Clean Energy Systems, Inc.

Clean Energy Systems' (CES) technology is a zero emission, oxy-fuel combustion power plant. CES' approach has been to apply gas generators and high-temperature, high-pressure, turbines from aerospace applications to power generation. The CES oxy-fuel combustion uses oxygen instead of air to combust gaseous fuels. Because air is excluded from the combustion process, the products of combustion are nearly pure CO_2 and water. Thus, the CO_2 can be easily isolated simply by cooling the flue gases. The efficiencies of the initial power plants will be approximately 30% and will improve to approximately 60% as new turbine designs, that can capture the benefits of the high temperature gas stream, are introduced. The primary opportunities relate to the fact that the technology is zero emission and the CO_2 production can be sequestered. Thus far, CES developed and demonstrated a 500 kW gas generator and a 5MW power plant.

SoCalGas' RD&D Investment in CES

SoCalGas is supporting Clean Energy Systems (CES) through its regulated RD&D program. CES' oxy-fuel power system is superior to other CO_2 capture technologies because it avoids the emission of other criteria pollutants such as NOx and particulates, and **i**t has the potential to be more efficient than today's most advanced combined cycle power plants once steam turbines that can handle 3000°F steam become commercially available. The growing concerns about GHG emissions has created a market zero emission power technologies in California and internationally. CES' gas generator is an enabling technology with a variety of applications including: enhanced oil and gas recovery, cost-effective[1] pollution-free power production, LNG-receiving terminal co-generation, fuel diversity and many other niche markets. Perhaps the biggest challenge to the CES technologies is to improve the cycle efficiency and to work with others to develop steam turbine technology capable of cost effectively operating at very high temperatures.

Clean Energy Systems Technology Overview

The basic CES zero-emission fossil fuel power plant design is shown in Figure 1. The core of CES' process is an oxy-combustor or "gas generator" adapted from rocket engine technology shown in Figure 2. The gas generator burns gaseous fuel with oxygen in the presence of water to produce a steam/CO_2 mixture at extremely high temperature and pressures. If uncontrolled, the

[1] The CES system represents the most cost-effective method for capturing power plant CO2 emissions available today.

combustion temperatures could reach 6000° F, causing the gas generator to melt. Water is injected into the combustion process reducing the steam temperature to 3200° F or less. The steam/CO_2 combustion products are then used to power steam turbines. Thus, the CES power system produces essentially pure water and "sequestration ready" CO_2.

Typical fuels include natural gas, syngas from coal, landfill gas and biogases. The CES process can also use inexpensive aqueous fuels such as emulsified refinery residues and glycerin

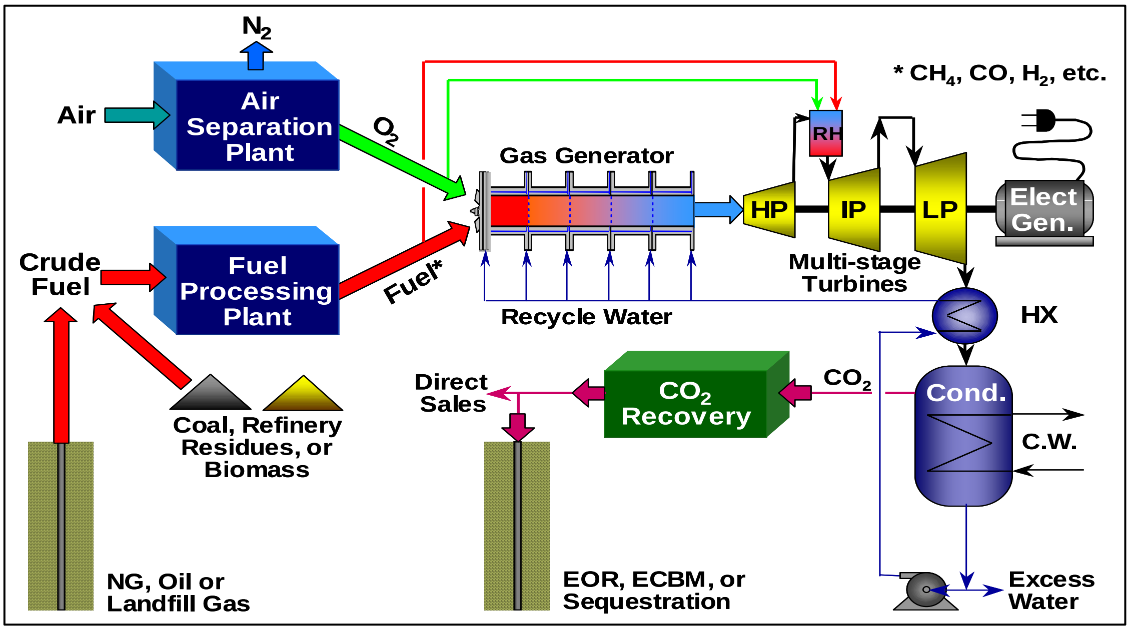

Figure 1: The CES Process

from bio-diesel production.

The CES gas generator can be started up quickly and can achieve full power in less than ten minutes. It also has excellent load following capabilities and CES believes the system can be used in peak power applications. Every component in the CES process, except for the gas generator, is commercially proven and standard in power generation. Figure 3 is a picture of a 5 MW gas generator located at the CES test site in Kimberlina, CA.

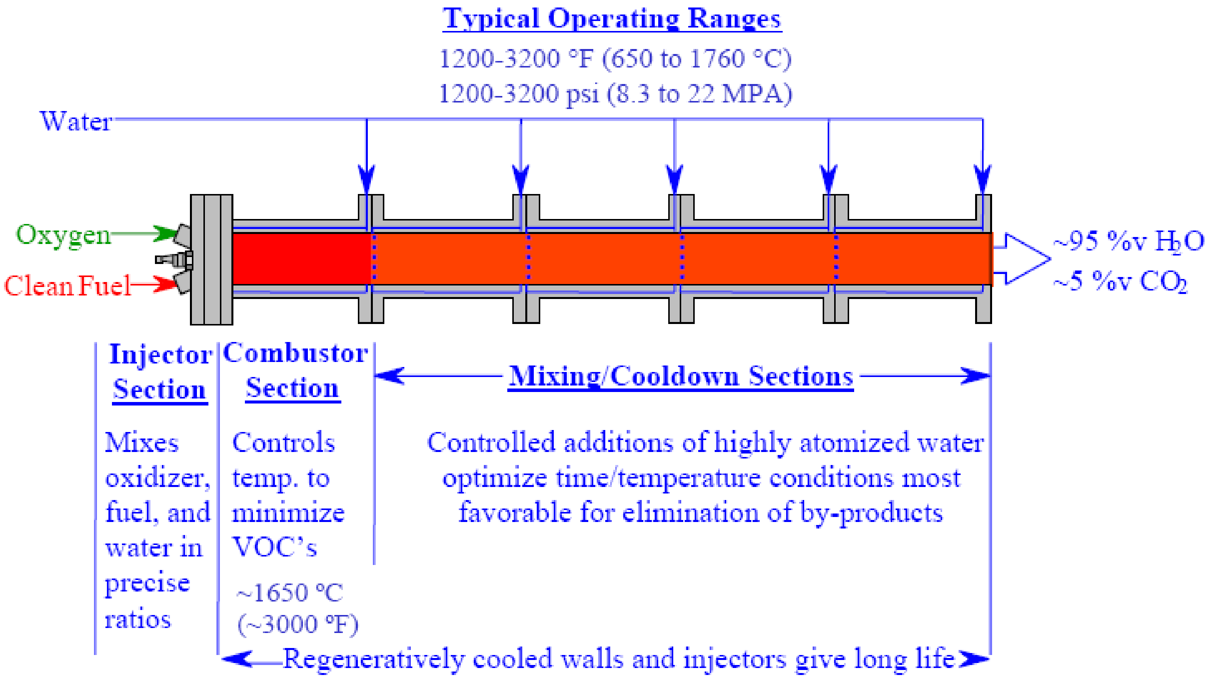

Figure 2: The CES Gas Generator

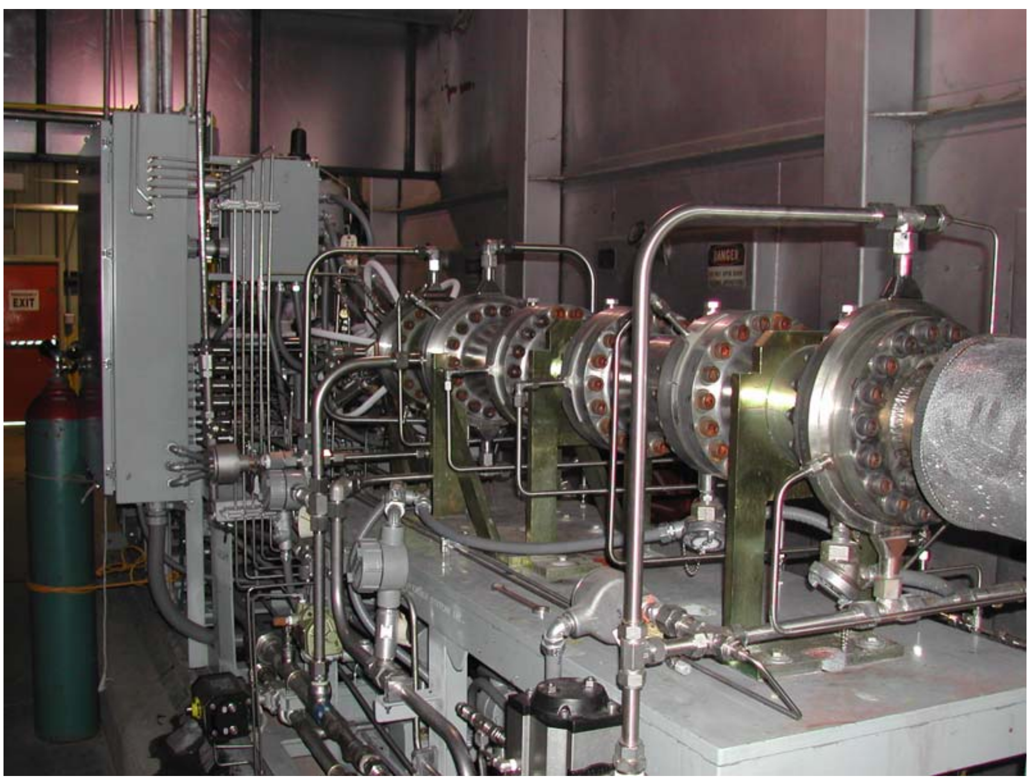

Figure 3: 5MW CES Gas Generator

Oxy-fuel Combustion Power Plants Potential Efficiency

The CES oxy-fuel cycle produces large volumes of ultra-super critical steam and CO_2 by combusting gaseous fuels with pure oxygen in the presence of water. Water is also used to cool the walls of the combustion chamber and to reduce the combustion gases to as low as 1200° F -- the upper temperature limit of today's steam turbine blades. In the current configuration the efficiency is about 30%. The potential exists to achieve efficiency levels approaching 60%, including the energy required by the oxygen plant, provided that steam turbines capable of tolerating temperatures in excess of 3,000° F become available.

Development and Testing

To date CES has focused on securing the intellectual property rights and on developing and demonstrating the first commercial oxy-fueled gas generator. Significant milestones have included:

- In 2000, CES successfully completed "proof of concept" testing with a 110 kW prototype, funded in part by the state of California. CES has fabricated a 10 MW gas generator, funded in part ($2.5 million) by the U.S. Department of Energy (DOE). Testing was successfully completed in February 2003.
- In 2002, the CEC awarded CES $4 million in funding to design and build a demonstration plant using its oxy-fuel technology as part of an $8 million project. Mirant and Air Liquide were participants. This effort was successfully completed in 2006.
- In August 2003, CES acquired a 5 MW idle biomass plant, which has been re-powered as a multi-fuel zero emission plant. Initial oxy-fueled tests have been conducted with natural gas. Simulated coal syngas, landfill gas, hydrogen and glycerin are currently being tested. The first synchronization to the grid occurred in February 2005, and more than 1300 hours and 300 starts have been logged.

In September 2005, DOE initiated two projects aimed at achieving high temperature, high efficiency turbines and combustors for oxy-fuel power systems. The award announcement states that these technologies must be conducive to 100 percent separation and capture of CO_2 and must achieve long-term power system efficiencies of 50–60 percent:

- **Siemens Westinghouse Power Corporation** will combine current steam and gas turbine technologies to design an optimized turbine that uses oxygen with coal-derived fuels in the combustion process. In this break-through project, system studies will show how this new turbine can be integrated into a highly efficient, near-zero-emission power plant. (DOE award: $14.5 million; project duration: 56 months).

- **Clean Energy Systems** will develop and demonstrate new combustor technology powered by coal syngas and oxygen. 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. (DOE award: $4.5 million; project duration: 39 months)

In addition to DOE funding, Siemens is investing its own resources to advance steam turbine technology in the following areas:

- Building upon ultra supercritical steam turbine technology (increasing working fluid temperature up to 3200°F)
- CO_2 sequestration
- Making step advancements to attain large plant (300 –600 MW) efficiencies above 50% by 2015 (HHV, coal-to-grid basis)

Siemens expects these advanced turbines are expected to become available in the 2012 -2017 time frame.

Near Term Commercialization Projects

CES has designed the combustor and control system for the 170 MW Dutch natural gas SEQ-1 Project. This project involves the use of a modified CES process in which Oxy-Fueled Gas Generator operates on recovered natural gas from a "depleted" gas field. The CO_2 exhaust stream from the plant will be used for enhanced gas recovery at the supply reservoir. Several unique factors combine to favor the commercial viability of this project: (1) the Dutch government has legislation in place that subsidizes climate-neutral sources, including zero-emissions combustion systems, (2) the geology of the gas field (3) the project will be located where governmental financial stimulation of employment and business activity is available, and (4) developers have brought together the necessary entities to evaluate the project. A decision to proceed to the next phase is anticipated in 2007.

The Zero Emissions Norwegian Gas (ZENG) Project is being jointly developed in Norway. The goal of this program is to develop and demonstrate "near commercial" technology for Zero-Emissions Power Plants (ZEPP) using Norwegian natural gas in combination with the CES oxy-combustion cycle. ZEPPs are of particular interest in Norway because of the high tax imposed on CO_2 emissions. The plan is to construct a 50 MW demonstration power plant near Stavanger, Norway that is expected to be commissioned in 2009. Later, a high-efficiency 200 MW plant will be built at another Norwegian location. Additional

Market Opportunities

Currently, a number of viable commercial opportunities exist for using the Oxy-Fueled Gas Generator with existing power turbine technology where the excess heat, CO_2 or ultra-low emissions are valued. CES is focusing specifically on developing zero emission power plant opportunities where the captured CO_2 has commercial value and/or results in the avoidance/reduction of licensing and emissions credit costs. Since the exhaust stream of CES combustion process is largely CO_2 and water, the CO_2 can be separated and either sequestered or used in a commercial process. These plants have no emission stacks and a represent the ultimate environmental solution to clean power generation.

The largest single market for CO_2 is enhanced oil recovery (EOR). The International Energy Agency (IEA) estimates that 140 billion tons of CO_2 could be sequestered as a result of EOR operations around the world. Currently, CO_2-EOR operations in the U.S. inject about 33 million tons per year into the ground. About 90% of CO_2 used for EOR in the U.S. is drawn from underground reservoirs. LNG facilities are frequently located in areas adjacent to oil and gas fields that may benefit from CO_2. The need to gasify LNG at a receiving terminal presents a good cogeneration opportunity for conventional technology. However, because the CES system can use the cryogenic LNG as a heat sink for its air separation unit, steam condenser and compressors, an overall efficiency advantage over conventional generation can be achieved.

The CES power system can also be configured for cogeneration at desalination plants. This concept is particularly attractive in desert areas near petroleum reservoirs where electricity, water and CO_2 are required. The CES plant has an efficiency advantage over conventional cogeneration systems, not only because it produces “injection ready” CO_2 for EOR, but because it is also a net producer of water. For example, a 550 MW CES power plant would produce about 180 million gallons of water per year.

A recent United Nations Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage documents the vital role that oxy fuel combustion and other carbon capture and sequestration (CCS) technologies can play in controlling CO_2 emissions. The UN report indicated the CCS technology can contribute an equal or greater amount of GHG reduction than that provided by renewable energy, conservation and energy efficiency.

Southern California
Zero Emission Power Plant Demonstration Project

CES is planning to construct a 50 MW zero emission natural gas power plant in southern California. As envisioned:

- DOE/WestCarb[2] has earmarked $60 million for a CO_2 sequestration demonstration project.
- DOE/WestCarb would purchase the CO_2 from this plant over a 3-4 year period for sequestration at an adjacent saline aquifer.
- Oil companies would purchase the CO_2 in years 5– 20 for EOR projects.
- A 50 MW power plant would produce enough CO_2 to meet the needs of WestCarb and subsequent CO2 flood operations.
- In addition to demonstrating CO_2 sequestration, it would serve as a test bed for progressively more efficient steam turbines and renewable fuels.
- In addition the DOE and CEC, potential project partners include Siemens, Occidental, AES and Paramount Resources (a Canadian oil producer).

Most of the details of this project are yet to be determined. Lawrence Livermore National Laboratory is the project lead for WestCarb. The initial economics as provided by CES are suggest power costs ranging from about 8¢/kWh to 10¢/kWh, depending on variables such as plant configuration, subsidies, CO_2 value and fuel costs.

[2] The West Coast Regional Carbon Sequestration Partnership (known as WESTCARB) is exploring opportunities in six Western states and one province for removing CO2 from the atmosphere by enhancing natural processes and by capturing it at industrial facilities before it is emitted, both of which will help slow the atmospheric buildup of this greenhouse gas and its associated climatic effects.