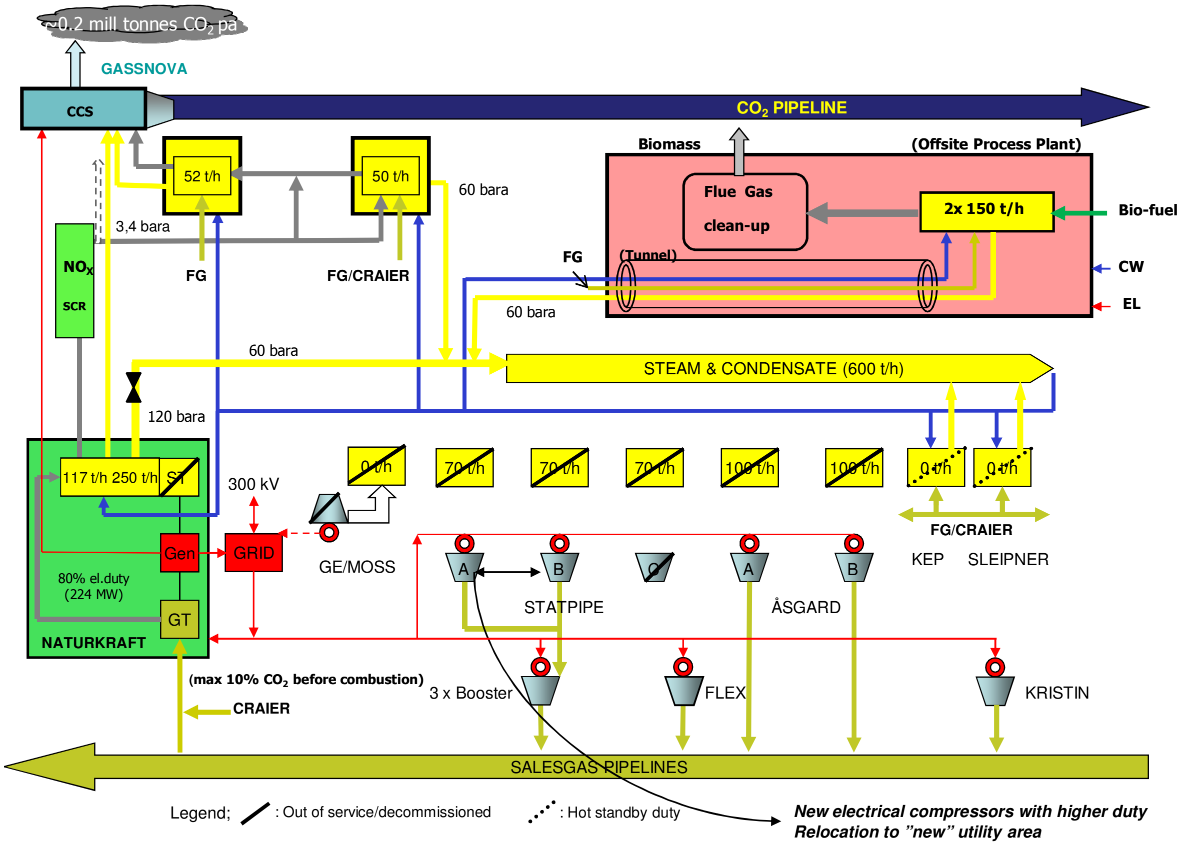

Figure 6-10 Schematic overview of scenario 5b

6.2.11 Scenario 5c (Pre-combustion)

Figure 6-11 is a schematic overview of scenario 5c.

In this scenario two dual hydrogen/natural gas boilers, each with a capacity of 200 tonnes per hour, are installed in parallel. The boilers burn hydrogen in air, with water as exhaust. The hydrogen will be produced in a natural gas reformer plant, where a pre-combustion separation of the CO_2 occurs (from the hydrogen).

Under normal operation the two hydrogen fired boilers will deliver 150 tonnes per hour each. Since the H_2 plant is designed for maximum steam production (400 t/h) it will be turned down to 75% during normal operation assuming no other users.

Dry gas to the H_2 plant should be supplied at minimum 30 bar pressure. It is not assumed that CO_2 rich CRAIER gas is used as feed gas to the reformer.

The CO_2 will be transferred to the CO_2 transportation and storage system.

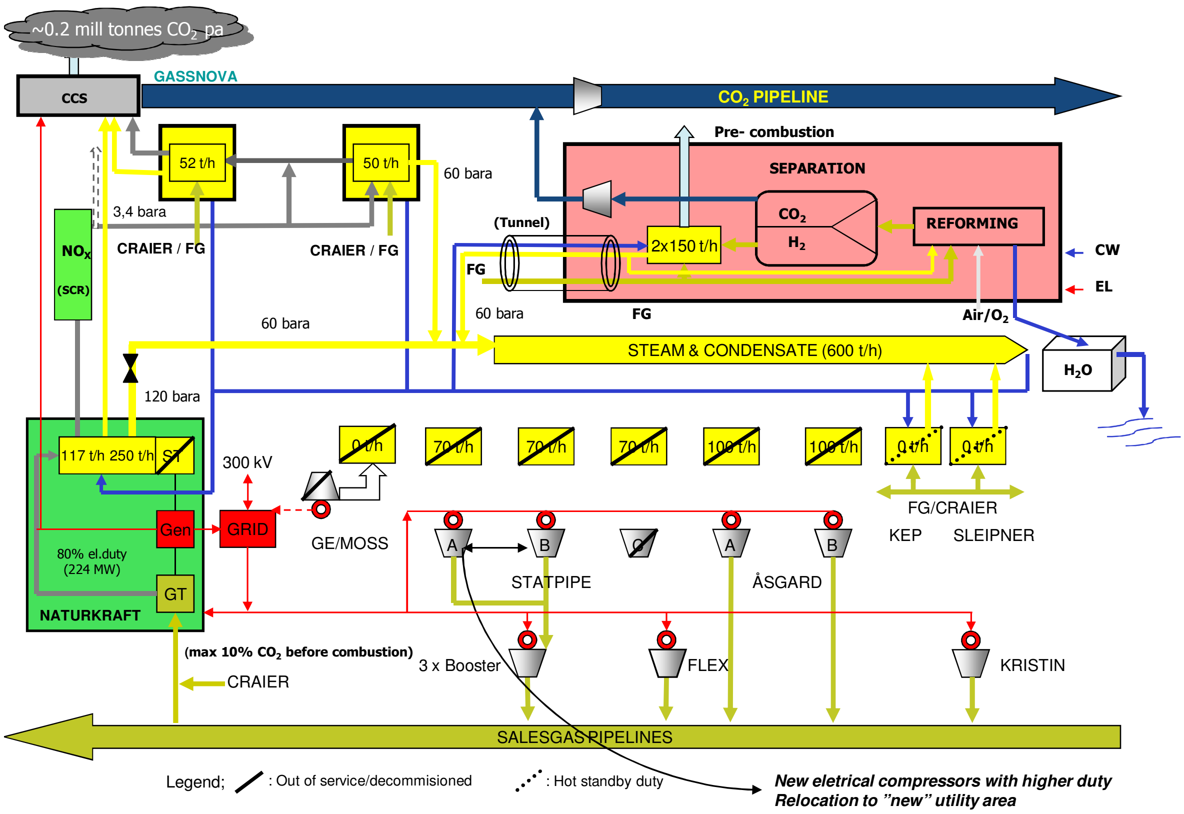

Figure 6-11 Scenario 5c – Pre-combustion

6.3 Description of carbon capture and storage for different scenarios

6.3.1 General / Scenario 0

The carbon capture and compression plant utilises amine solvent based on proven technology to capture CO_2 from Naturkraft's gas power plant exhaust gas. The design of the carbon capture and compression plant is based on the report from the former CO_2 Kårstø project [7].

The plant consists of the following main process areas:

1. Stack connection
   The exhaust gas from the gas power plant is transferred to the carbon capture and compression plant by ducting connected to the bottom of the existing stack at the gas power plant. The existing stack is modified to allow the exhaust gas to go to the carbon capture and compression plant with as little impact to the pressure at the stack tie-in point as possible. As the tie-in is based on a partly closed damper in the stack, the risk of disturbance to the gas power plant is limited but not negligible.

2. Flue gas conditioning
   A large electric driven fan is installed to make the necessary draft for the exhaust gas to be transported from the gas power plant stack through the flue gas conditioning and absorber towers. The flue gas at 90° C is redirected from the gas power plant's stack by large ducts to the CCC plant where it is cooled in a direct contact cooler by circulating water to approx 20-40°C and then sent to the absorption area by a blower. The heat absorbed from the exhaust gas by the circulating water is rejected to seawater by heat exchange. The cooling of the exhaust gas is the largest consumer of seawater coolant in the carbon capture and compression plant, consuming around 40-50% of the total cooling water demand.

3. CO_2 absorption
   The cooled flue gas flows upwards through the absorber column in which circulating amine solvent is flowing downwards. The absorber column is the largest process component, being approx 40-50 m in height. During its passage, about 85% of the CO_2 in the flue gas is absorbed into the amine solution. The residue flue gas then flows through a packed bed to be washed by circulating water to minimize solvent emissions to air.

4. Solvent regeneration
   The CO_2 rich solvent leaving the absorber is heated by the returning hot solvent from the regeneration unit in a heat-exchanger and then flows down through a packed column where it is stripped of its CO_2 by additional heat in the form of steam generated in the reboiler. This is the single main consumer of thermal energy in the process, requiring ~180 t/h of low pressure steam. The released CO_2 is then sent to the compression and treatment area.

   Due to presence of oxygen in the flue gas, some of the circulating solvent is degraded into heat stable salts (HSS) during the absorption/regeneration cycle and has to be reclaimed. A small percentage is not regenerated during the reclaiming operation, resulting in waste production of approximately 1000 t/y which has to be disposed of.

5. CO_2 compression and conditioning
   The recovered CO_2 is at low pressure and needs to be compressed for transport and disposal by injection into sub-sea reservoirs at 75-200 bar(g) pressure. To prevent corrosion of compression equipment and the transport pipeline, the product CO_2 is dried by molecular sieve dehydrators. The CO_2 compressor has an electrical drive, consuming

approx. 40% of the total 37 MW electrical power requirement of the carbon capture and compression plant.

6. CO_2 transport and storage
   The CO_2 product from the Kårstø carbon capture and compression plant is transported through a 12" piggable, carbon steel pipeline 224 km to the unlicensed block 16/11 (Utsira South) and injected into two permanent wells via a 4-slot sub-sea template (i.e. with the possibility for tie-in of a future pipeline from the Mongstad capture plant). Well-control is performed from the Draupner S/E platform.

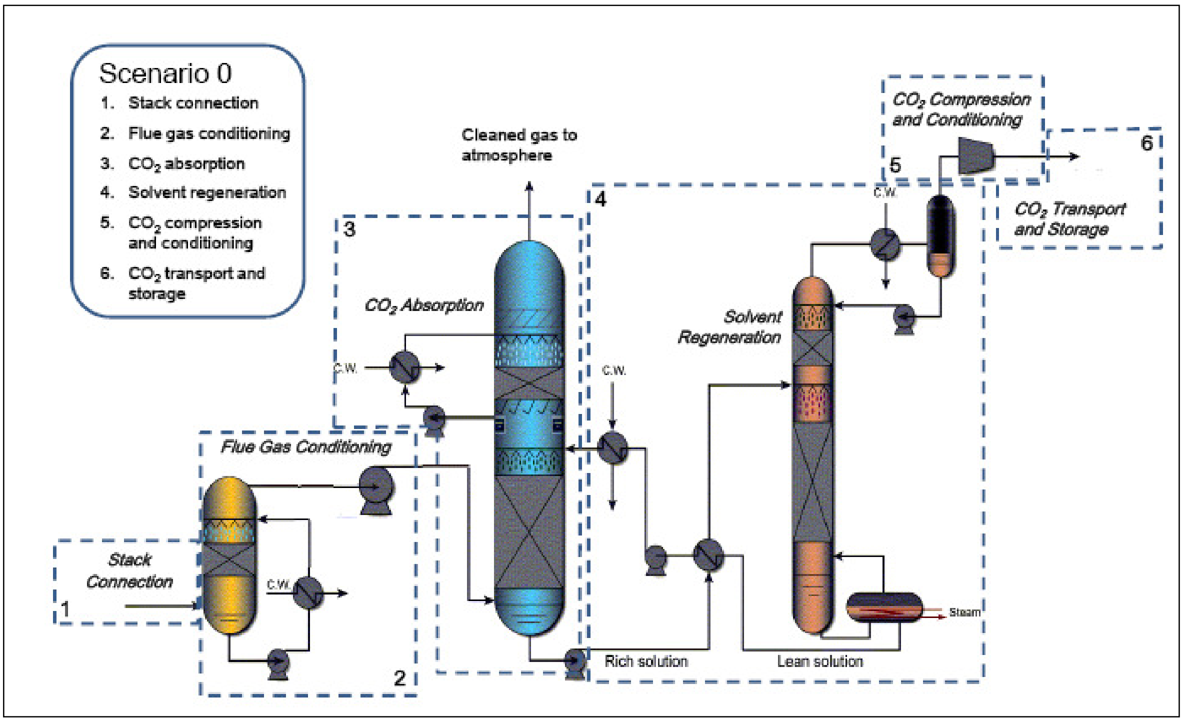

Figure 6-12: Process sketch of scenario 0

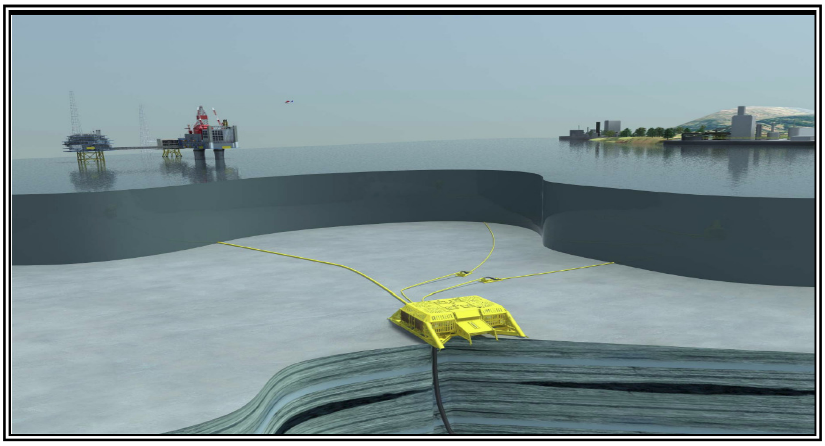

Figure 6-13: CO_2 injection well

The initial capacity of the pipeline is 3.5 million tonnes CO_2 per year. A booster pump configuration is installed onshore at Kårstø to ensure the required delivery pressure to the reservoir during the CCS life time. It is important that CO_2 remains in a dense phase during transportation and a down-hole choke is therefore introduced in the well to control the operating pressure in the pipeline.

6.3.2 Scenario 1

This scenario is a turndown case of the original design in scenario 0. Since the Naturkraft gas power plant is running on reduced load, the exhaust gas feed to the capture plant is decreased with the result that the amount of captured CO_2 drops from scenario 0.

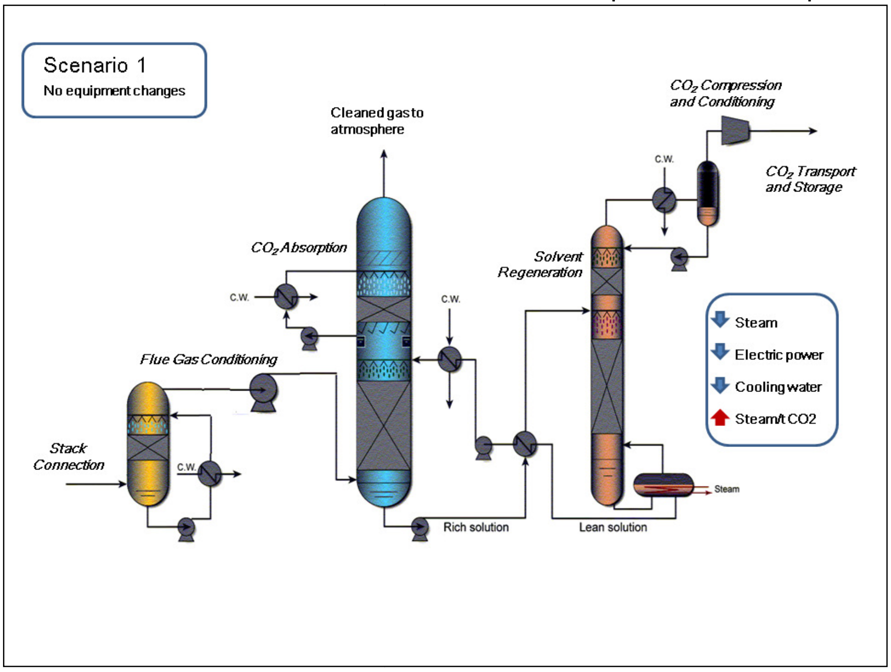

Figure 6-14: Process sketch of scenario 1

<u>Impact on design and operation of carbon capture and storage</u>

There is no impact on the capture plant with respect to design. All equipment will be able to operate satisfactorily under the new feed conditions. Changes from scenario 0 to scenario 1 are identified below:

1. Stack connection – No impact.
2. Flue gas conditioning – Cooling load is reduced.
3. CO_2 absorption – Circulation of amine solvent is at a reduced rate. Solvent loss and degradation losses is estimated to be somewhat lower compared to scenario 0.
4. Solvent regeneration – Demand for low pressure steam is reduced.
5. CO_2 compression and conditioning – Power demand is reduced due to decreased product rate. No impact compared to the compressor design of scenario 0. The compressor shall be operated at the minimum turn down flow rate.
6. CO_2 transport and storage – No impact.

6.3.3 Scenario 2

This scenario is also a turndown case of the original design in scenario 0. The Naturkraft gas power plant has the same load as scenario 1, but with combustion of the CRAIER gas with its high CO_2 content (35 – 65%). The exhaust gas feed to the capture plant results in a higher concentration of CO_2, hence the amount of captured CO_2 increases from scenario 1 to scenario 2.

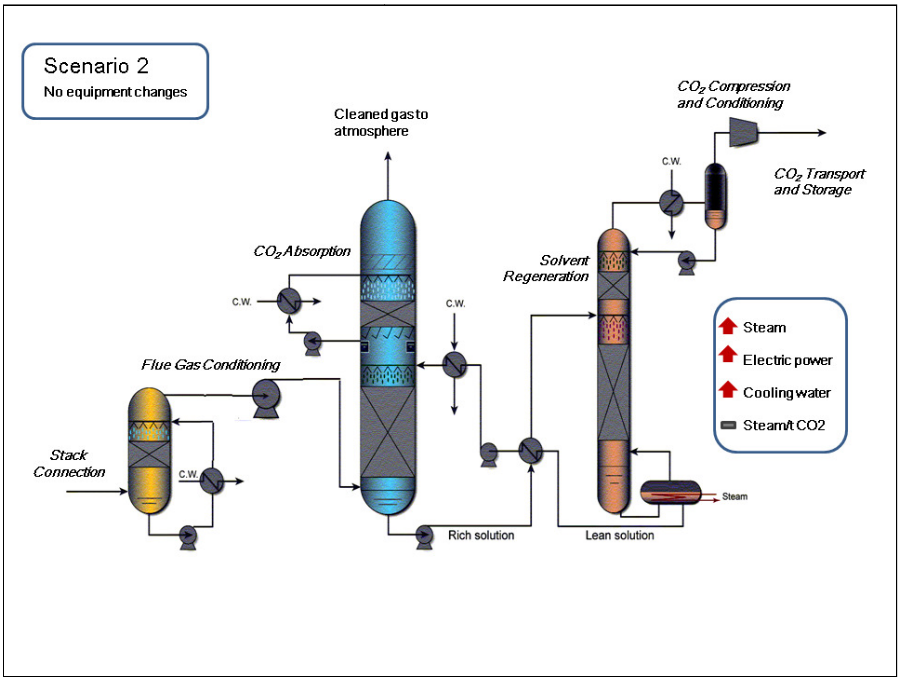

Figure 6-15: Process sketch of scenario 2

<u>Impact on design and operation of carbon capture and storage</u>:

There is no impact on the capture plant with respect to design. All equipment will be able to operate satisfactorily under the new feed conditions. However there will be an impact on operation and the change from scenario 1 to scenario 2 is identified below:

1. Stack connection – No impact in comparison to scenario 1.
2. Flue gas conditioning – No impact.
3. CO_2 absorption – No impact. Solvent make-up costs and degradation loss are similar
4. Solvent regeneration – Demand for low pressure steam is increased from scenario 1 due to higher CO_2 capture rate.
5. CO_2 compression and conditioning – No impact compared to the compressor design of scenario 1. The compressor shall be operated above the minimum turndown flow rate, i.e. an increased power demand compared to scenario 1.
6. CO_2 transport and storage – No impact.

6.3.4 Scenario 3

This scenario is the first scenario where the overall design capacity is changed compared to scenario 0 to be able to capture more CO_2. In this mode of operation, with combustion of the CO_2-rich CRAIER gas, in both the gas turbine and the new high pressure exhaust boiler, the exhaust gas feed to the capture plant contains higher concentration of CO_2. This results in a larger amount of captured CO_2 than scenario 2.

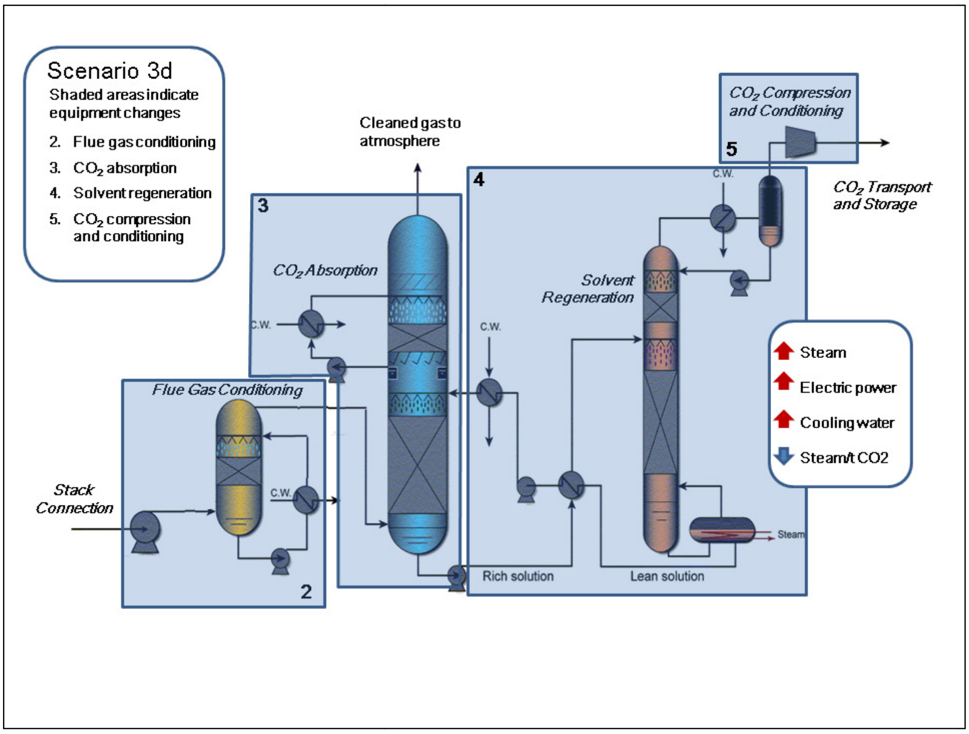

Figure 6-16: Process sketch of scenario 3

<u>Impact on design and operation of carbon capture and storage</u>

In this scenario, there is major impact on the capture plant with respect to design and operation. The main changes of design and operation (compared to scenario 2) are identified below:

1. Stack connection – Due to the installation of the high pressure and low pressure steam boiler in the exhaust gas stream, the duct arrangement from the gas power plant to the carbon capture and compression plant is modified compared to scenario 2. Since both stacks from the gas power plant and from the high pressure boiler are connected to a common fan in the carbon capture and compression plant, there is a risk of process upsets at Kårstø if the tie-in design is not adequate. In addition, as the CO_2 concentration is high, a special stack design is required for the high pressure boiler in order to limit the air ingress in the stack and the losses of flue gas to the atmosphere to less than 1%. A careful design must be developed to ensure no negative impact of the gas power plant outlet pressure in the stack when the exhaust gas boiler system is operated. The risk for trip of the gas power plant and the high pressure boiler due to the tie-in is negligible as a result of the open design identical to the scenario 0 design. The mechanical design pressure of the high pressure boiler shall take into account the additional pressure drop due to the special stack. Downstream the stacks tie-in, registers are necessary in the ducts in order to control the flows from the stacks to the carbon capture and compression plant. The tie-in point to the carbon capture and compression plant will be the exhaust gas outlet of the low pressure boiler.
2. Flue gas conditioning – Due to increased flue gas temperature and higher flue gas flow, the need for cooling load increases from scenario 0 and hence the whole system has to

be enlarged. Transfer duct size is increased and the direct contact cooler is increased. Additionally, the blower duty is increased from scenario 0 and also the blower has to be relocated to the upstream side of the cooler in order not to create a vacuum in the system.

3. CO_2 absorption – Due to increased concentration of CO_2 in the exhaust gas feed, solvent circulation rate needs to be increased from scenario 2 to maintain the required annual recovery of 85%. Hence larger capacity solvent circulation pumps are required and an increase in absorber column area is necessary. Solvent losses are estimated to be somewhat higher than scenario 2 due to increase in throughput. Due to increase in the solvent circulation and CO_2 feed rate, degradation losses are estimated to be higher than for scenario 2.
4. Solvent regeneration – Due to the increase in the absorbed CO_2, more energy in the form of low pressure steam is required to regenerate the rich solvent. Larger capacity reboiler and an increase in column volume is necessary.
5. CO_2 compression and conditioning – Due to increased product rate, larger capacity compressor and treating equipment are required. Power demand is similarly increased. The compression system shall include two compressors in parallel in order to comply with the operation and design flow rates.
6. CO_2 transport and storage - Due to increased product rate additional CO_2 booster pumps are required.

6.3.5 Scenario 4

The scenario 4 is covered by the same design as scenario 3. The only change is that the load of the high pressure and low pressures boilers increases and the amount of CO_2 capture increases.

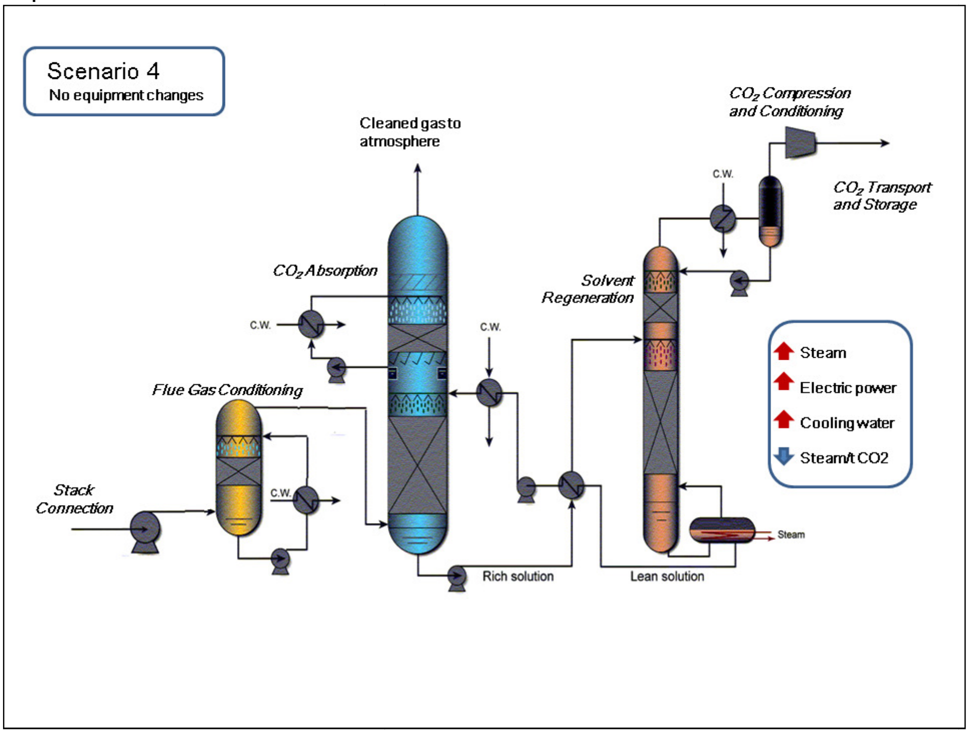

Figure 6-17: Process sketch of scenario 4

<u>Impact on design and operation of carbon capture and storage</u>

In this scenario, there is no impact on the capture plant with respect to design. The main changes regarding operation (compared to scenario 3) are identified below:

1. Stack connection – No impact.

2. Flue gas conditioning – No impact.
3. CO_2 absorption – No impact.
4. Solvent regeneration – Higher low pressure steam demand due to higher CO_2 amount.
5. CO_2 compression and conditioning – Higher power demand due to higher CO_2 amount.
6. CO_2 transport and storage – No impact.

6.3.6 Scenario 5d

In this scenario the Naturkraft gas power plant is at 80% load, the low pressure boiler is in operation and two of the high pressure boilers are operating while the third unit is on hot-standby. With the high amount of gas consumption (including the CO_2-rich CRAIER gas), in both the gas power plant and the exhaust boilers, the exhaust gas feed to the capture plant contains still higher concentration of CO_2 with the result that the maximum amount of captured CO_2 increases.

Concerning the design of the carbon capture and compression plant scenarios 5d has bigger impact than 3.

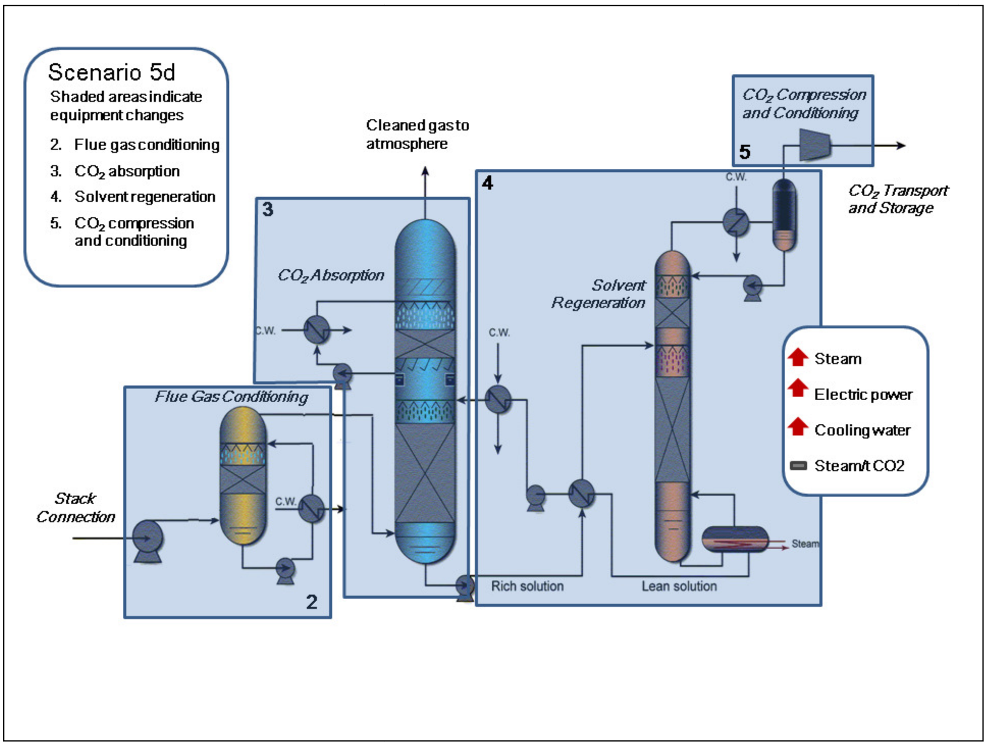

Figure 6-18: Process sketch of scenario 5d

<u>Impact on design and operation of carbon capture and storage</u>

In this scenario, there are minor changes to the capture plant design and larger changes regarding operation. The main impact under scenario 5d compared to scenario 3 is identified below:

1. Stack connection – Due to the installation of 2 high pressure steam boilers, the duct arrangement from the boilers to the main duct out of the Naturkraft gas power plant is modified compared to the scenario 3.
2. Flue gas conditioning – Due to increased flue gas flow, some of the system has to be enlarged. However this increase is within the design margins of scenario 3.
3. CO_2 absorption – Larger capacity pumps from scenario 3 and small increase in column diameter is necessary. Solvent losses are estimated to be similar to those of scenario 3 as flow rates are similar. Although there is an increase in the solvent circulation and CO_2

feed rate, degradation losses are estimated to be a little lower than for scenario 3 due to lower oxygen content of the feed gas.

4. Solvent regeneration – Due to an increase in absorbed CO_2 and also increased solvent circulation rate, an increase in column diameter is necessary. Also the reflux system equipment is larger.
5. CO_2 compression and conditioning – Larger capacity compressor and treating equipment are required compared to scenario 3.
6. CO_2 transport and storage - Due to increased product rate additional CO_2 booster pumps are required.

Table 6-1 Summary comparison of the key carbon capture and compression plant parameters

Kårstø carbon capture and compression plant Key process parameters								
Scenario	[Unit]	0	1	2	3	4	5a/b/c	5d
Load of Naturkraft gas power plant	%	100 %	62 %	62 %	62 %	62 %	80 %	80 %
CO_2 concentration in feed,	mole%	3.8 %	3.5 %	3.8 %	4.5 %	5.2 %	4.6 %	6.3 %
LP steam to reboiler,	t/h	180	130	145	155	170	180	235
Steam t/t CO_2 recovered	ratio	1.4	1.5	1.5	1.35	1.25	1.35	1.25
Cooling water	m^3/h	19 700	13 500	14 400	18 100	20 000	21 600	27 500
Electrical power	kW	37 000	29 400	30 400	35 500	38 300	40 100	47 800
CO_2 recovered	t/year	1 060 000	710 000	770 000	910 000	1 070 000	1 090 000	1 520 000

Operational data for maximum designed load	[Unit]	Common design for scenario 0,1 and 2	Common design for scenario 3, 4 and 5a/b/c	Scenario 5d
CO_2 concentration in feed	mole%	3.8 %	5.2 %	6.4 %
Low pressure steam to reboiler	t/h	180	220	260
Steam ratio vs. recovered CO_2	ratio	1.4	1.2	1.2
Cooling water	m^3/h	19 700	27 100	31 200
Electrical Power	kW	37 000	48 200	54 000
CO_2 Recovered	t/year	1 060 000	1 480 000	1 810 000

6.3.7 Scenario 5a and 5c

The two scenarios 5a (oxyfuel) and 5c (pre-combustion) will capture their own production of CO_2, however the CCS will have responsibility for transport and storage. The interface will be on a CO_2 manifold at the CCS booster area. The CO_2 is routed to the CO_2 booster pump area part of CCS at 75 bar to go into the CCS transport and storage system. Due to increased product rate additional CO_2 pumps are required at the CCS booster pump area.

The operational scenario 5a/c for the CCS part is covered by the same design as 3. The only change is the duty of the power plant will increase and that the load of the high pressure and low pressures boilers decreases. The total load of the CCS will be at approximately the same level as scenario 4. In addition the amount of CO_2 for transport and storage will include the CO_2 mentioned above. See Table 6-1 for operational change.

6.4 Layout

The new exhaust gas boilers in scenario 3 to 5 are located close to the gas power plant and the carbon capture plant, due to integrated exhaust ducts and steam and condensate piping. This location is the area prepared for a future second train of the gas power plant.

The location for the new electric driven compressors in scenario 4 and 5 is selected to avoid contemporary construction and operational activities to reduce risks.

The main grid intake is due to safety reasons relocated to a new area in scenarios 3 to 5.

Location of tie-in points are identified but a more detailed survey needs to be done in order to identify exactly where the tie-in shall be and also the method of the tie-in connection.

The layout for each scenario is included in Appendix B (scenario 1, 2, 3, 4 and 5) and Appendix C (scenario 5a/b/c). Figure 6-19 is an example of the layout for scenario 5d which also includes the building blocks of the other scenarios.

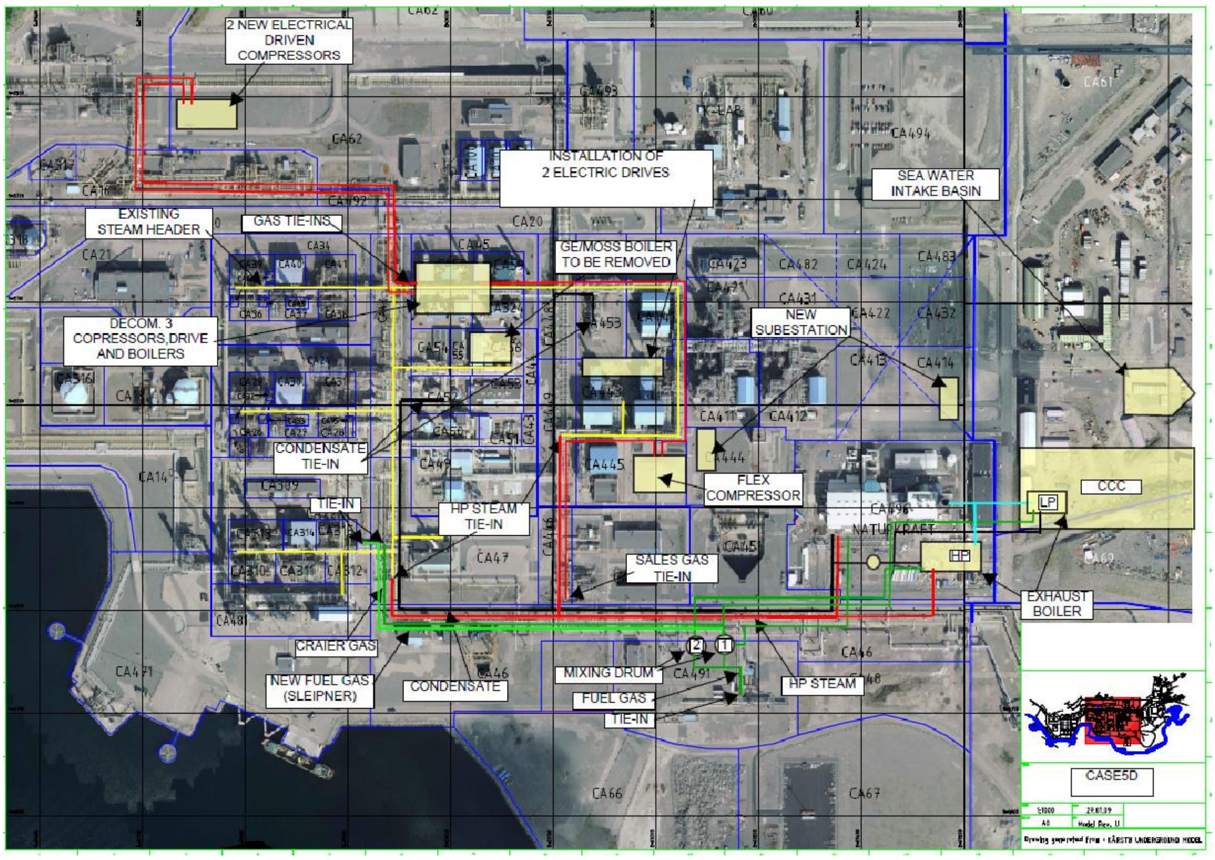

Figure 6-19 Layout scenario 5

Figure 6-20 illustrates the design of the new exhaust boilers. The three high pressure boilers (green) are located at the proximity of the stack (blue) of the Naturkraft gas power plant (grey). The low pressure boiler(blue) is located at the carbon capture plant (yellow).

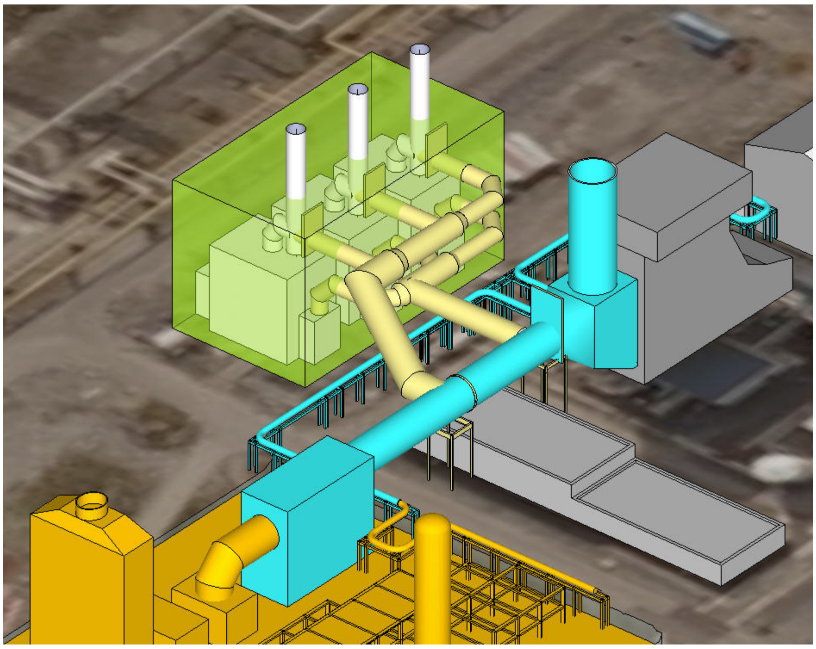

Figure 6-20 Layout exhaust stack and high pressure boilers system scenario 5d

Due to safety reasons, the Ognakalven island is selected for scenario 5a/b/c. Figure 6-21 shows a layout for scenario 5a at Ognakalven, and Figure 6-22 shows the tunnel entrance at the Kårstø processing plant. Scenario 5b and 5c will have a similar layout.

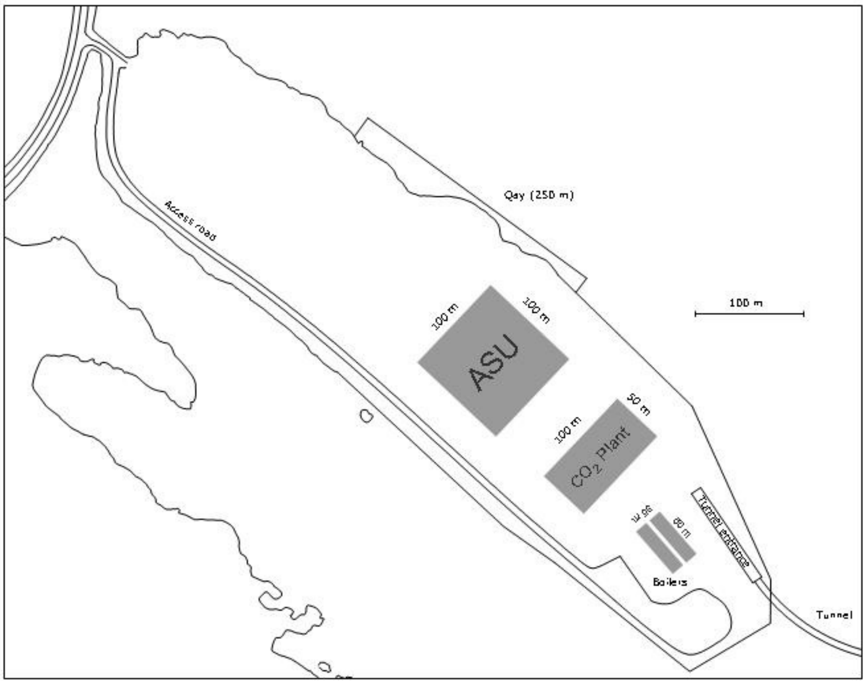

Figure 6-21 Location of the Oxyfuel facilities at Ognakalven

Ognakalven will be connected to the Kårstø processing plant via a 2 km long subsea tunnel, crossing Frekasundet. The tunnel will contain pipes for steam, condensate, natural gas as well as cables for electricity and communication. At the low point in the tunnel, draining point on the steam pipe will be installed. Figure 6-22 shows a possible route for the tunnel.

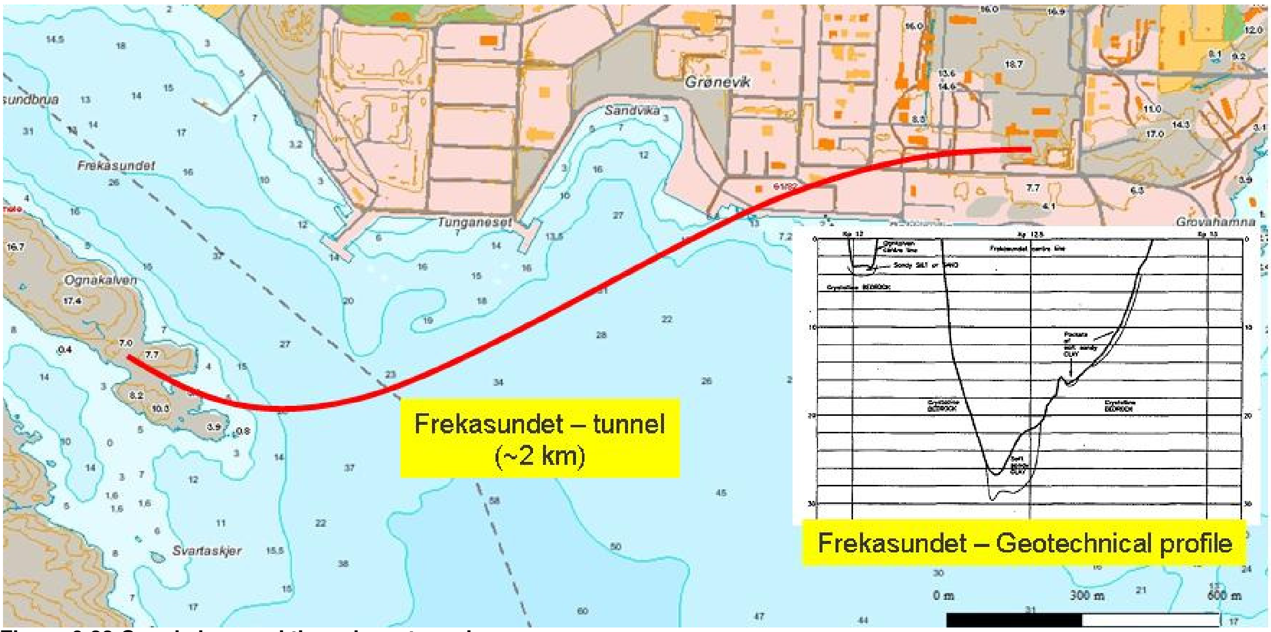

Figure 6-22 Ognakalven and the subsea tunnel

7 HEALTH, SAFETY AND ENVIRONMENT (HSE)

All the scenarios studied are assumed to meet the current HSE requirements and regulations at Kårstø related to noise and emissions to air and sea.

The overall goal of HSE is to avoid harm to humans, the environment and material values. The integration scenarios will, as a minimum, be required to meet all relevant regulations at Kårstø. These requirements will be detailed later as part of the authority regulation process.

The main hazards for each scenario have been identified for both the operation and construction phase [4].

7.1 Operational risk evaluation

Kårstø has undergone large expansions in later years which have resulted in higher equipment density in various areas. This has affected the risk level at Kårstø in a negative way as the leak frequencies increases, the ignition probability per area increases, the maximum explosion pressure increases, the probability to get explosions increases and the escalation probability between equipment increases. This is particularly a challenge in highly congested areas.

All scenarios that include a further congestion of existing areas will require further analysis to assess their risk impact.

The new flexibility compressor is evaluated to have a potential negative safety impact in scenario 5.

All changes that lead to reduction in leak sources, ignition sources or reduced congestion in the existing facility reduces the risk level, provided new equipment does not replaces these units.

7.2 Construction risk evaluation

Construction work will generally introduce increase in risk driving elements such as:

- Manning level
- Increased number of vehicles on the plant
- Introduction of new ignition sources like hot work
- Work on safety systems
- Work on or close to equipment containing hydrocarbon

Increase in one or more of these elements above the normal operation levels are considered an increased risk level during the construction period. All simultaneous construction activities at Kårstø must be considered together and be included in future construction analysis.

7.3 Scenario risk evaluation

The main conclusions from the risk evaluation of each scenario are presented below.

Scenario 1 is assumed to be feasible. Scenario 1 will lead to reduced risk during normal operation and requires limited construction work.

Scenario 2 and 3 are assumed to be feasible. Risk assessment should be performed to evaluate the location and design of the mixing drum. The construction will require a limited construction period; however, the work must be considered in relation to simultaneous construction activities at Kårstø.

Scenario 4 is assumed feasible and the new location of the new Statpipe compression facilities leads to reduced risk in the central, high risk areas of the plant in the operation phase.

Scenario 5 requires installation of a new flexible compressor in the congested, high risk Åsgard area. The installation of the new compressor and the construction work during electrification of the Åsgard compressors have been identified as potential high risk construction activities. For the operation phase a risk analysis with an explosion analysis is required to assess the risk impact of this scenario. The construction period must be carefully assessed to avoid long period with high risk levels at the Kårstø processing plant.

All three alternative technologies of fuelling high pressure steam boilers based on Oxyfuel, biomass and hydrogen - scenarios 5a/b/c - are recommended to be installed at a new location outside the Kårstø processing plant's safety zone, at the island of Ognakalven. The new facilities will be connected to the Kårstø processing plant by a new underwater tunnel from the facility at Ognakalven to the area south of the Naturkraft gas power plant. The construction work is significant and both the tunnel and the new facilities will be further analysed to feasibility if selected to be further matured in the next phase.

7.4 Environmental considerations

Discharges to sea are related to the use of cooling water. The cooling water discharges impact the temperature in the fjord outside Kårstø. If a new sea water cooling supply system will be installed it is recommended to discharge the used water at 40 m depth with good spreading to reduce the negative impact on the fjord systems to a minimum. The sea water system for the carbon capture plant has been evaluated and is described in the EIA for CO_2 capture at Kårstø.

The impact of expected ammonia content in cooling water discharge has been evaluated by NIVA in the CO_2 Kårstø EIA study ref [14]. The conclusion is that good water quality will be maintained in the fjord after mixing of ammonia in the sea water discharge stream.

The noise levels at Kårstø are very close to current requirements and any new installations are challenging to keep within the existing requirements. All design changes, including new equipment, shall not increase the noise impact to third party. Electrification of the export compressors may be a benefit, but the consequence requires further assessment.

Emissions to air are covered in section 10.

8 REGULARITY ASSESSMENT

8.1 Introduction

The regularity assessment [6] has the following objectives:

- Identify challenges and evaluate regularity consequences of integration on high pressure steam production, necessary for rich gas and Sleipner condensate processing.
- Identify systems that will be affected by the integration and give more dependencies.

Several systems will be part of the integration. In the regularity assessment the following systems are considered:

- High pressure steam system
- CRAIER CO_2-rich fuel gas
- Power
- Control system
- Sales gas export compressors

Basis for this study is to maintain or improve the regularity at Kårstø processing plant compared to current operation.

8.2 Conclusion

The conclusion from the regularity assessment is that the different scenarios will maintain or improve the Kårstø processing plant regularity, provided new steam model predictive control system (MPC) and CRAIER CO_2-rich fuel gas monitoring and control system are successfully installed. The proposed scenarios of integration of Naturkraft gas power plant with Kårstø processing plant will have varying impact on the regularity of the steam production available for the Kårstø processing plant, ranging from marginally improvement to significant improvement with increased steam production redundancy.

9 TECHNOLOGY ASSESSMENT

9.1 Dual fuel – new burner development

The dual fuel burner design for the KEP and the Sleipner boilers has been designed for both ordinary fuel gas and CO_2-rich gas to be combusted simultaneously. These burners do not function according to design. A development project is established and has developed a new burner design that will allow for such simultaneous combustion. A technology qualification program with acceptance criteria and supporting test program is under development.

The new boilers in scenario 3 to 5 are assumed to handle both CO_2-rich CRAIER gas and ordinary fuel gas, by mixing the fuels in a mixing drum with a new measuring and control system, and will not be dependent on the new burner development design. If successfully implementation of the new burner design on the KEP boiler (end of 2010), this burner concept can also be used for the new boilers in scenario 3 to 5.

9.2 Post-combustion

There are several amine based capture plants in operation and there are a few suppliers available. Existing facilities are, however, limited to around 300,000 tonnes CO_2 per year, and larger scale capture plants are not yet demonstrated.

The main challenges with regards to capture of CO_2 with post-combustion based technology today are related to investment- and operating costs, energy supply and environmental aspects. Estimated capture costs are subject to significant uncertainty, since industrial experience and cost reference basis from a full scale plant in operation is yet not available. There is still a challenge to minimize the reduction in gas power plant efficiency when post combustion capture is introduced. Also, there are environmental issues that still need to be resolved regarding release of amine solvent to atmosphere, and the formation of degradation products and their HSE impact. These issues are under investigation and there are several parallel studies ongoing in Norway addressing this topic including mitigating measures.

9.3 Oxyfuel

Oxyfuel boiler technology has not been demonstrated in the required scale for Kårstø and significant scale-up (5 to 6 times) is required from existing demo plants. There are areas of uncertainty with regards to Oxyfuel operation (e.g. burner performance, boiler control system, transient operation and scale-up) that remains to be qualified. A technology qualifications program is recommended with a timescale of two 2 years.

Use of CRAIER CO_2-rich fuel gas will be feasible in an Oxyfuel fired boiler since the boiler will be designed for operating in a CO_2 rich environment. Using CRAIER gas may also reduce the need for flue gas recycle, but the CO_2 processing unit must be scaled up to handle the increased amount of CO_2. About 7% more CO_2 must be compressed and treated in the control process unit. Since the control process unit is designed for the maximum steam production case (400 t/h) the control process unit, however, will have the capacity to handle the increased amount of CO_2 during normal operation (75% of design).

Since a large scale air separation unit (2,400 t/d) is needed as well as storage of 800 tonnes of oxygen a risk assessment is needed related to acceptable localisation of the air separation unit as well as the Oxyfuel boilers. The boiler supply pipeline may contain about 300 kg pure gaseous oxygen and should not represent a major risk.

9.4 Biomass

Technology used for large scale steam production based on solid biomass is mature.

Although biomass boiler technology in the required scale for Kårstø and even larger, a simple technology qualification program may be needed in order to meet the requirements at Kårstø. There are some areas of uncertainty with regards to biomass operation (e.g. 100% effect when firing on gas as backup, transient operation, speed of ramp up/down, gas as co-fuels for ramp up/down) that remains to be qualified.

9.5 Pre-combustion

Hydrogen production technology is well proven and commercial at the size required for Kårstø, but hydrogen fired boiler technology has not been demonstrated in the required scale for Kårstø. Commercial boiler applications in scales of 35-60 tonnes/hr of steam are however currently in operation, also with dual fuel natural gas applicability. A technology qualification program of up to approximately 2 years will be required for the scales considered here.

It was decided to evaluate the potential for either air or oxygen blown auto thermal reforming (ATR) technology, since nitrogen would be available (either from the ASU or nitrogen supplied with the air) for dilution of the hydrogen fuel for NO_x control. A SMR will produce pure hydrogen only and no nitrogen will be available for dilution.

During this work it was found that NO_x reduction equipment in any case must be installed to reduce NO_x down to acceptable levels. Thus the need for dilution most likely will not be needed since the cost of added ammonia is less than the cost of compressed nitrogen. This is relevant for oxygen blown ATR only since in an air blown ATR process the fuel will be diluted with nitrogen in any case.

Application of SMR technology can also be an alternative, but high degree of CO_2 capture will be more challenging since about 40% of generated CO_2 will be emitted from the SMR flue gas at low pressure. In that case, integration with Gassnova's CO_2 capture plant should be evaluated.

Introducing hydrogen as fuel represents a new risk factor at Kårstø. However, hydrogen is normally produced and used at refineries for upgrading. Procedures for handling H_2 inside hydrocarbon plants are established.

Principally CRAIER gas can be used as feed gas to the H_2 plant if the feed gas preparation, reformer, shift and CO_2 removal sections are designed for handling the increased amount of CO_2 as well as the CO_2 compression and drying process. The amount of CO_2 will increase with approximately 7 %. If the H_2 plant is designed for the 400 t/h steam case it will normally be operated at turndown to 75% (assuming no other customers). In this case the process will have the capacity to handle CRAIER gas (about 10 t/h).

10 EMISSIONS AND ENERGY BALANCE

Currently the Naturkraft gas power plant and the Kårstø processing plant are two independent plants located in the same area and operated by separate organisations. The total amount of CO_2 and NO_x emitted from the Kårstø area can be reduced through an integration where the Naturkraft gas power plant is redesigned to a heat and gas power plant with the Kårstø processing plant as a heat consumer.

A simple model of the Kårstø processing plant gas turbines and boilers has been developed. This model has been used to estimate the amount CO_2 and NO_x produced in boilers and turbines in the various cases, together with the fuel gas consumption.

A sketch of the model used is shown in Figure 10-1

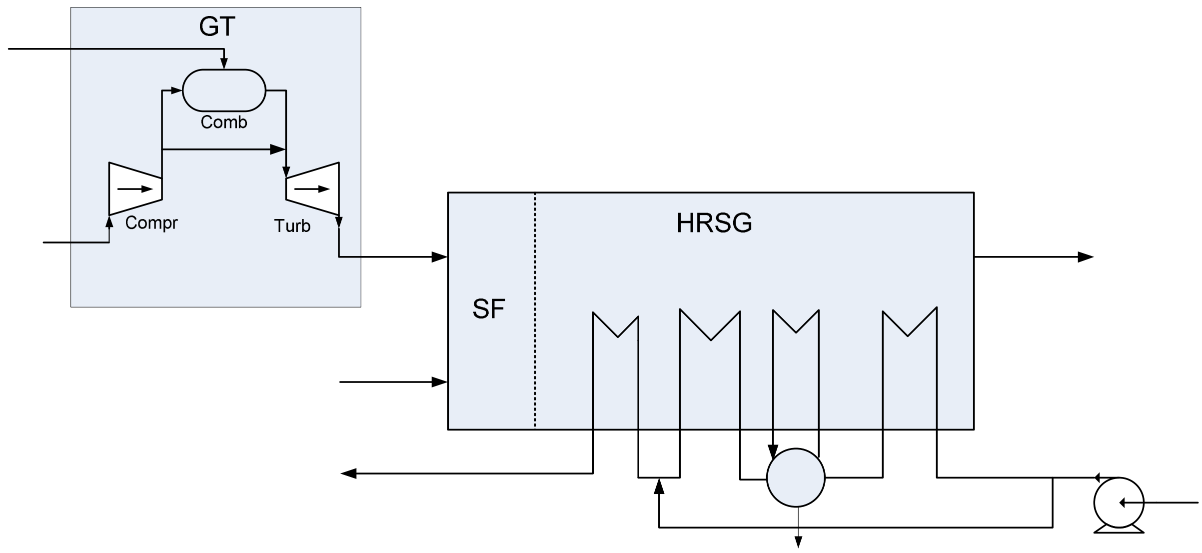

Figure 10-1 Gas turbine and heat recovery unit model

10.1 Emissions

The CO_2 and NO_x emissions per scenario are shown below. Biomass is sun energy captured by photosynthesis and hence emissions are regarded as CO_2 neutral.

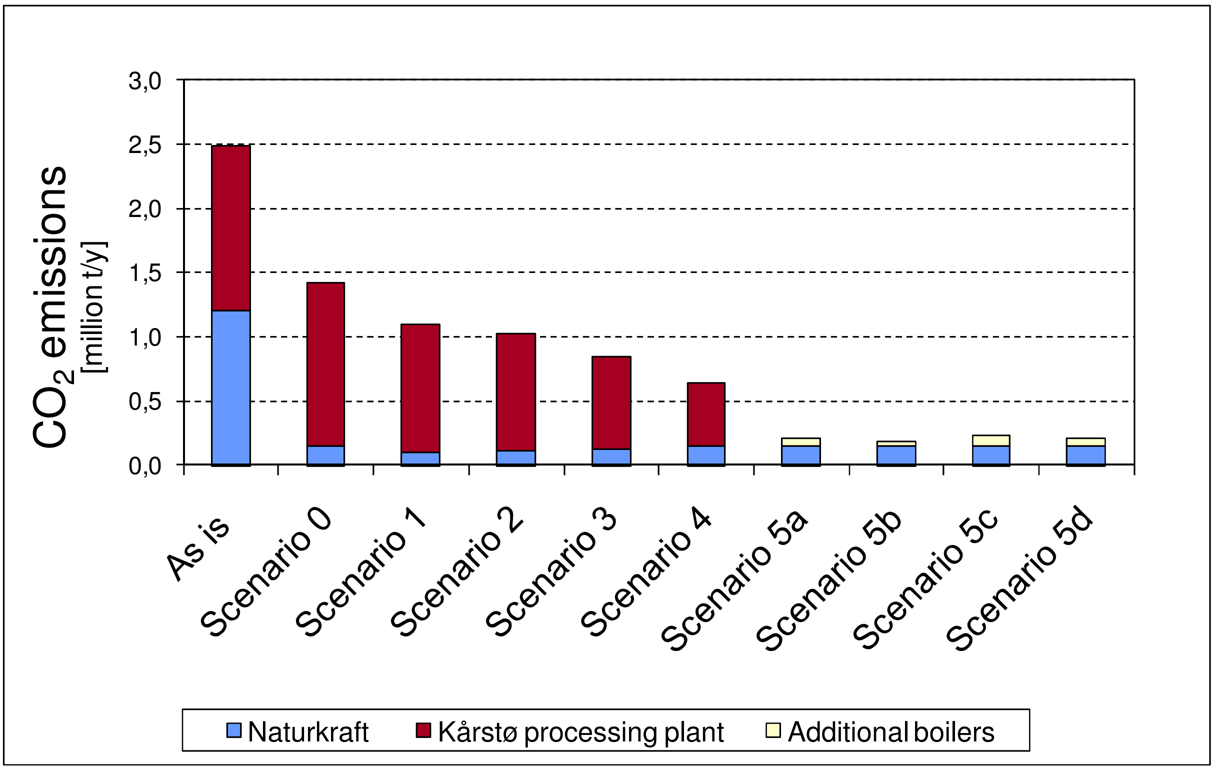

Figure 10-2 Estimated CO_2 emissions per scenario

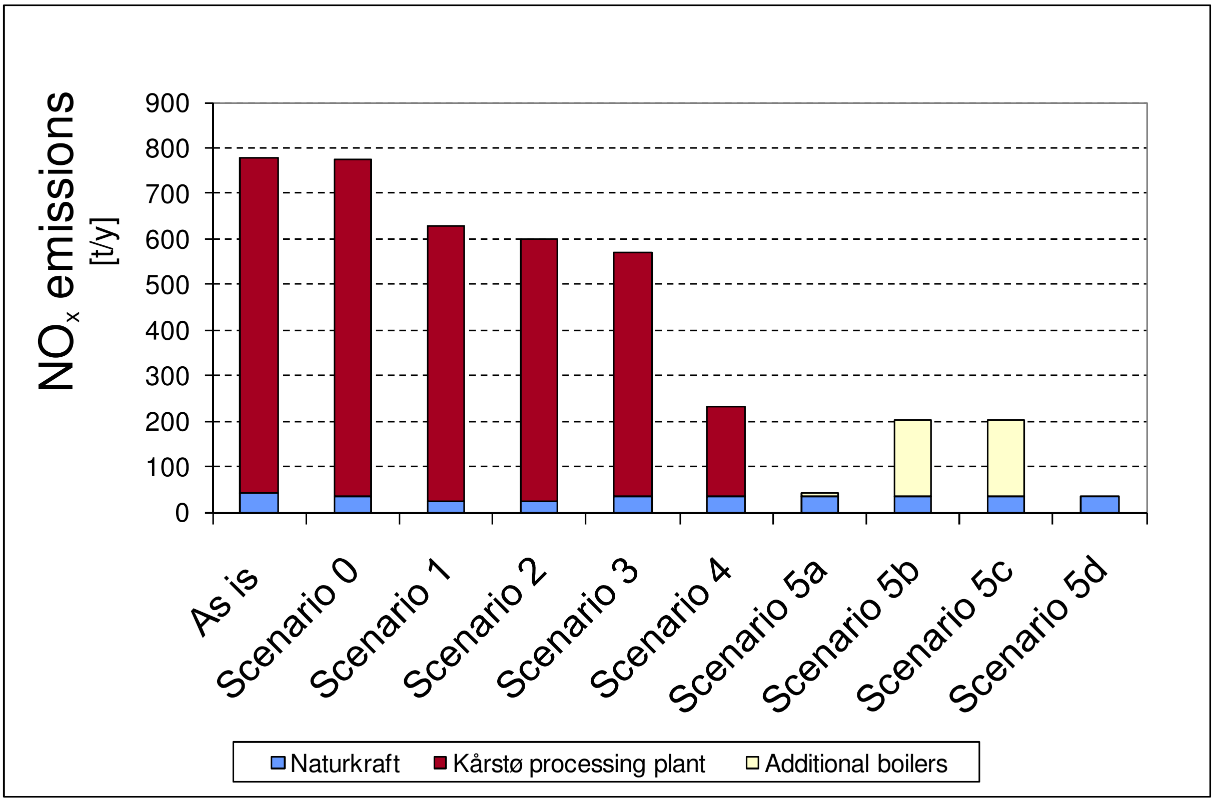

Figure 10-3 Estimated NO_x emissions per scenario

The carbon capture and compression plant emits amine in low concentrations together with the treated exhaust gas. Due to the relative high quantities of exhaust gas the amine amounts released will be considerable as shown in Figure 10-4. The calculations of amine emissions for each scenario are based on the following assumptions:

- The amine used is Monoethanolamine (MEA)
- The emitted quantity is 1 ppm(v) of total amine (gas and liquid form)
- No difference in behavior of gaseous amine and amine contained in droplets/aerosols

The estimated emissions are based information published by amine technology vendors. Further studies will be needed to evaluate the emission and formation of degradation products based on the actual amine used in the carbon capture plant.

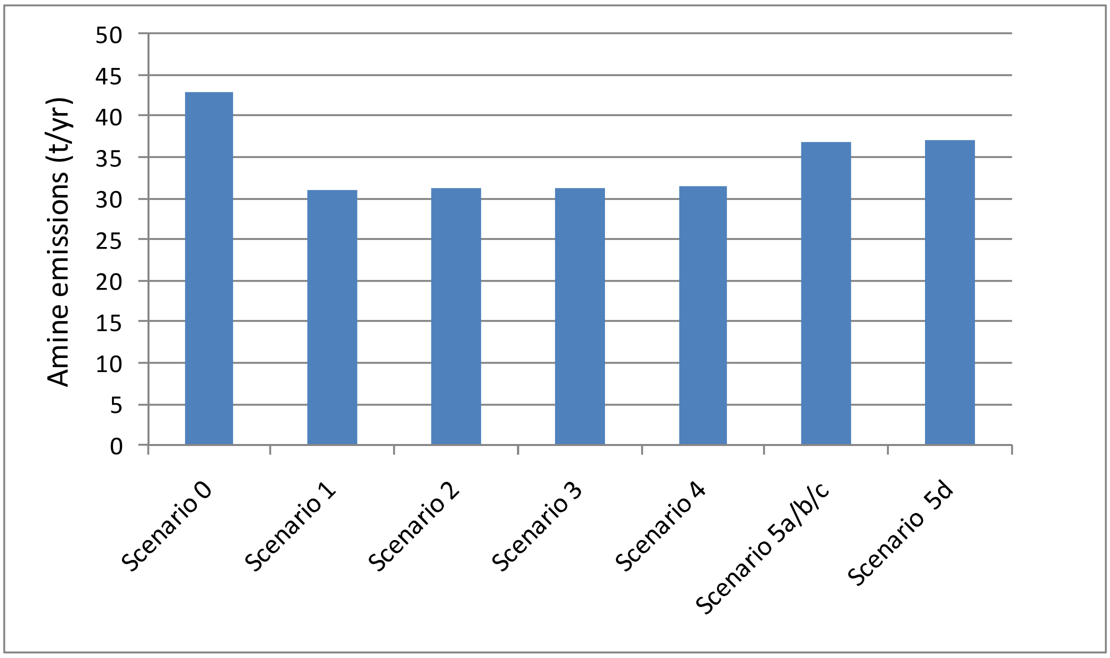

Figure 10-4: Estimated amine emissions from the carbon capture plant

10.2 Energy balance

10.2.1 Fuel gas

Fuel gas at Kårstø consist of 3 sources, sales gas, CRAIER gas and Sleipner gas. The CRAIER gas is a CO_2 rich fuel gas and the integration scenarios 2 to 5 has the opportunity to use this as fuel gas at boilers with CO_2 capture. The Sleipner gas is natural gas from the Sleipner process with high content of heavy components and is not in compliance with the gas export specifications.

In scenario 5 Sleipner gas is mixed into the high pressure boilers located in the vicinity of the carbon capture and compression plant.

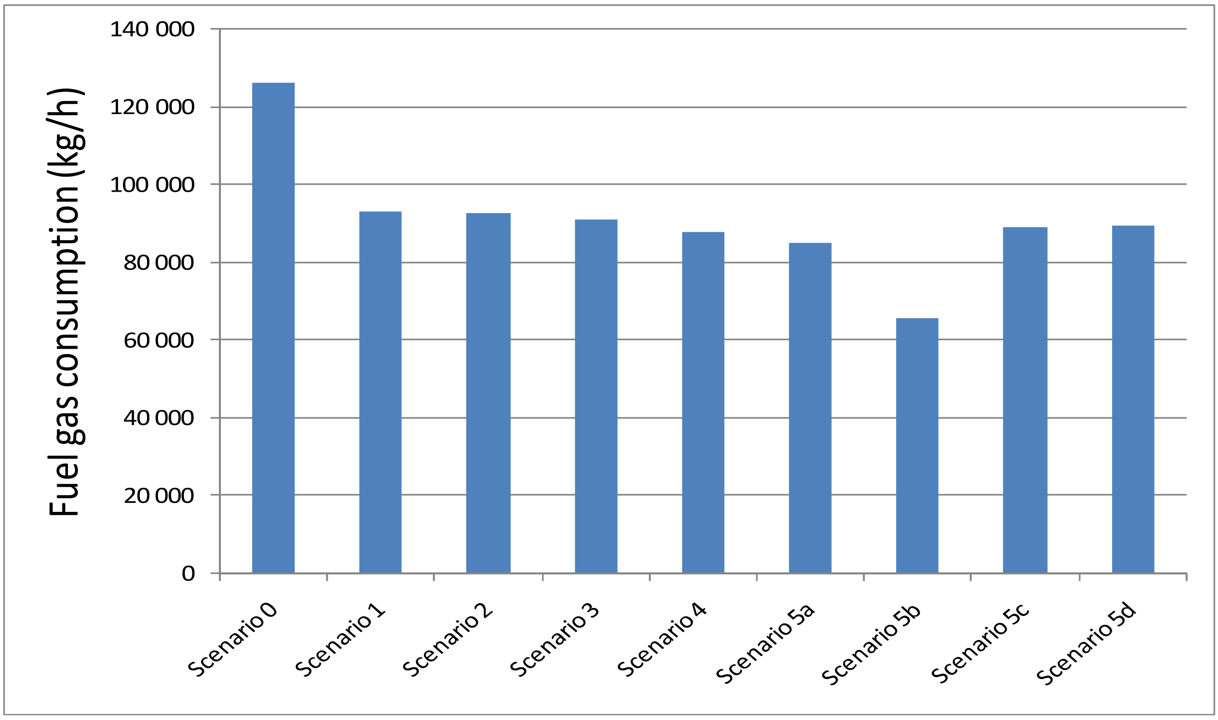

Figure 10-5 fuel gas consumption for the various scenarios

10.2.2 Power balance

A power balance for the various scenarios is shown in Table 10-2.

Table 10-2 Overview of power balance in the various scenarios, all values in MW

Scenario	As is	0	1	2	3	4	5a	5b	5c	5d
Naturkraft el production	420	397	174	174	174	174	224	224	224	224
Kårstø processing plant consumption	-65	-65	-105	-105	-105	-141	-197	-197	-197	-197
Carbon capture and compression plant	0	-37	-29	-30	-36	-38	-40	-40	-40	-48
Additional steam facilities	0	0	0	0	0	0	-28	-6	-20	0
Net el. power to grid	355	295	40	39	33	-5	-41	-19	-33	-21

Reduced load at the Naturkraft gas power plant and steam supply to the Kårstø processing plant in scenario 1 to 5 results in a reduced power production compared to scenario 0. The power consumption in the carbon capture and compression plant is proportional to the CO_2 captured and compressed.

The basis for the power balance calculations is included in Appendix B (Appendix D for CCC).

10.2.3 Energy balance

The overall energy balance taking into account all energy input and output for the various facilities at Kårstø shows a positive effect on the net energy efficiency as a result of steam integration between the gas power plant and the processing plant at Kårstø, primarily caused by reduced condenser losses at the gas power plant (sea water cooling).

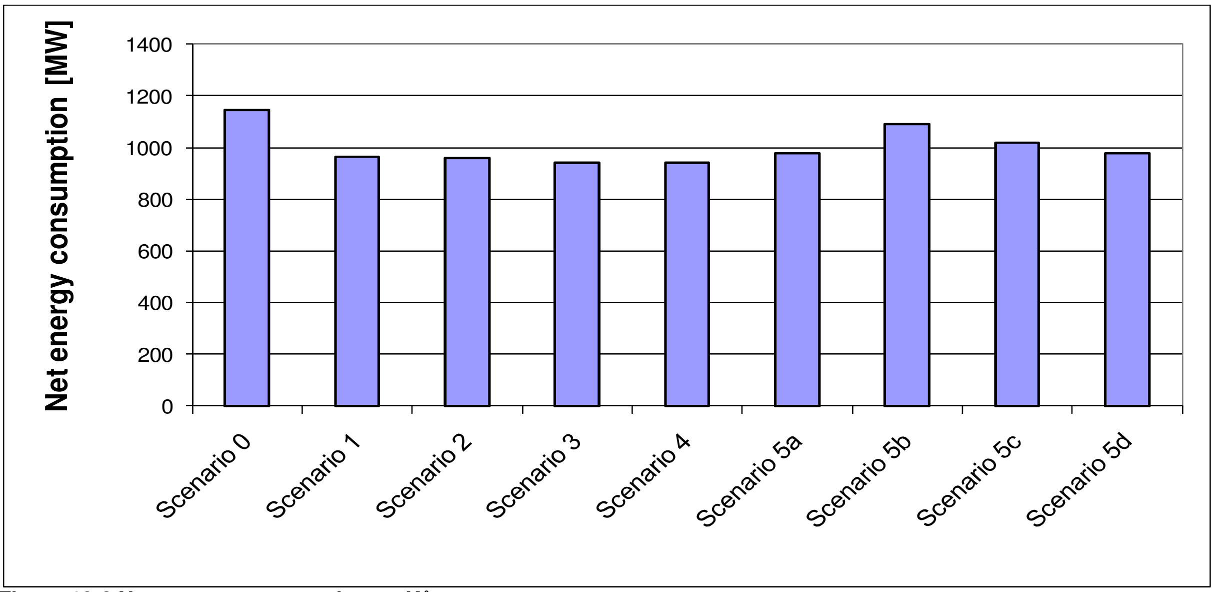

Figure 10-6 Net energy consumption at Kårstø

The reason for the slightly higher energy consumption in scenario 5 is the increased need of energy for the increased CO_2 processing. Scenario 5b energy consumption is higher caused by lower energy efficiency in the biomass process.

11 COSTS AND EVALUATIONS

11.1 Kårstø processing plant cost per scenario

Each building block consists of one or more cost element. Some of the cost elements change with increasing capacities for the various building blocks. Air blown concept is used in scenario 5c. Decommissioning and removal cost as applicable has been included in the calculations and no residual value is assumed.

11.1.1 Kårstø processing plant CAPEX

The estimates are unclassified cost estimate with 2009 cost level and no projected escalation, based on Norwegian cost level.

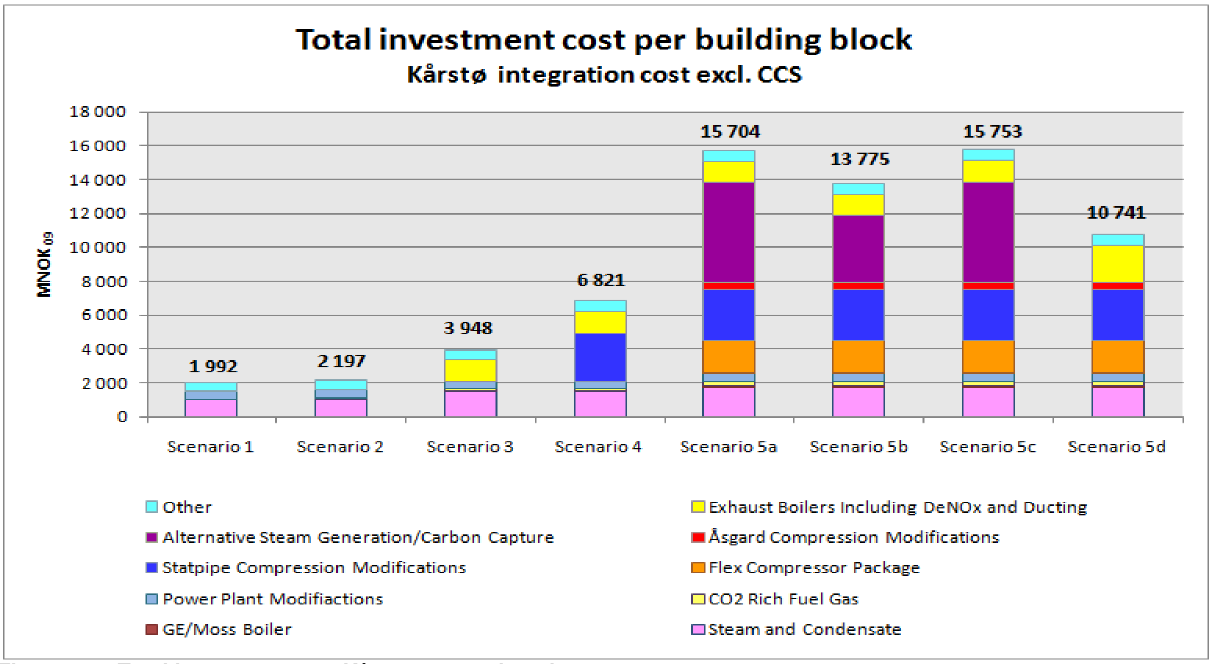

Figure 11-1 Total investment cost Kårstø processing plant

11.1.2 Kårstø processing plant OPEX

All scenarios except scenario 5a, b and c assume no additional operating cost compared to existing operating cost except for power cost (manning and service are assumed constant). Scenario 5a, b and c are based on establishing the new steam boilers and associated facilities at a new location and include operating cost for additional personnel and chemicals.

Table 11-1: Operating cost scenario 5a, 5b and 5c

SCENARIO	Yearly operating cost (MNOK)
Scenario 5a	17
Scenario 5b	23
Scenario 5c	24

Scenario 5b replaces use of fuel gas and power with biomass. The price of the biomass is assumed to be 500 NOK_{09}/tonne with anticipated consumption of 93 tonnes/hour (370 MNOK/year).

11.2 Carbon capture and storage costs per scenario

11.2.1 Gassnova cost basis and assumptions

The estimates given in this pre-feasibility study are so called “unclassified estimates”, meaning the estimates are generated so early in a project phase on a so low definition of the project that they yet do not confirm to the requirements given in internationally accepted cost estimation standards, e.g. the “Association for the Advancement of Cost Estimates” (AACE) and their 5 classes of estimates.

A predominant part of the content of this report builds on or is excerpts from several referred to documents, including [5], [7], [8], [9], [10], [11] and [12].

All assumptions regarding cost estimation given in the above referred to documents applies also for this study (ref. also to assumptions in the design basis section of this report), including:

- Lifetime of 25 years
- Rates, productivity and services are based on previously experienced data from earlier execution projects at Kårstø
- Effective availability to the construction site at Kårstø
- Price of electric power 450 NOK/MWh
- Price of steam NOK 95.85 per t/h (or saturated steam price of NOK 85.04)
- The Gassnova CO_2 Kårstø, as well as Transport and Storage, DG2 Report +/- 30% cost estimates from 2008 (ref. [5] and [7]) are assumed to have the same price in 2009 (i.e. no increase or decrease from 2008 to 2009)

The scenario 0 presumes installation of the CCC as designed in the February 2009 CO_2 Kårstø DG2 Report, Ref.:[7].

11.2.2 CCS CAPEX

In order to illustrate the total scope of work included in the CCS CAPEX, the detailed CCS cost breakdown structure that shows the various cost elements of the CCS cost estimate is shown in Table 11.2 below.

Table 11.2 Summary cost breakdown structure (numbering and cost items) for the CCS

CBS #	Cost Item
0	**Complete CCS Project Cost**
1	**Total CCC Cost of the Owner**
1.1	Tie-Ins
1.2	Site & Cooling Water
1.3	Company provided services during construction

1.4	Owner's and Owner's Engineer Cost
1.5	Contingency
2	**Price/Cost of the CCC EPCI Contract**
2.2	General i.e. indirect costs
2.3	Stack connection / modification and all ducting within the Naturkraft property
2.4	Flue gas conditioning from Naturkraft fence to absorber inlet flange
2.5	CO_2 absorption from flange in flue gas conditioning & utility systems to flange towards Solvent Regeneration system
2.6	Solvent Regeneration
2.7	CO_2 compressor and conditioning from flange solvent regeneration system & utility system to flange of the CO_2 pipeline to transport project
2.8	General utility system
2.9	Automation
2.10	Civil structural work
2.11	Main power supply, all distribution system and auxiliary system
3	**Transport and storage**
3.0	Booster pump (cost included in item 2.7 for this study)
3.1	Transport pipeline 12" (Kårstø – Utsira sør)
3.2	Seabed equipment
3.3	Control Cable (umbilical)
3.4	Marine Operations
3.5	Platform modifications and tie-ins to Draupner
3.6	Drilling & well

The overall CCS CAPEX cost estimates from the Gassnova CO2 Kårstø DG2 Report (ref. [7]) and the Gassnova transport and storage CAPEX estimates (ref. [5]) becomes the Scenario 0 estimates and totals to 10.4 billion NOK.

The CCS will have 3 different designs to cover the different operations scenarios. Design scenario 0 will cover scenarios (0/1/2), design 3 will cover scenarios (3/4/5a/b/c) and finally the 5d design will cover the scenario 5d. Hence only scenario 0, 3 and 5d comes relevant for the CCS CAPEX estimate. It is important to note that the estimated cost of the carbon capture plant does not take into consideration the additional cost to revamp the plant using the staged development approach. The CAPEX estimates are based on a "greenfield" development and that the carbon capture and compression plant is built to one of the three desired maximum capacities in one step (design scenario 0, 3 or 5d). This estimate has not considered the revamp and constructability by starting with the CCC as in scenario 0, and to rebuild it to fit scenario 3 or further scenario 5d.

The total CAPEX estimates for these scenarios are given below.

Table 11.3 Total CCS CAPEX estimates (MNOK 2009 excl. VAT, +/-50%)

Scenario	Total CAPEX	Cost increase	Increase in %
Scenario 0	10 444	-	-
Scenario 3	11 626	1 182	11
Scenario 5d	12 007	1 563	15

The CAPEX estimate for scenario 3 and 5d was generated by developing CCC process simulation on a process flow diagram level (in HYSYS) and looking at the anticipated changes (percentage increase) towards scenario 0 of detailed process, construction and cost elements. The transport and storage CAPEX estimates are the same for all scenarios.

11.2.3 CCS OPEX

The overall CCC OPEX cost estimate from the CO_2 Kårstø DG2 report [7] and the transport and storage OPEX estimate [5] becomes the CCS OPEX estimate for this study's scenario 0 and totals to 480 million NOK per year.

The total OPEX estimates for the scenarios are given below.

Table 11.4 Total CCS annual OPEX estimates per scenario @ operational conditions (MNOK 2009 excl. VAT, +/-50%)

Scenario	Total OPEX	Cost increase	% Increase
Scenario 0	480	-	-
Scenario 1	413	-67	-14
Scenario 2	427	-53	-11
Scenario 3	452	-28	- 6
Scenario 4	472	- 8	- 2
Scenario 5abc	489	9	2
Scenario 5d	554	74	15

The CCC OPEX estimate for scenario 1 to 5d was generated by performing heat balance calculations and developing CCC process simulation on a process flow diagram level (in HYSYS) and thus looking at the anticipated changes towards scenario 0 of detailed consumables and cost elements. The transport and storage OPEX estimates are the same for all scenarios.

11.3 Summary and evaluations

11.3.1 Assumptions

All evaluations are based on the assumptions described above. The NO_x taxation system is assumed maintained with a price of 16 NOK_{09}/kg. The reduced NO_x in the different scenarios compared with the existing emission are included as reduced cost (upside potential). The effects of the NO_x tax are marginal.

The energy consumption for carbon capture and compression plant is adjusted to enable comparison of cost figures in the different scenarios. The evaluations is based on a common gas price for fuel of 1.70 NOK_{09}/Sm^3 and a power price of 0.33 NOK_{09}/kWh. The values of fuel and power are based on the need as described in section 10.2.

The integration scenarios require regular steam supply from the gas power plant to the processing plant and hence continuous operation of the gas power plant is assumed. Operating the power plant at base load will result in losing the opportunity stop generating power when the value of the power is below the value of the gas. Such lost opportunity is not quantified in this report.

11.3.2 CAPEX

Total investment costs and the resulting CO_2 emissions for the carbon capture and storage system and Kårstø processing plant are presented in the figure below. All figures are in million NOK 2009 values and exclusive of VAT.

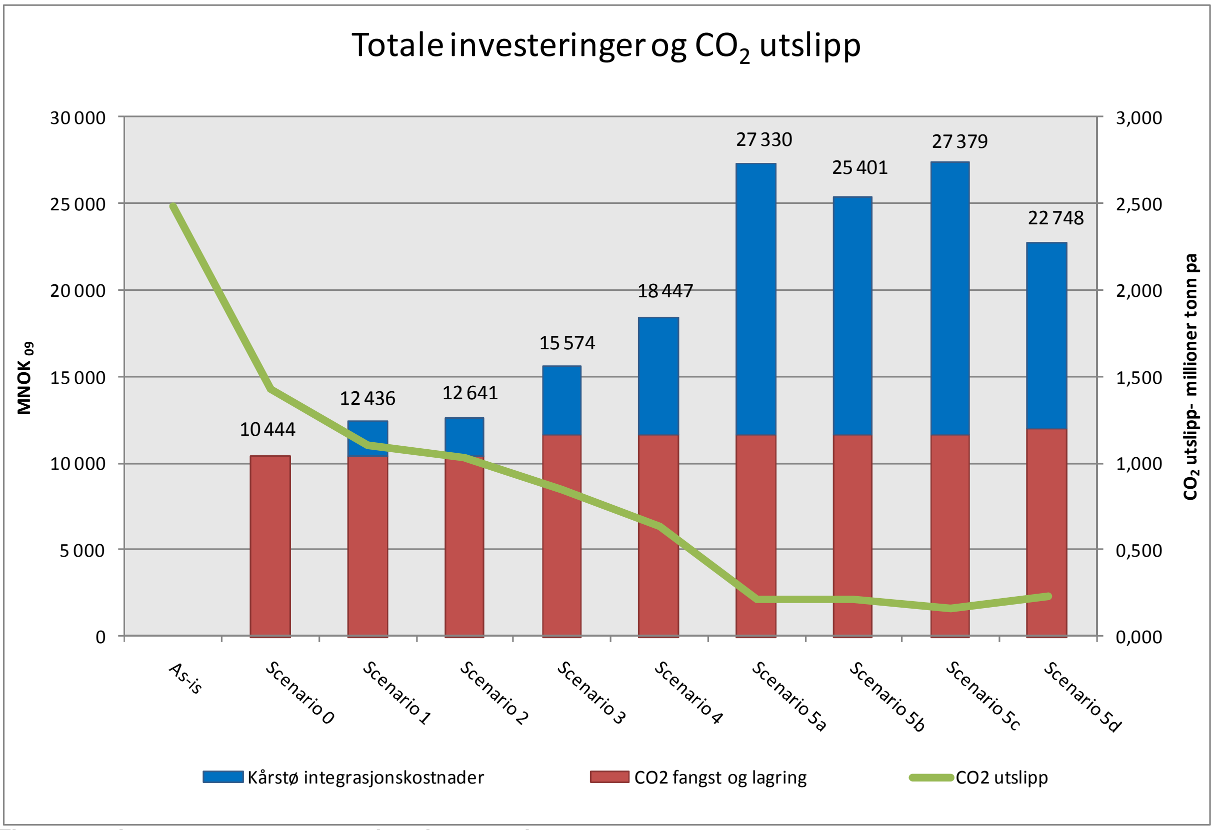

Figure 11-2 Investment costs comparison by scenarios

11.3.3 Unit cost

Unit costs of CO_2 reductions are dependent on modus of operation of the gas power plant and future utilisation of the Kårstø processing plant. The unit cost is calculated as discounted investments and operational costs related to the CO_2 capture, transport and storage divided by the reductions in CO_2 emissions (discounted figures) over assumed economical lifetime. CO_2 reductions consists of both captured and avoided CO_2. The discount rate used is 7% real rate. The investment costs are assumed phased equally over a three year period before start of operation. Fuel, power and NO_x costs are included in the OPEX. CO_2 quotas and tax are excluded from the calculations to enable comparison of unit cost of CO_2 reducing initiatives with CO_2 quota cost. All scenarios are compared to the current situation ("as is") identifying all relevant cost reductions and increases (CAPEX and OPEX).

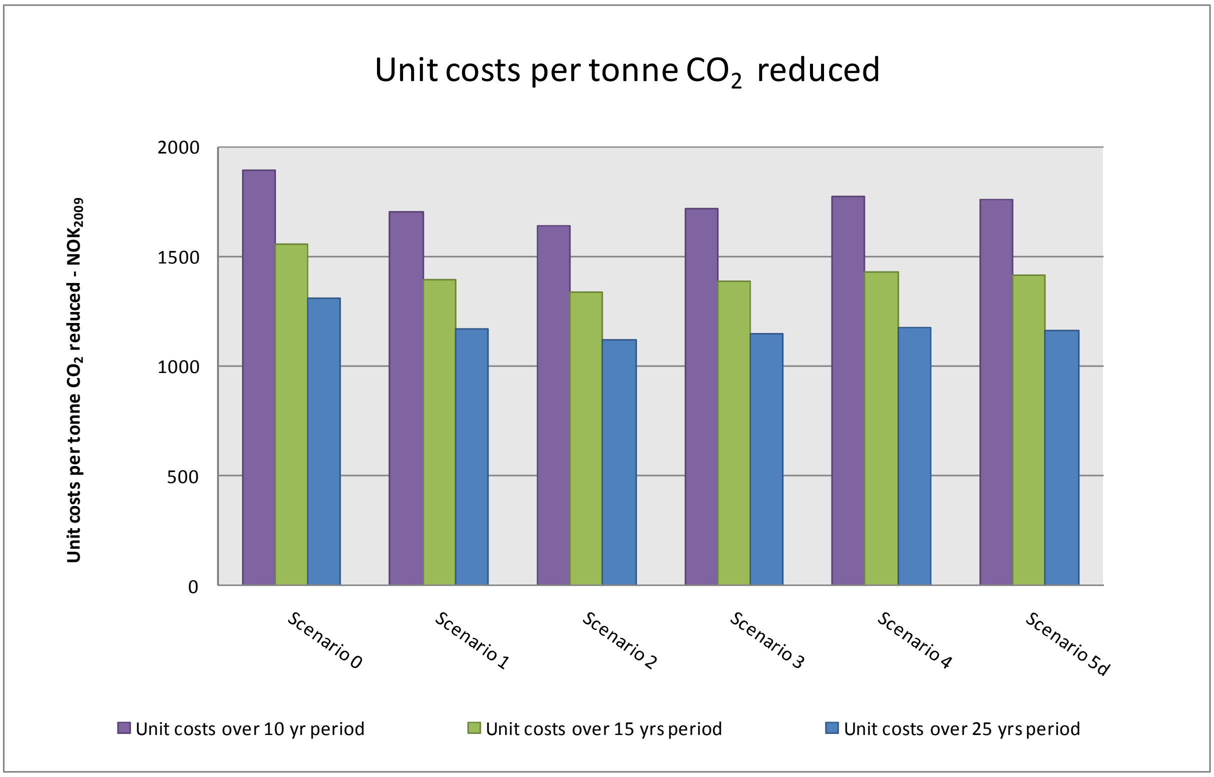

Figure 11-3 Total unit cost per tonne CO_2 reduction over 10, 15 and 25 years, exclusive of CO_2 quotas.

Figure 11-3 illustrates the range of unit costs based on full utilisation of the gas power plant and the processing plant at Kårstø assuming economical lifetime of 10, 15 and 25 years. Unit cost per tonne of reduced CO_2 emissions for the Naturkraft gas power plant (scenario 0) is estimated to 1,600 NOK based on full utilisation of the gas power plant over 15 years period from start of operation. Such unit cost corresponds to CO_2 quota cost around 200 € per tonne. The unit cost in scenario 0 would be doubled if the assumed utilisation of the gas power plant is reduced from eight to four thousand hours per year.

The unit costs for all integration scenarios are below the unit costs for scenario 0, except for scenario 5a (Oxyfuel) and 5c (hydrogen fuelled). The reductions of the unit costs compared to scenario 0 are caused by the lower unit costs for the additional CO_2 reductions at the Kårstø processing plant. Such marginal costs varies between 700 and 1,200 NOK per tonne.

Any investment to avoid CO_2 emissions at Kårstø by integration with the Naturkraft gas power plant includes risks related to investing for an unknown future demand. The design basis for this pre-feasibility study is based on high utilisation of the Kårstø processing plant and assumes the current operational services and steam demand. The future utilisation is uncertain beyond 2020. Scenario 3 is more flexible with regard to future development of the Kårstø processing plant. The risk for overinvestment's increases with the investment level. Scenario 1 and 2 do indicate lower unit costs, but such unit costs do not include potential cost of capacity at the carbon capture plant to handle additional CO_2 above the emissions from the gas power plant.

12 COMMERCIAL ISSUES

12.1 Introduction

The mapping of commercial issues revealed challenges in finding any commercial business drivers for realising any of the integration scenarios, taking into account all relevant costs, potential income from power production and expected CO_2 quotas and other savings.

The commercial arrangements in place or needed between the relevant facility owners to operate the integrated scenarios have been mapped. The envisaged change to continuous operation of the Naturkraft gas power plant implies a fundamental change in Naturkraft's business model of spark spread optimisation. Naturkraft's operation will shift to continuous steam supply to the Kårstø processing plant and the associated electricity is produced independent of the relative prices between gas and electricity. However, a potential to maintain independent operation of the Naturkraft gas power plant and the Kårstø processing plant have been identified through the maturing of the various integration scenarios. This prepare for a solution where Naturkraft's gas power plant is based on a continuation of the current business model of spark spread optimisation. The commercial complexity may therefore be reduced if any of these scenarios are selected for further maturing.

Reference is made to section 3.1 to 3.3 for a description of the current operation modus for the Kårstø processing plant, Naturkraft gas power plant and the planned operation of the carbon capture plant. The changes in the operation of the respective plants under the integration scenario(s) is briefly described in section 6. Below follows a mapping of the current commercial agreements for Naturkraft, Gassled and Gassnova and a mapping of required changes to prepare for integration of the respective plants as described in this study.

12.2 Mapping of current commercial arrangements

Below follows a brief mapping of current commercial framework for the Kårstø processing plant, Naturkraft gas power plant and the planned carbon capture plant at Kårstø.

12.2.1 Kårstø processing plant

Statoil is as part of the Technical Service Agreement buying electricity for the Kårstø processing plant on the Nordpool spot market. Fuel gas for production of steam is included in the allocation system in Gassled area C Kårstø. The system is based on a tolling scheme where parts of shippers gas is allocated to fuel gas based on a pro rata adjustments, in return for steam used for the extraction and fractionation services in area C Kårstø.

12.2.2 Naturkraft gas power plant

Naturkraft AS was on 30.10.1996 granted a licence from NVE to construct and operate a natural gas fired power plant at Kårstø. This licence has been amended over time and current operations are based on SFT approval of 10.05.2005. Naturkraft's licence covers production of up to 430 MW electrical power, this requires 1.8 MSm^3/d of gas. The annual production may reach 3.5 TWh/year at a gas consumption of 650 million Sm^3/year.

Naturkraft AS is a limited company owned 50% by Statoil and 50% by Statkraft (Owners). The Owners make their capacity to convert gas to power available to their tollers. The existing Naturkraft tollers are Statoil and Statkraft (Tollers).

When the difference in gas price, also including the CO_2 cost, and the power price is sufficient the Tollers will decide to commercialise on this difference in gas and power prices (spark-spread).

Such Tollers decision to run the power plant will cause the Owners to take the Tollers' gas and redeliver the produced power to the Tollers. The power will be sold on Nordpool. The Tollers' decision to stop the gas power plant will cause the Owners to stop producing power. Decisions to stop or run the gas power plant are made each day by the Tollers.

In addition to the above spark-spread operation the Tollers also deliver grid balancing services to Statnett. Such service implies that the Tollers turn-up or reduce Naturkraft generating output on Statnett request and compensating mechanisms (regulerkraft-markedet).

To ensure current operation of the gas power plant each Toller has arranged for adequate natural gas sourcing.

The Owners receive a fixed tolling fee on the capacity made available to the Tollers. The commercial risk in the Naturkraft arrangement described above is with the Tollers.

12.2.3 Carbon capture and compression plant

Gassnova, on behalf of the carbon capture and compression plant and the transport and storage system projects, was in the process of establishing draft agreements prior to the decision to suspend the investment schedule of the carbon capture and storage system.

The services from Gassled to Gassnova is not decided upon and will depend on the need from Gassnova and the level of available services from Gassled, e.g. fire water and other utilities and services.

The planned carbon capture plant needs utilities and services during construction and in operation.

12.3 Mapping of commercial issues

The various integration scenarios require certain modification of the Kårstø processing plant as further described in section 6 in addition to modifications at the Naturkraft gas power plant and at the carbon capture plant. Cost, responsibilities and liabilities related to the modification work during construction and operation need to be regulated by amendments to existing agreements and/or new agreements. Below follows a description of the commercial framework in the different scenarios.

To prepare the carbon capture plant to handle the increased CO_2 from scenario 3 to 5 some pre-investments are identified. Applicable agreements for regulating such investments and modification work at the carbon capture and compression plant may be necessary for all scenarios.

A potential change from spark spread to base load operation would impose a material impact and costs for the Naturkraft owners, which may lead to change in ownership or potentially regulated by amendments to and/or replacements of the following agreements:

- Terms for steam supply
- Tolling agreement for Naturkraft
- Tollers's gas supply contracts
- Terms for regulating Naturkraft electrical power supply as base load
- Naturkraft's license and permits

Such amendments/new agreements are applicable for all integration scenarios. The need for new agreements and/or amendments to existing agreements identified for the various scenarios is described in the following sections.

<u>Scenario 1</u>

Continuous production of steam from Naturkraft's gas power plant will in normal operation generate 174 MW. The combined cycle gas power plant does not provide much flexibility with regard to variation in electricity output, but some flexibility to increase or decrease the electricity output will still remain. The steam production represents a new service from the Naturkraft gas power plant that, among other, provides for an increased utilisation factor. Any integration at Kårstø implies that steam is produced partly or fully from other sources than the processing plant.

The below agreements will be established or amended as applicable:

- Terms and conditions for steam supply to Kårstø processing plant
- Applicable agreements for regulating investments and modification work at the Kårstø processing plant and Naturkraft gas power plant

Scenario 2

Extended scope to include CO_2-rich CRAIER gas supply to the Naturkraft gas power plant, and establishing or amending agreements as follows:

- Terms and conditions for CO_2 handling (capture, transport and storage) between Gassled, Naturkraft and Gassnova
- Gas supply from Gassled to the gas power plant

Scenario 3

Extended scope for the agreements to include new exhaust boilers.

- Applicable agreements for regulating investments and modification work at the carbon capture and compression plant
- No new agreements anticipated beyond previous scenarios

Scenario 4

Extended scope to include new electrical Statpipe compressors at new location.

- No new agreements anticipated beyond previous scenarios

Scenario 5a

Extended scope to include new Oxyfuel based boilers.

- New licences and permits for establishing oxygen plant
- Supply arrangements for supply of oxygen and nitrogen?

Scenario 5b

Extended scope for the agreements to include new biomass boilers.

- New licences and permits for establishing biomass plant
- Supply arrangements for biomass and high pressure steam
- Arrangements for developing new construction site outside the Kårstø safety zone

Scenario 5c

Extended scope for the agreements to include new hydrogen fuelled boilers.

- New licences and permits for establishing hydrogen plant?

Scenario 5d

Extended scope to include additional exhaust boilers.

- No new agreements anticipated beyond previous scenarios

12.4 Way forward

The pre-feasibility study has been performed on behalf of the Ministry of Petroleum and Energy. The Ministry is assumed to be the decision maker for a possible further maturing of the study to a feasibility level. The focus in this pre-feasibility study has been mapping of the current commercial framework for the relevant facilities at Kårstø. The timing and scope for establishment of required commercial arrangement are dependent on the integration scenarios as well as the commercial model for such integration.

A plan for commercial agreements will have to be further matured during a feasibility study. An illustration of the plan for commercial arrangement is shown in figure 12.1 below.

Identifications of applicable sponsors for a possible further maturing of the project to concept study will have to be performed in the feasibility study. The aim is to identify potential parties interested in a possible further maturing of the project to a concept study, with such parties as gatekeeper for the concept selection decision. Also agreements regulating rights and responsibilities between users and owners may be established as part of the feasibility study. Such clarifications need to be established no later than start up of a pre-engineering study. The gatekeeper for start up of pre-engineering will be the investors and therefore have to be in place no later than start up of pre-engineering.

The business model for the project will have to be established at latest during the pre-engineering study, e.g. regulations of steam supply etc. Steam can be supplied by the Naturkraft gas power plant as service to the Gassled shippers. Alternatively Naturkraft can be integrated as a utility for the Kårstø processing plant. Gas sourcing to Naturkraft may depend on the commercial model for the steam supply.

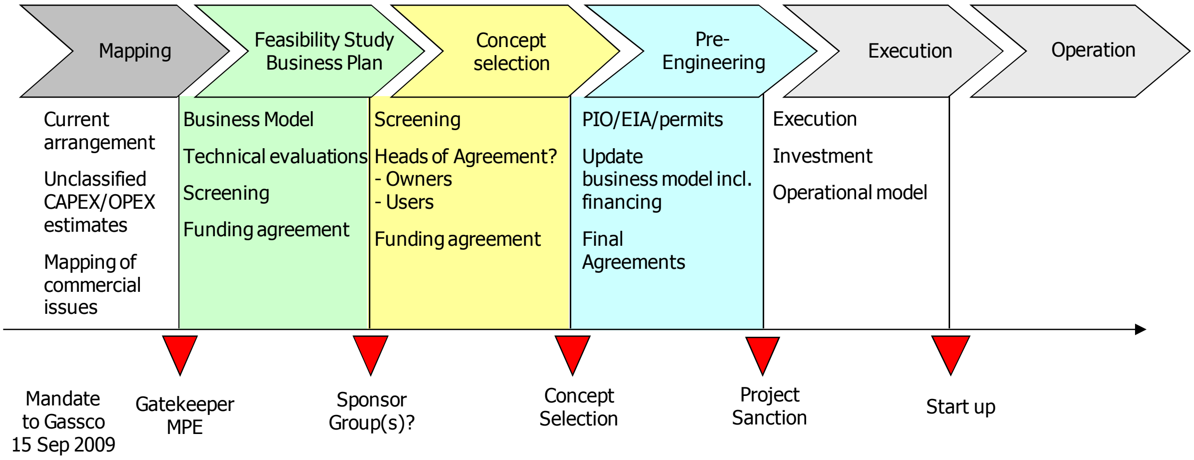

Figure 12.1 Commercial plan

13 MASTER SCHEDULE

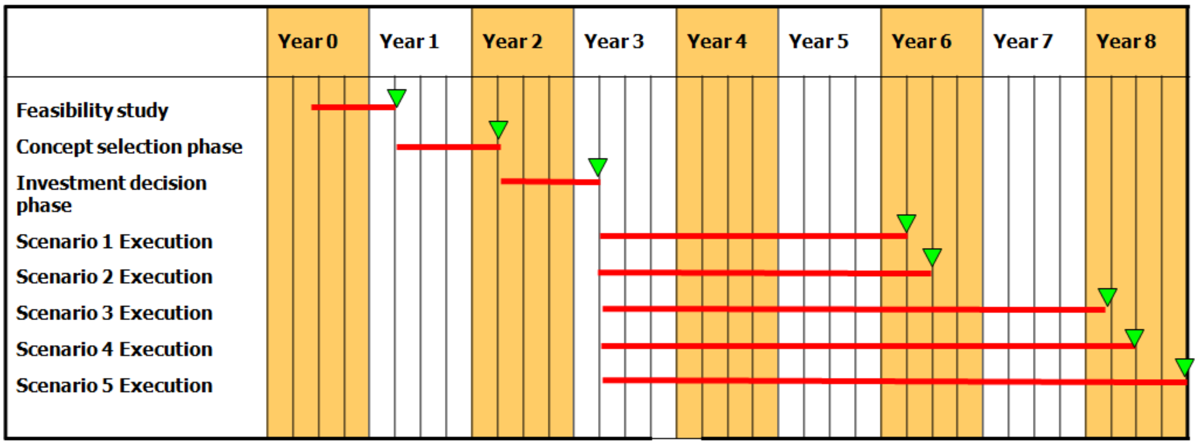

Figure 13-1 Project schedule

A detailed master schedule is attached in Appendix A. The various scenarios follow a maturing process of 30 months from project start up to and including the concept selection, thereafter each scenario will have its own development path as indicated below.

The overall schedule for the integration scenarios is based on the assumption that there will be a common feasibility and concept phase for all scenarios, after which each scenario follows individual paths from FEED to project completion.

13.1 Schedule, cost and organisation for a feasibility phase

The potential next phase for the integration scenarios described herein will be to mature selected scenarios to a feasibility level, e.g. demonstrating technical feasibility of the selected scenario(s) and maturing cost estimations to an uncertainty level of +/- 40%.

The schedule is based on a decision to start the feasibility study will be made the first half of 2010.

13.1.1 Schedule

The time for preparing a feasibility report is estimated to take at least 9 months from a decision to proceed. Gassco and Gassnova are both prepared to undertake a feasibility study based on the assumptions described below.

13.2 Cost of a feasibility study

The expected costs of maturing selected scenarios to a feasibility level are indicated below;

Gassnova CCS studies:	30.0 Mill NOK
Naturkraft CCP studies:	4.5 Mill NOK
Gassco Kårstø studies:	10.0 Mill NOK
System design by contractor:	12.0 Mill NOK
Total:	56.5 Mill NOK exclusive of VAT

13.3 Organisation

A potential further maturing will be according to established work processes and procedures required for project development at the Kårstø processing plant.

In a potential feasibility phase it is expected to identify the funding parties to the potential investments and to clarify the commercial arrangements between the investors.

14 INTERFACE MANAGEMENT

There are several complex upgrading projects at the Kårstø processing plant such as:

- KEP 2010 – Upgrade of Instrument, Control and Safety systems
- Emergency Power
- Utility
- Foster Wheeler B Waste Heat boiler
- NGL Metering (completed 2012)
- Coating and Insulation of pipes and vessels (ISO completed 2014)
- Operational investments to improve Plant Integrity (project and study face)

In addition several potential projects are studied with respect to increased flexibility, environmental issues and infrastructure development (capacity/compression increase).

All activities at Kårstø are organised and managed through the Kårstø master plan (KMP) with the aim to prioritise development based on safety, environmental, operational and commercial criteria. The Kårstø master plan will also describe dependencies between sanctioned projects and studies. Of major importance is the safety impact (construction and operational risk and explosion escalation) the development and study portfolio generates.

An interface management procedure shall be developed to establish a standard framework for effective management of all interfaces in the project, and to facilitate the interface management process between the companies and entities involved.

15 REFERENCES

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[2] Letter from the Ministry of Petroleum and Energy to Gassnova, dated 15.09.2009

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[4] DNV Report: "Screening of Naturkraft integration scenarios at Kårstø". Doc. No. 2010-0016/12ILWOJ-4, Rev. 0 (11.01.2010).

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[8] The Gassnova Cost Estimate and Capture Cost DG2 Status Report (Doc. No. 10112936-0368-PRP, rev 01, dated 20.02.2009)

[9] Fichtner input to Pre-feasibility study steam boiler scenarios (Doc. No. 10112936-FI-A-TDO-0005, rev 03, dated 25.01.2010)

[10] Gassco Transport and Storage DG3 report 04.12.2008 Doc. no PG23-BY.RF-08.14869

[11] Gassnova Cost and CO2 Input to Gassco – Kårstø Integration DG1 Report, (Doc. No. 10112936-0426-PRP)

[12] Gassnova Internal Cost Estimate and CO2 Capture Report – Basis for inputs to the Gassco Coordinated Kårstø Integration Pre-feasibility Report (Doc. No. 10112936-0428-PRP, Rev 01).

[13] Gassnova Kårstø Integration Studies Phase 1 Report (Doc.no. 10112936-EI-04380

[14] CO2 fangstanlegg Kårstø – Konsekvensutredning(Doc. Nr: 10112936-TDI-0027-TDIN)

16 LIST OF APPENDICES

Appendix A - Master Schedule

Appendix B - Aker Engineering and Technology Report

Appendix C - Statoil report, new technologies

Appendix D - Electrical tie-in for carbon capture and compression