Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Session 16, "Capture - Feasibility Studies"

A Zero-Emission Multi-Fuel Power Plant Demonstration Facility with Carbon Capture and Sequestration Capabilities

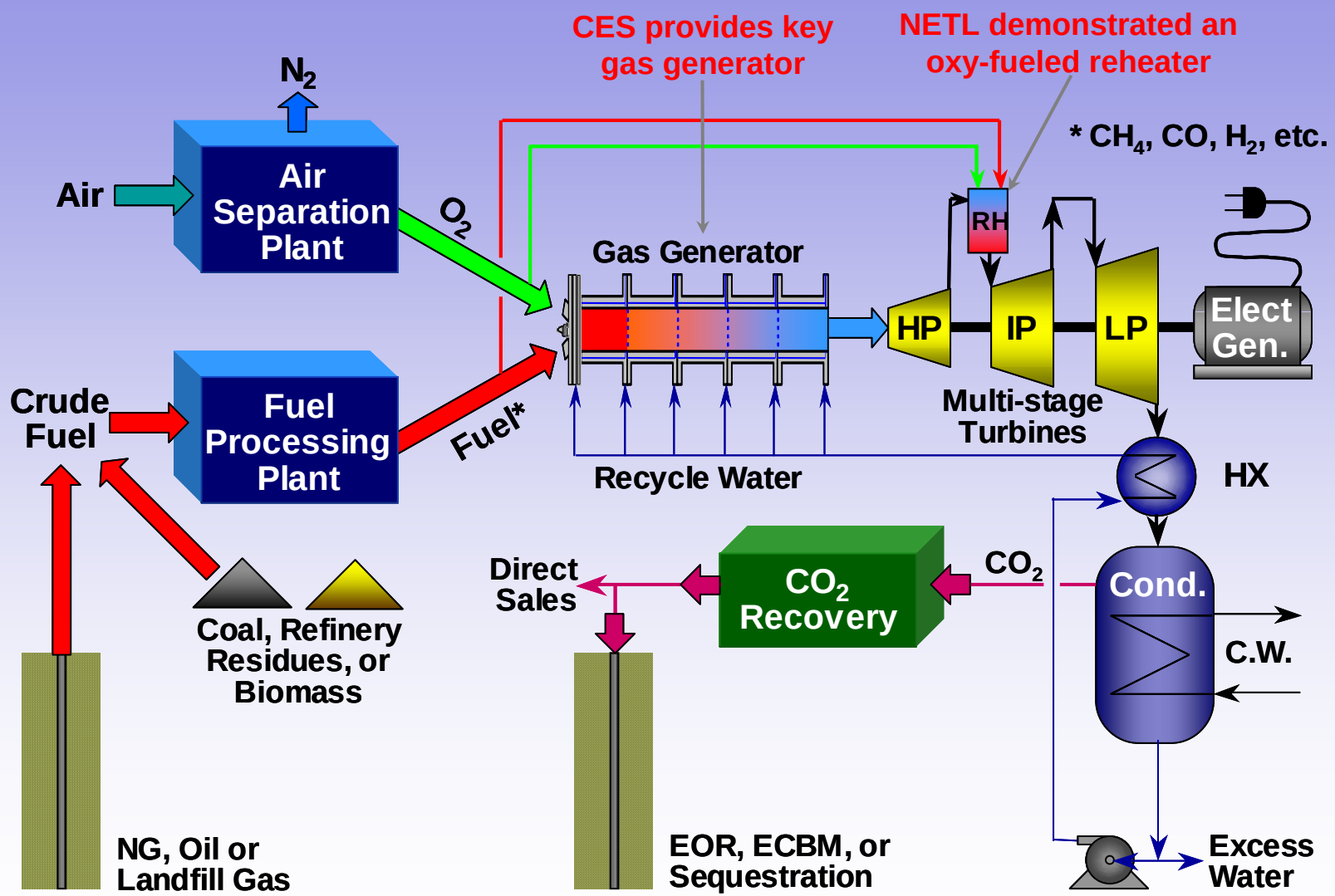
Brian C. Griffin, President, Clean Energy Systems, Inc.

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia

Kimberlina Power Plant

Clean Energy Systems

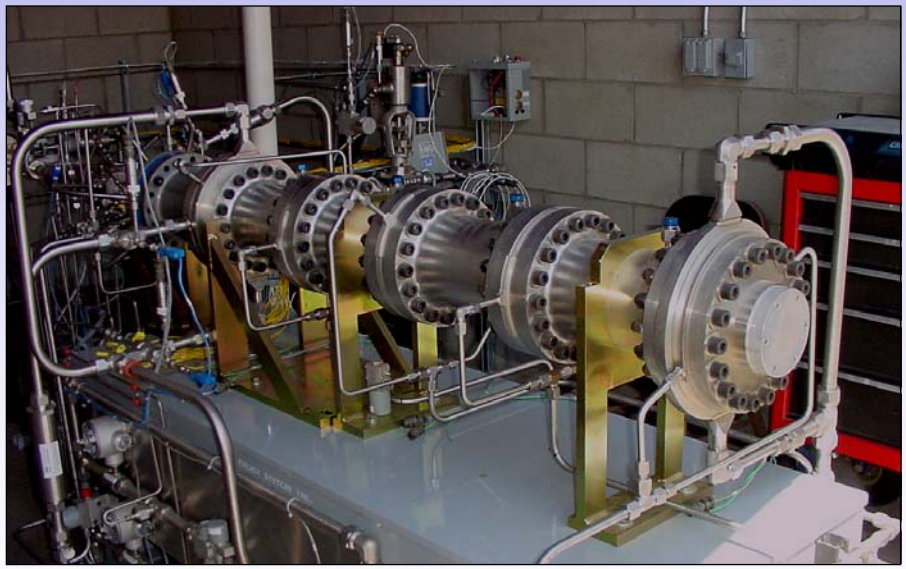
The CES Direct Process



Clean Energy Systems

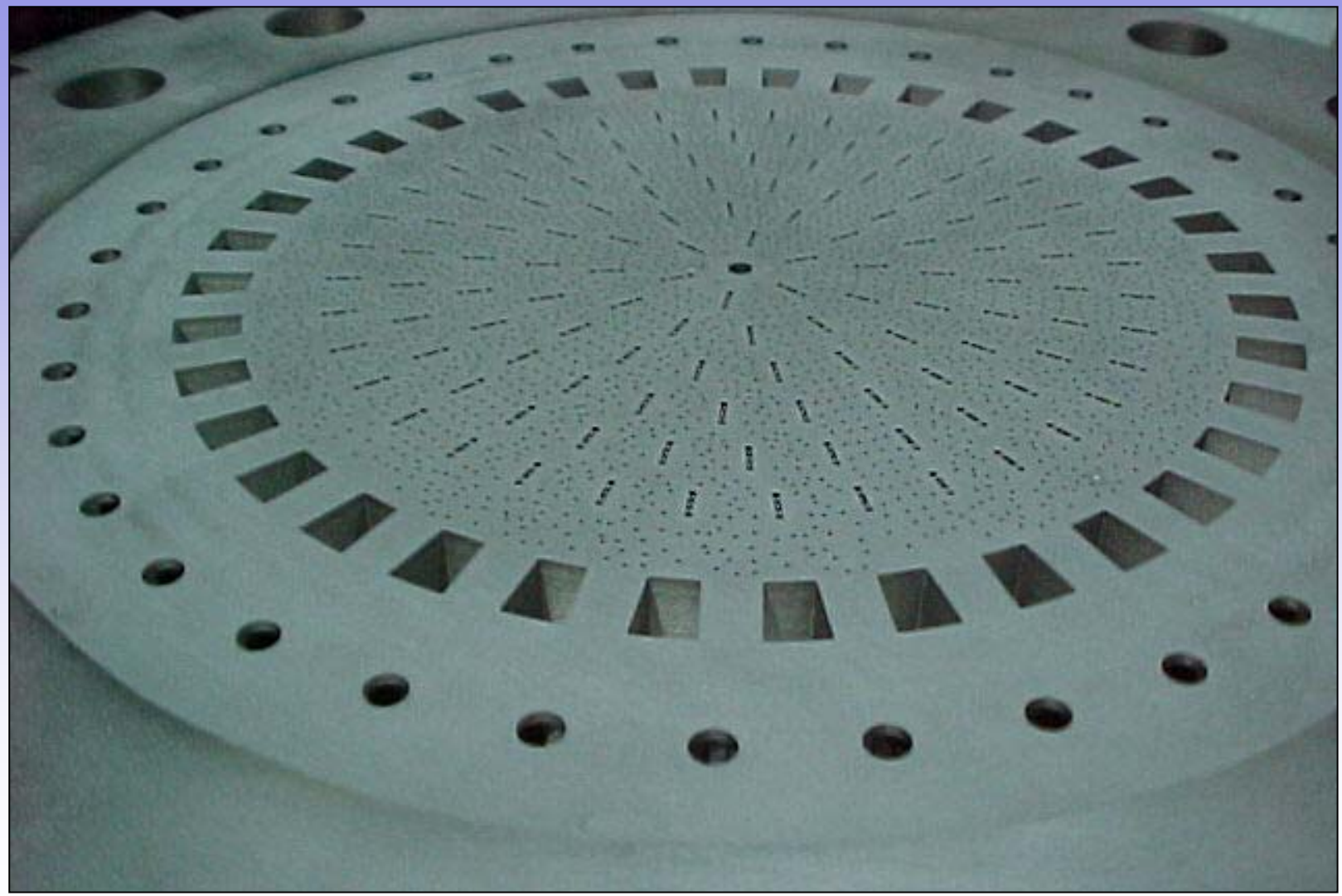
20 MW_t Gas Generator

- CES awarded $2.5 million (of $3.7 million project) in Sept. 2000 under DOE/NETL Vision 21 program
- Designed, fabricated and tested a 20 MW_t gas generator
- Operating pressure of 1500 psi (100 bar) and temps from 1200-3000 ºF (650-1650 º C)
- Testing completed Feb. 03
- Final report submitted June 03
- 100 starts and durations up to limit of test facility

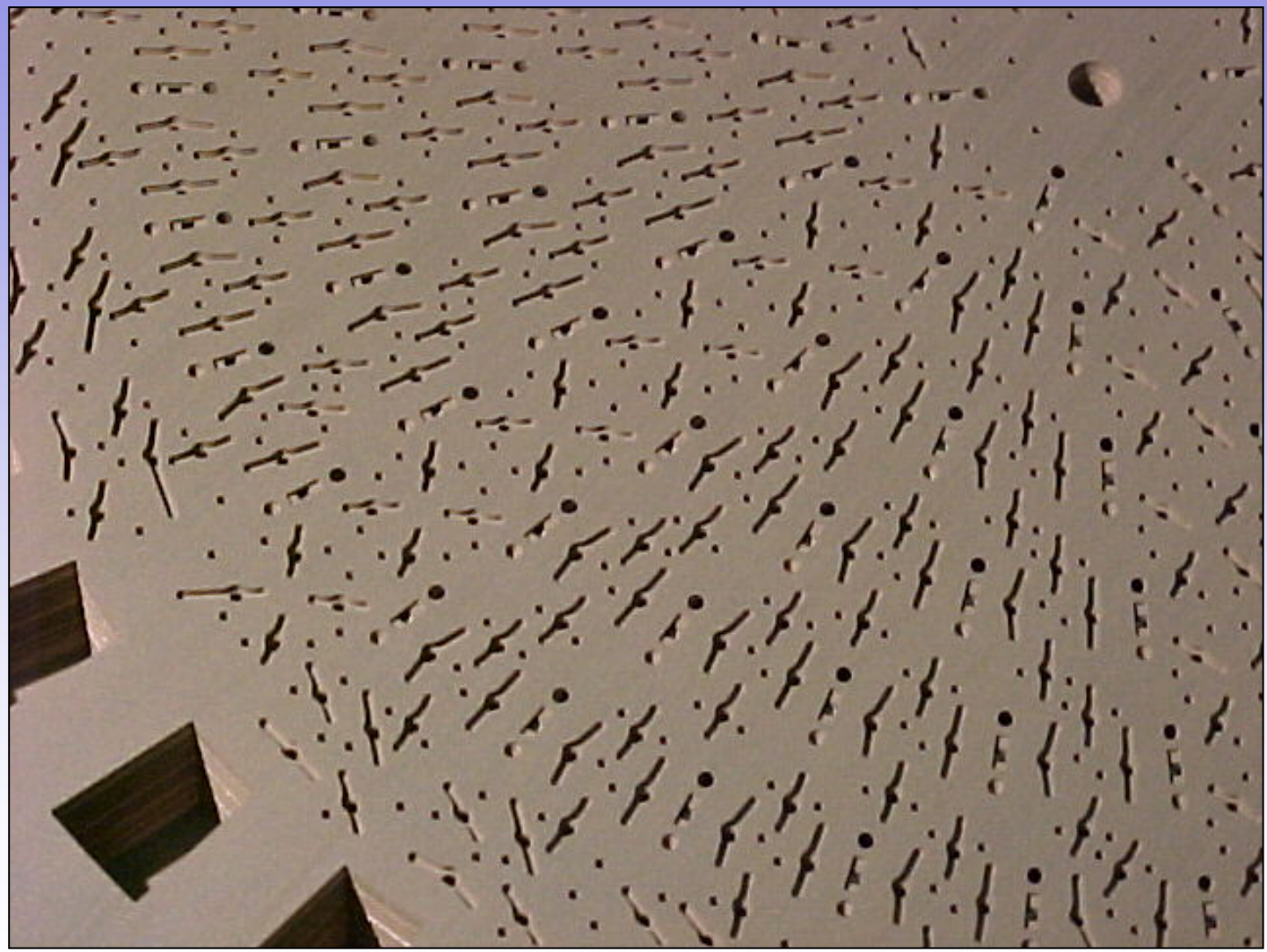


- Produces ~50,000 lb gas/hr (23 mt gas/hr)

10 MW Gas Generator – Platelet Detail

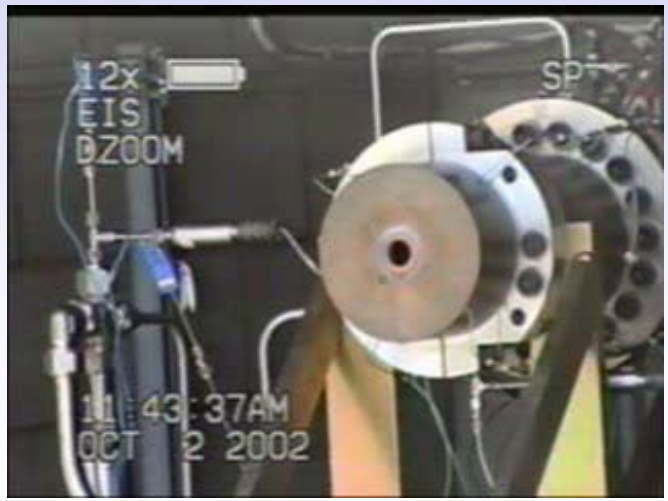


10 MW Gas Generator – Platelet Detail



Gas Generator Demonstration

- Operation compatible with both steam turbines and gas turbines (300-1650 psia, 600-3000 °F) (20-114 bar, 315-1650 ° C)
- Products simplify zero-emissions power generation and enable low-cost CO_2 capture for EOR or sequestration
- Proved enabling technology and set the stage for a small-scale ZEPP demonstration



Zero-Emission Power Plant Demonstration

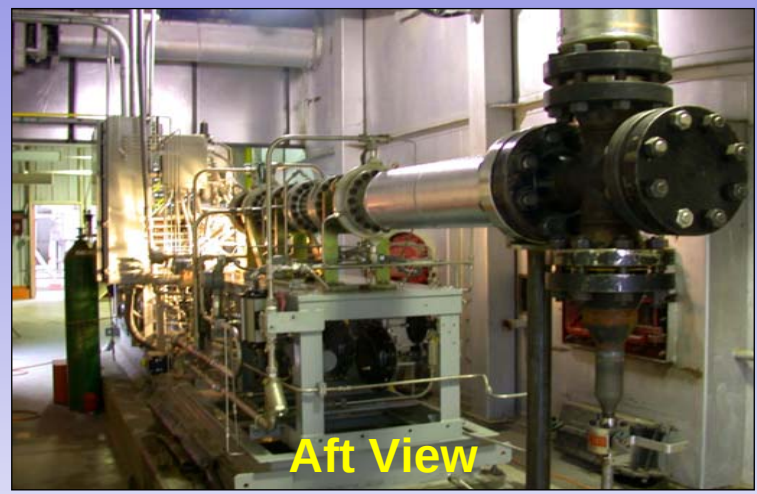
- In early 2002 CEC awarded CES $2 MM to demonstrate its GG technology in a 0.5 MW_e power plant
- CES acquired 5 MW Kimberlina power plant in Aug. 2003.
- In Nov. 2003 CEC approved relocation to Kimberlina site site and increase of power level to 5 MW_e
- CEC and DOE have supplemented funding ($2.4 MM) to support increased scope.
- Installation of integrated GG/ control system and facility additions are now complete.

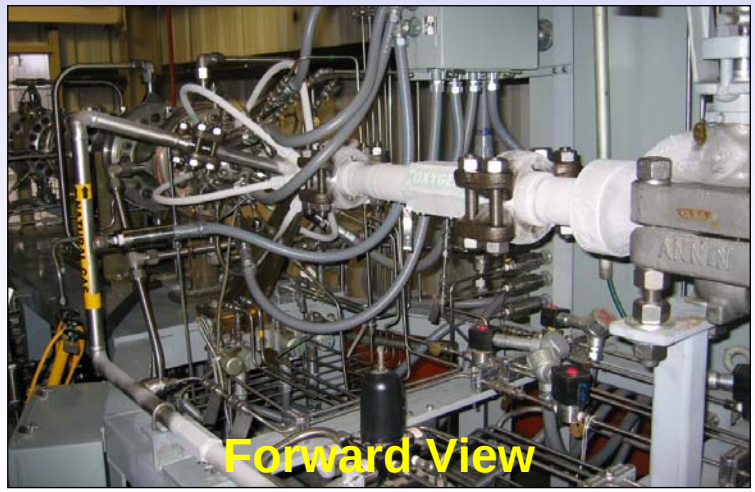
Kimberlina 5 MW Test Facility and Power Plant

Clean Energy Systems

Integrated GG/Control System

GG Installed in 5 MW_e Plant


Aft View


Forward View

Kimberlina Phase 1 Development

Facility Additions

O_2 Supply System

NG Compressor

S.S. Condenser

Feed Water Pump

Liquid Ring Vacuum Pump

Clean Energy Systems

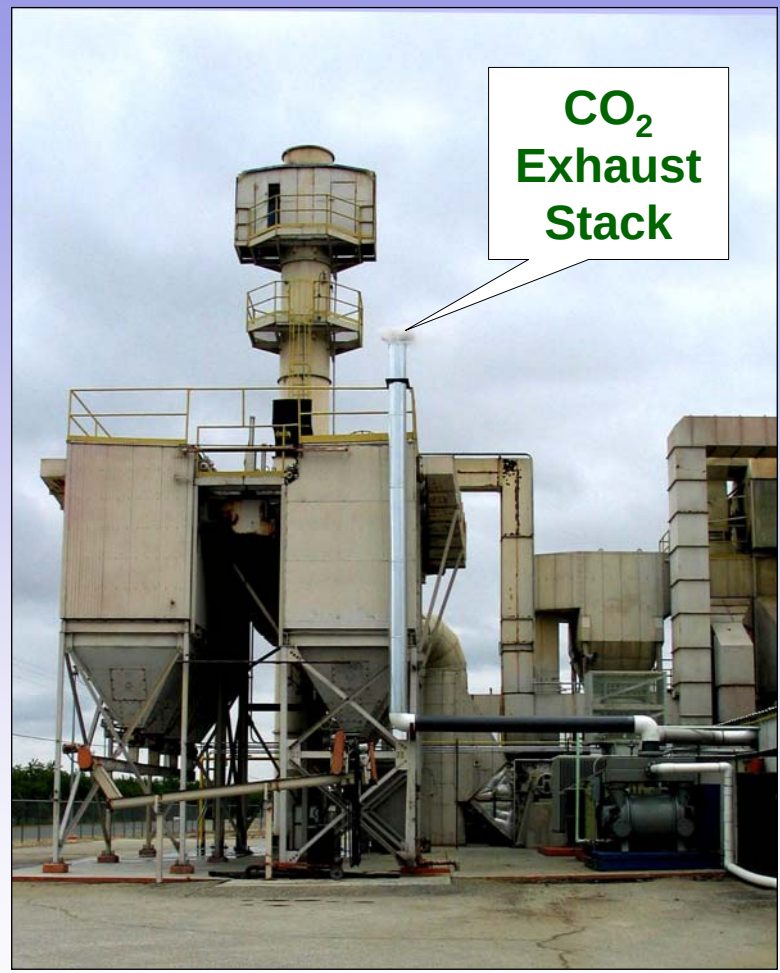
Phase 1 Demonstrations

- Install & commission new facility subsystems
  - ✓ Completed Jan. 05 except for LRVP commissioning
- Validation tests on integrated GG/control system
  - ✓ Completed nearly-3-hour test Dec. 04
- Connect GG to existing turbines & re-power plant
  - ✓ Produced first power late Feb. 05
  - ✓ Exported power to the grid mid-Mar. 05
- Determine operating constraints
  - ✓ Controls loops (P, T, power levels, stoichiometry)
- Initiate endurance tests
  - ✓ Completed more than 90 starts and 150 hr operation

Clean Energy Systems

Kimberlina Power Plant Update

GG Testing in Bypass Mode -
All Drive Gases to Stack



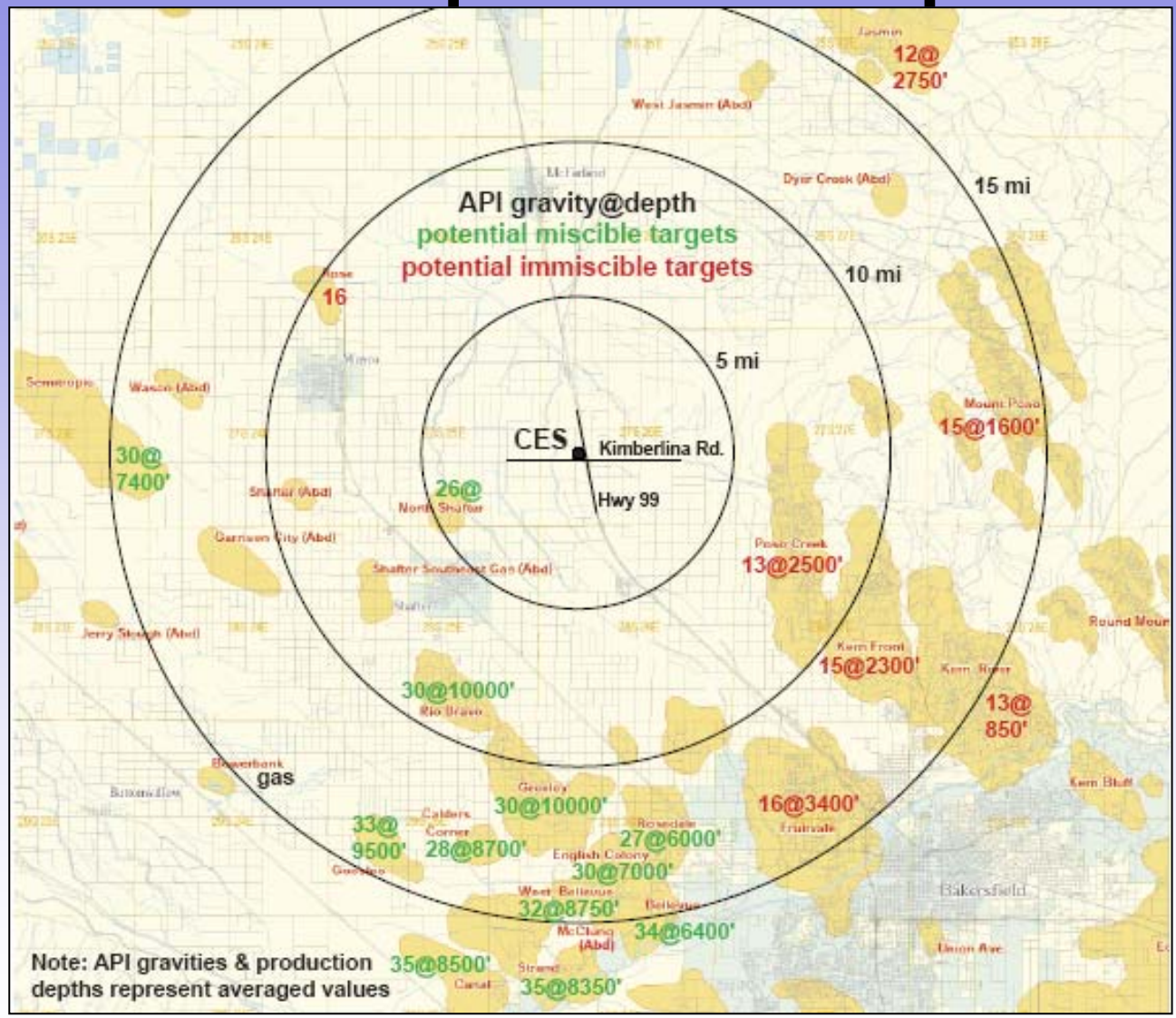
Power Producing Mode -
Only CO_2 Exhausted

Clean Energy Systems

Kimberlina Phase 2 Development

- **Facility Additions** (2005-7)
  - CO_2 recovery/conditioning system
  - Air separation unit (cryogenic, OTM, other))
  - Oxygen-blown gasifier (coal or biomass)
  - Advanced steam-type turbine (HP expansion)
  - Reheater & gas-type turbine (IP expansion)
- **Phase 2 Demonstrations**
  - Extend endurance tests
  - CO_2 sequestration (EOR, EGR, or saline aquifer)
  - Operation on gasified coal and/or biomass
  - Higher efficiency turbine systems

Carbon Sequestration Options



Kimberlina Location

1st Generation Commercial ZEPPs

First-Generation ZEPP Projects (Go-ahead 2004-5)

- The Dutch project
  - Nominal 50 MW_e power plant
  - Uses captured CO_2 for enhanced gas recovery (EGR)
  - Completed a preliminary project design book
- The Norwegian Project (ZENG)
  - Phase 1-Concept & Feasibility Study of a 40 MW_e plant
  - Phase-2: Pre-Engineering and Qualification
- California Projects
  - Nominal 70 MW_e ZEPP in a declining oil field
  - Use captured CO_2 for enhanced oil recovery (EOR)

Clean Energy Systems

2nd Generation Commercial ZEPPs

Second-Generation ZEPP Projects (<5 Years)

- May include oxy-fueled reheaters
- Use IP turbines based on gas turbine technology
- Will exhibit much improved cycle efficiencies
- Three areas of application foreseen
  - Relatively small gasified biomass or biogas systems
  - Modest-sized (50-100 MW_e) gasified coal systems
  - Larger natural-gas-fired systems (200-400 MW_e)

Clean Energy Systems

Advanced Turbine Development Status

- CES technology works with today's steam turbines operating at 550 °C to 600 °C.
- Modifications of gas turbines to run on a steam/CO_2 drive gas is feasible in the near-term.

- For more information:

www.cleanenergysystems.com

IEA GREENHOUSE GAS R&D PROGRAMME

Number 74, September 2004

Greenhouse Issues

In this Issue:

mail@ieagreen.demon.co.uk

www.ieagreen.org.uk

GHGT-7

The 7th international conference on greenhouse gas control technologies (GHGT-7) was held in Vancouver, Canada from 5th-9th September. The conference was a major success with more than 640 delegates attending and over 200 papers presented as well as many posters. A full report on the conference will be included in the next edition of this newsletter.

Clean Energy Systems Demonstration

CES, a privately funded Californian company, aims to demonstrate a complete oxy-combustion, zero-emissions power generation system, based on rocket propulsion technology.

Current work is directed towards the prolonged demonstration of the natural gas/oxygen fired burner with water recycle and the demonstration of a complete CO_2 capture system. This will be done at CES Kimberlina site near Bakersfield, CA, USA, which was formerly a 5.5 MW power generation plant burning biomass. A steam turbine will be used in conjunction with the novel burner to enable the complete power cycle to operate for extended periods.

The 2-year project is in two sections:

The first step involved the development of a high-pressure gas generator that burns natural gas or any gaseous hydrocarbon fuel in pure oxygen in the presence of a large amount of water to control flame temperature. The gas generator produces a mixture of high-pressure steam and CO_2 that can drive an expansion turbine to generate power. Successful tests of up to three minutes duration and more than 100 starts were achieved on the 20 MW (thermal capacity) gas generator in 2003, at a dedicated test facility.

The second part of the development is to demonstrate the complete power cycle by adding the turbine, condensing the steam, recycling the condensate, and capturing the CO_2 at a nominal 5 MWe scale.

The final stages of development will involve developing turbines capable of operating at higher temperatures and pressures in order to maximise the efficiency of the power cycle. In the future CES plans to use the site for demonstration of a zero-emission coal and/or biomass facility, following installation of a solid-fuel gasification system.

As of 1 August 2004, CES had renovated or upgraded all of the original biomass power generation plant systems, having successfully tested each item and repaired or replaced components as necessary. These systems include plant cooling water, steam turbo-generator, instrument air, domestic water, site lighting, fire protection,

% continued

Norwegian Government Supports Development of New CO_2-Capture Power Plants

The Norwegian Government have confirmed their intention to promote and support the development of natural gas fired power plants with capture and handling of CO_2. As outlined in their earlier White Paper on natural gas presented in October 2002, the government will set up an independent innovation company located in Gronland, near Porsgrunn. Furthermore they propose that the company will oversee and manage a fund of NOK 2 billion ($285 million) that is specifically earmarked to promote and demonstrate this 'new generation' of power plants. In practice this will result in an estimated 80 MNOK per annum being available for development and demonstration activities.

The government also emphasised that it has set aside 150 MNOK ($21 million) for R&D activities, and is actively participating in international collaborative efforts such as those of the U.S. Department of Energy. A meeting took place in May where approximately 50 participants from government, industry and research gathered to discuss collaboration and specific projects that may be jointly pursued by the two countries within the areas of Carbon Sequestration, Hydrogen and New Energy Technologies. The Norwegian Ministry for Oil & Petroleum (OED) also indicated that, if necessary, it might consider increased funding for specific projects to secure the demonstration and implementation of new technology. One criterion for a positive decision to proceed has always been a need for firm government commitment to encourage this endeavour - either directly or through market mechanisms that create incentives for investment in zero emission power generation.

With these latest events, one of the Norwegian groups involved, CO_2-Norway and Lyse Energi AS, expect to be well positioned to continue to develop their proposed 40 MWe ZENG Pilot/Demonstration power plant at the Energy Park, Risavika. The Zero Emission Norwegian Gas (ZENG) Program is currently investigating Phase-1 of the project – the Concept & Feasibility Study for a 40 MWe zero-emission power plant, that may be operating by 2008.

The ZENG Program proposes to develop and demonstrate "near commercial" technology for power generation with natural gas using the oxygen (O_2) combustion cycle developed by Clean Energy Systems Inc. (CES), Sacramento, Ca. It also plans to address issues such as CO_2-handling, transportation and long-term storage, including evaluating the potential for enhanced oil recovery (EOR).

In June 2003, the organisation CO_2-Norway received 1 MNOK as part-funding support from OED to initiate Phase-1, which was due to be completed in June 2004.

To date the work has indicated that a cycle efficiency of 40.5% can be attained using currently available steam turbines. The efficiency and power output of the CES-cycle is therefore already similar to state-of-the-art single-cycle gas turbines. Furthermore the cost of electricity is said to be competitive with wind power whilst having a baseload (8000+ hr/annum) generating availability.

The path and challenges to achieving increased power output, reduced cost of electricity, improved cycle efficiency and CO_2-capture are claimed to be well understood. This would not require new turbine cycles but instead can come about through a gradual increase in turbine working pressures and temperatures. For intermediate pressure (i.e. 20 - 40 bar) steam turbines this would entail a development path that has already occurred within the gas turbine industry through use of improved cooling and blade metallurgy.

Whilst maintaining a focus on R&D, the CES strategy is to demonstrate commercial application in today's niche markets for their existing cycle. This requires working alongside turbine manufacturers to improve cycle performance from current limitations of 85 bar/ 600 °C, raising this, over an 8–12 year period, towards 220 bar/ 1500°C. In this manner (and also through other cycle optimisation techniques) it is thought possible to attain a cycle efficiency approaching 60% by year 2012-14.

At the same time, the goal would be to get the "specific capital expenditure" for a large 400 MW plant down towards $750 /kW (installed), which would be competitive with current combined-cycle generating plant.

A New Combustion Technology

By Anders Lyngfelt

At 22 minutes past five, 12th August 2003, the reactor system had reached operating temperature and the valves were opened for natural gas addition. This was the start-up of a new combustion technology with inherent CO_2 capture, chemical-looping combustion. This was the culmination of more than five years of work at Chalmers University, involving the development of methods for manufacture and testing of particles for the process, numerous applications, a search for industrial and university partners, work with reactor system design, testing in cold flow models, and two years of intensive work in the EU/CCP co-sponsored project GRACE (Göteborg Reactor for Advanced CO_2 Capture) together with CSIC-ICB in Zaragoza, Technical University of Vienna, Alstom Power Boilers and managed on behalf of the consortium by BP (CCP). What would happen? Work on this process was going on in Japan, US and Korea but to our knowledge the actual process had