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Kimberlina – A Zero-Emissions Multi-Fuel Power Plant and Demonstration Facility

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Clean Energy Systems, Sacramento, California

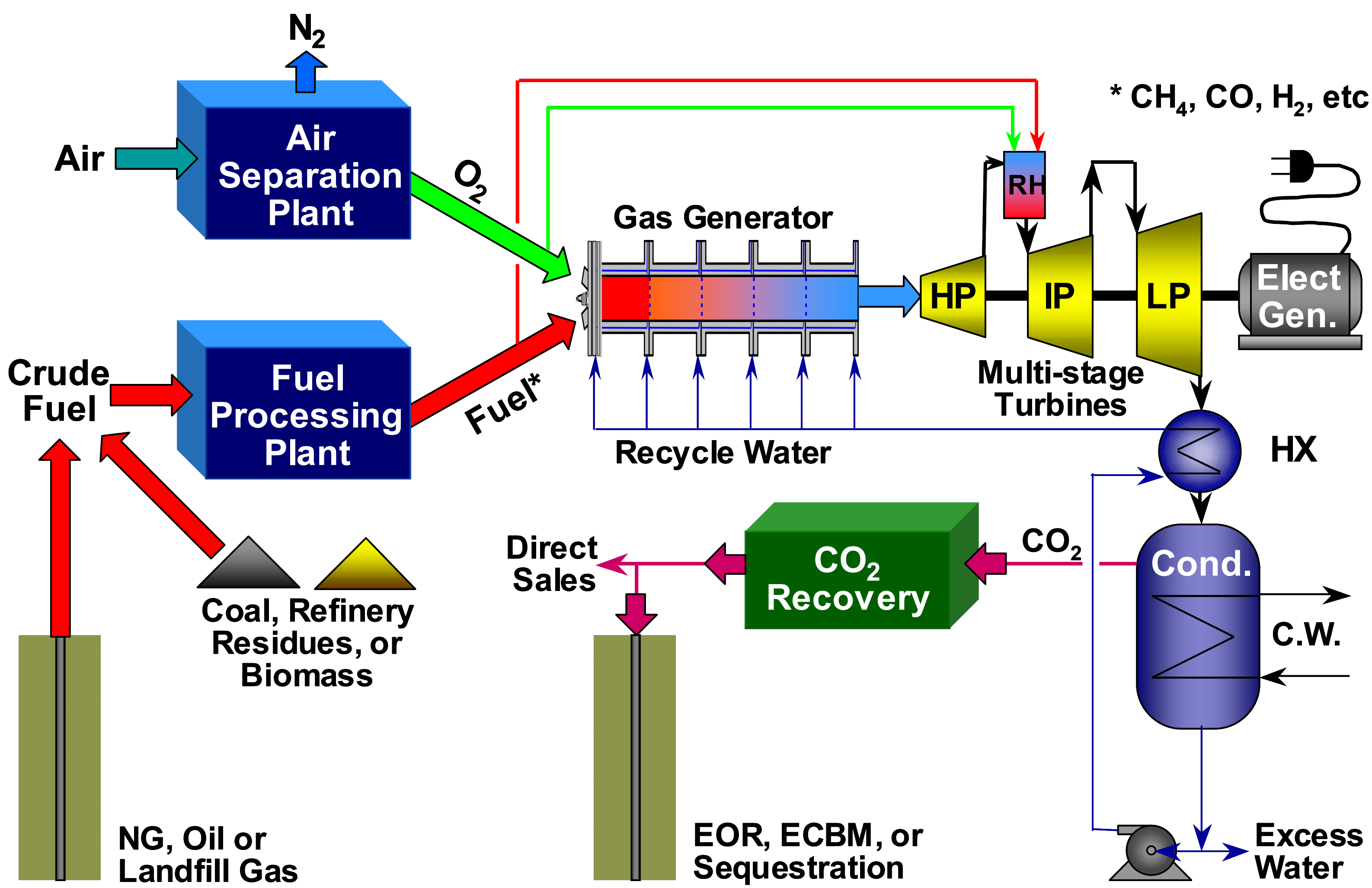
Fifth Annual Conference on Carbon Capture & Sequestration, May 8-11, 2006

Alexandria, VA

Outline

- CES zero-emissions power generation process
- Combustor development and demonstration
  - 20 MW_t combustor
  - Integrated 20 MW_t combustor and control system
- Zero-emissions power plant demonstration at 5 MW_e Kimberlina facility
- Combustor and turbine development for oxy-syngas systems
  - Power plant analyses
  - Syngas combustion testing at Kimberlina
  - Turbine development program

The CES Process



20 MW_t Combustor

- 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 combustor
- Operating pressure of 1500 psi (100 bar) and temps from 1200-3000 ºF (650-1650ºC)
- Testing completed Feb. 03
- Final report submitted June 03
- 100 starts and durations up to limit of test facility

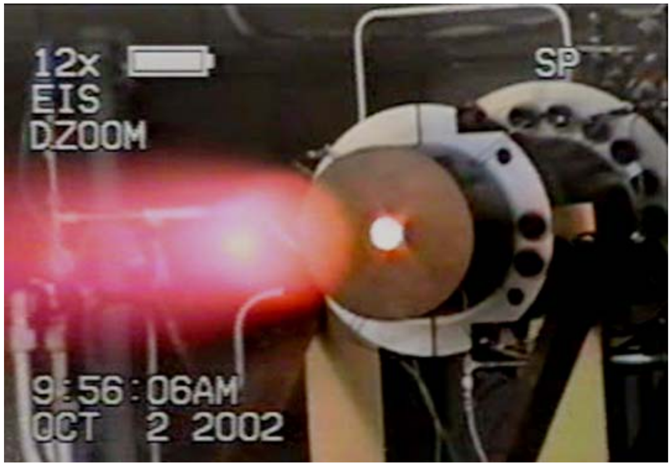
- Produces ~50,000 lb gas/hr (23 mt gas/hr)

Combustor Demonstration

- Operation compatible with both steam turbines and gas turbines (20-114 bar, 315-1650°C) (300-1650 psia, 600-3000°F)

- 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 demonstration



Zero-Emissions Power Plant Demonstration

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- CES acquired 5 MW Kimberlina power plant in Aug. 2003.
- In Nov. 2003 CEC approved Kimberlina location and provided supplemental $2.4 MM funding.

Kimberlina 5 MW Test Facility and Power Plant

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Kimberlina Combustor and Power Plant

20 MW_t Combustor


5 MW_e Steam Turbine


Condenser

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Kimberlina Demonstration Milestones

- Installed & commissioned new facility subsystems
  - ✓ Completed Jan. 05
- Validation tests on integrated combustor/control system
  - ✓ Completed ~3-hour test Dec. 04
- Connected combustor to steam turbine
  - ✓ Produced first power late Feb. 05
  - ✓ Exported power to the grid mid-Mar. 05
- Initiated endurance tests
  - ✓ First long-duration test completed May 05
- Completed demonstration program
  - ✓ Over 1,300 hours and 300 starts by April 06
  - ✓ Continuous run of 105 hours

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Oxy-Syngas Combustor Development

- DOE awarded CES $4.6M to develop oxy-syngas combustion technology
  - Using coal-derived syngas
  - With CO_2 capture
  - Three year project, started 10/1/05
- In collaboration with Siemens Power Generation, Inc.
  - $14.5M DOE funding for first two phases of their project
- Partners and Subcontractors: Nexant, Air Products, ConocoPhillips, GC Broach, Kinder-Morgan

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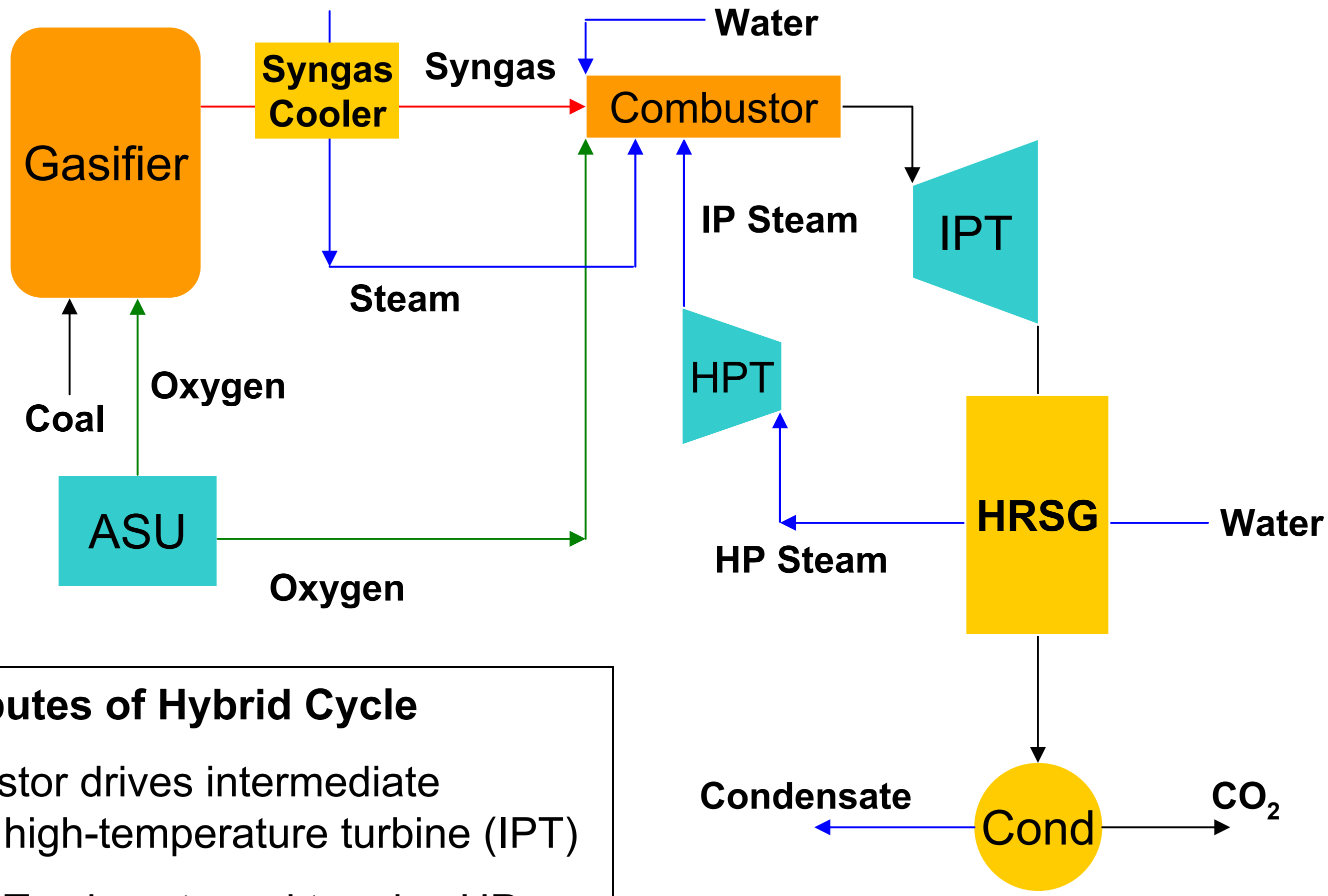
Outline of DOE Program

- Cycle modeling (Phase I)
  - Cases include CES cycles for current (2006), near-term (2010), and long-term (2015-17)
  - Modeling performed by Nexant, Inc. with input from partners.
- Syngas testing at Kimberlina (Phase I)
  - Existing combustor modified for syngas operation
  - Blending station installed to supply simulated syngas
  - Testing starts in May 2006
- Design, fabrication, and testing of 50 MW_t pre-commercial combustor (Phases II and III)
  - Design based on prior combustor experience and preliminary syngas test results
  - To be tested at Kimberlina or third party location (gasifier)

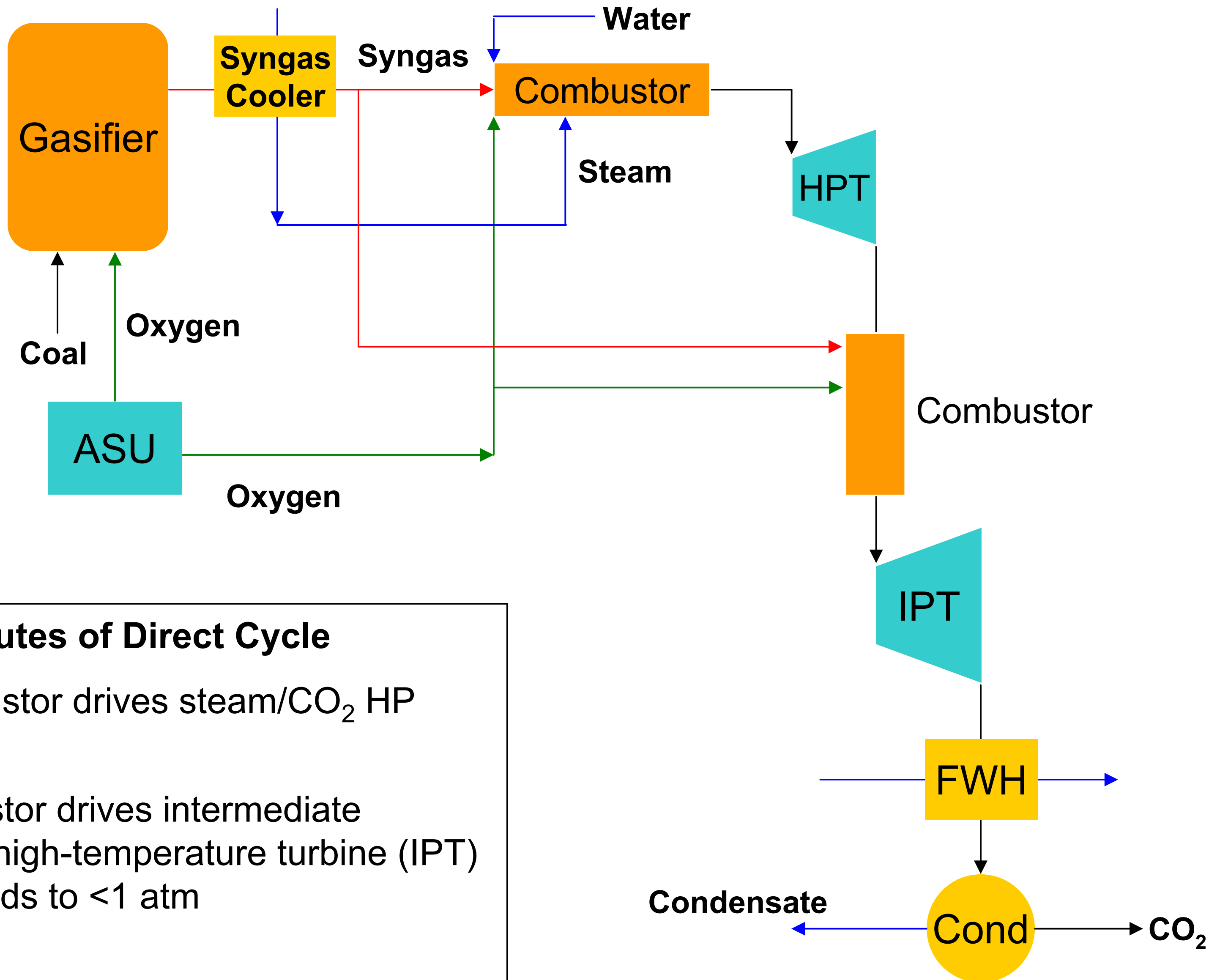
Cycle Modeling: CES Hybrid Cycle



Key Attributes of Hybrid Cycle

- IP combustor drives intermediate pressure, high-temperature turbine (IPT)
- Heat in IPT exhaust used to raise HP steam for back-pressure HPT

Cycle Modeling: CES Direct Cycle



Key Attributes of Direct Cycle

- HP combustor drives steam/CO_2 HP turbine
- IP combustor drives intermediate pressure, high-temperature turbine (IPT) that expands to <1 atm

Preliminary cycle modeling results

- Near-term (2010) results:
  - Cycle utilizes steam/CO_2 IP Turbine with inlet conditions of 1450°C and 30 bar.
  - Cycle efficiencies of ~30-35% (HHV) coal-to-grid, with Hybrid Cycle.
- Long-term (2015-2017) results:
  - Steam/CO_2 HP Turbine at 760°C and 100 bar, and IP Turbine at 1760°C and 30 bar, expanding to <1 bar
  - Cycle efficiencies of 40-50% (HHV) coal-to-grid, with Direct Cycle
  - Higher efficiencies (i.e. >50%) attainable with advancements in supporting technologies such as ITM (oxygen production), warm syngas cleanup, high-efficiency compressors etc.

Syngas Testing at Kimberlina

- Objective
  - Modify Kimberlina combustor for operation on syngas, and collect combustion and emissions data.
- Approach
  - Install blending station to supply simulated syngas.
  - Modify existing combustor, fuel/oxygen delivery systems, and control system to allow operation on syngas.
  - Conduct parametric testing at power levels of up to 5 MW_t
  - Use test data to prepare preliminary design of 50 MW_t pre-commercial syngas combustor

Turbine Development Program

- Objective
  - Demonstrate commercial feasibility of an advanced turbine for oxy-fueled power systems with near-zero CO_2 emissions.
- Approach
  - Build on ultra supercritical steam turbine and advanced gas turbine technology.
- Challenges
  - New working fluid: mostly H_2O with CO_2, plus N_2 (from syngas and ASU) and O_2 (excess from combustion).
  - New turbine materials: strength and corrosion resistance with new working fluid at new temperatures.
  - New turbine cooling: "steam turbine" blades with "gas turbine" cooling; coolant is steam and/or water instead of working fluid.
  - Integrated system controls: harmonize ASU, combustor, and turbine.

Conclusions

- CES and Siemens projects will demonstrate key components needed for zero emission coal-fueled power plants.
- First-generation plants serve as a catalyst to technology development. Projects include peaking power and cogen, and government-supported demo plants (SEQ-1, ZENG).
- The turbines and combustors will benefit other advanced cycles (Matiant, Graz, AZEP, HiOx, etc).
- Further optimizations include the ability to produce high-value hydrogen, especially during off-peak periods.