CES Gas Generator plant: a new kind of aeroderivative

It's rocket science. The Gas Generator under development by Clean Energy Systems, Inc, is bringing technologies well established in rocketry into the power generation arena. A facility in California has been demonstrating the feasibility of the concept for potential development as a zero emissions power generation technology. Fossil fuel is combusted with oxygen in the presence of pure water to produce a high energy gas consisting of a CO_2/steam mixture. This drives a turbine and lends itself to low cost CO_2 capture.

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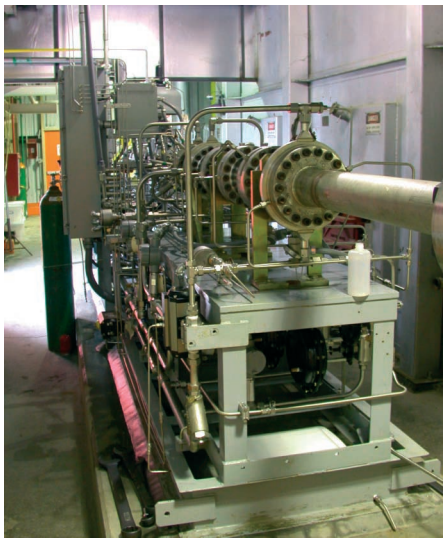
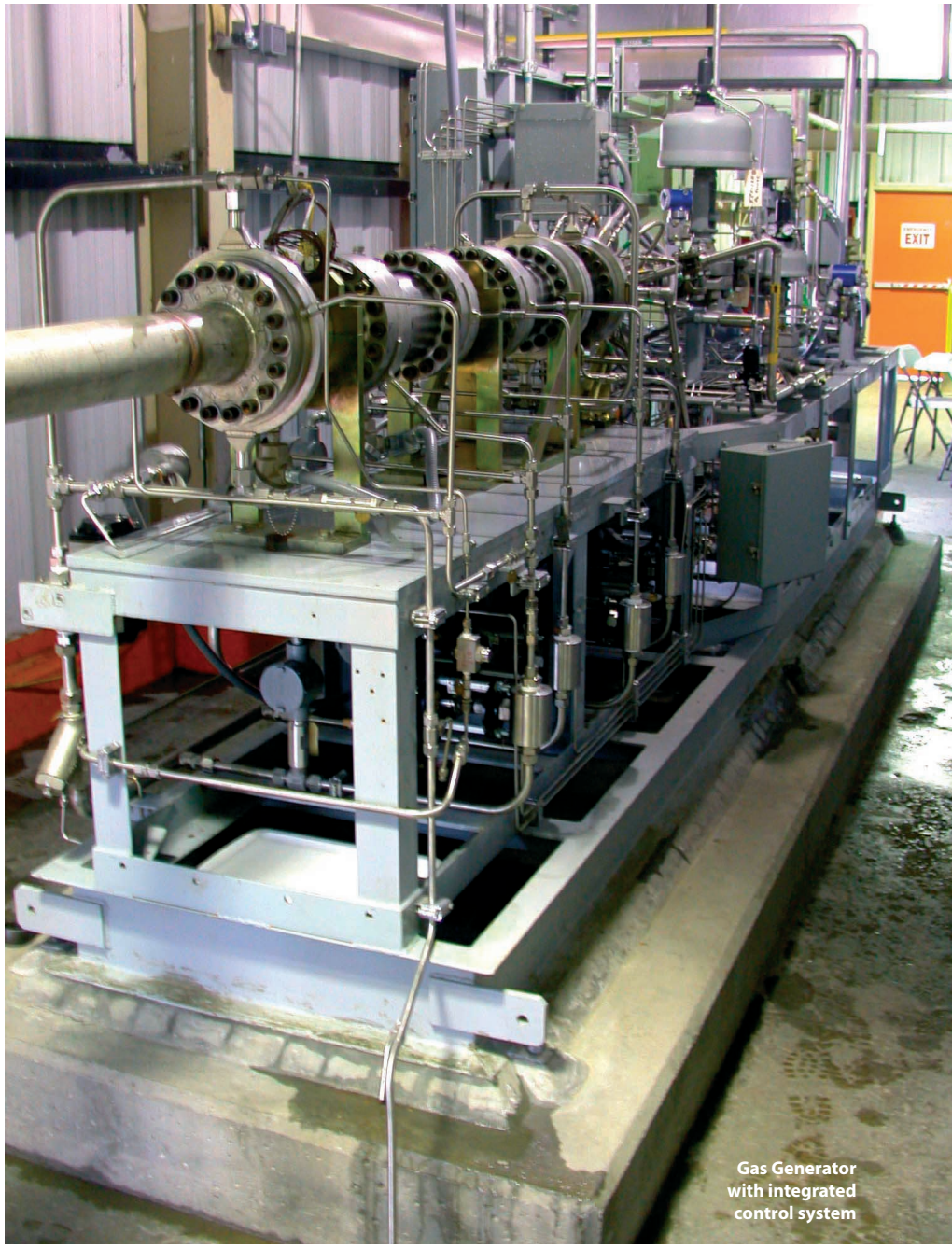
At the end of March 2006 the innovative CES Gas Generator at the Kimberlina development facility near Bakersfield, CA, achieved 1340 cumulative operating hours of durability testing on natural gas and was temporarily shut down in preparation for transition to operation on simulated syngas. This will emulate coal-derived syngas under a DOE-funded programme aiming to develop a syngas combustor able to produce emission-free electrical power from coal.

The Gas Generator produces a mixture of steam and carbon dioxide at high temperature and pressure. At Kimberlina the gas stream has been used to drive an old Elliott 5 MWe steam turbine generator (part of the original Kimberlina biomass plant). This has successfully exported electricity to the grid over nearly 12 months during the durability tests, with over 300 starts.

Rocket science

The Gas Generator technology being developed by Clean Energy Systems, Inc (CES) is adapted from rocket engines. The Gas Generator burns a combination of gaseous oxygen and any gaseous fuel composed primarily of the elements carbon, hydrogen, and oxygen. Acceptable fuels include syngas from coal, refinery residues, or biomass, natural gas, landfill gas, or anaerobic bio-digester gases. The combustion is performed at essentially stoichiometric conditions in the presence of re-



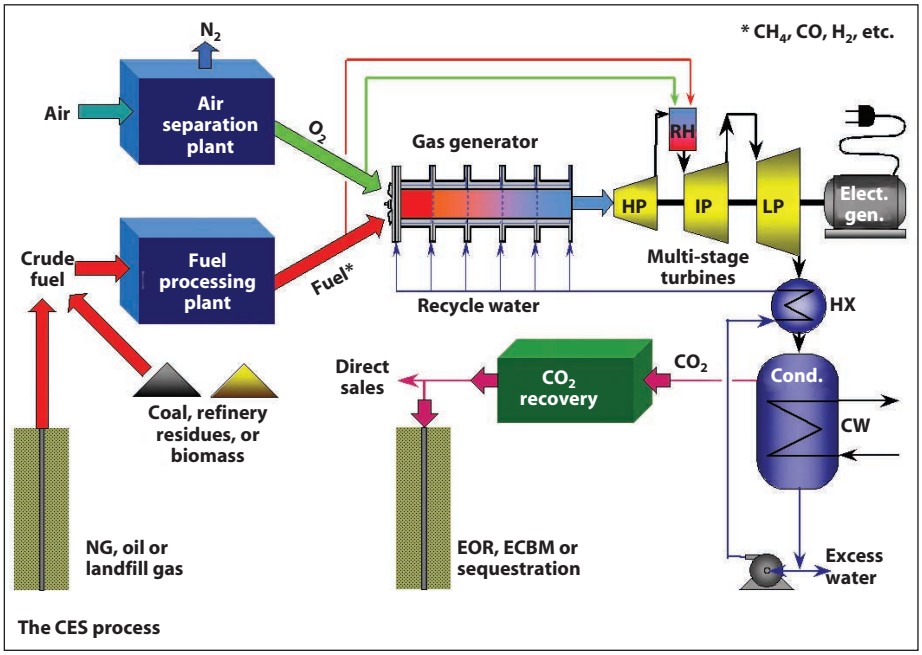


Gas Generator with integrated control system

cycled water to produce a steam-rich mixture with carbon dioxide at high temperature and pressure. These combustion products can be used to power steam turbines (as in the case of Kimberlina) or modified gas turbines.

As the flow diagram shows, the CES process concept envisages that the mixed gas leaving the turbines enters a condenser/separator where it is cooled, separating into its components, water and CO_2. The recovered CO_2 can be conditioned and purified as appropriate for possible sale or sequestration. Most of the water is recycled to the gas generator but excess high-purity water is produced and available for export.

The basic Gas Generator technology has been used successfully in aerospace applications for decades. The CES innovation is to adapt the aerospace technology to power generation, in much the same way that aircraft jet engines were adapted for use in power plants as aero-derivative gas turbines.



The CES process

A brief history of the Gas Generator

In 1999 the California Energy Commission (CEC) awarded CES an Energy Innovation Small Grant (EISG Grant 99-20) to assist in the construction of a laboratory-scale gas generator capable of demonstrating near stoichiometric oxy-fuel combustion in the presence of injected water. Under the EISG program, CES built a test bench and operated a lab-scale gas generator at temperatures up to 1482°C (2700°F) and pressures up to 20.7 bar (300 psia).

The Gas Generator operated repeatedly, reliably, and stably on O_2, CH_4, and water, with more than 75 starts and individual test durations of up to 48 minutes. This programme, completed in January 2001, experimentally established the "proof of principle" for the new method of producing clean, high-energy drive gases for the generation of power.

In September 2000, DOE/NETL funded CES under the Vision 21 Program to design, fabricate, and test a 20 MWt gas generator to operate on O_2, CH_4, and water. That gas generator was tested during late 2002 and early 2003.

The tests successfully demonstrated operation at temperatures ranging from ~1649 °C (~3000 °F) to as low as 316 C (600 °F) at pressures from 75.8 to 106.2 bar (1100 to 1540 psia). The gas generator operated successfully at both low power (20% of rated power) and full power (20 MWt) in more than 95 tests.

In early 2002 the California Energy Commission awarded CES $2 million in funding to build and operate a natural gas fired zero-emission demonstration power plant using the Gas Generator, with Mirant and Air Liquide as participants. The original plan envisaged a 500 kWe demonstration plant at a Mirant power plant in Antioch, CA, using a modification of the 20 MWt Gas Generator. Preliminary design for the 500 kW plant was completed in April 2002 and initial operation of that power plant was planned for late 2002. But because the Gas Generator testing was not completed until February 2003, the 500 kWe plant demonstration was delayed.

The Kimberlina project

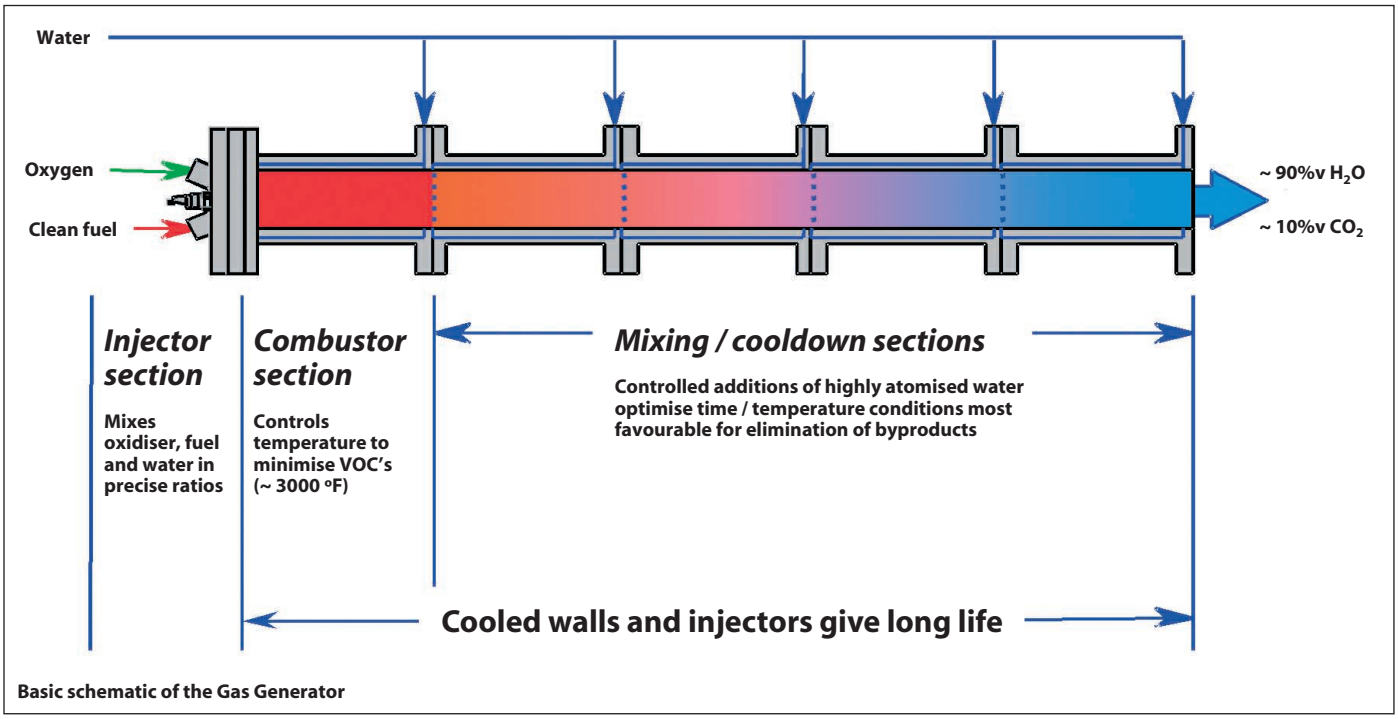
In August 2003 CES acquired the idle 5 MW Kimberlina power plant from AES (originally biomass fuelled). The project was therefore restructured to shift the plant demonstration to the Kimberlina site and to increase the power level to about 5 MWe. Relocation of the demonstration project to Kimberlina was approved in November 2003 by the CEC and $2 million in supplemental funding was approved in March 2004.

Subsequent to the acquisition of the Kimberlina power plant, CES had designed a complete control system for the 20 MWt Gas Generator and integrated it with the completed CES Gas Generator "skid", which was installed at Kimberlina.

Kimberlina provides a permanent test facility for the CES Gas Generator and related oxy-combustion technologies.

The Kimberlina facility can also directly support the activities of the West Coast Regional Carbon Sequestration Partnership (WCRCSP) in which CES is a partner.

The facility provides an excellent opportunity to test and study carbon sequestration, both via



Basic schematic of the Gas Generator

injection into deep underlying saline aquifers and CO_2 flooding for enhanced oil or gas recovery (EOR or EGR) in nearby oil and gas fields.

The Kimberlina site has been identified as a possible candidate for future WCRCSP projects and studies. The facility is already linked to the grid and offers extensive open space for plant expansion and future test projects using fuel sources such as coal and/or biomass.

The plan is to develop the Kimberlina facility in stages. In the first stage, it is being used as a test facility for evaluating the durability of the Gas Generator and to define desirable design refinements. Initial development of the facility has involved installation of an oxygen supply system, natural gas compressor, a high-pressure feedwater pump, a new condenser, and a liquid ring vacuum pump. The new condenser and vacuum pump separate "non-condensable" CO_2 from the condensable steam; however, recovery of CO_2 to a condition suitable for immediate sale, EOR, or EGR purposes is excluded from the scope of the existing CEC contract to reduce programme costs.

Effectively, the "front end" of the power plant and the CO_2 extraction system were procured in the course of preparing the facility for endurance testing of the gas generator and validation of its integrated control system. The installation and activation of all these additions to the facility were completed in January 2005.

During a nearly three-hour test on natural gas in late December 2004 drive gas from the Gas Generation system was partially directed to the 5 MWe turbo-generator, which was brought to synchronous speed, and partially bypassed to the stack. In February 2005, the Kimberlina turbo-generator was synchronised to the grid for the first time. In early March 2005, the power plant was operated in a pure power island mode disconnected from the grid. Shortly thereafter permission to connect to the grid was granted and power began flowing from the Kimberlina power plant.

Future plans for Kimberlina

Several plant additions are planned for the next phase of development of the Kimberlina facility. The first new addition is anticipated to be a CO_2 capture and conditioning system. This will be a separate project, perhaps as part of a WCRC-SP sponsored CO_2 sequestration project, or a commercial venture to supply high quality CO_2 to the local market.

The Kimberlina plant site is easily adaptable to the demonstration of zero-emissions power generation from coal, refinery residues, or biomass by addition of an on-site air separation unit (ASU) and an oxygen-blown gasification system. Efforts are currently underway to identify a potential supplier of an oxygen-blown gasification system in the 20 MWt to 100 MWt range. The installation of such a system would result in the first zero-emissions solid fuel power plant.

In addition to traditional biomass fuels (wood products) in the immediate vicinity and existing biomass handling facilities on-site, large amounts of animal wastes suitable for anaerobic digestion are available nearby. These features make the use of the Kimberlina facility as a demonstration site for solid fossil-fueled or biomass-fueled zero-emissions power plant possible within two to three years.

Reheater development

In parallel with work on the Gas Generator, development work was completed on a sub-scale version of the reheater shown as 'RH' in the process diagram (see p23). Under a US National Energy Technology Laboratory programme, gas turbine combustor design concepts were adapted to produce a direct-fired, oxy-fuel reheater.

The reheater is not essential to achieve zero-emissions plant operation, but it provides a means to dramatically increase cycle efficiency. Early recognition of that fact prompted NETL to undertake design, fabrication, and testing of a small-scale version of such a reheater.

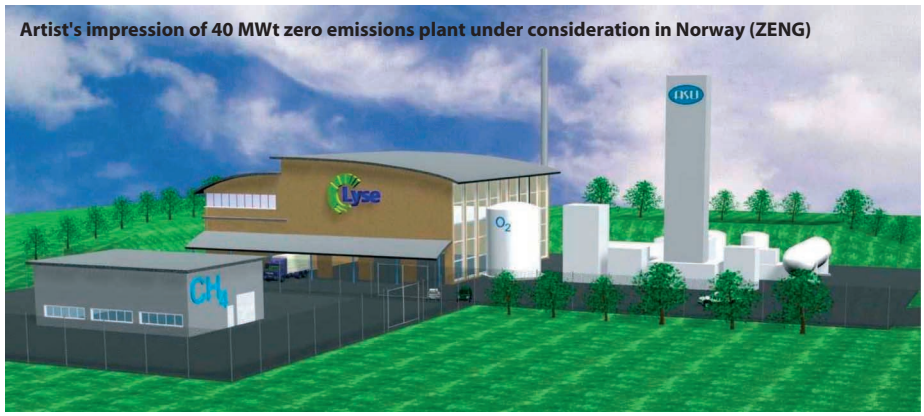
Tests on this showed that it is possible to construct and operate a reheater that can dramatically improve the efficiency of the power cycle. Oxyfuel combustion was shown to be a simple, viable method for achieving reheat to temperatures similar to gas turbine inlet temperatures. The tests of the oxyfuel steam combustor, operating at a pressure of 10.1 bar (147 psia) and more than 1 MWt output, were considered successful. Measured CO emissions were in reasonable agreement with equilibrium calculations, indicating efficient mixing and combustion were achieved.

Scaling up

Sufficient experience and confidence has been gained to push ahead with contracts for modest-sized (20 to 70 MWe) first generation zero emissions power plants based on present-day steam turbine technology.

These first-generation plants would most likely operate on natural gas and will be situated where zero-emissions (CO_2 capture and no pollutants) has sufficient value to offset the relatively low efficiencies of the first-generation plants. CES is now developing several projects that fit these criteria, in the Netherlands, Norway, and California.

The Kimberlina facility



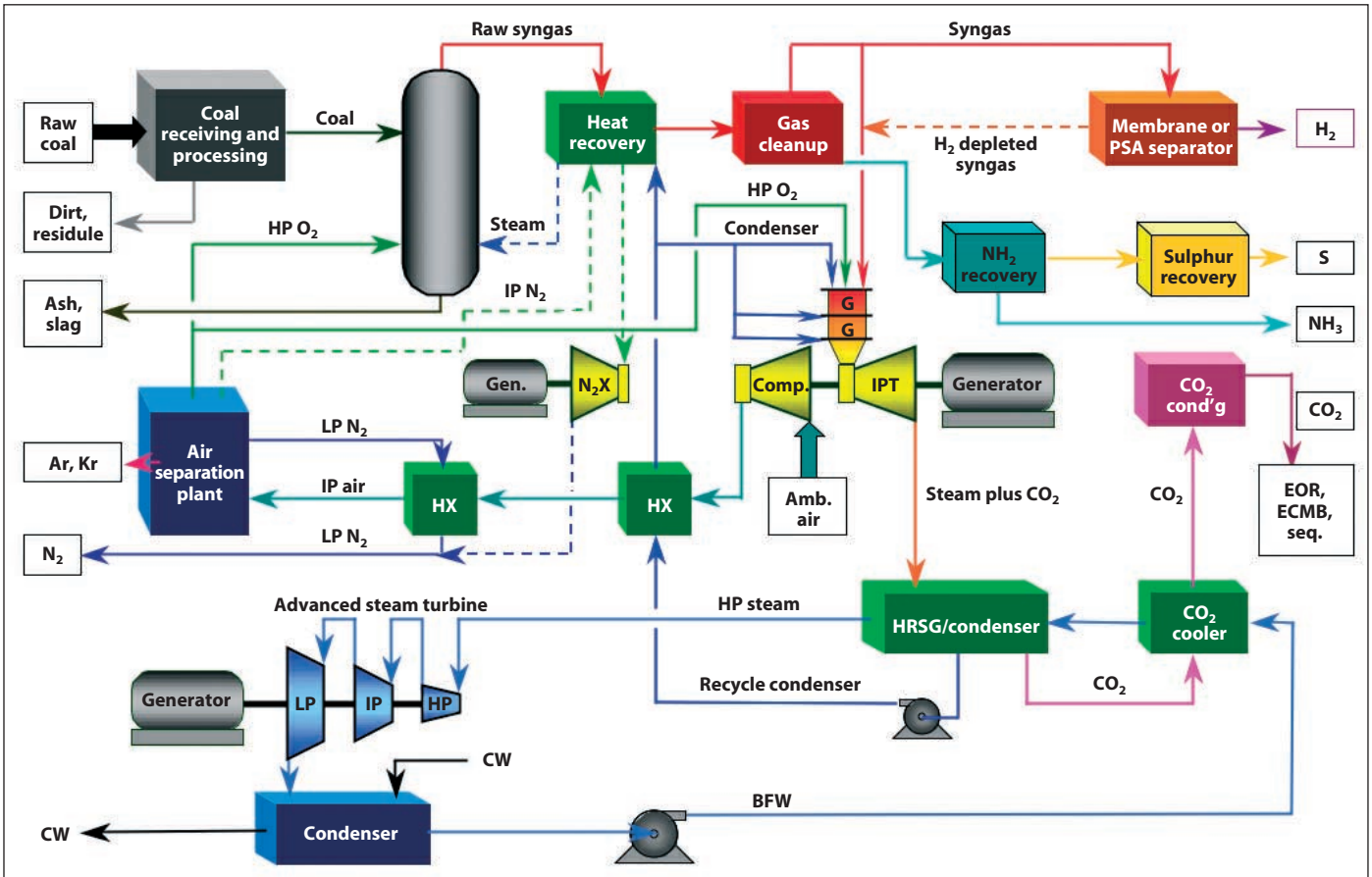
Artist's impression of 40 MWt zero emissions plant under consideration in Norway (ZENG)

The Dutch project is called SEQ-1, a 50 MWe plant with CO_2 capture for enhanced gas recovery. It involves the use of a modified CES process with a Gas Generator operating at modest pressure (~20.7 bar, 300 psia) on recovered natural gas from a "depleted" gas field. This raises steam in a compact HRSG that drives conventional steam turbines.

Several unique factors combine to favour the commercial viability of this project:

- The Dutch government has legislation in place that subsidises climate-neutral sources, including zero-emissions combustion systems, in a similar fashion to wind, solar, and biomass.
- The geology of the targeted gas field has been determined to be suitable for effective EGR.
- The project is to be located where governmental financial incentivisation of employment and business activity is available. And
- Dutch developers, working with CES, have brought together the necessary entities to evaluate the project and achieve a consensus that the project is viable. A consortium to develop the project has been formed, including participation from ONS, a Dutch municipal utility, and a major European oil and gas company.

The Zero Emissions Norwegian Gas (ZENG) Project is being developed by ZENG AS, a special purpose company consisting of Lyse Energi AS and other Norwegian companies. The project has received support from the Norwegian Oil and Energy Department (OED), Lyse Energi AS, and the US DOE. The goal of this programme is to develop and demonstrate "near commercial" technology for zero-emissions power generation using Norwegian natural gas in combination with



Possible scheme for integrated gasification CES coal plant (ICCES)

the oxy-combustion cycle developed by CES. Zero emissions power plants are of particular interest in Norway because of the high tax imposed on CO_2 emissions. It is a multi-phase effort . Phase 1 is a concept and feasibility study, which has been completed. and phase 2 involves pre-engineering and qualification.

Subsequent phases entail construction of a 50 MWe demonstration power plant near Stavanger, Norway, with commissioning envisaged in 2009. Later, a high efficiency 200 MWe zero-emissions power plant would be built at a Norwegian location to be determined. The Phase 1 study was completed in July 2004 and provides the necessary information for considering a decision to initiate phase 2.

In the USA direct incentives are not available for zero emissions power generation, but commercially viable projects featuring first-generation CES technology appear possible where the captured CO_2 has value and/or "clean" power has added value because of premium pricing or avoidance/reduction of licensing and emissions credits costs. In California, these market forces are found in oil producing areas, in severely impacted environmental control districts, and where "clean" power is premium priced. One prospective project in California involves placing a zero emissions power plant in or very near an oil field that is in a declining production stage and previously shown it can effectively use the captured CO_2 for EOR. The power generated would replace relatively expensive power currently being purchased to operate the oil field and the excess power would be sold to a local utility that accepts the power as "clean", affording it premium pricing. No other economic source of CO_2 is available for EOR and other types of power plants are unlikely to be licensable in the environmentally impacted area. Other prospective projects involve the partial repowering of existing gas-fired steam power plant that have excess turbine capacity that cannot be fulfilled by the boilers because of emission restraints.

Projects such as these would set the stage for a second generation of zero emissions power plants based on oxy-fuelled reheaters and/or IP turbines based on gas turbine technology. They will exhibit much improved cycle efficiencies and produce electricity at significantly lower cost. The second generation of zero emissions plants appear most likely to find application in three areas:

- Larger natural gas fired systems (200-400 MWe) where the recovered CO_2 can be used beneficially for such purposes as EOR, EGR, or enhanced coal-bed methane (ECBM) recovery.
- Small to modest-sized (50 MWe and over) plants operating on syngas from direct or *in situ* gasification of coal. And
- Relatively small systems operating on gasified plant, animal, or municipal waste biomass or bio-derived gaseous fuels that represent nuisance wastes and/or present environmental problems.

Truly commercial, large-scale (400-1000 MWe) zero emissions power plants based on gasified coal or opportunity fuels such as petcoke appear feasible within 10 years. They would produce power at a cost comparable with or below that of today's very best combined cycle systems, and would be emissions free.

Siemens–CES collaboration

Work to date has suggested that coal based oxy-fuel systems could produce power with cycle efficiencies ranging from 32% to over 50% depending on turbine operating temperatures, type of oxygen production technology used and the level of system integration. Significantly increased efficiency is achievable, for example, by greater integration of the air separation unit with the power plant and of the Gas Generator with the turbine, as well as development of advanced turbines operating on the steam-CO_2 drive gas.

In this regard the CES concept took a further important step forward in September 2005 with the award of contracts under the US Department of Energy's Office of Fossil Energy Turbine Technology R&D Program.

The DoE said "Studies indicate that replacing air with nearly pure oxygen in a turbine's combustion chamber is a promising approach to achieving highly efficient, near-zero-emission coal-based power systems...These technologies will be conducive to 100 percent separation and capture of CO_2 and will achieve long-term power system efficiencies of 50-60 percent."

CES received a $4.5 million contract (39 months duration) to develop and demonstrate a new turbine combustor technology powered by coal syngas and oxygen based on its Gas Generator system. The project team will evaluate and redesign the combustion sequence to achieve the ideal ratio of oxygen to fuel, a critical parameter in achieving optimum combustion and reducing costs.

In parallel CES partner Siemens will combine current steam and gas turbine technologies to design an optimised turbine that uses oxygen with coal-derived fuels in the combustion process. As part of this $14.5 million, 56 month, project system studies will show how this CES Gas Generator based turbine can be integrated into a highly efficient, near-zero-emission power plant.

CES and Siemens believe that improved integration can increase cycle efficiencies to the 45-55% range.