Regulatory Control of a 10 MWe Supercritical CO_2 Recompression Closed Brayton Cycle

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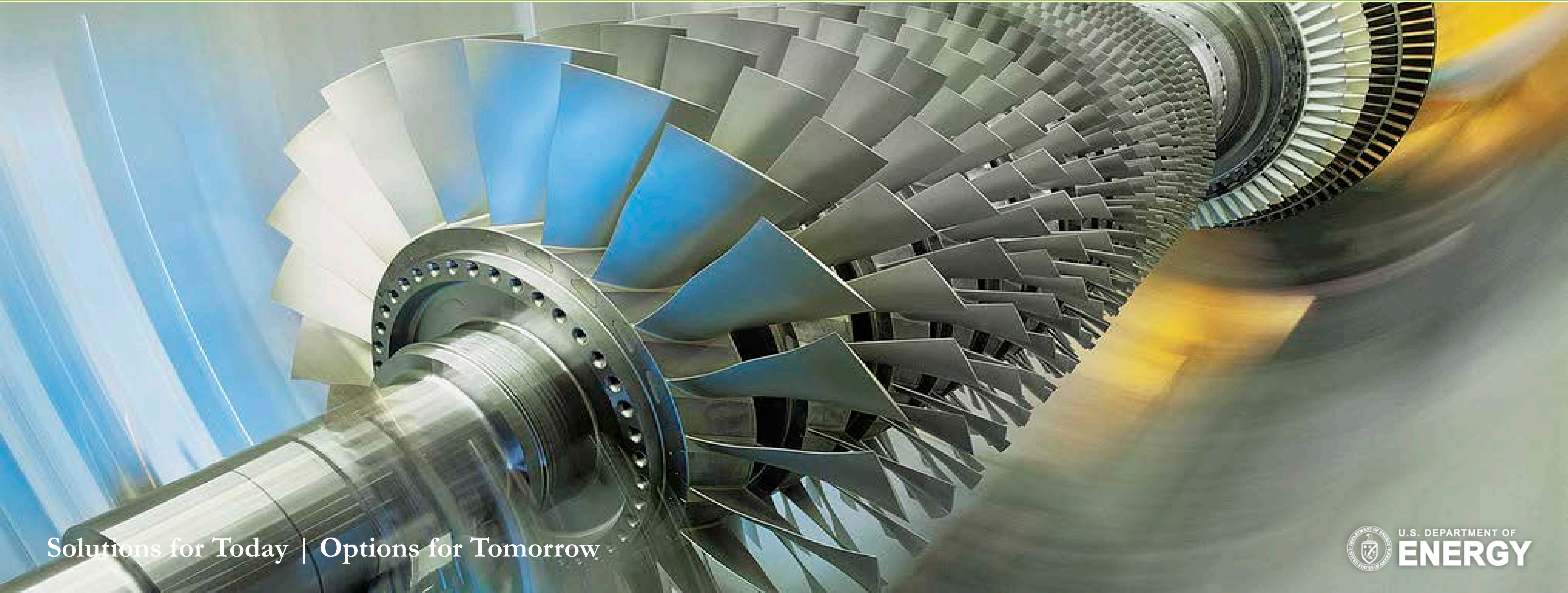
National Energy Technology Laboratory

2019 Annual Review Meeting for Crosscutting, Pittsburgh, PA, April 9-11, 2019



A Few Acronyms

- **SEA – Systems Energy Analysis Division at NETL**
- **PSER – Process Systems Engineering Research team in SEA**
- **sCO_2 – Supercritical CO_2**
- **RCBC – Recompression Closed Brayton Cycle**
- **STEP – Supercritical Transformative Electric Power. A 10 MWe net power demonstration plant being built at SwRI in San Antonio TX.**

Presentation Overview

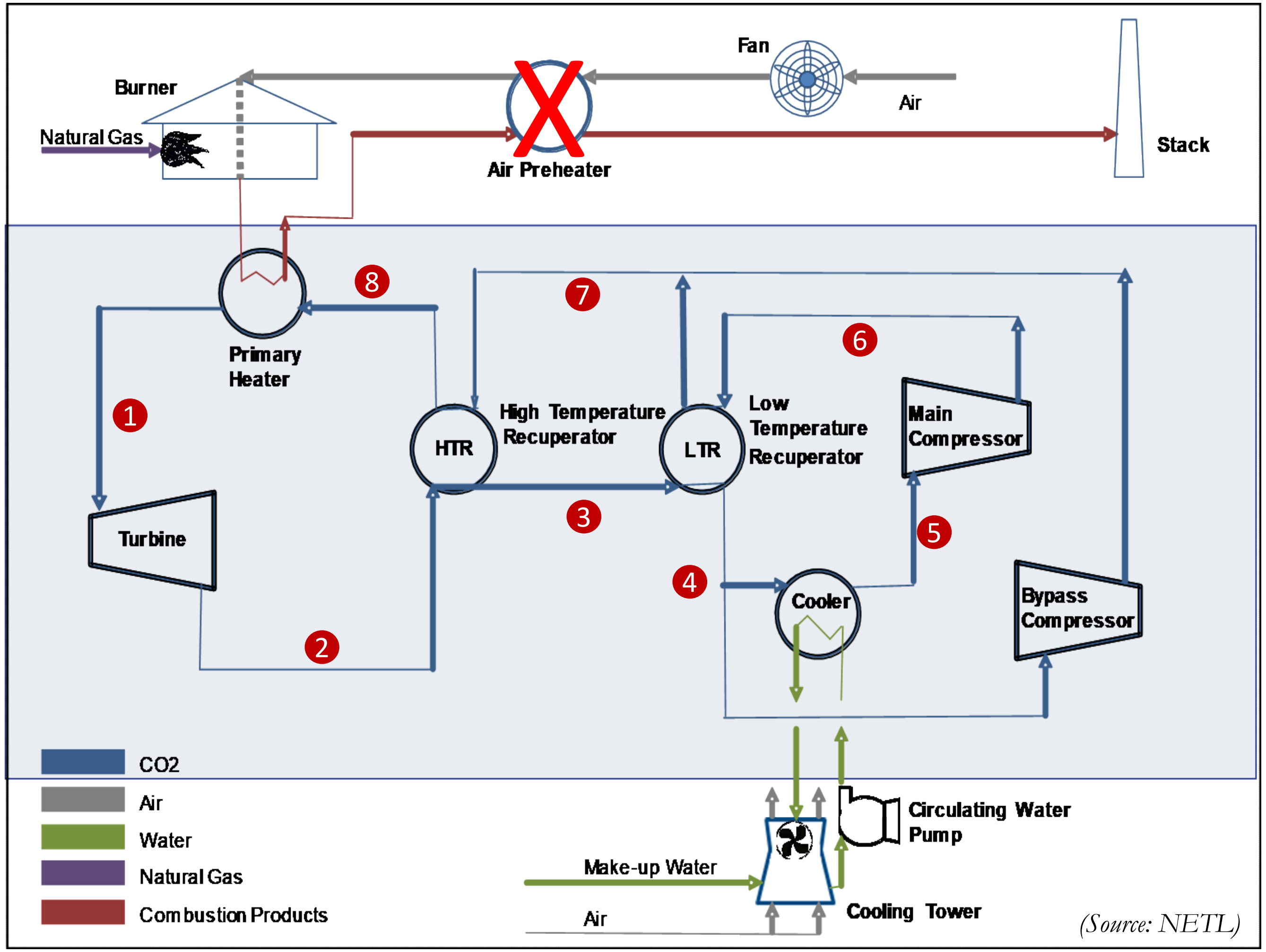
- **SEA PSER sCO_2 Activities Overview**
- **Motivation for Control Studies of STEP Facility**
- **Control Methodology**
  - Steady-State and Dynamic Simulation Framework
  - Control Objectives
  - Control Architecture
- **Control Response Results**
  - Ramp down and up in RCBC cycle MW demand
  - Heat rejection water cooler temperature control
- **Future Work**

SEA PSER sCO_2 Cycle Modeling Activities

- **Indirect Fired Cycles**
  - STEP pilot plant
    - Cycle models for dynamics
      - Recompression Closed Brayton Cycle (RCBC)
      - Simple Cycle – First year of facility operation, starting ~Oct 2020
    - Equipment models
      - Heat exchangers
      - Control of primary heat rejection water cooler
  - 550 MW commercial scale with circulating fluidized bed
    - Turbomachinery arrangement options
      - Off Design (Part-load, Ambient temperature) → Control
- **Direct Fired Cycle**

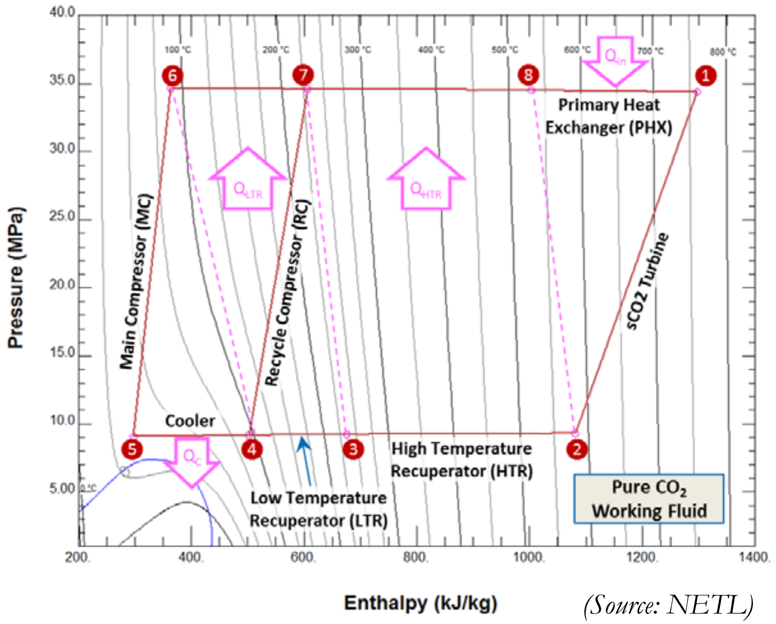
10 MWe sCO_2 Recompression Brayton Pilot Plant

Process Overview



(Source: NETL)

- External gas-fired heat source
- sCO_2 circulates in closed loop (noncondensing)
- Two stages of recuperation used to pre-heat compressed sCO_2 with hot turbine exhaust
- Cooler rejects heat that is not converted to power
- Coupled compressors, decoupled turbine expander



(Source: NETL)

Motivation

- **Understand control-related challenges of a MW scale sCO_2 Recompression Closed Brayton Cycle (RCBC)**
  - **Load changes**, Startup, Shutdown, Trips
  - Operation close to sCO_2 critical point
  - Maintain turbine inlet temperature during load changes (high efficiency)
  - Other operational constraints, e.g. surge/stonewall limits
- **Applicable to 10 MWe RCBC facility within Supercritical Transformational Electric Power (STEP) program**

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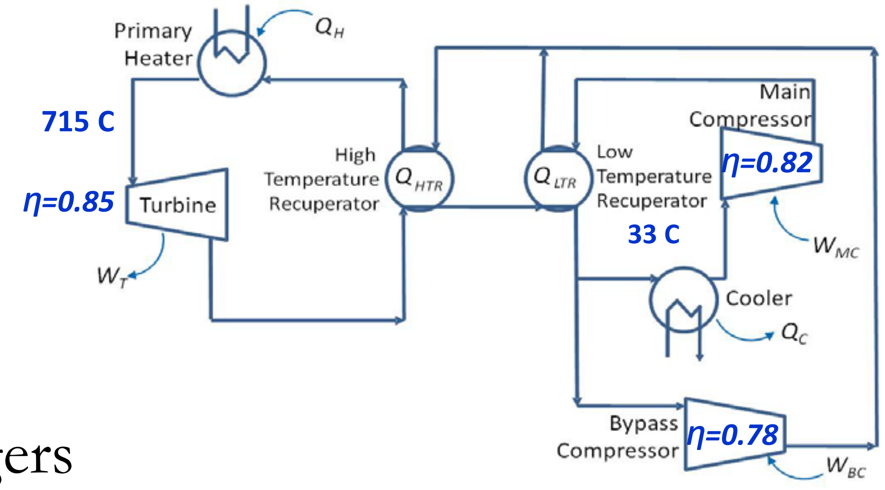
Control Methodology

Steady-State and Dynamic Simulation Framework

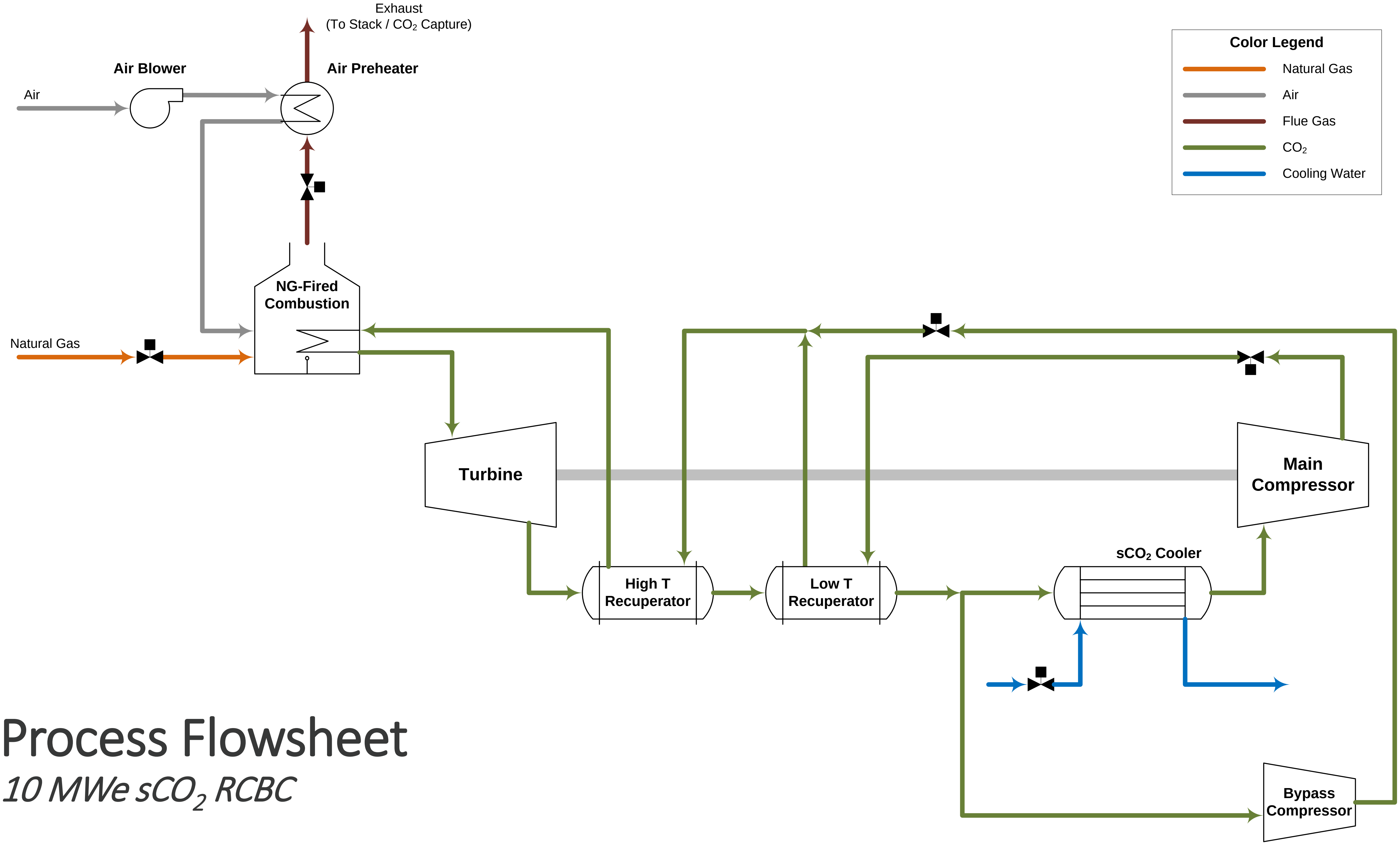
- **Software Tools**
  - Aspen Plus/Dynamics/Custom Modeler (ACM) v10.0
- **Property Method**
  - NIST REFPROP
- **Aspen Library Models**
  - Turbomachinery (currently), piping, some heat exchangers
- **Aspen Custom Modeler (ACM) Models**
  - ACM compact heat exchangers models - microtube† and printed circuit††
- **Dynamic Model of 10 MWe sCO_2 RCBC Pilot Plant†††**



† Jiang Y., Liese E., Zitney S., and Bhattacharyya D., "Optimal Design of Microtube Recuperators for an Indirect Supercritical Carbon Dioxide Recompression Closed Brayton Cycle", Applied Energy, Volume 216, 15 April 2018, Pages 634-648, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2018.02.082.

†† Jiang Y., Liese E., Zitney S., and Bhattacharyya D., "Design and Dynamic Modeling of Printed Circuit Heat Exchangers for Supercritical Carbon Dioxide Brayton Power Cycles", Applied Energy, Volume 231, 1 December 2018, Pages 1019-1032. https://doi.org/10.1016/j.apenergy.2018.09.193

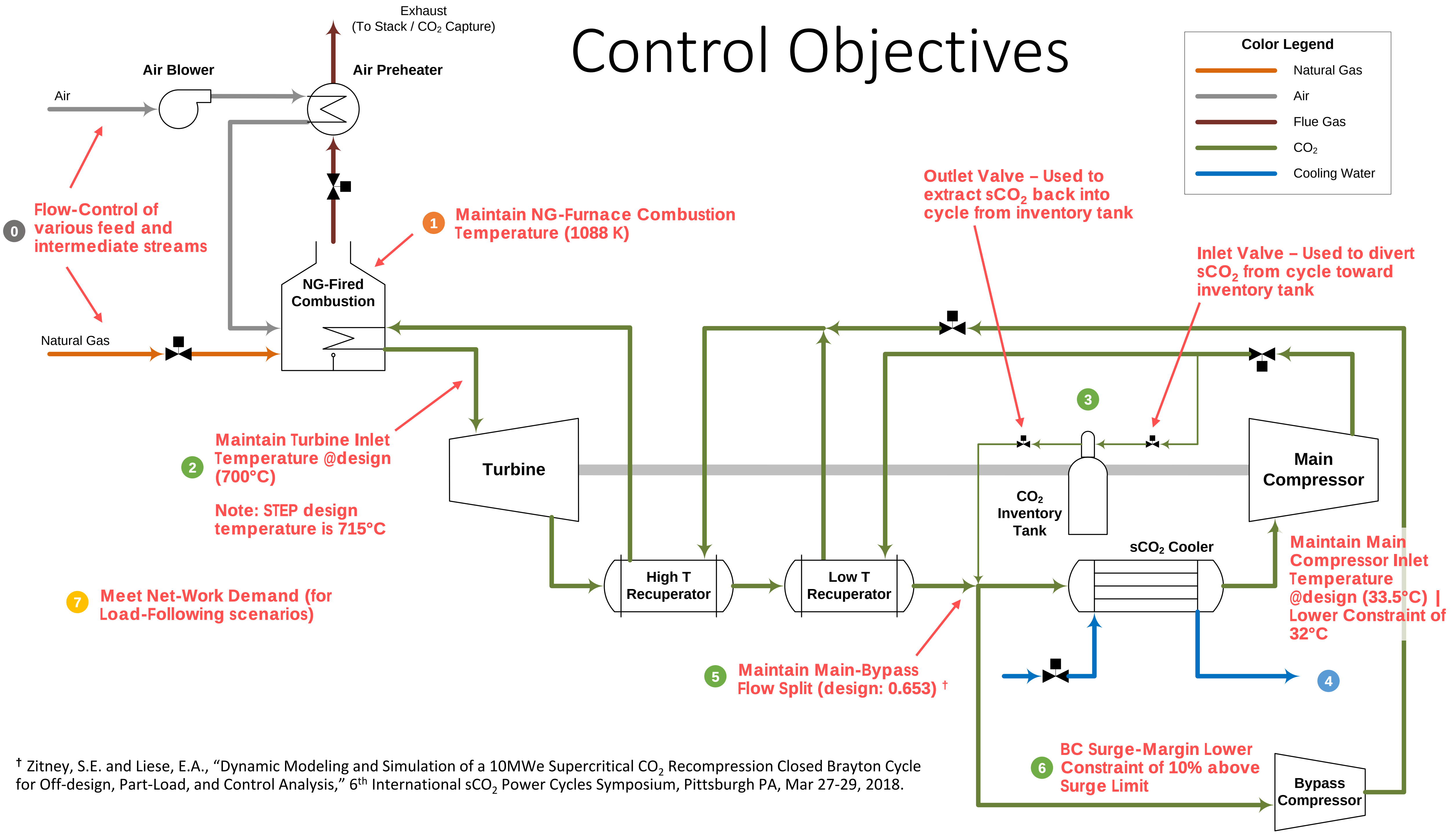
††† Zitney, S.E. and Liese, E.A., "Dynamic Modeling and Simulation of a 10MWe Supercritical CO_2 Recompression Closed Brayton Cycle for Off-design, Part-Load, and Control Analysis," 6th International sCO_2 Power Cycles Symposium, Pittsburgh PA, Mar 27-29, 2018.



Process Flowsheet

10 MWe sCO_2 RCBC

Control Objectives



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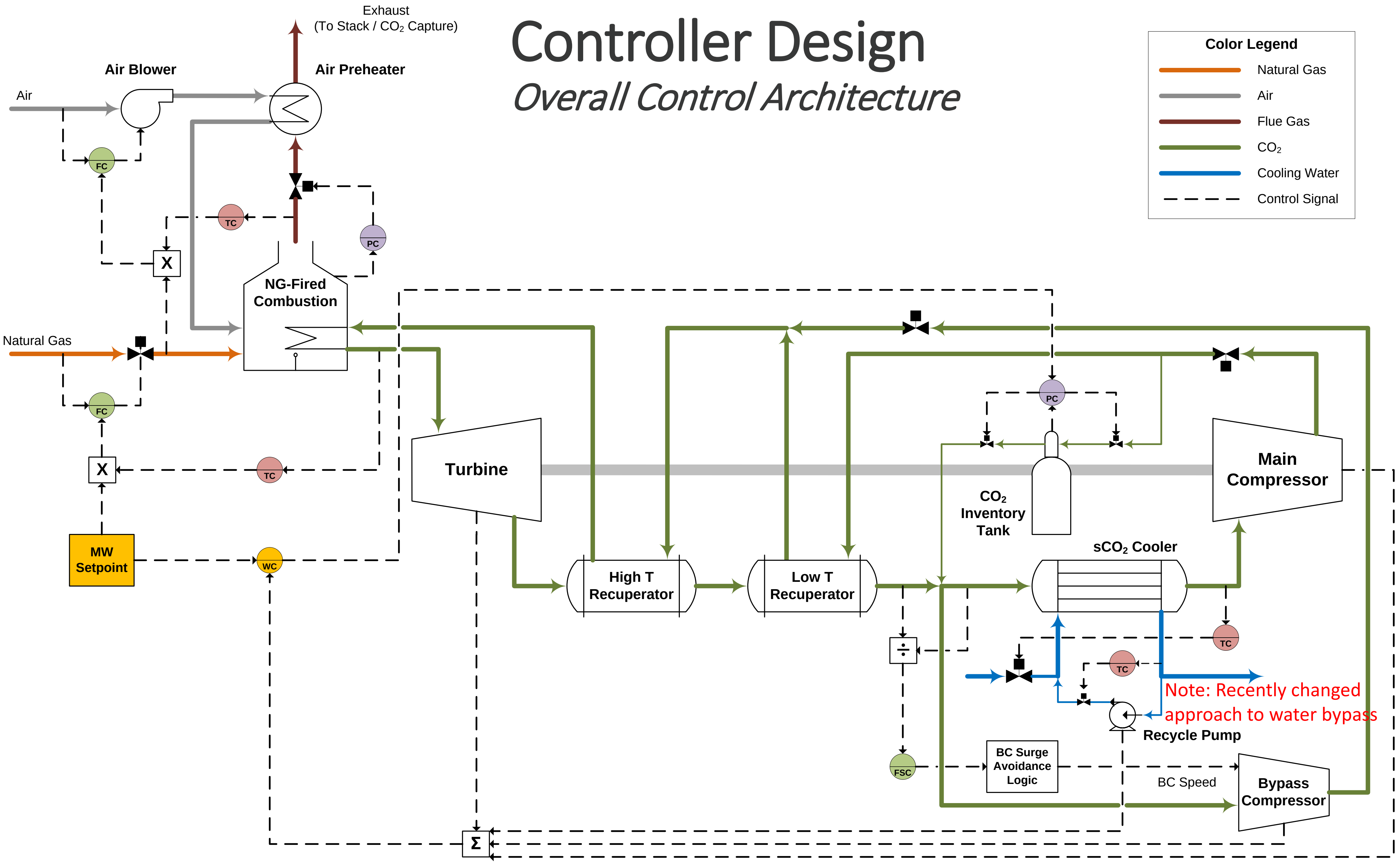
Controller Design

Overall Control Architecture



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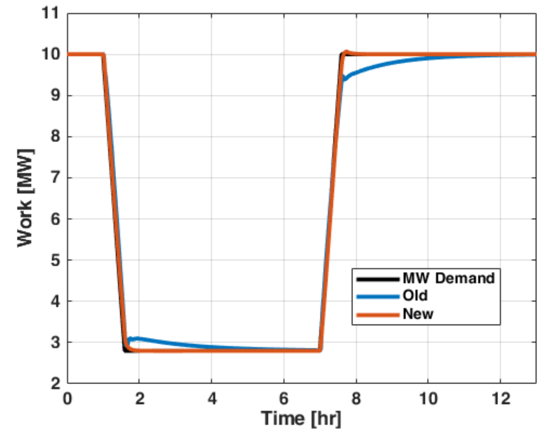
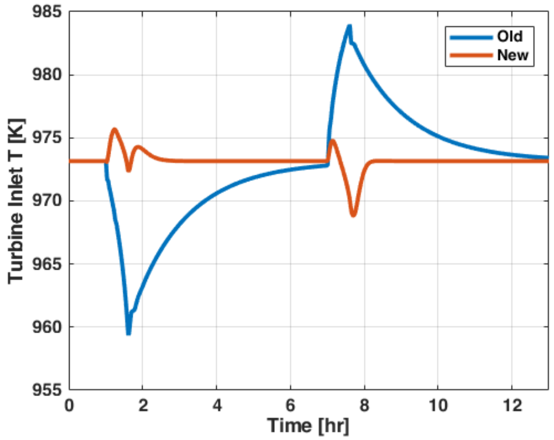
Advanced Sensors & Controls Task 61: Control Strategies for a 10 MW sCO2 Power System

STEP Cycle Model Control Investigations

Technical Progress:

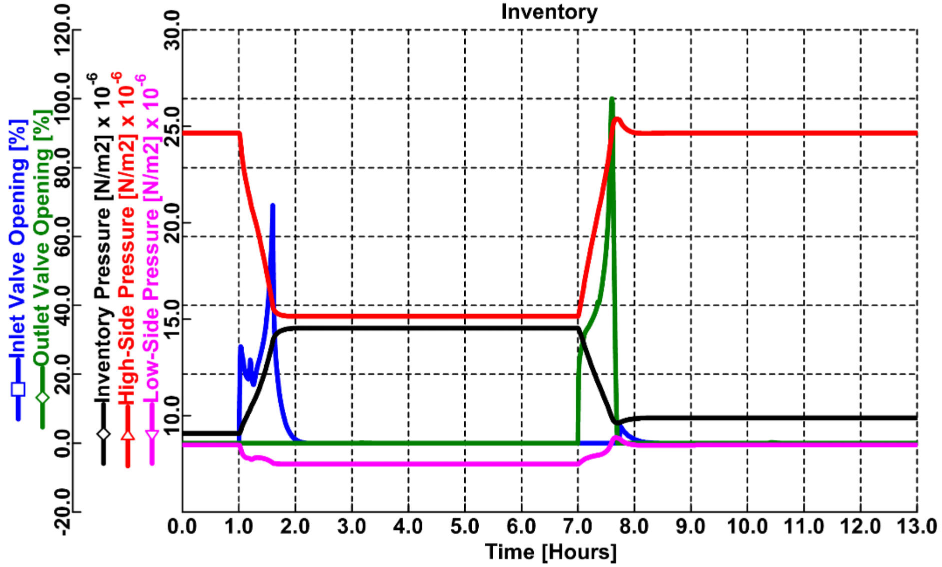
- Discussed previous NETL control studies and future interests with STEP development team (GTI, SwRI, GE)
- Implemented turbine inlet temperature control by manipulating external combustor and load setpoint tracking using inventory management control. Used microtube ACM models for high and low-temperature recuperators. Details in Aug 31, 2018 Milestone Report





Figures Above: Updated control improves Work and Turbine Inlet Temperature setpoint tracking

Figure Right: Response of inventory tank valves and system pressures to work ramps



Advanced Sensors & Controls Task 61: Control Strategies for a 10 MW sCO2 Power System

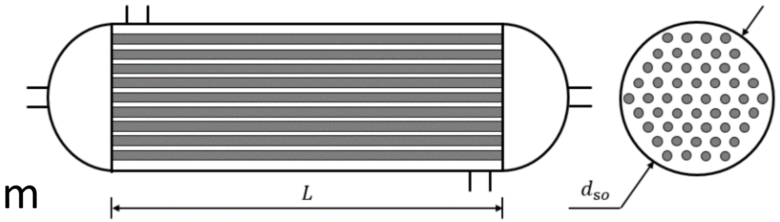
Water Cooler Studies for STEP

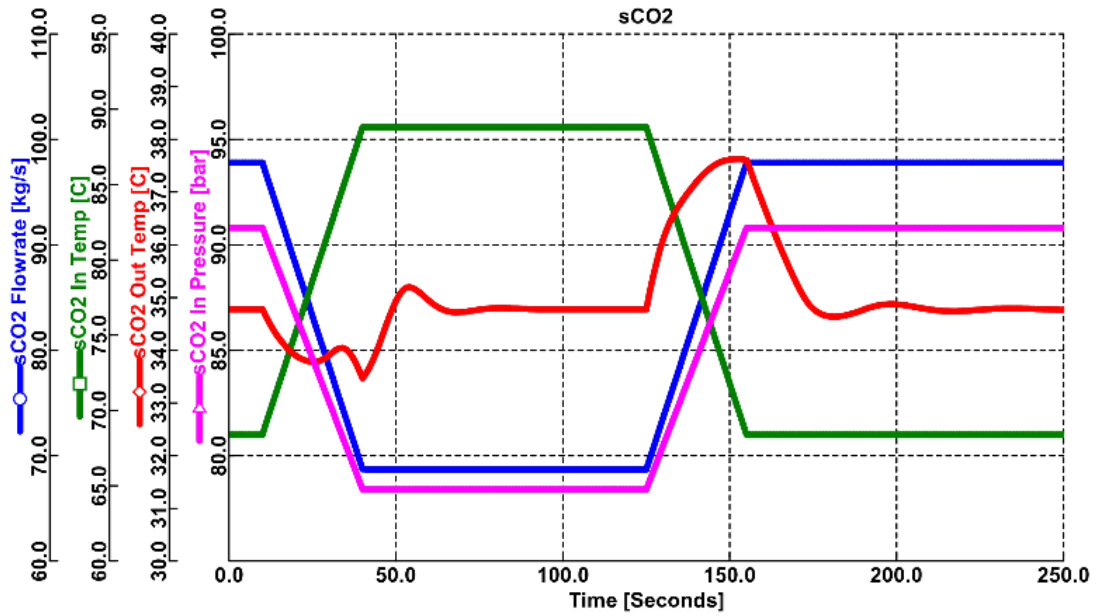
Objective: Analyze water cooler CO_2 temperature control approaches being considered for STEP. A 1°C change in this temperature can effect temperature at turbine inlet by 10°C (if uncontrolled)

Technical Progress:

- Completed microtube type CO_2-water cooler 1D design and dynamic model using Aspen Custom Modeler

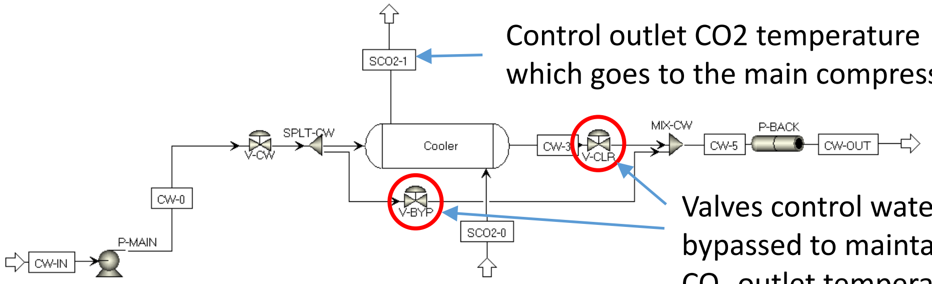
Shell OD 20 in.
11,000 tubes
Tube L 5 ft.
Tube OD 2.77 mm





Plot: Aggressive inlet CO_2 flow ramps (blue) of 1%/sec. Control of CO_2 outlet temperature (red) within 2.5°C of setpoint

- Performed control studies†.



Control outlet CO2 temperature which goes to the main compressor

Valves control water bypassed to maintain CO_2 outlet temperature

†Liese E., Mahapatra, P., and Jiang, Y., "Modeling and Control of a Supercritical CO_2 Water Cooler in an Indirect-fired 10 MWe Recompression Brayton Cycle near Supercritical Conditions", Proceedings of the ASME Turbo Expo, Phoenix, Arizona, June 17-21, 2019

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Future Work
10MWe sCO_2 Recompression Brayton Cycle

- **Updating cycle model based on STEP design in progress**
  - Added pipe models and prelim turbomachinery performance maps including compressor inlet guide vanes
- **Simple cycle model development in progress**
- **Increase model fidelity with custom models using Aspen Custom Modeler (esp. heat exchangers)**
- **Numerous scenarios to investigate**
  - Startup, Shutdown, Trips…
- **Numerous control approaches to try**
- **Improve simulation robustness**