Nebb Engineering AS
PO Box 112
Solbråveien 41
N-1371 Asker, NORWAY
Org. nr.: 977 337 798
Tel.: +47 66 90 21 10
Fax: +47 66 90 21 11

ZENG – Zero Emission Norwegian Gas

Phase-2: Concept Definition

General Project Specification

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Zero Emission Norwegian Gas (ZENG)

Phase-2: Concept Definition

General Project Specification

Document prepared by

Nebb Engineering AS

Solbråveien 41, PO Box 112,
N-1371 Asker, Norway

on behalf of

ZENG AS

Work sponsored by

Statoil ASA

Shell Technology Norway

Gassnova

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List of Acronyms and Abbreviations

AS	Norwegian registered limited liability share-owned company.
ASU	Air Separation Unit
CCS	Carbon Capture & Storage
CES	Clean Energy Systems Inc.
CO2	Carbon dioxide – a greenhouse gas (also denoted by CO_2).
EOR	Enhanced oil recovery – using CO2 as injectant gas.
FEED	Front-End Engineering & Design
HRCS	Heat Recovery Condenser / Separator
NCS	Norwegian Continental Shelf – offshore petroleum sector.
NG	Natural gas fuel
NOx	Nitrogen-based oxides – subject to strict permitting.
ZENG	Zero Emission Natural / Norwegian Gas

Scope of Document

This document defines overall project specifications for the ZENG Project Phase-2: Concept Definition Study. The Study is being conducted by Nebb Engineering AS on behalf of the project owner ZENG AS in the period from 02.05.05 through to 02.04.06.

The Phase-2 Study will document and conceptually define an oxyfuel process cycle having 100% capture of CO2 and negligible emissions of NOx. The process will be based upon use of the Gas Generator developed and demonstrated by Clean Energy Systems, Inc.

It is proposed that the nominal 70 MWe Zero Emission Natural Gas (ZENG) Demonstration Power Plant will be located at Risavika, near Stavanger, South Norway. The plant will have a targeted efficiency of ~48% based on LHV.

Furthermore the process cycle shall demonstrate a capability of attaining an efficiency of ~55% (including oxygen separation and CO2-handling) when implemented in a large-scale 400 MWe commercial zero-emission gas-fired power plant located in Norway during the 2010-12 timeframe.

The Phase-2 Study shall provide all pre-requisite information defining key technologies and development partners that will need to be in place in order to enable realisation of the Demonstration Power Plant and the longer term development goals of the ZENG Program.

Furthermore, the Study shall provide sufficient assessment of technology status and development risk in order that the project owners and project sponsors can decide whether to move forward to Project Phase-3: Front-End Engineering & Design (FEED) and prepare for an investment decision during 2007.

The Project Phase-2 receives financial support from Shell Technology Norway and Statoil, as well as Gassnova, the Norwegian government funding agency specifically set up to promote demonstration and commercialisation of gas-fired power plants with CO2 capture and handling.

1. PROJECT OWNER

The project owner is ZENG AS, a Norwegian company which was formed in May 2006 by the early project developers in order to formalise further development of the ZENG – CES process cycle within a business entity that would also enable commercialisation of the zero emission power plant concept.

The present owners are Lyse Energi AS (51%), CO2-Norway AS (30%), Procom Venture AS (10%) and Nebb Engineering AS (9%).

The company is organised with Main Office in Stavanger and is led by the Managing Director, Frank Blaker from Procom Venture.

2. PROJECT SPONSORS

The ZENG Project Phase-2: Concept Definition Study is sponsored by Shell Technology Norway AS and Statoil ASA. Both companies have indicated a strong commitment to develop zero emission power generation in Norway, and also enable the early use of CO2 for enhanced oil recovery (EOR) on the Norwegian Continental Shelf (NCS).

The ZENG Program has since 2003 received support from the Norwegian government, and is presently sponsored by the government funding agency Gassnova, which has been specifically mandated to promote and provide financial support for early demonstration of power generation deploying Carbon Capture & Storage (CCS) technology.

3. THE ZERO EMISSION POWER GENERATION CYCLE

The ZENG – CES power cycle is based upon use of the oxyfuel Gas Generator developed by Clean Energy Systems (see www.cleanenergysystems.com). This permits combustion of gaseous hydrocarbon fuels with oxygen, resulting in production of a high-temperature and high-pressure steam (combined with ~10%-wt CO2) gas mixture.

The steam (and CO2) process fluid is expanded in a reconfigured steam turbine, as shown in Fig. 1, following which the CO2 is separated in the steam condensation process. The cycle has net positive production of water, enables 100% capture of CO2 and has zero emissions of NOx.

The CES Gas Generator technology was originally developed from the aerospace and launch-rocket propulsion industry. However, with growing focus on low emissions

and carbon capture, it is also finding multiple applications within terrestrial power generation, where either natural gas (NG) or "clean coal" gasification technology can be combined with carbon capture and storage (CCS).

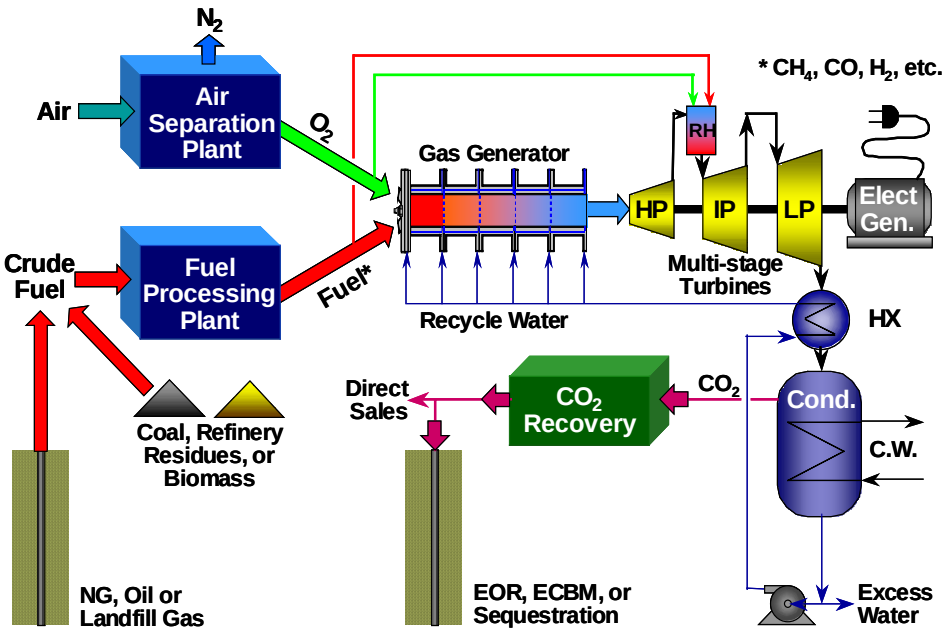

Fig. 1: Overview of the CES Gas Generator configured in an oxyfuel Rankine cycle. For the ZENG – CES configuration Fuel Processing will be based on stoichiometric combustion with Natural Gas.

A 20 MWth CES Gas Generator has been in operation since December 2004 at the Kimberlina Test Plant, near Bakersfield, California. The Gas Generator has completed more than 1,500 hours firing with approximately 300 start and shutdown sequences. A standardised 150 MWth Gas Generator is currently being designed and manufactured for first projects in the Netherlands and the United States.

4. PROJECT HISTORY – SUMMARY

The ZENG Development Program emerged from initial meetings in Feb 2002 when CO2-Norway, supported by Clean Energy Systems (CES), approached Lyse Energi regarding collaboration for a Norwegian-based zero emission power plant concept based on the CES Gas Generator. Subsequently, it was decided to pursue joint studies evaluating siting of a Pilot Plant at the Energy Park, Risavika where Lyse Gass was making landfall with a NG pipeline from Kårstø—the main Norwegian export terminal for the European market.

4.1 PROJECT PHASE-1: OCTOBER 2003 – AUGUST 2004

The ZENG Project Phase-1: Concept & Feasibility Study was conducted by CO2-Norway and Nebb Engineering on behalf of Lyse Energi. The study also received financial support from the Norwegian Ministry for Petroleum & Energy (OED) and the U.S. Department of Energy (US-DOE).

The study presented a preliminary engineering and techno-economic analysis for a 40 MWe oxyfuel power plant cycle. The "Base Case" configuration was completely founded upon commercially available components that should be available for start of construction in 2006!

Although far from optimised, the cycle configuration indicated a thermodynamic efficiency of 40.3% based on LHV, which was acknowledged to be low. But we also identified improved features indicating that an efficiency of between 46 – 48% could be achievable for a 50 – 70 MWe Demonstration Power Plant—given availability of "near-term" turbine development and process cycle optimisation.

Primarily, this focussed on increasing the turbine inlet temperature (TIT) for the intermediary pressure (IP) steam turbine above the commercially available 565º C.

We also identified other potential improvements through;

- integration with the air separation unit (ASU),
- introduction of a low-pressure "pure" Rankine steam cycle,
- optimised re-circulation of the steam / CO2 working fluid medium, and
- improved design of the low-pressure condenser / separator.

A cost-estimate breakdown for the major components, combined with cost factors based on our engineering project experience, indicated a total capital investment cost of $91 million (~600 MNOK) for the Pilot Plant (inclusive of the air separation unit). Again, at that time, this was considered to be expensive, but realistic when taking into account the small size and early status of the technology.

4.2 INTERIM PHASE-1.5: OCTOBER 2004 – DECEMBER 2005

Process design development work was subsequently pursued by Nebb Engineering and CO2-Norway; and sponsored by the Research Council of Norway (RCN). This confirmed the longer term opportunities for achieving efficiencies above 55% (including oxygen separation and CO2-handling) for a larger 400 MWe NG-fired zero emission power plant.

During this period, the project organisation was also strengthened through the addition of Procom Venture AS; a company specialising in project management and technology commercialisation within the petroleum and offshore industry.

The Phase-1.5 work also provided sufficient motivation for the project owners to form the technology development company ZENG AS and pursue the next phase of development towards realisation of the Demonstration Power Plant at Risavika.

5. PROJECT PHASE-2 – OVERVIEW

5.1 MAIN OBJECTIVES

The ZENG Phase-2 Study shall develop and document a conceptual design for an improved efficiency oxyfuel process cycle (with 100% capture of CO2) using the CES Gas Generator. The conceptual Demonstration Power Plant design shall include technology elements that clearly extend the current performance envelope for the oxyfuel Rankine process cycle.

Technologies that shall be designed, implemented and demonstrated in an early commercial operational context at the Demonstration Power Plant are:

- The standardised 170 MWth CES Gas Generator, with complete power plant control system.
- The intermediary pressure (IP) re-heat (RH) oxyfuel combustor.
- A modified intermediary pressure (IP) turbine expander operating (probably) with 1st stage stator row blade-cooling to permit a process fluid temperature level high enough for obtaining an overall thermal efficiency of approximately 48% based on LHV.
- Improved turbine material properties to ensure extended operation between maintenance and overhaul, when taking account for the presence of 10 to 15%-wt of CO2 in the process working fluid.
- Optimised integration of the process cycle with the air separation unit (ASU) and possible use of nitrogen expansion for power generation.
- Optimised design of the low-pressure section of the process cycle in combination with a “new design” heat recovery condenser / separator (HRCS) unit.

Furthermore, the process cycle shall, when implemented in a large-scale commercial NG-fired power plant (with CO2 capture, drying and compression to 100 bar), clearly demonstrate a medium-term capability towards achieving overall plant thermal efficiency greater than 55% based upon LHV.

The Phase-2 Study comprises work to be undertaken in two consecutive Stages, each of six months duration, as indicated below.

5.1.1 Project Phase-2 / Stage-1: May – October 2006

Work covering all aspects of preliminary process design specification in order to be able to define and freeze (preferably) one conceptual design case before moving on to Stage-2.

5.1.2 Project Phase-2 / Stage-2: November 2006 – April 2007

Work covering all aspects of power plant design including the following activities;

- Equipment specification.
- Power train specification, size and layout.
- CO2 processing and handling (within plant battery limits).
- Layout, piping and utility systems.
- Instrumentation, control and electrical systems.
- Buildings, structural and civil engineering.
- Safety and environmental.
- Cost estimation for capital costs and operating expenses.

5.2 SUMMARY OF TECHNICAL DESIGN DATA

The information in Table 1 summarises the specified data for the main process design of the proposed Demonstration Power Plant.

Design Base	Performance
Plant Thermal Power Input	~150 MW
Plant Net Electrical Power	~70 MW
Targeted Thermal Efficiency	~48% (LHV) 7,850 Btu/kWh
Operations / Availability	Base load

Table 1: Summary of Plant Design Base.

5.3 DESCRIPTION OF THE SITE

The Energy Park at Risavika, near Stavanger, South Norway emerged from redeployment of land following closure in 1999 of the A/S Norske Shell oil refinery. The Energy Park is now part of a regional commitment to promote new technology and attract industry focussing on use of NG, zero emissions, renewable energy and sustainable value creation with a focus on both knowledge and job creation.

Fig. 2: Artist impression of future development in the Energy Park at Risavika.

The proposed Demonstration Power Plant site is located immediately adjacent to landfall for the 10-inch Rogass NG pipeline (owned and operated by Lyse Gass) and the emerging Risavika Gas Test Centre.

The site location is therefore in close proximity to existing infrastructure and there may also be opportunities to share facilities and develop synergy with others co-located in this industrial development area.