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Coal-Based Oxy-Fuel System Evaluation and Combustor Development

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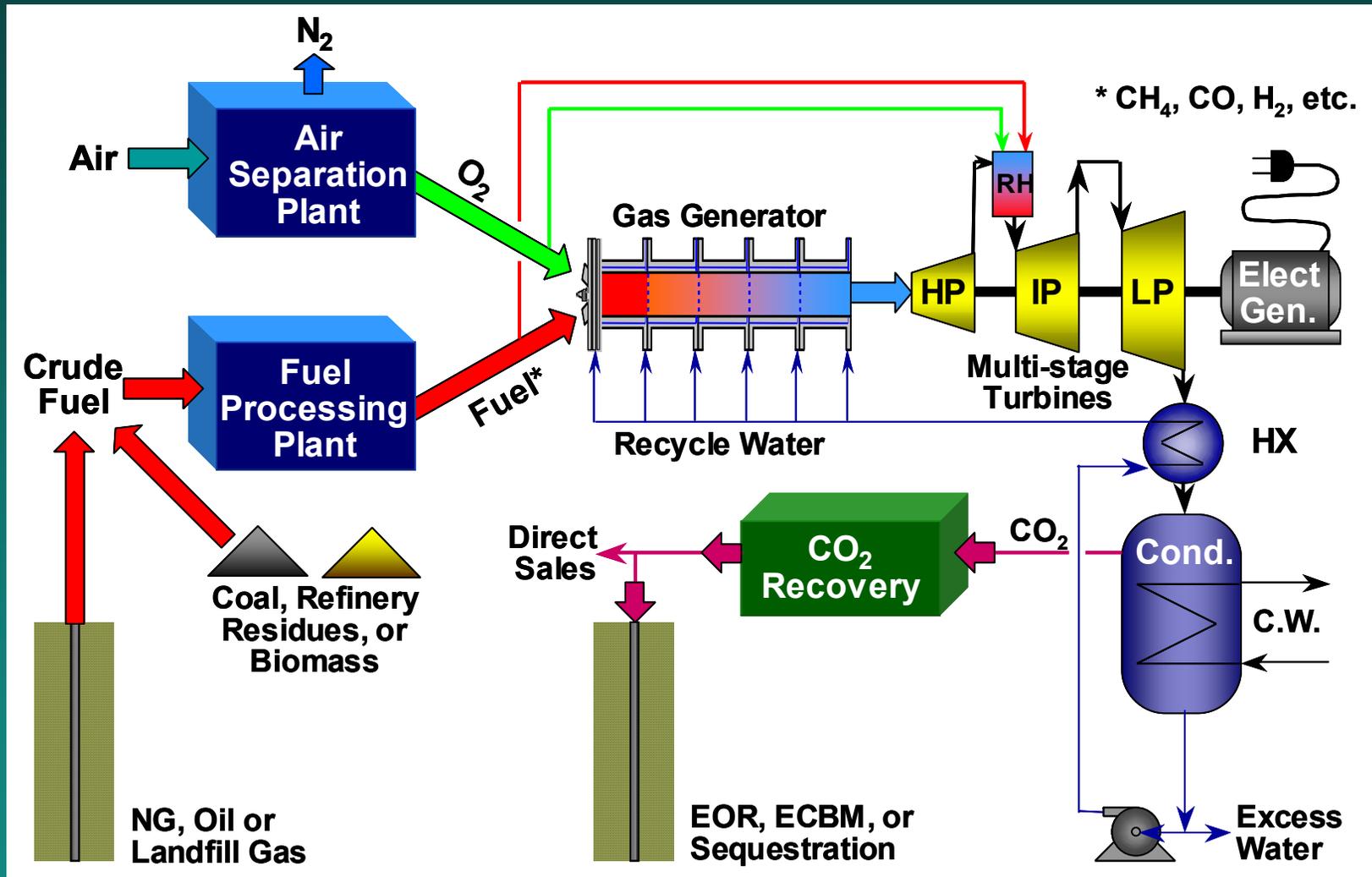
Clean Energy Systems, Inc. (CES)

- Founded in Sacramento in 1993, incorporated in 1996. Aerospace legacy.
- Pressurized oxy-combustion power generation process that enables CO₂ capture from wide range of fuels, including syngas.
- We focus on process rights (IP) and we manufacture the “enabling technology” – the gas generator (oxy-combustor.)
- We own and operate the 5 MW_e Kimberlina demonstration power plant in California.
- Strong Investors (AES, Sempra, Quadrise, Paxton) and Partners (Siemens, Air Products, GC Broach, Kinder Morgan)



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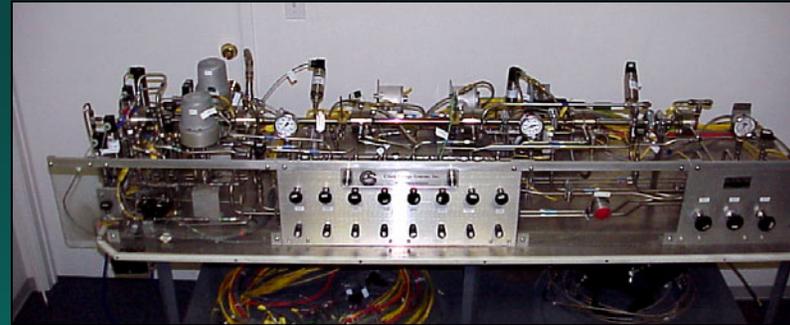
The CES Process



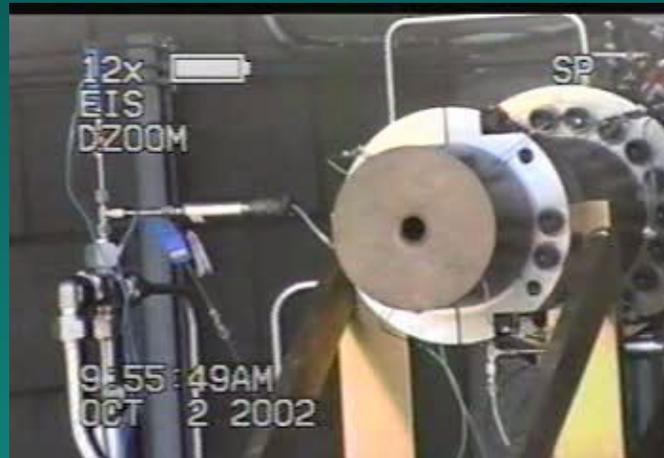
The need: high-temperature steam-CO₂ turbines

Development Milestones

Jan 2000 – fabricated and tested 110kW_t bench scale combustor



Jan 2003 -
fabricated 20 MW_t
pilot-scale
combustor and
conducted short
duration tests



Mar 2005 – installed 20 MW_t combustor
in Kimberlina Power Plant and powered
5 MW_e steam turbine





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Development Milestones

Apr 2006 – completed durability test program at Kimberlina – over 1400 hours and 300 starts



Sep 2006 – tested combustor on simulated coal-derived syngas





Zero-Emissions Power Plant Demonstration

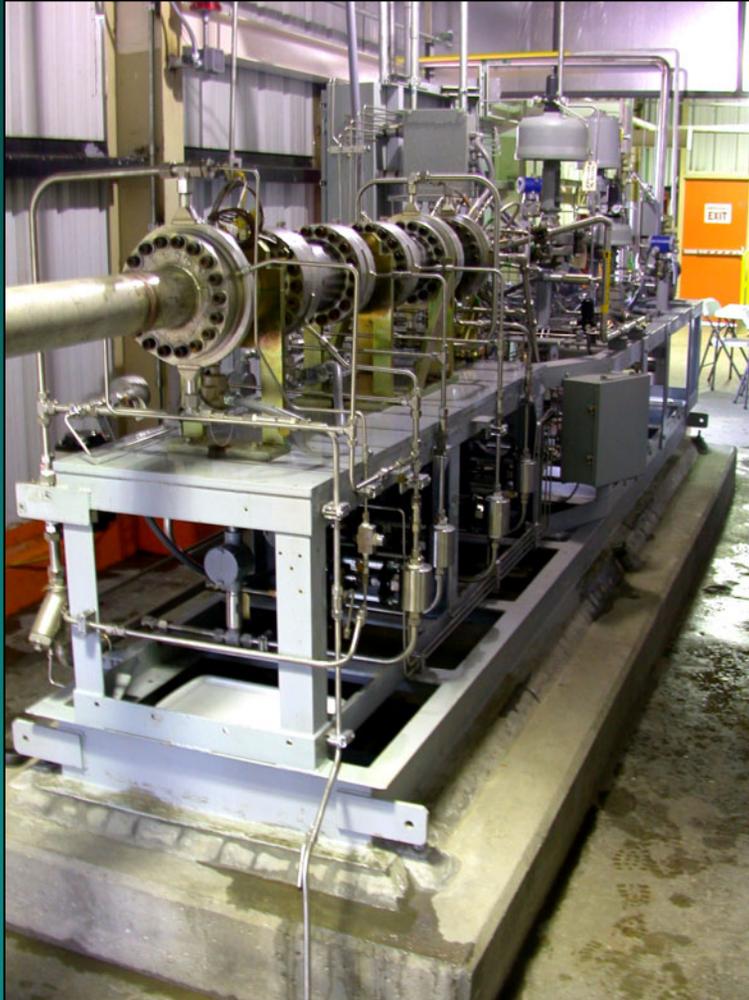
- CES acquired 5 MW_e Kimberlina power plant in Aug. 2003
- In April 2004 CEC approved Kimberlina location and provided \$4 million of \$8.5 million program
- Tests conducted on natural gas, simulated syngas, glycerol, and emulsified bitumen





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Kimberlina Combustor and Power Plant



20 MW_t Combustor (Gas Generator)



5 MW_e Steam Turbine



Original & New (CO₂) Stack



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Oxy-Syngas Combustor Development

- DOE awarded CES \$4.6M to develop oxy-syngas combustion technology: DE-FC26-05NT42645
 - Three year project, started October 2005
 - Using coal-derived syngas and H₂-depleted syngas
 - With > 99% CO₂ capture
- In collaboration with Siemens Power Generation, Inc.
 - \$14.5M DOE funding for first two phases of their project
- Partners and Subcontractors: Siemens Power Generation, Siemens Fuel Gasification (*was Future Energy*), Air Products, GC Broach, Kinder-Morgan



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Outline of Oxy-Syngas Program

➤ Phase I (completed)

- Performed process modeling on long-term (2015) coal-based oxy-syngas cycles
- Installed syngas blending station at Kimberlina
- Modified Kimberlina combustor for syngas operation and tested at 5 MW_t on simulated syngases

➤ Phase II (underway)

- Detailed design of 50 MW_t syngas combustor
- Fabrication of syngas injector
- Contract amendment to add reheater development

➤ Phase III (future)

- Fabrication of remaining combustor components
- Testing at Kimberlina or at third party location
- Looking for testing capability at 50 MW



Results of Systems Evaluation

- Long-term oxy-syngas cycle complements development of IGCC with CO₂ capture
- Need to identify fast-track deployment strategy

	Oxy-Syngas	IGCC w/ CO ₂ Capture
Cycle Efficiency (HHV)	34-38% [1]	31-32% [2] 32-38% [3]
CO ₂ Capture Rate	>99%	85-90%

1. Range depends on availability of supporting technologies such as warm syngas cleanup, advanced compressors, advanced ASU
2. From "The Future of Coal" MIT Interdisciplinary Study, 2007
3. From EPRI Overview of CoalFleet RD&D Augmentation Plan, 2006



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Syngas Testing at Kimberlina

- Blending station installed to supply simulated syngas (mixtures of CO, H₂, CO₂, N₂, and CH₄)
- Combustor modified for syngas operation
 - Fuel delivery system modified for low-BTU fuels
 - Control system expanded
 - New oxy-syngas combustion injector installed
- Parametric testing completed
 - Fuels: Syngas and H₂-depleted syngas
 - Power levels: 2.3 to 4.7 MW_t
 - Combustion pressures: 220 to 340 psia (15 to 23 bar)
- Test data being used to prepare detailed design of 50 MW_t syngas combustor



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Syngas Testing at Kimberlina



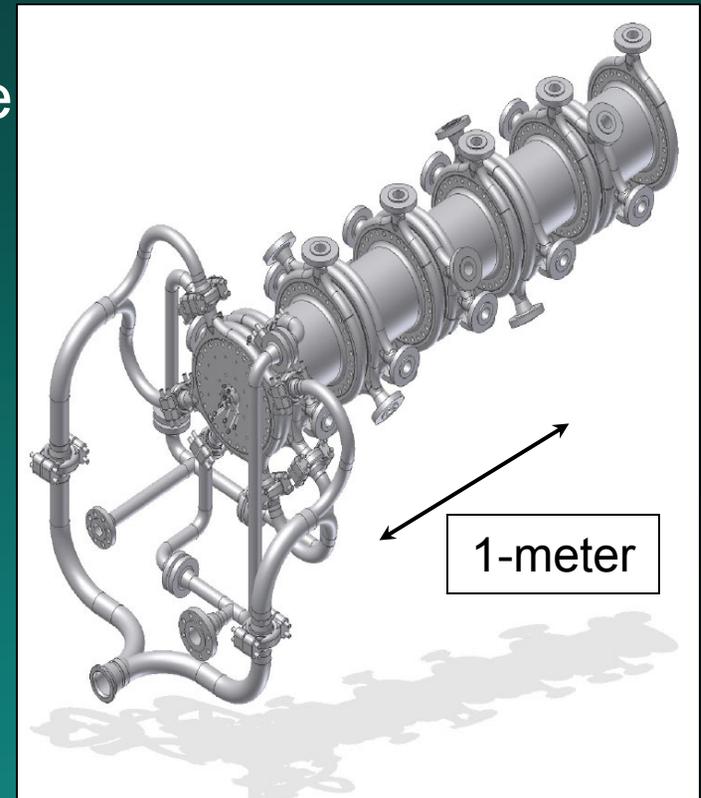
Kimberlina Power Plant during syngas testing. CO and H₂ tube trailers in foreground



Syngas blending station

50 MWt Syngas Combustor

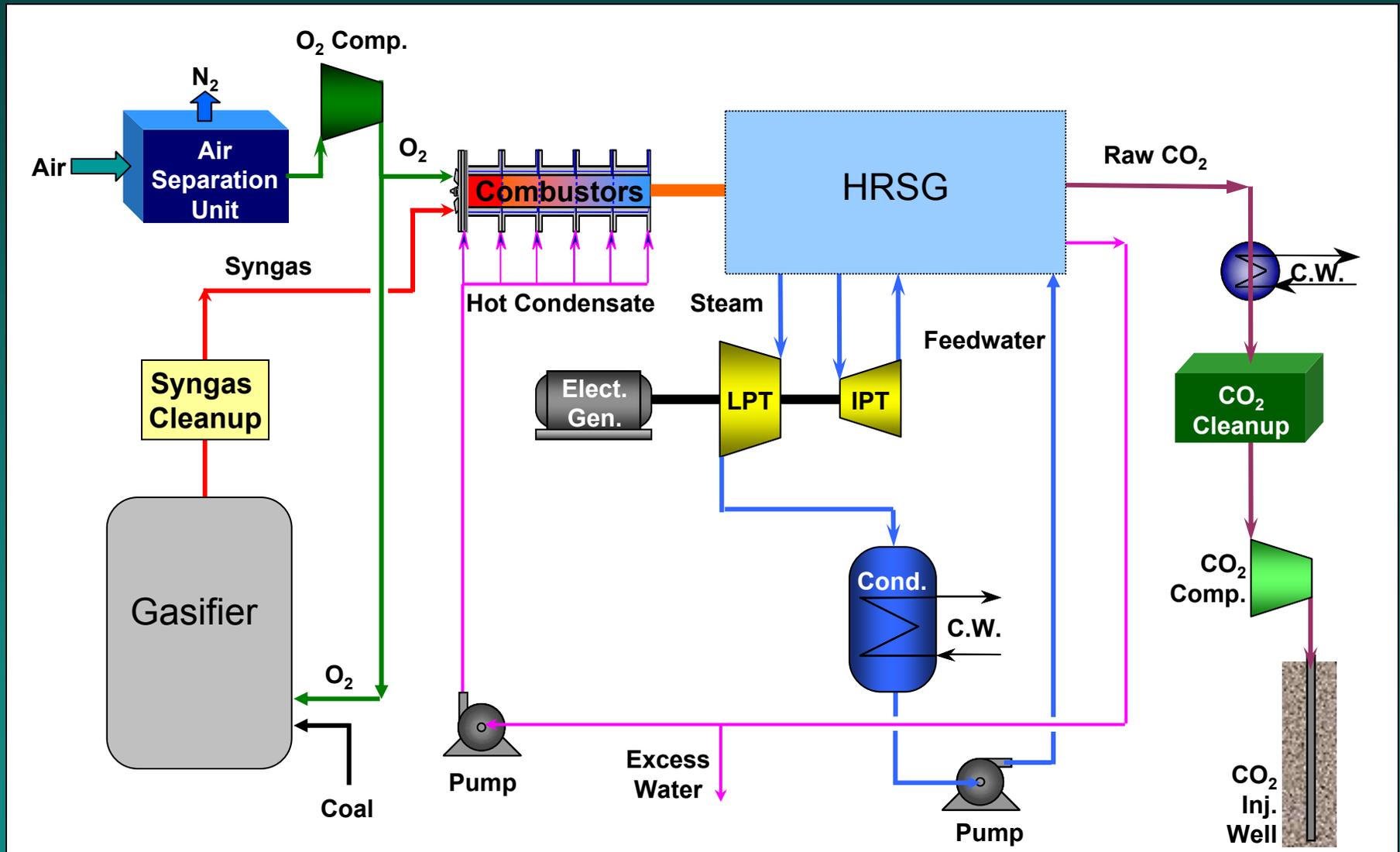
- Represents commercial-scale size
- Combustor scaled up by increasing diameter from 10-cm (Kimberlina) to 30-cm
- O₂-syngas injector based on 10-cm syngas injector tested in Phase I
- Remaining components very similar to those in planned commercial natural gas systems (synergies with other CES projects)





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CES First Generation Integrated Gasification (IGCES) Plant





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1st Generation Zero Emission Coal Plants

- Zero Emission Coal does not compete w/ conventional coal
- Zero Emission Coal with CO₂ sales competes with gas
- An alternative to “mega projects”

	CCGT Long-Term (400 MW)	Utility Coal Today (400 MW)	IGCES Today (50 MW)	IGCES Tomorrow (400 MW)
Cap Cost (\$/kW)	900	1,500	4,000	1,800
Efficiency (%)	55	40	20	33
Gross Electricity Cost (\$/MWH)	53	39	95	47
Byproduct Sales or Credits (\$/MWH)	0	0	46	0
Net Electricity Cost (\$/MWh)	53	39	49	47
Air Emissions	NO _x , CO ₂ , PM	NO _x , CO ₂ , SO _x , PM, Hg	None	None

- 85% load factor, \$20/ton CO₂ credit for EOR Sales today
- Gas at \$6.00/MMBtu, Coal at \$1.50/MMBtu
- Cap Recovery Factor of 10%



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Other Commercial Prospects

- CA-ZEPP 1
 - Natural Gas 50 MW
 - Commercial sale of electricity and CO₂
 - Electricity: \$.085-\$.06/kWh; CO₂: \$20-\$30/ton
 - Gas Generator (combustor) manufacturing underway
- SEQ-1
 - 40 MW Project in the Netherlands. EGR use of CO₂. Nitrogen to be sold to gas transportation company – helps economics
 - Project pending government-issued RFP – expected May 07.
- ZENG
 - 40-70 MW Project in Stavanger, Norway.
 - ZENG AS formed: Lyse Energi, CO₂ Global, Procom Ventures, NEBB Engineering. Additional funding from Shell, Statoil, and Norwegian government.
 - Target is a cycle with 48% efficiency using a 1240°C turbine. Decision to proceed expected summer of 2007