The 7th International Supercritical CO_2 Power Cycles Symposium
February 21 – 24, 2022, San Antonio, Texas
Paper #120

sCO_2 Primary Power Large-Scale Pilot Plant FEED Summary

Fossil Fuel Large-Scale Pilots

“transformational coal technologies aimed at enabling step change improvements in coal powered system performance, efficiency, and cost of electricity”

- Phase I: Feasibility – completed March 2019
  - 9 projects
- Phase II: FEED – completed January 2021
  - 6 projects
    - sCO_2 (1 project)
    - Gasification (1 project)
    - Advanced combustion (1 project)
    - CO_2 capture (3 projects)
- Phase III: Construction/Operation – began June 2021
  - 2 projects
    - CO_2 capture (2 projects)

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Intended Outcomes of Three-Phase Program

- Prove sCO_2 Recompression Brayton Cycle (RCBC) at large pilot scale
  - Transformational efficiency improvements (2 to 8 points)
  - Range of potential commercial plant sizes (50 to 500 MWe)
  - Flexible heat source
    - Pilot – coal, biomass, natural gas
    - Technology – fossil, nuclear, CSP, biomass, waste heat recovery
- Operate sCO_2 system in power plant environment
  - Connection to grid
  - Duration testing at various loads and ramp rates
- Advance sCO_2 component technology
  - Solid-fuel fired heater (applicable to biomass as well as coal)
  - Parallel turbo-compressors (maximizing sCO_2 efficiency for primary power)
  - Multi-stage axial power turbine (maximizing turbine efficiency at commercial scale)

Technology at TRL 7 upon completion of pilot program

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Project Team

- Echogen Power Systems
  - Power cycle design and fabrication
  - Turbomachinery design and fabrication (Barber Nichols)
- Louis Perry and Associates, a CDM Smith Co.
  - EPC – FEED contractor
  - Balance of plant engineering and Phase III construction
- Electric Power Research Institute
  - Economic analysis
  - Test planning and Phase III test support
  - Industry voice
- University of Missouri
  - Host site
  - Permitting
  - Plant operations
- Riley Power
  - Coal-fired heater design and fabrication
  - Air quality control systems (AQCS) design and fabrication

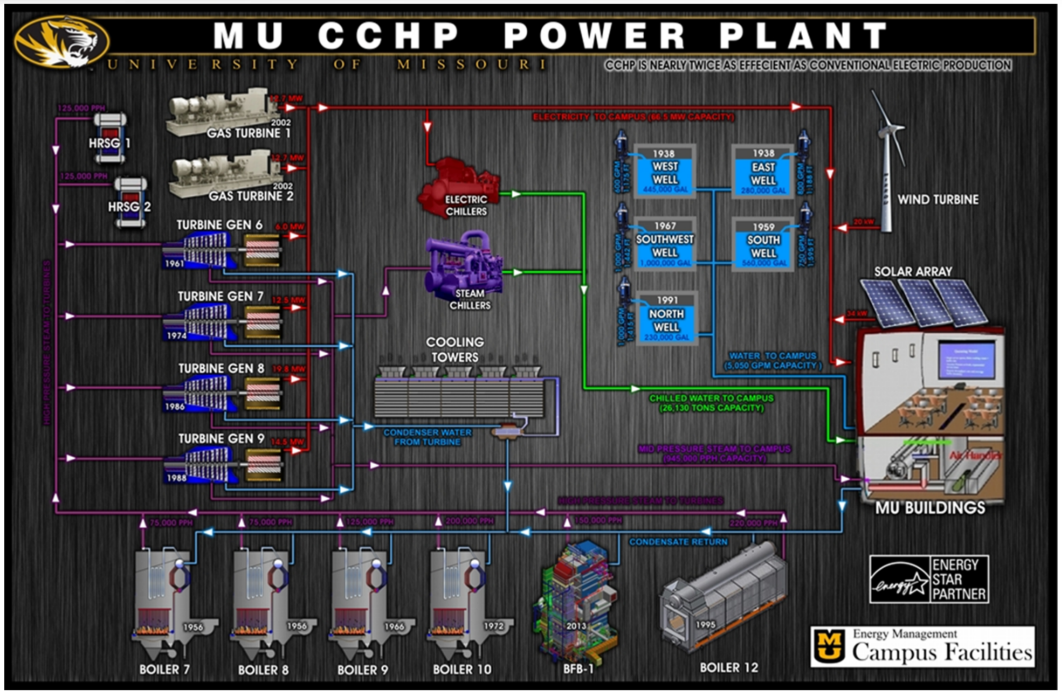
MU Combined Cooling Heat and Power (CCHP) Plant

Plant Summary

- 66 MW electric power generation
- 1.1 MMlb/hr of steam
- Provides heat, power, and chilled water to MU campus

Equipment

- 5 solid fuel boilers
- 1 package boiler
- 2 combustion gas turbines w/ HRSG
- 4 steam turbine generators
- Electric and steam chillers
- Cooling towers and wells



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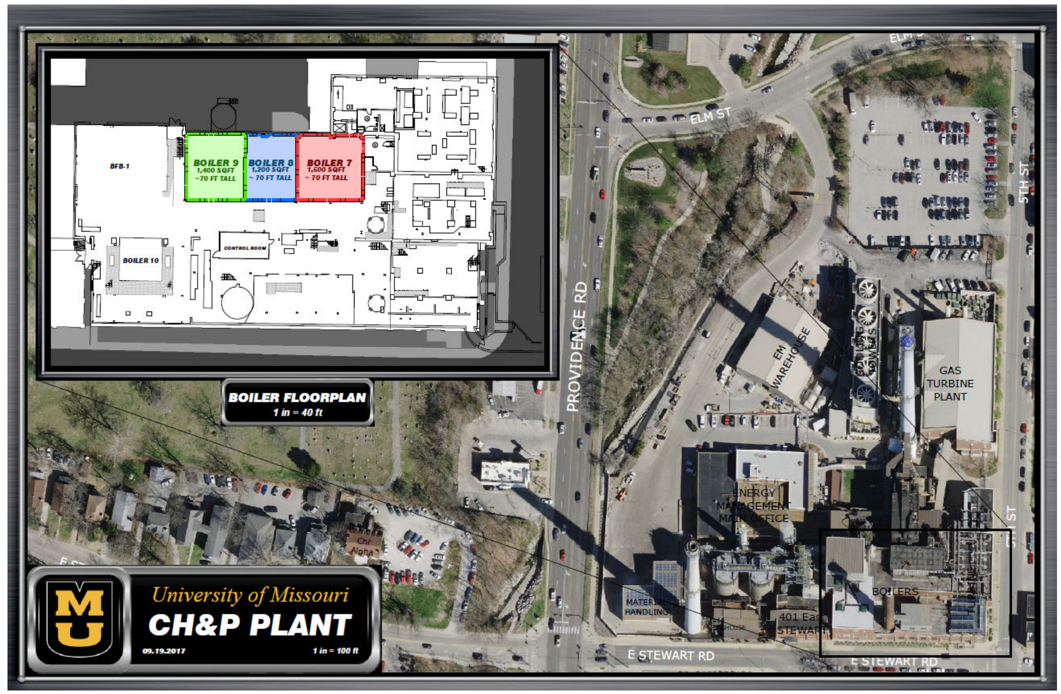
MU CCHP Existing Boiler Building Layout

- Power plant located on MU college campus
- Boilers 7, 8, 9 to be removed and replaced with new CO_2 fired heater and power cycle equipment



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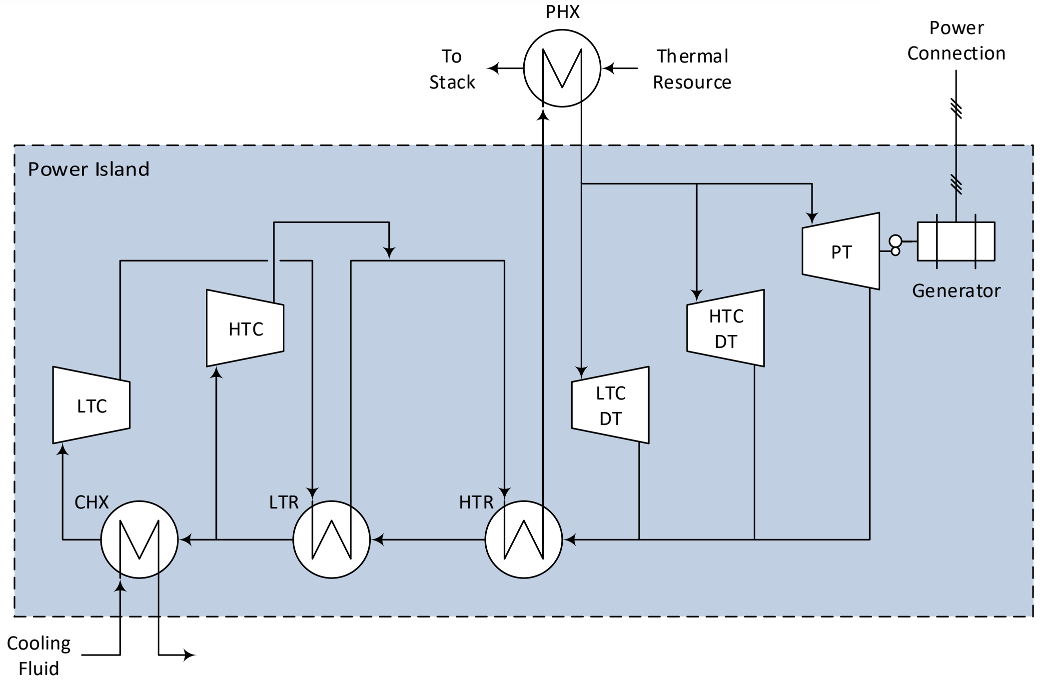
RCBC Configured with Turbine-driven Compressors



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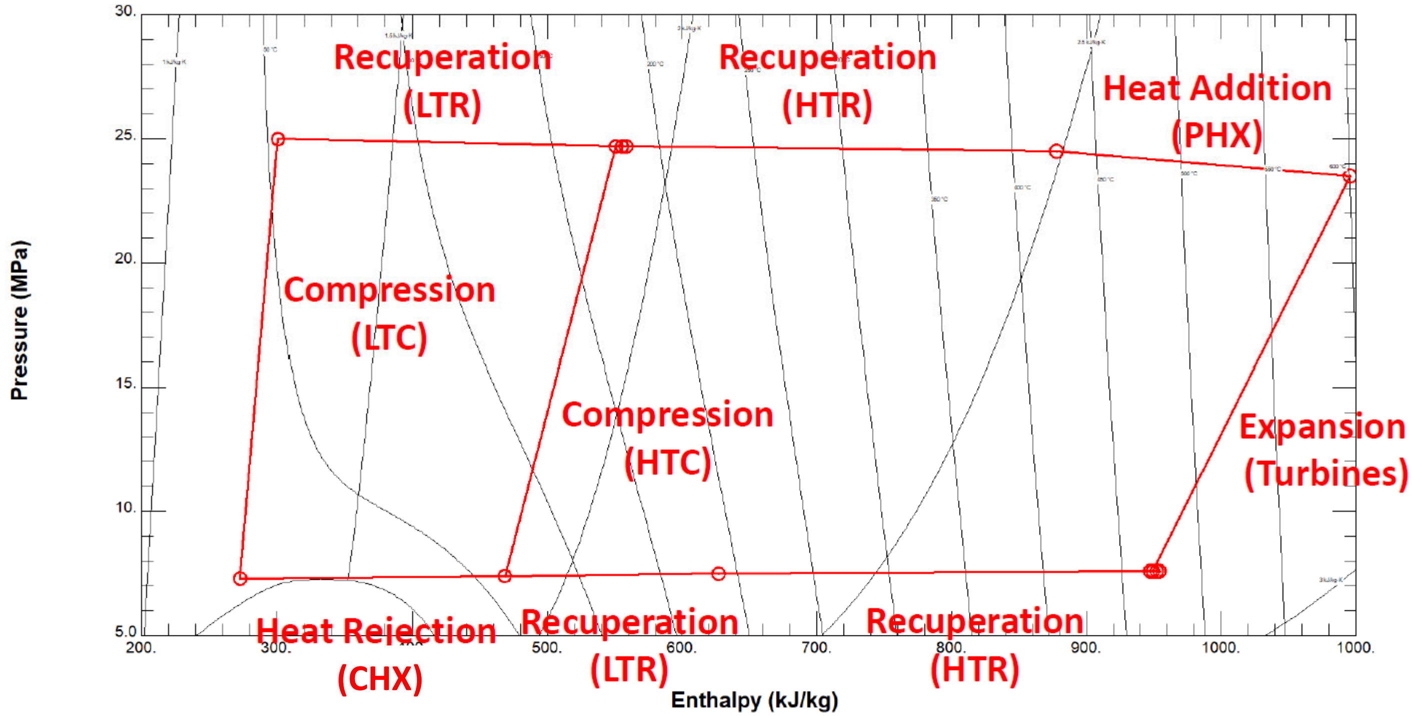
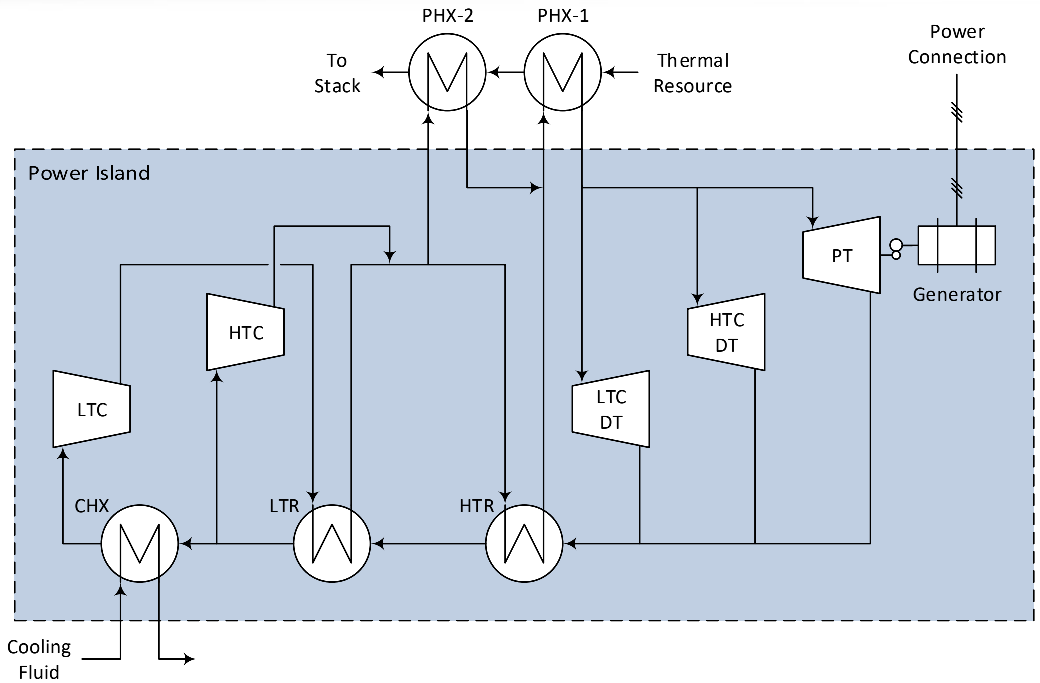
RCBC Pressure-Enthalpy Diagram

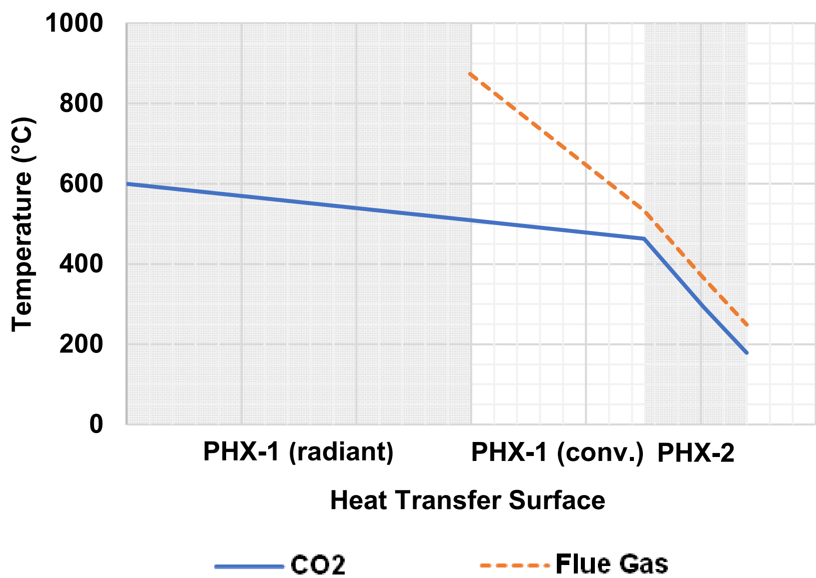


RCBC-E with an sCO_2 Economizer (PHX-2)



sCO_2 Economizer Impact: Fired Heater Efficiency

PHX Temperature Profiles

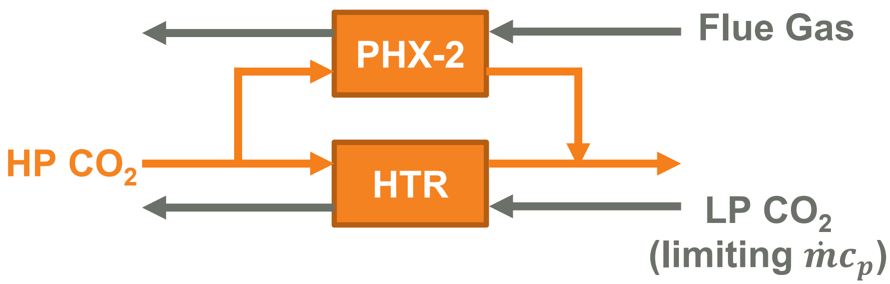


Efficiency Impact

- Economizer (PHX-2) critical for overall plant efficiency with combustion byproduct as the thermal resource
- Added ~10% points to fired heater efficiency

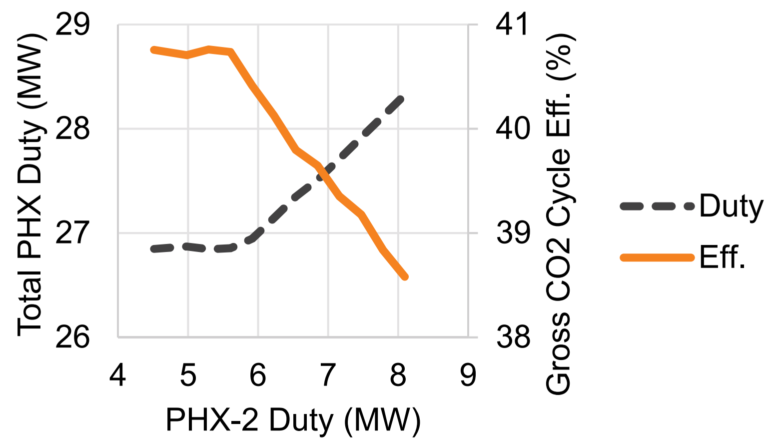
sCO_2 Economizer Impact: Power Cycle Efficiency

HTR Impact



With rising PHX-2 duty…
→ HP CO_2 flow shifts from HTR to PHX-2
→ HTR: Higher $\Delta T_{HP\ CO_2}$, Lower ΔT_{hot}
→ HTR: Lower $\Delta T_{LM,corr}$, Higher UA

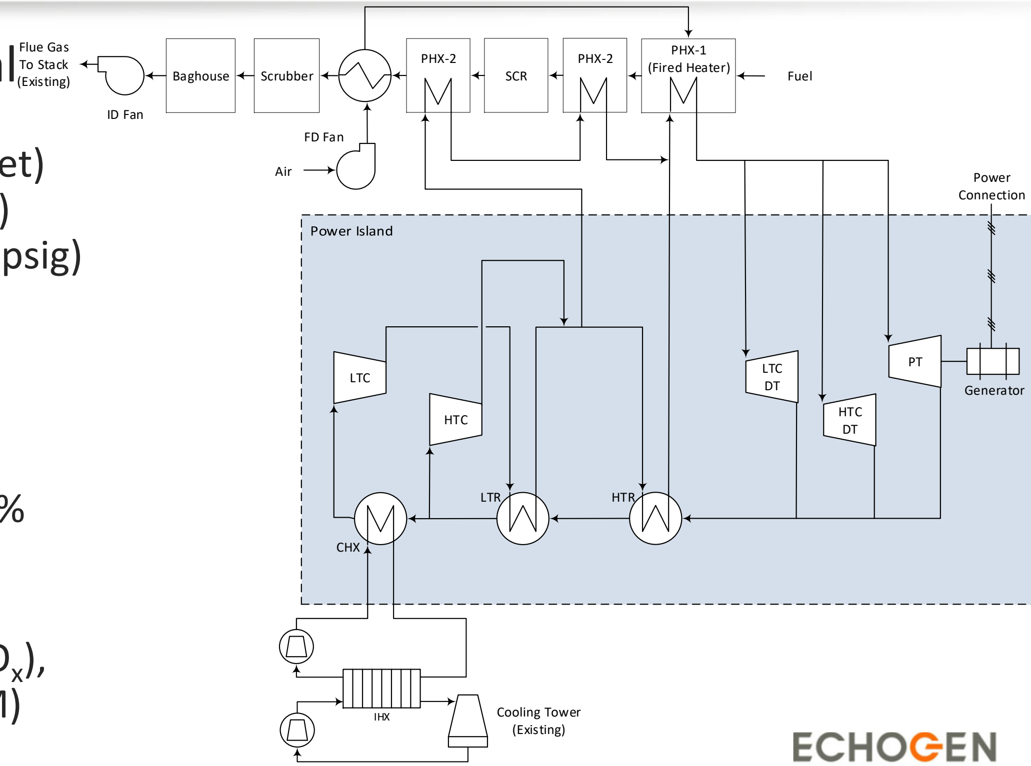
Efficiency Impact



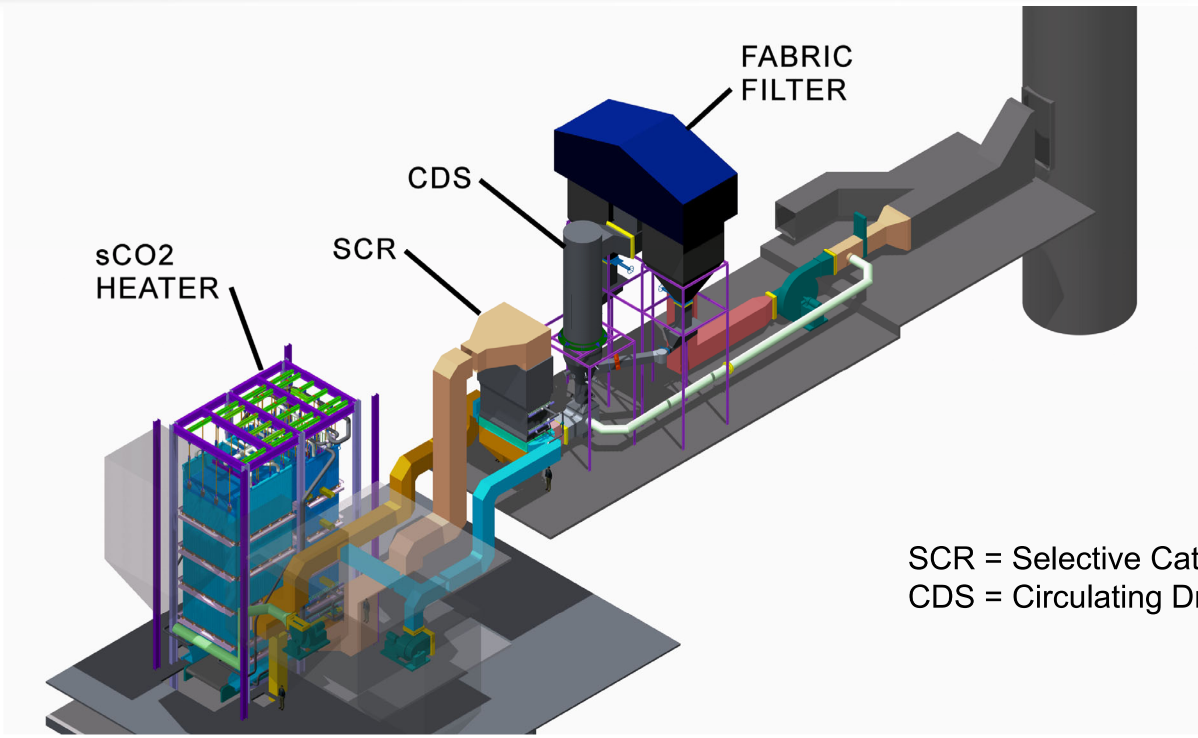
PHX-2 duty not large enough to penalize power cycle efficiency

Process Overview – Fired Heater and sCO_2 Power Cycle

- Power Cycle – 10 MW_e nominal
  - Modified Recompression Brayton Cycle: η = 39.4% (gross), 35.3% (net)
  - Turb. Inlet Temp. = 600°C (1112°F)
  - Turb. Inlet Pres. = 23 MPa (>3300 psig)
- Process Cooling
  - Water cooled (existing system)
  - Cooling water temp. = 26°C
- Fired Heater – 32 MW_{th}
  - Stoker style combustion: η = 84.3%
  - CO_2 cooled walls
- Air Quality Control Systems
  - Full AQCS scope including SCR (NO_x), scrubber (SO_2), and baghouse (PM)

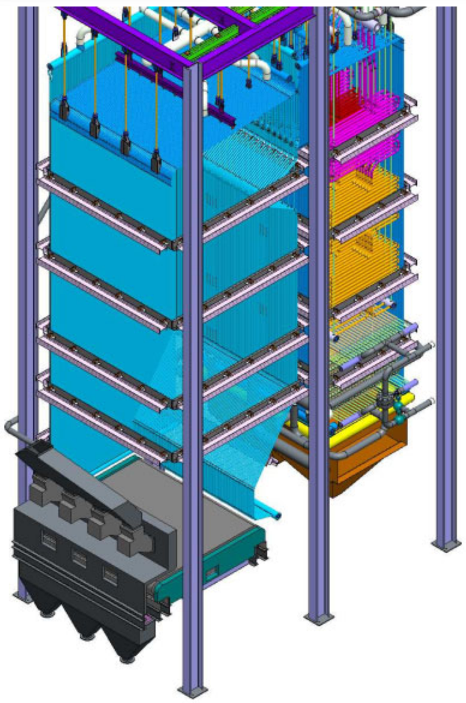


Fired Heater and AQCS



SCR = Selective Catalytic Reduction
CDS = Circulating Dry Scrubber

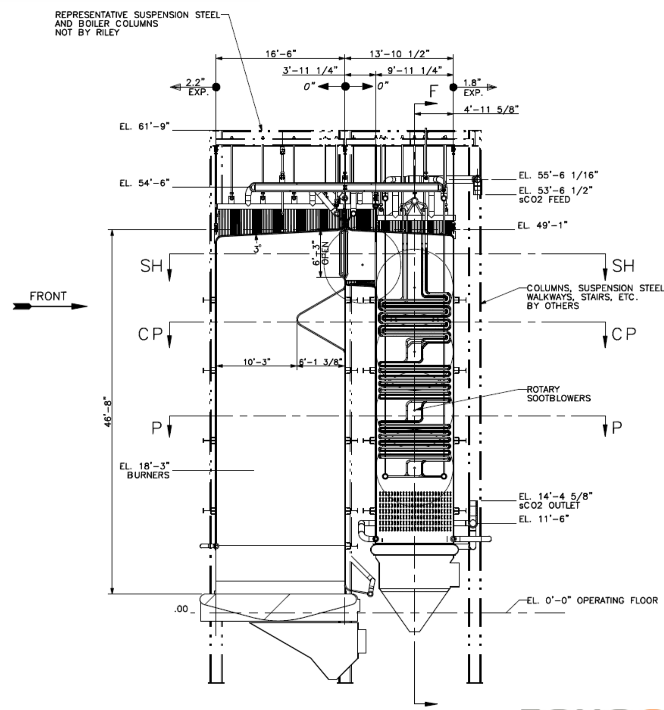
Fired Heater Design Highlights



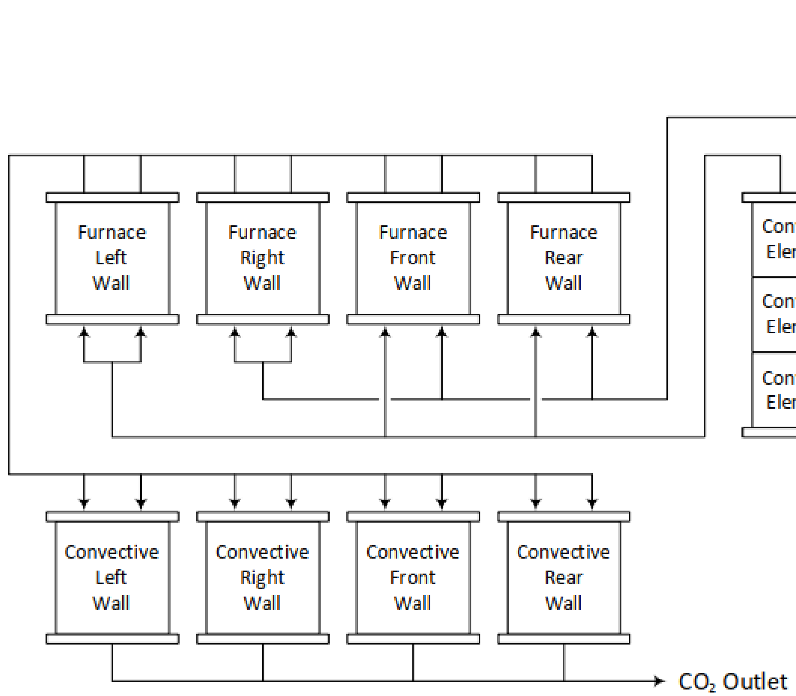
- Fuel
  - Up to 100% Bituminous coal (Illinois #6)
    - HHV 11,338 Btu/lb
  - Up to 100% Natural gas
  - Up to 20% biomass
- Efficiency
  - 84.3% (90% coal / 10% natural gas)
  - 84.6% (100% coal)
  - Stoker technology limitations
    - High excess air (27-30%)
    - High unburned carbon loss (2%)
- CO_2 temperature control
  - Natural gas firing as temperature trim (limited enthalpy differential for attemperation)
- Sootblowers
  - CHP plant steam

Heater Design – Primary Circuit and Economizer

- PHX required to combine
  - Turbine inlet temperature (TIT) comparable to steam-Rankine USC
  - CO_2 wall cooling
  - Solid fuel firing
  - Large pilot scale
- Features
  - Designed similarly to a traditional utility steam boiler (CO_2 is utilized for wall cooling)
  - Radiant furnace for combustion and final CO_2 heating (to 600°C)
  - Convection pass for initial CO_2 heating (three tube banks for CO_2 primary heating followed by one tube bank for CO_2 hot economizer)
  - Features a split economizer system for control of flue gas temperature entering the SCR



CO2 Fired Heater Flow Path



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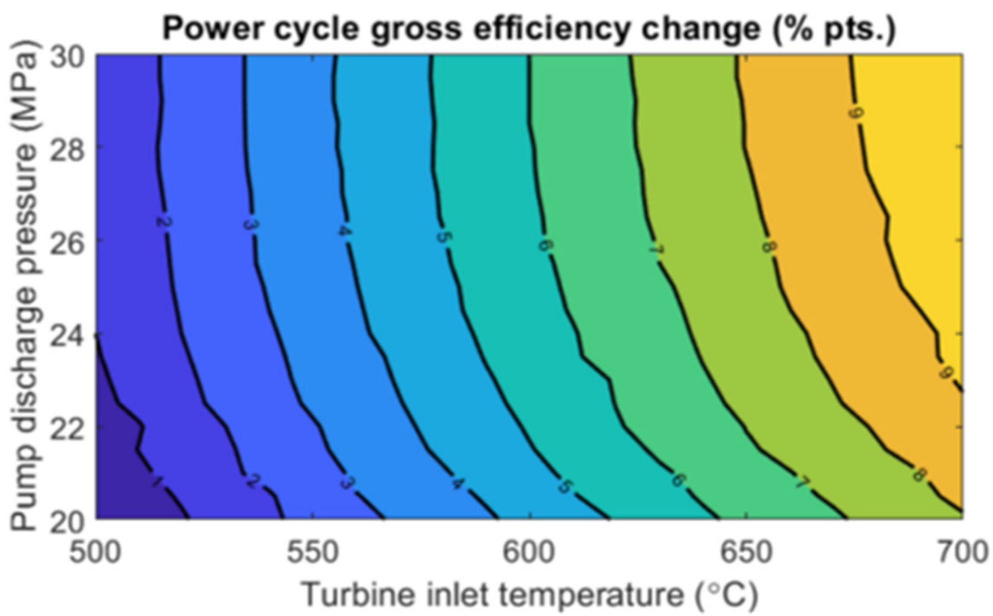
Design Pressure and Temperature



- Efficiency datum
  - PDP = 20 MPa
  - TIT = 500°C
- PDP
  - Diminishing returns above 25-26 MPa
  - LSP: 25 MPa (+10% for design pressure)
- TIT
  - ≥ 600°C to compare with steam-Rankine USC
  - ≥ 600°C reduced allowable stress for SS (or step change cost change for nickel alloy)
  - LSP: 600°C (+10°C for design temperature)

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FEED Performance Predictions

Description	Initial Value (FEED Basis)	Final Value (FEED Results)
Fired heater (%)	86.0	84.3
Power cycle, gross (%)	40.6	40.0
Power cycle, net (%)	37.0	35.8
Overall plant (%)	31.8	30.2

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Acknowledgements

- This material is based upon work supported by the Department of Energy under Award Number DE-FE0031585.
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