Start-up Modeling for a 10MWe sCO2 Primary Power Plant

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ECHOGEN
power systems

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Supercritical CO_2
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Symposium

Presentation Agenda

- Introduction
  - Fossil Fuel Large Scale Pilots DOE Project
  - Large Scale Pilot sCO2 Power Cycle
  - Simulation Study Motivation
- Modeling Methodology
- Start-up Modeling
  - Overview
  - Procedure
  - Results
- 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"

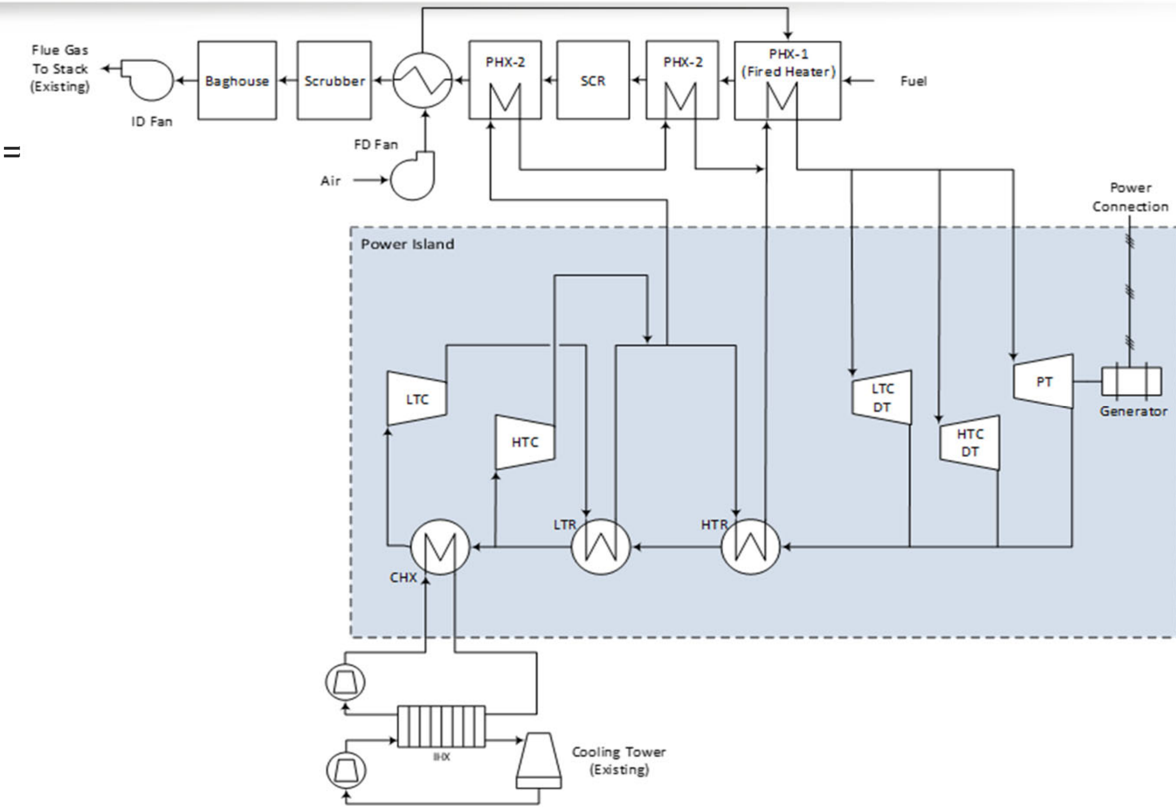
- Phase I: Feasibility
  - 9 projects
- Phase II: FEED
  - 6 projects
    - sCO_2 (1 project)
    - Gasification (1 project)
    - Advanced combustion (1 project)
    - CO_2 capture (3 projects)
- Phase III: Construction/Operation
  - 1–2 projects

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

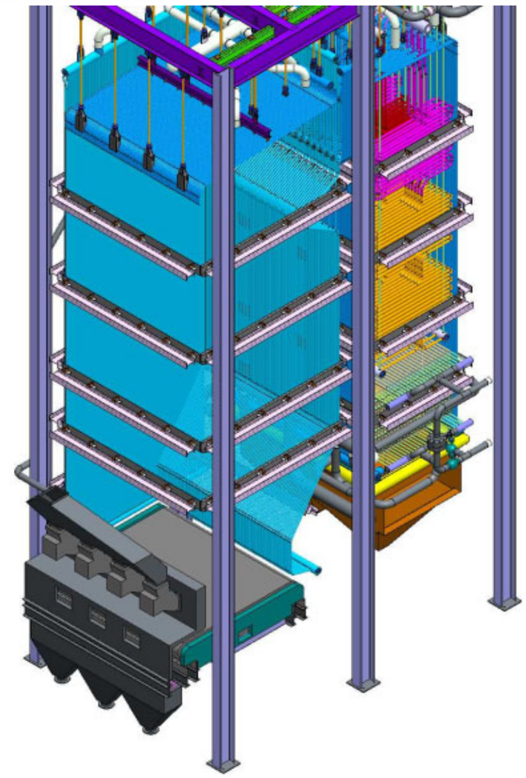
Large Scale Pilot sCO_2 Power Cycle

- Power Cycle – 10 MW_e nominal
  - Modified Recompression Brayton Cycle: h = 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)
- Fired Heater – 32 MW_{th}
  - Stoker style combustion: h = 84.3%
  - CO_2 cooled walls
  - Up to 100% Bituminous coal (Illinois #6)
    - HHV 11,338 Btu/lb
  - Up to 100% Natural gas



Simulation Study Motivation

- LSP applied stoker-fed coal fired heater as sCO2 power cycle primary heat exchanger
  - Large CO2 side volume – majority of system volume
  - High heat source temperature
  - Limited ability to control heat input
- Fired heater uses natural gas during start-up and switches to coal firing when CO_2 flow is established
  - Targets CO_2 outlet temperature
- Novel start-up method developed to avoid need to fill fired heater with liquid CO_2 to achieve start-up
  - Minimize CO_2 inventory requirement
- **Transient simulation of 1D LSP system model used to evaluate the effectiveness of novel start-up method**



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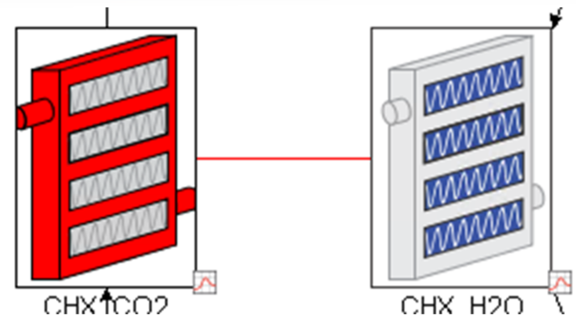
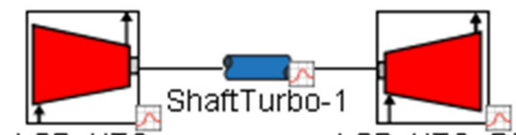
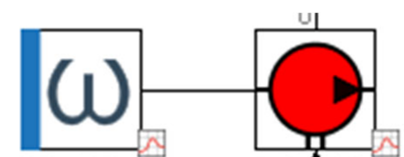
Modeling Methodology

- Modeling Platform
  - GT-SUITE v2020
- Heat Exchangers
  - Fired Heater (PHX1 + PHX2)
    - Co-simulation Functional Mock-up Unit (Riley Power, Inc.)
  - Printed Circuit Heat Exchangers (CHX, LTR, HTR)
    - Empirical correlations using exchanger geometry



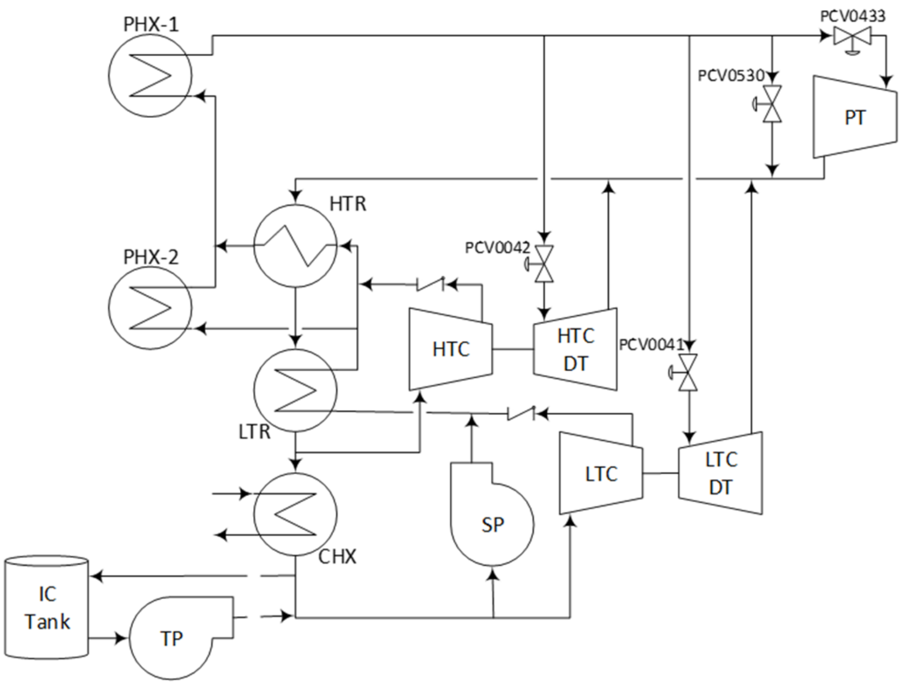
- Turbomachinery
  - Turbines (HTC DT, LTC DT, PT) + Compressors (HTC, LTC)
    - Performance maps (Barber Nichols): isentropic enthalpy change, corrected mass flow rate, corrected speed, and ETA
  - Pumps: positive displacement (TP), centrifugal (SP)
    - Performance map: pressure rise, volumetric flow rate, speed, and ETA (SP)
    - Fixed volumetric ETA and displacement with variable speed (TP)





Start-up Overview

- Start-up process transitions system from initial vapor fill to turbo-compressor (LTC DT + LTC) self-sustaining operation in 3 steps
- Minimize CO_2 inventory requirement
- Avoid two-phase at electrically-driven start pump (SP) inlet
- System CO_2 below saturation pressure of cooling heat exchanger (CHX) process water during start-up
  - CHX acts as evaporator
    - Danger of two-phase inlet to SP
  - Three process water temperatures (Tcw) simulated
    - 18 °C, 26 °C, and 32 °C



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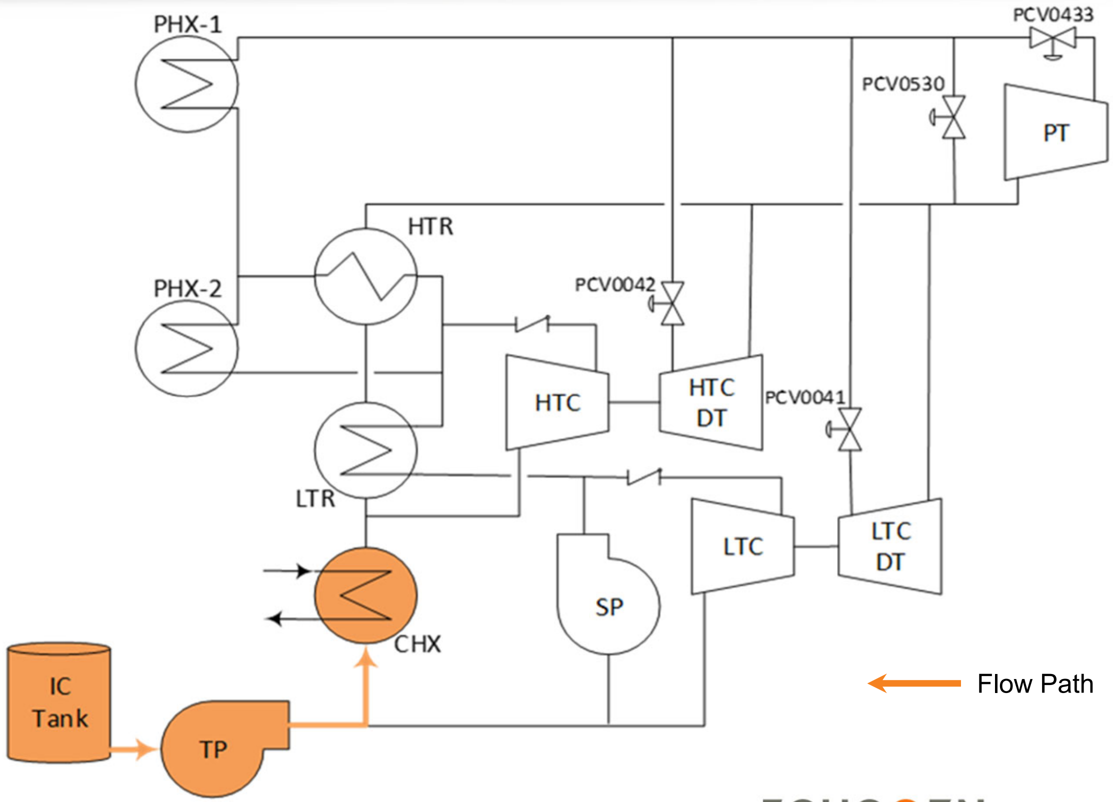
Start-up Procedure – Step 1

- Liquid CO_2 pumped from inventory (IC Tank) to system through the transfer pump (TP)
- Liquid enters the CHX and boils
  - CO_2 pressure is below saturation pressure at Tcw
- Heat and mass addition increases system CO_2 pressure
- Transition to step 2 once system CO_2 pressure reaches saturation pressure at Tcw



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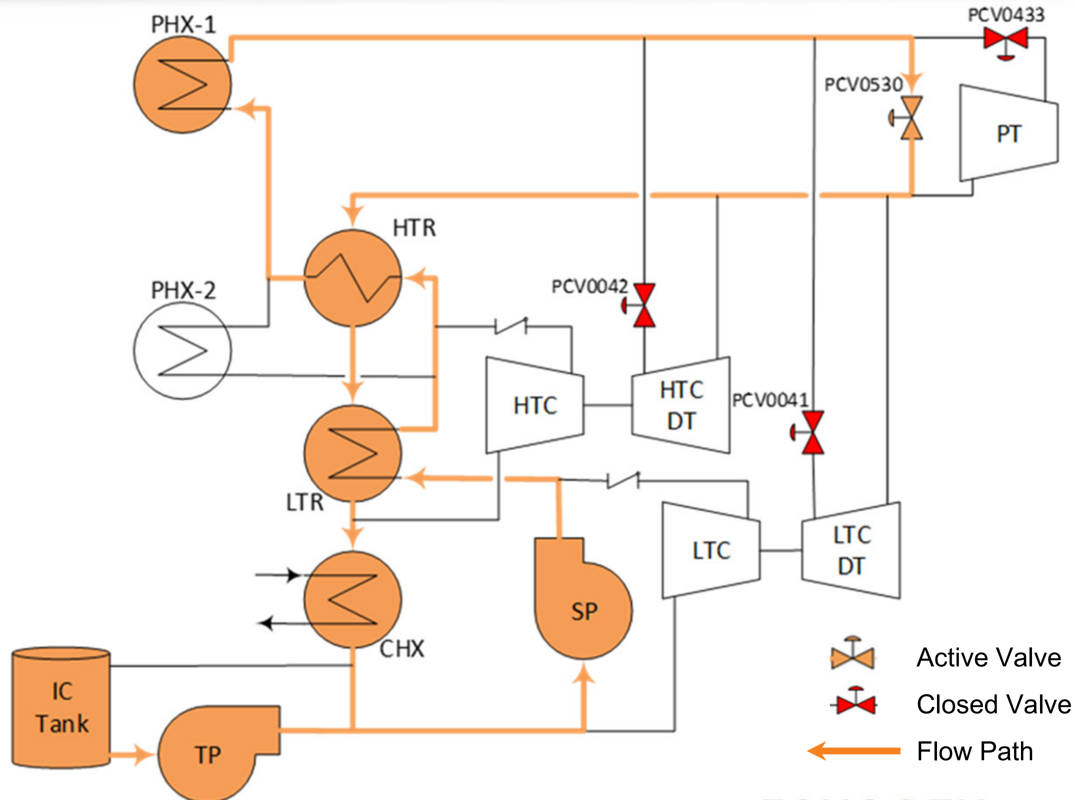
Start-up Procedure - Step 2

- SP begins to circulate CO_2 through the system with target of 8 kg/s
- PCV0530 used to control SP mass flow rate
- Fired heater gas burners are lit
  - No coal at this stage
  - Heat addition to system through PHX-1
- Fired heater CO_2 outlet temperature target set to 100 °C
- Transition to step 3 when CO_2 pressure at SP inlet reaches target design pressure



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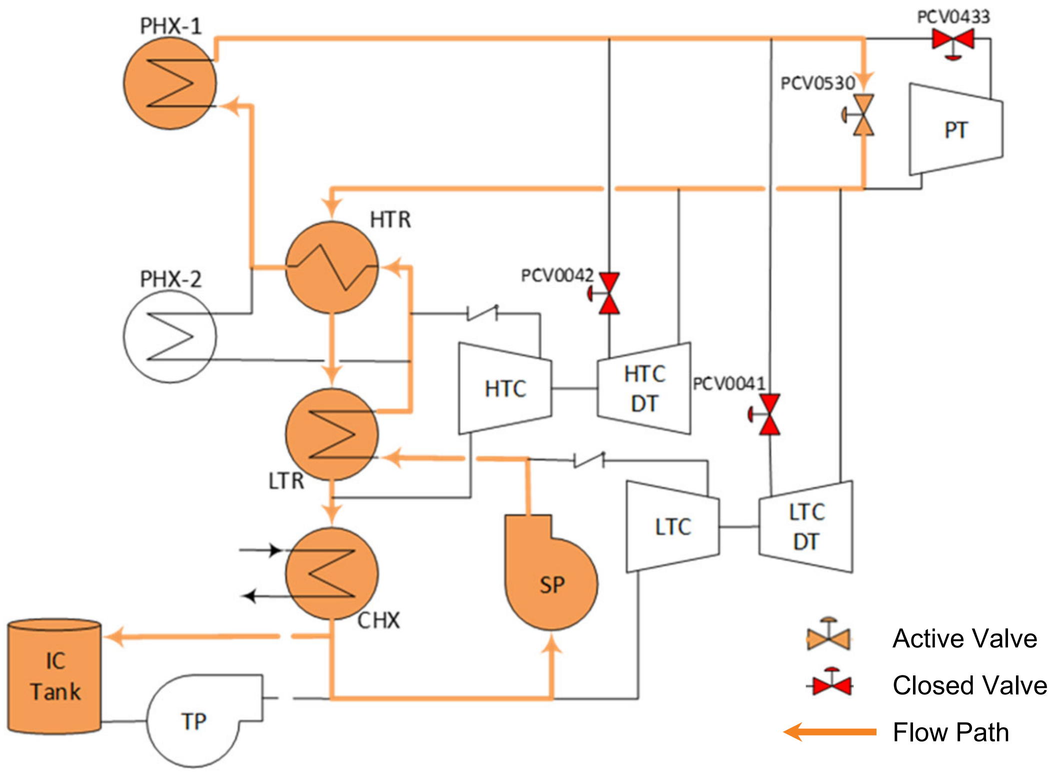
Start-up Procedure – Step 3

- Inventory control system (ICS) activates
  - Maintains target SP inlet pressure by addition or subtraction of CO_2 mass
- SP mass flow rate target increased to 20 kg/s
- Fired heater target CO_2 outlet temperature increased to 250 °C



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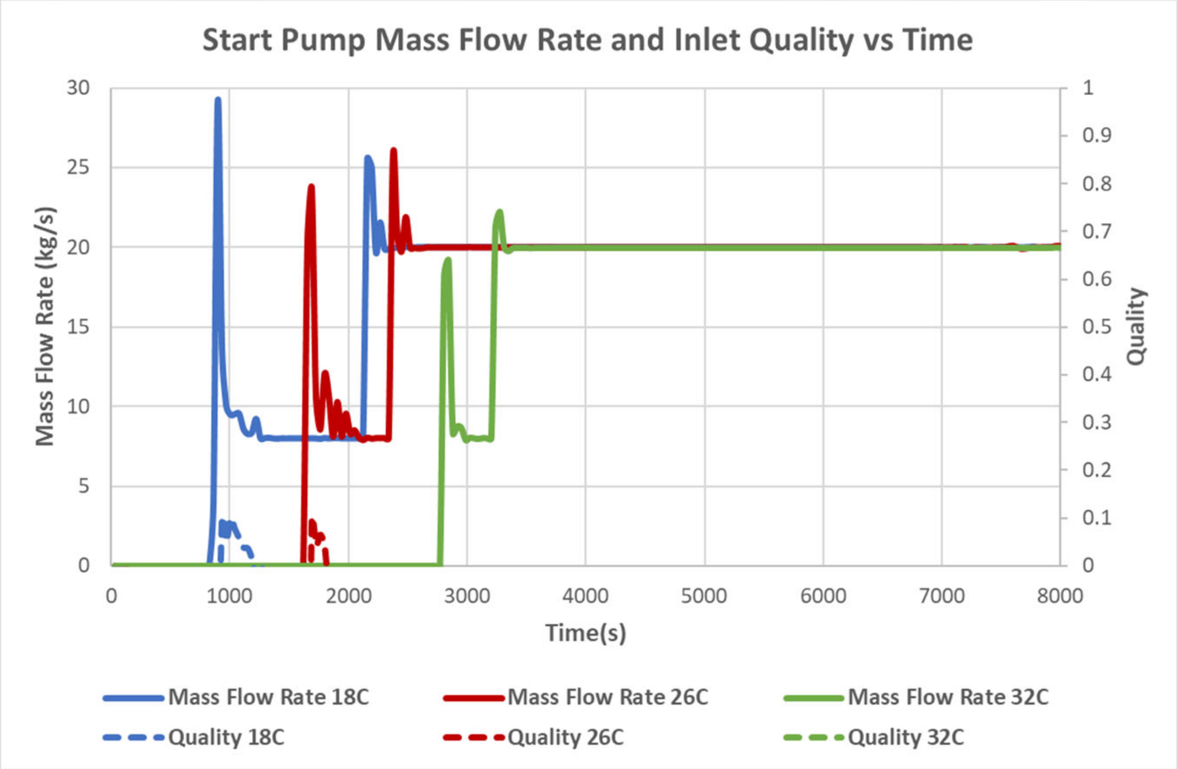
Start-up Results

- Two-phase flow observed at SP inlet during transition from Step 1 to Step 2 for Tcw = 18 °C and 26 °C
  - No two-phase in 32 °C case
- Mass flow rate spikes during step transitions
  - Magnitude greater for lower Tcw cases



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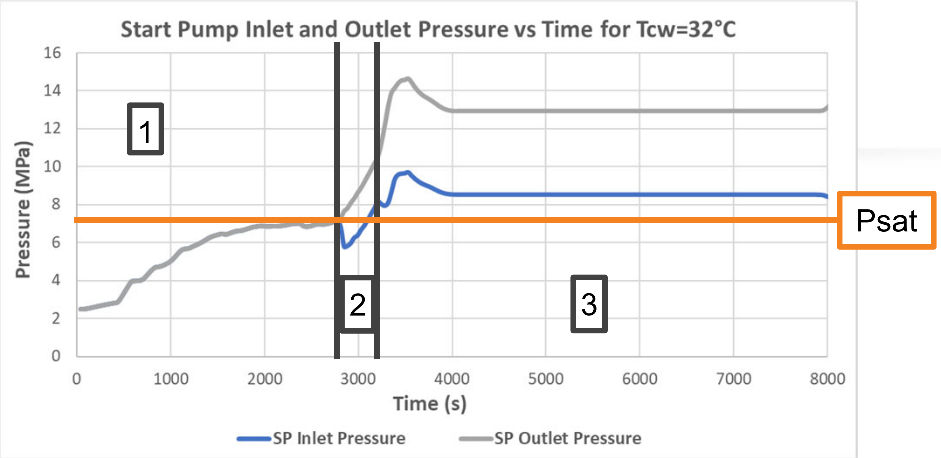
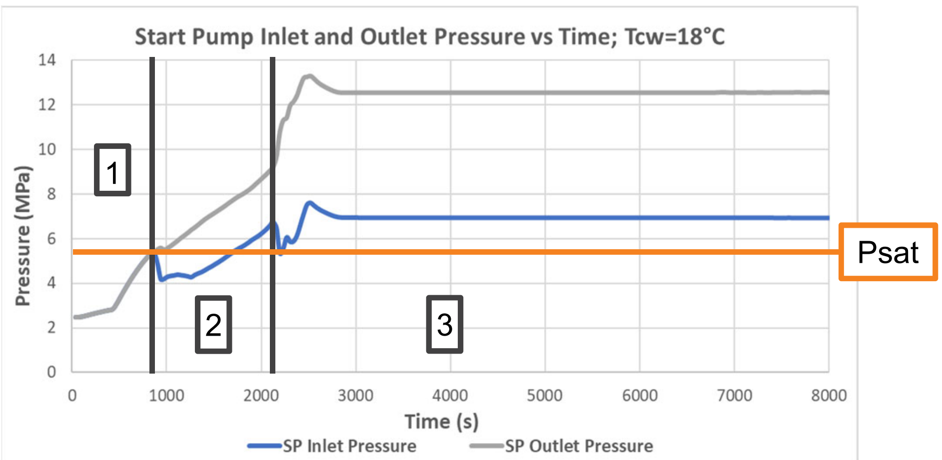
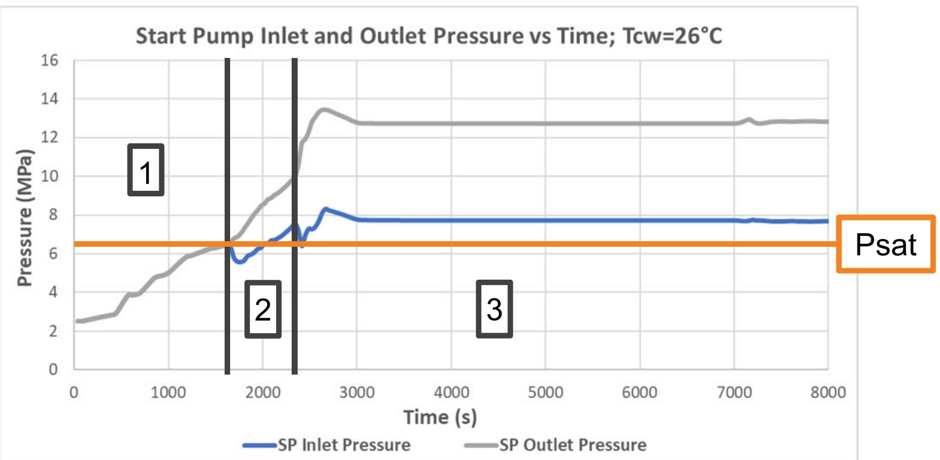
Start-up Results

- Sharp decrease in SP inlet pressure at step transitions
  - Below saturation pressure for step 1 to step 2
  - Two-phase flow at CHX outlet
- Slow pressure rise build across the pump
  - Mass flow rate spikes







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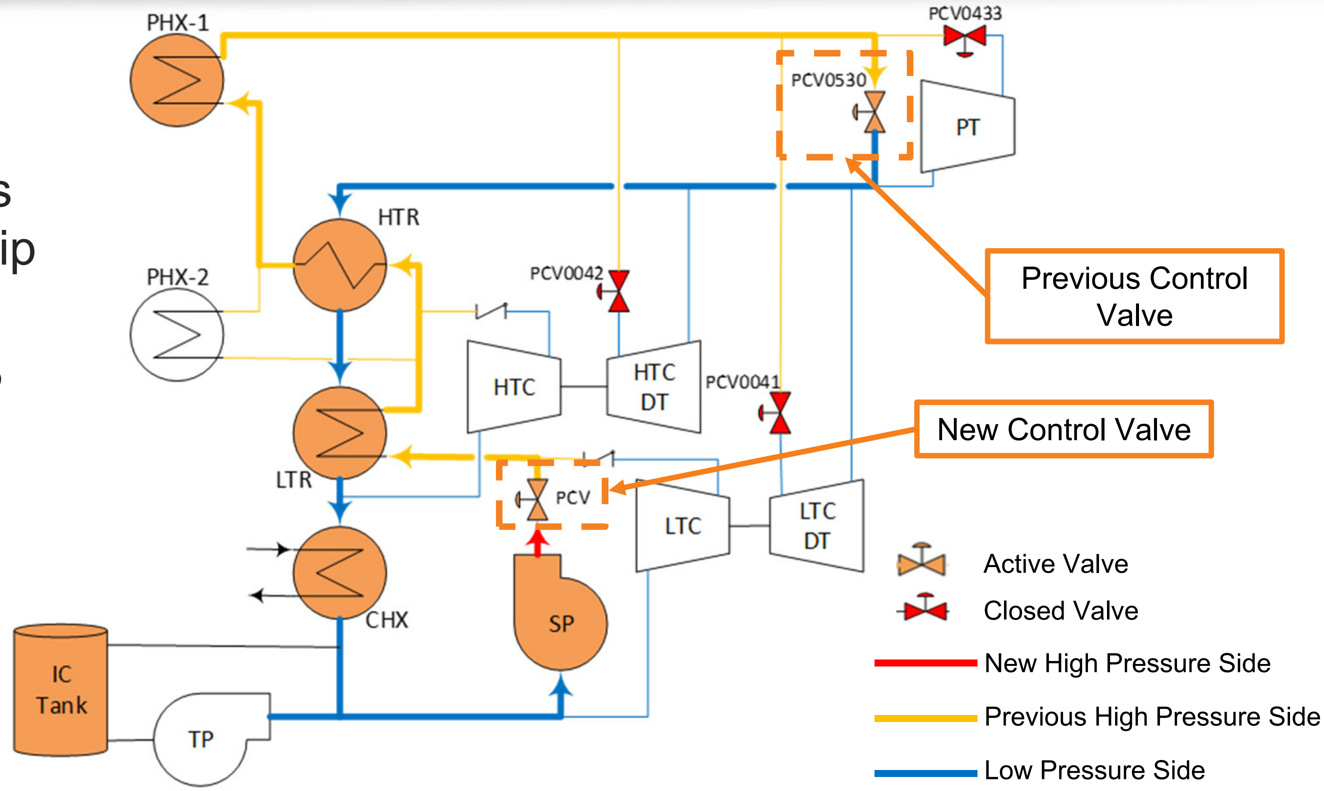
Start-up Results

- Add control valve close to SP outlet (PCV)
  - Prevent mass flow rate spikes
  - Eliminate low side pressure dip
- Transition flow rate control back to PCV0530 after Step 3



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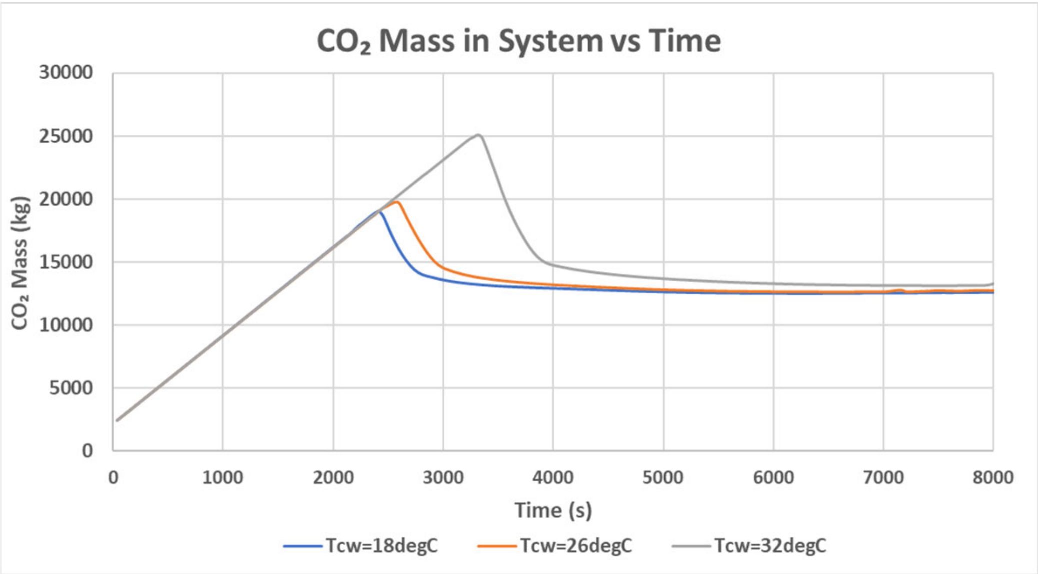
Start-up Results and Discussion

- 44,850 kg of CO_2 needed to fill the system
- Novel start-up method reduced CO_2 mass required by 44% (worst case)
- Greater reduction predicted with controls refinement and additional control valve

Tcw (°C)	PEAK CO_2 MASS (kg)	PEAK CO_2 MASS REDUCTION (%)
18	18998	57.6
26	19766	55.9
32	25093	44.1



Summary

- Project team lead by Echogen Power Systems awarded funding for a phase II FEED study of a proposed stoker-fed, coal-fired, 10MW_e sCO_2 Economized Recompression Brayton Cycle Primary Power Large-Scale Pilot Plant as part of the DOE Fossil Fuel Large-Scale Pilots program
- Novel start-up method was developed in response to the application of a stoker-fed coal fired heater as sCO2 power cycle primary heat exchanger
- Transient simulation of 1D LSP system model used to evaluate the effectiveness of the novel start-up method
- Start-up method reduced required CO_2 inventory by 44% over filling the fired heater with liquid CO_2
- Control valve at SP outlet should be added to prevent two-phase flow at SP inlet and improve CO_2 inventory reduction

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