Development of Control Strategies for a 10 MWe Supercritical CO_2 Recompression Brayton Cycle

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Presentation Overview

- **Introduction**
- **Control Methodology**
  - Steady-State and Dynamic Simulation Framework
  - Control Objectives
  - Control Architecture Design
- **Control Response Results**
  - Large-ramps in MW demand
- **Conclusions and Future Work**

Mahapatra, P., Albright, J.T., Zitney, S.E. and Liese, E.A., "Advanced Regulatory Control of a 10 MWe Supercritical CO_2 Recompression Brayton Cycle towards Improving Power Ramp Rates," 6th International sCO_2 Power Cycles Symposium, Pittsburgh PA, Mar 27-29, 2018.

Introduction / Motivation

- **Understand control-related challenges**
  - MW scale sCO_2 Recompression Closed Brayton Cycle (RCBC)
  - Limited studies (see paper† for references)
  - Load changes, Startup, Shutdown, Trips
- **Applicable to 10 MWe RCBC facility within Supercritical Transformational Electric Power (STEP) program**
- **Rigorous underlying simulation-based pressure-driven dynamic model††**

† Mahapatra, P., Albright, J.T., Zitney, S.E. and Liese, E.A., "Advanced Regulatory Control of a 10 MWe Supercritical CO_2 Recompression Brayton Cycle towards Improving Power Ramp Rates," 6th International sCO_2 Power Cycles Symposium, Pittsburgh PA, Mar 27-29, 2018.
†† 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.

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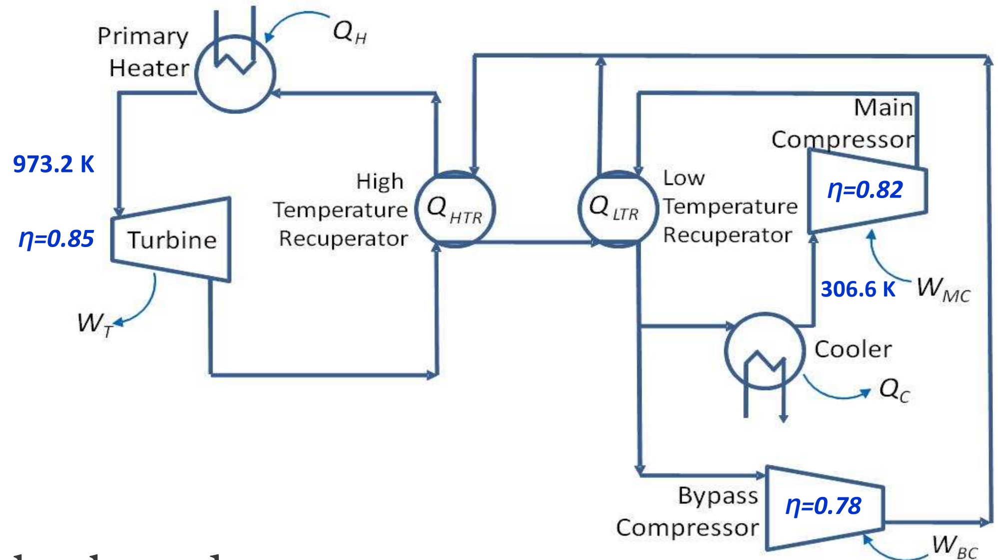
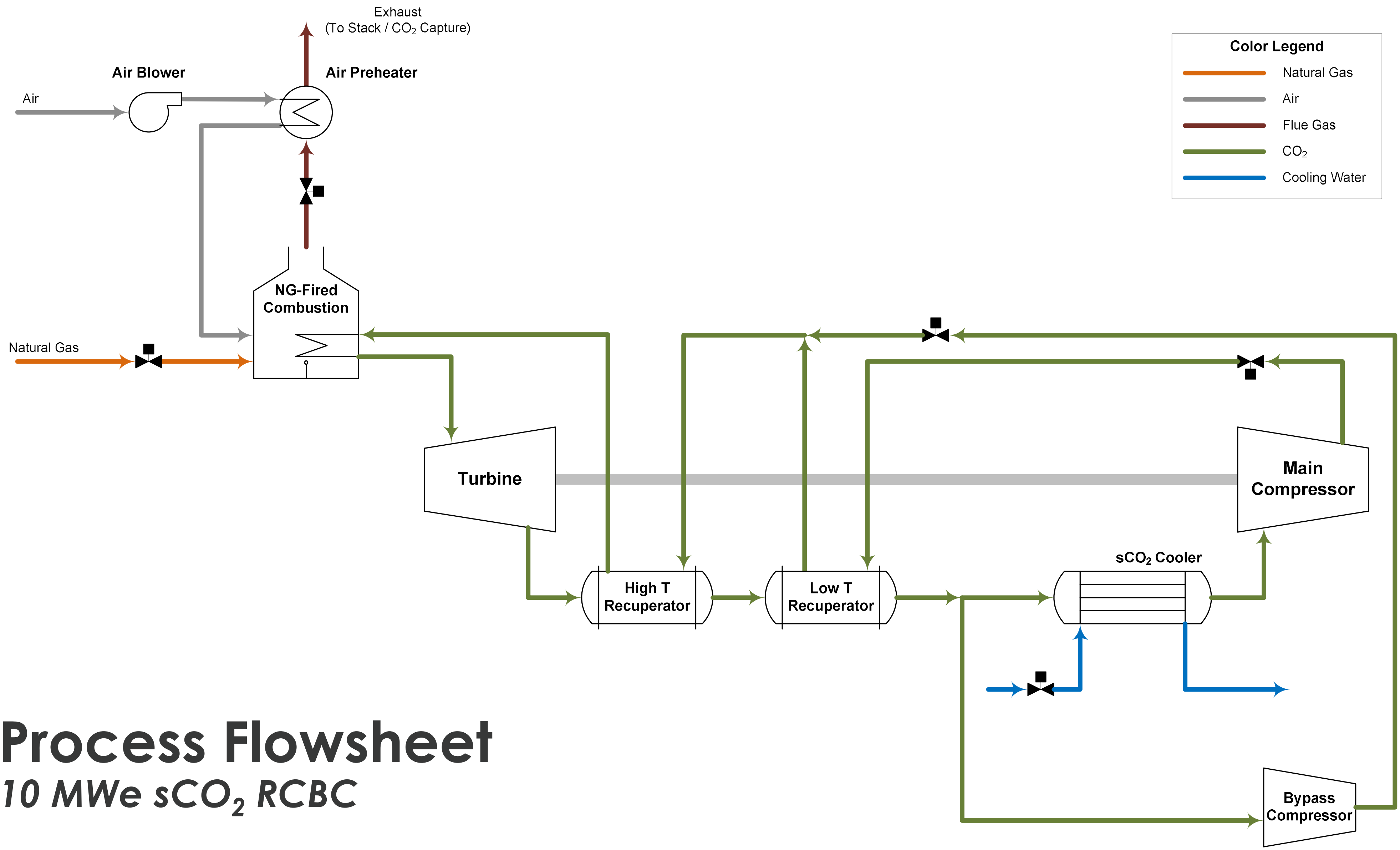
Control Methodology

Steady-State and Dynamic Simulation Framework



- **Software Tools**
  - Aspen Plus/Dynamics v8.8
- **Property Method**
  - NIST REFPROP
- **Unit Operation Models†**
  - Turbomachinery
  - Piping
  - Heat Exchangers†† - custom microtube-based recuperators
- **Dynamic Model of 10 MWe sCO_2 RCBC Pilot Plant†††**

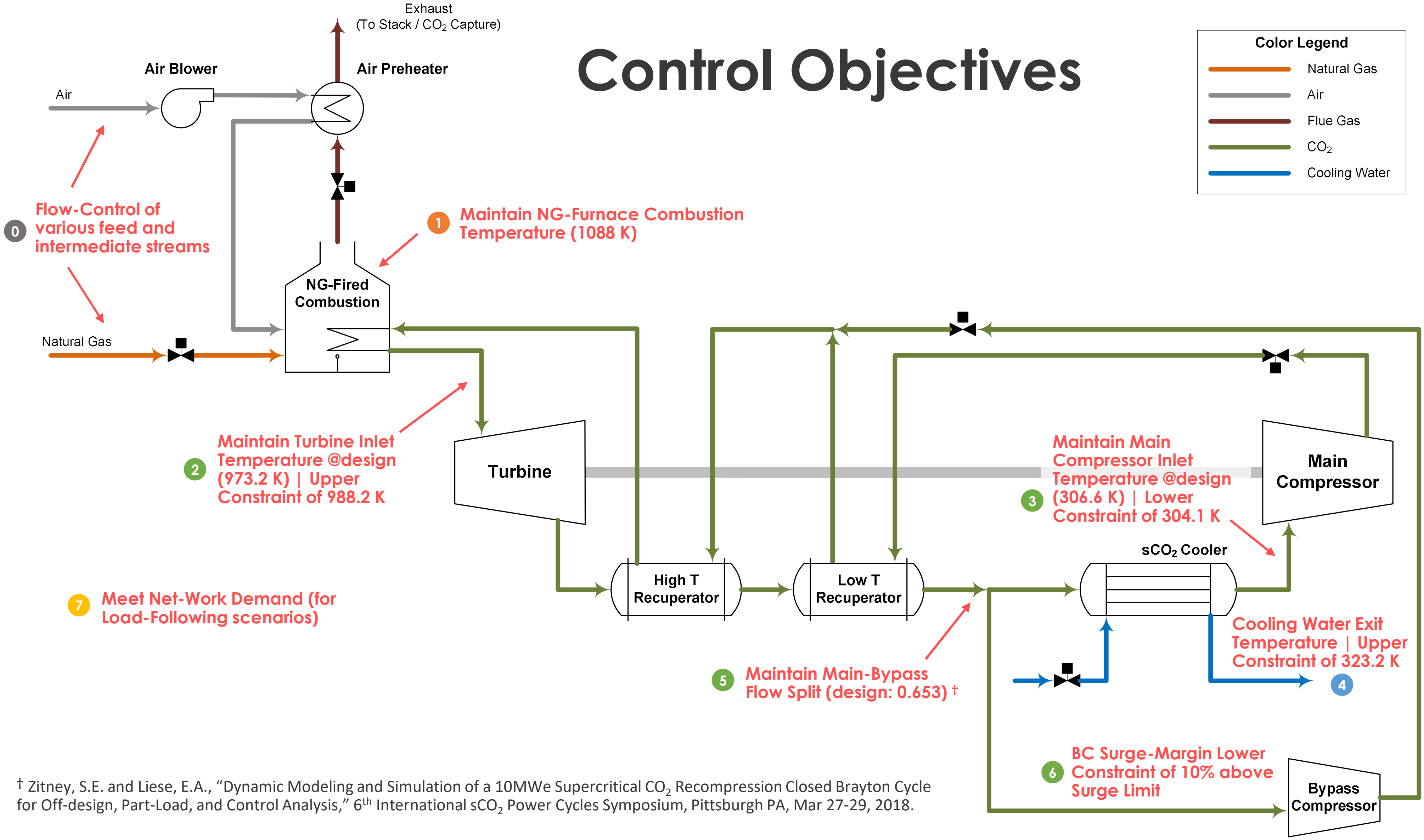
† Zitney, S.E. and Liese, E.A., "Design and Operation of a 10MWe Supercritical CO_2 Recompression Brayton Cycle," 2016 AIChE Annual Meeting, San Francisco, CA, Nov 13-18, 2018.
†† Jiang, Y., Liese, E.L., Zitney, S.E., and Bhattacharyya, D., "Optimal design of microtube recuperators for an indirect supercritical CO_2 recompression closed Brayton cycle," Applied Energy, 216, 634-648, 2018.
††† 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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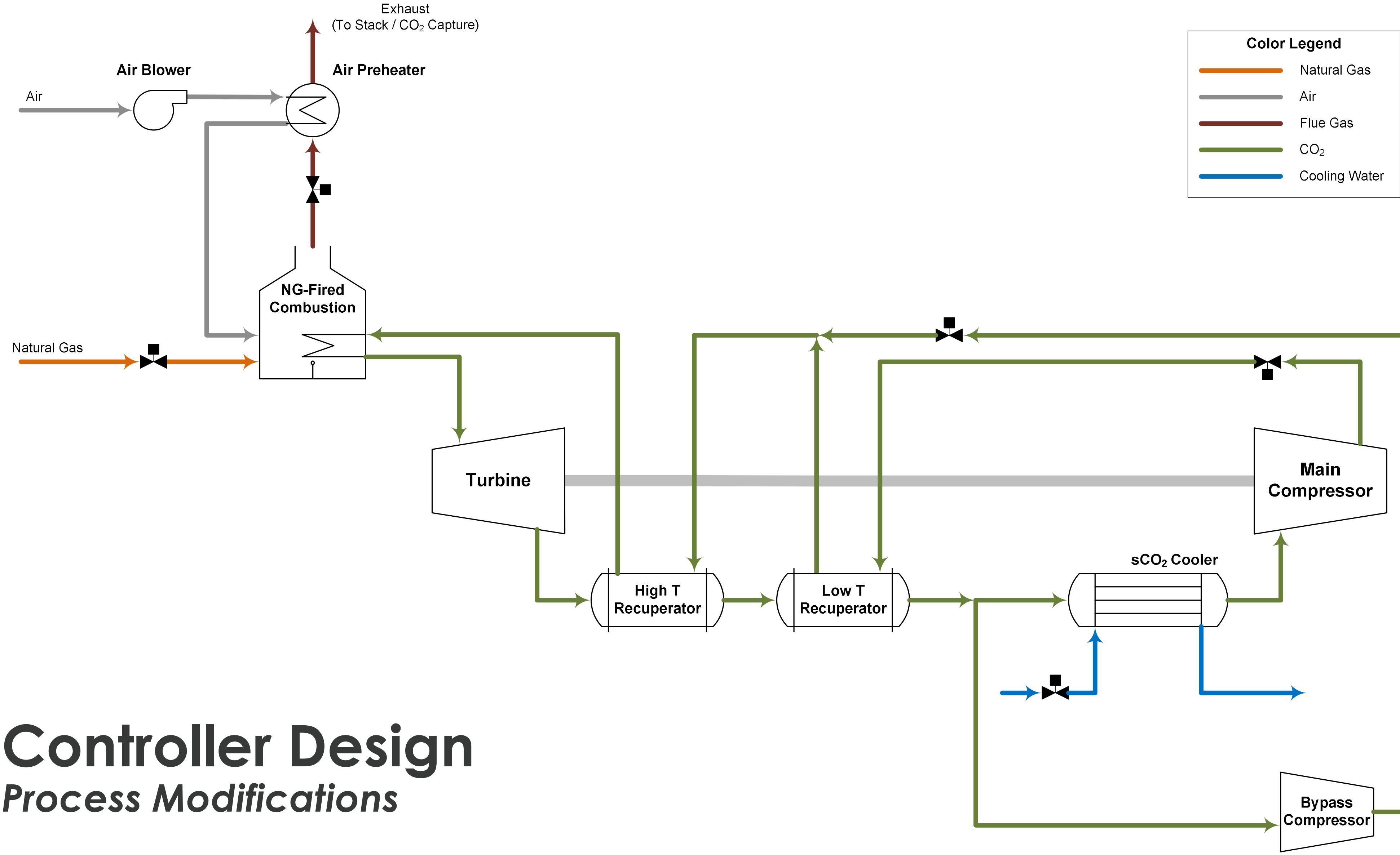
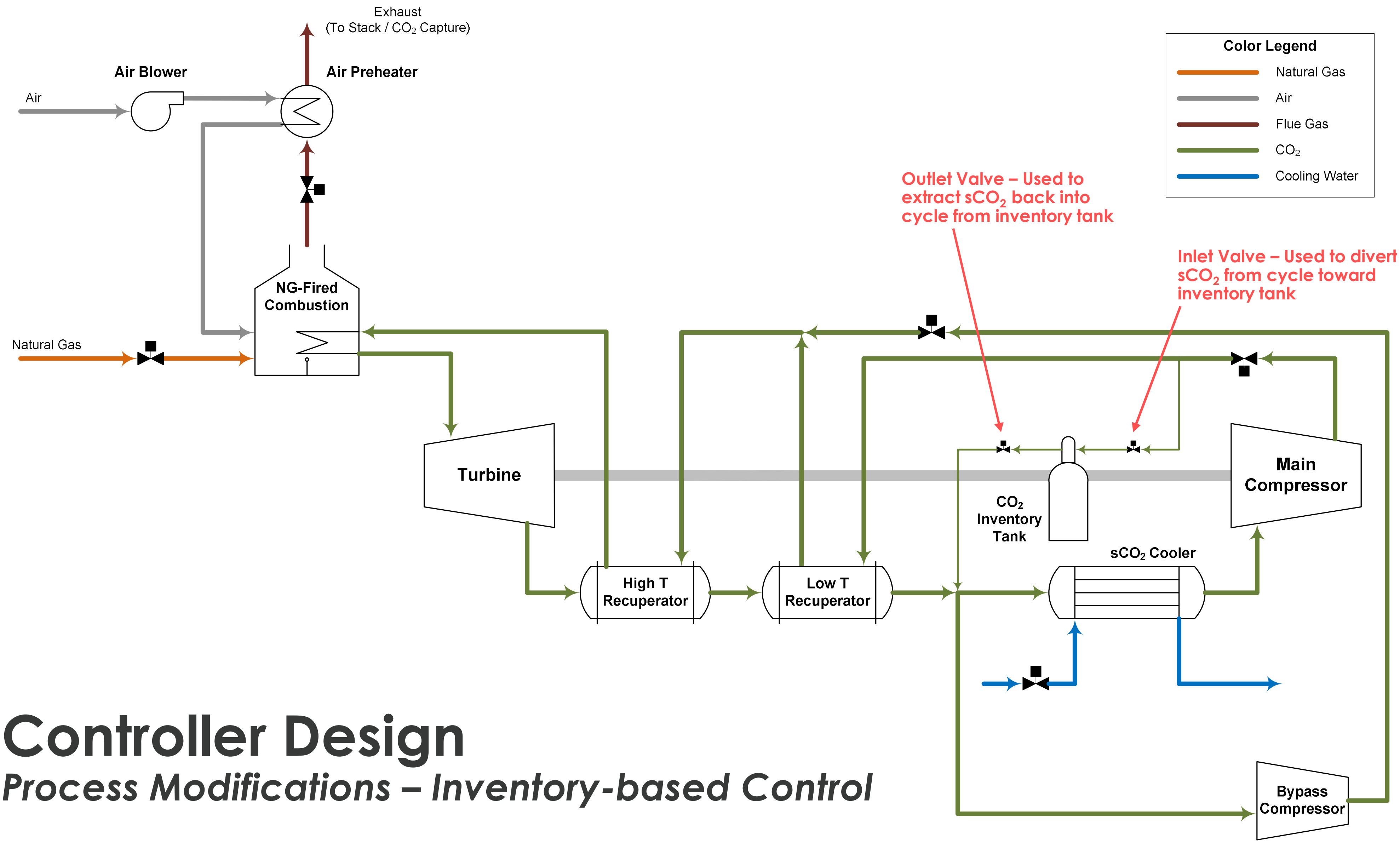


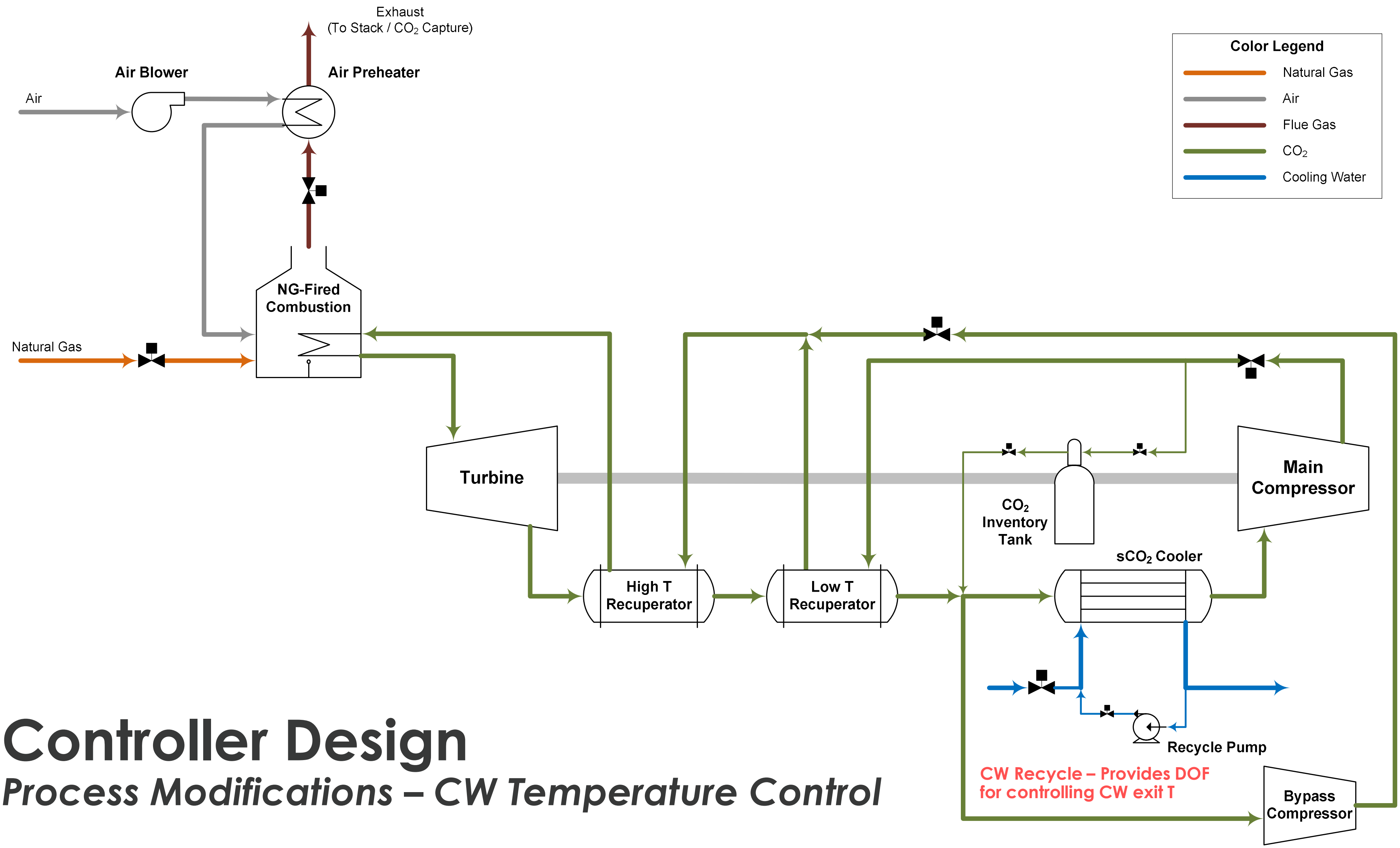
Controller Design

Process Modifications



Controller Design

Process Modifications – Inventory-based Control

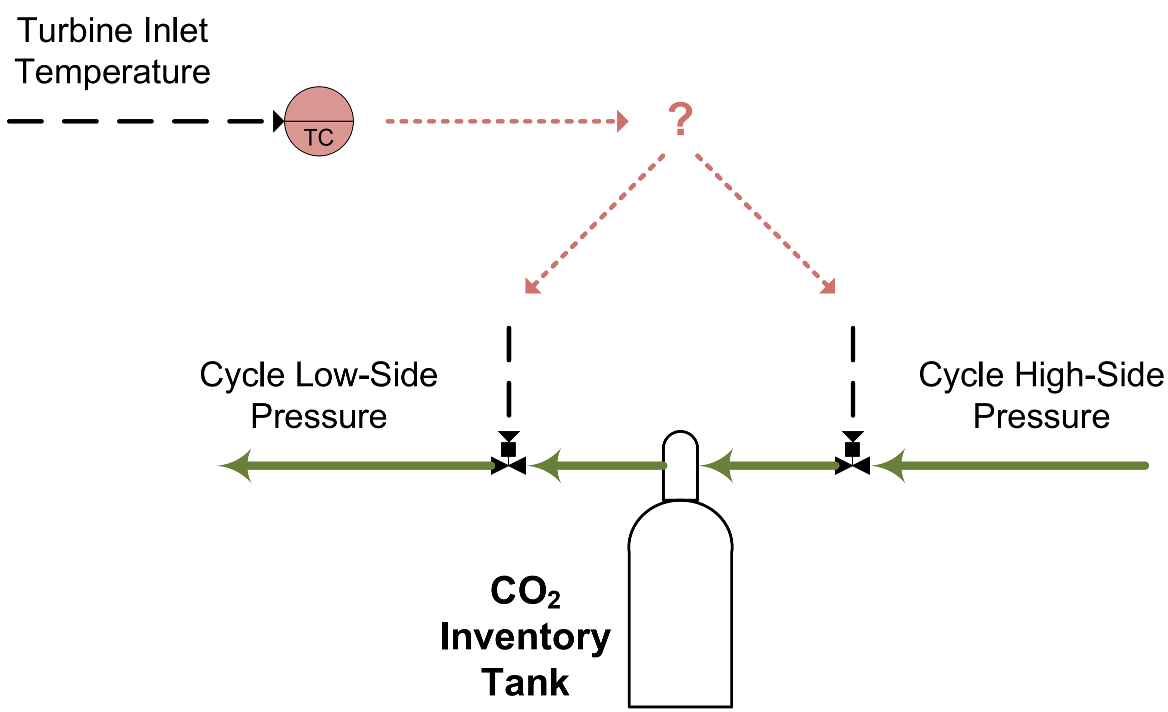


Controller Design

Process Modifications – CW Temperature Control

Controller Design

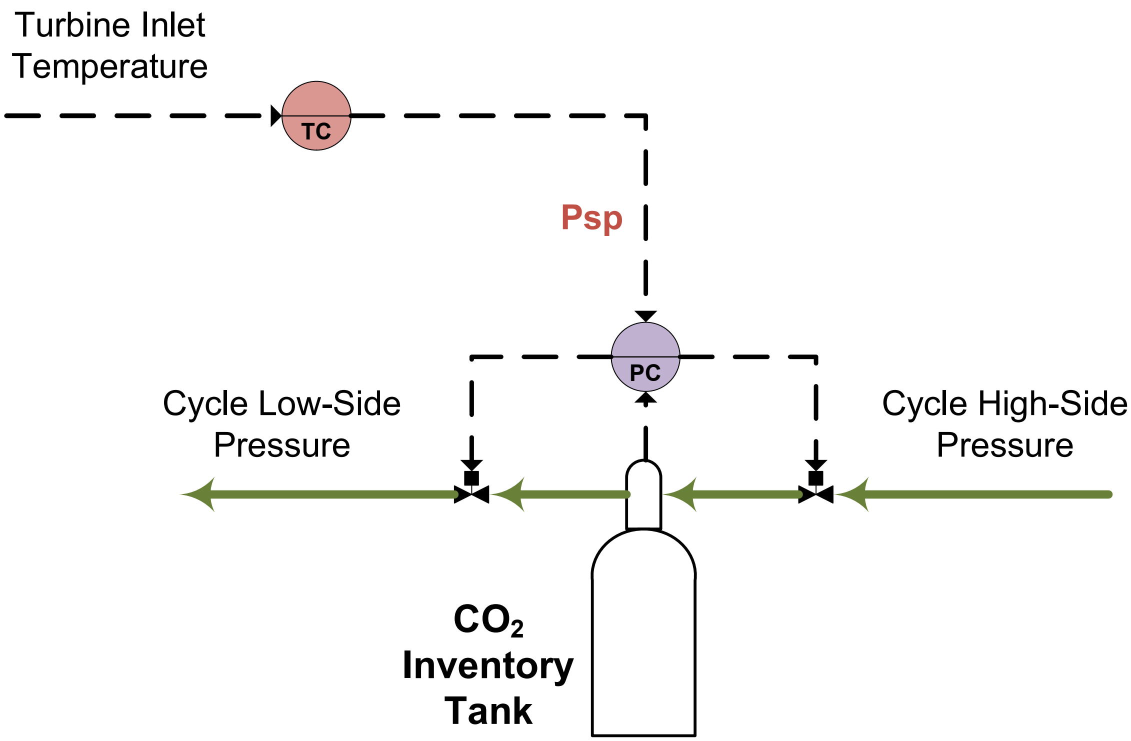
Inventory-based Control for Turbine Inlet Temperature



How to correlate inventory tank inlet-outlet valve actuations with TIT?

Controller Design

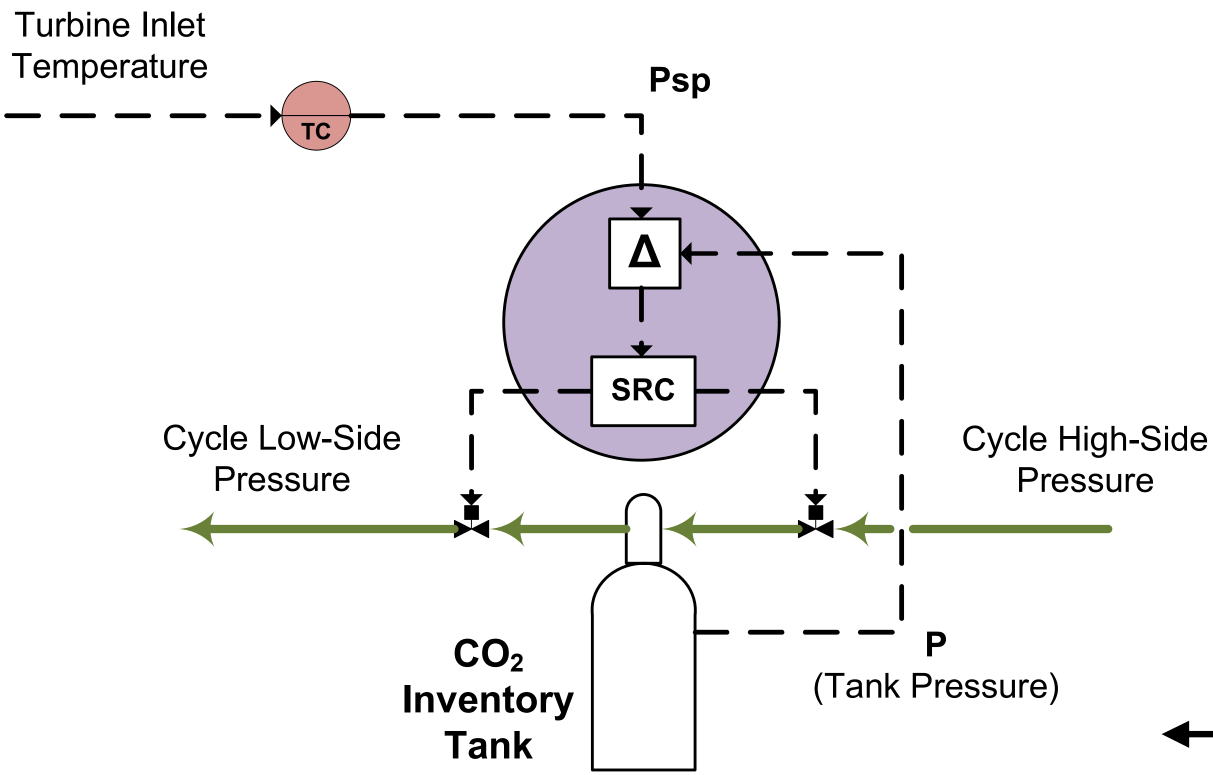
Inventory-based Control for Turbine Inlet Temperature



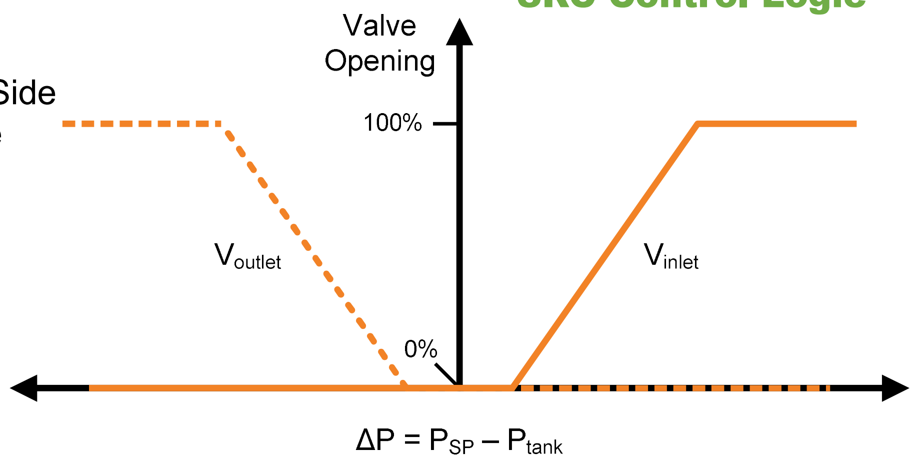
- **Inventory Tank Pressure**
  - Monotonic relationship with TIT
  - High P indicates less sCO_2 in the cycle and vice versa
- **Control challenges**
  - For a given P both valves may remain open – unnecessary recycle and efficiency loss
  - May involve jittering effect – inlet/outlet valves may open/close at high frequency

Controller Design

Inventory-based Control for Turbine Inlet Temperature

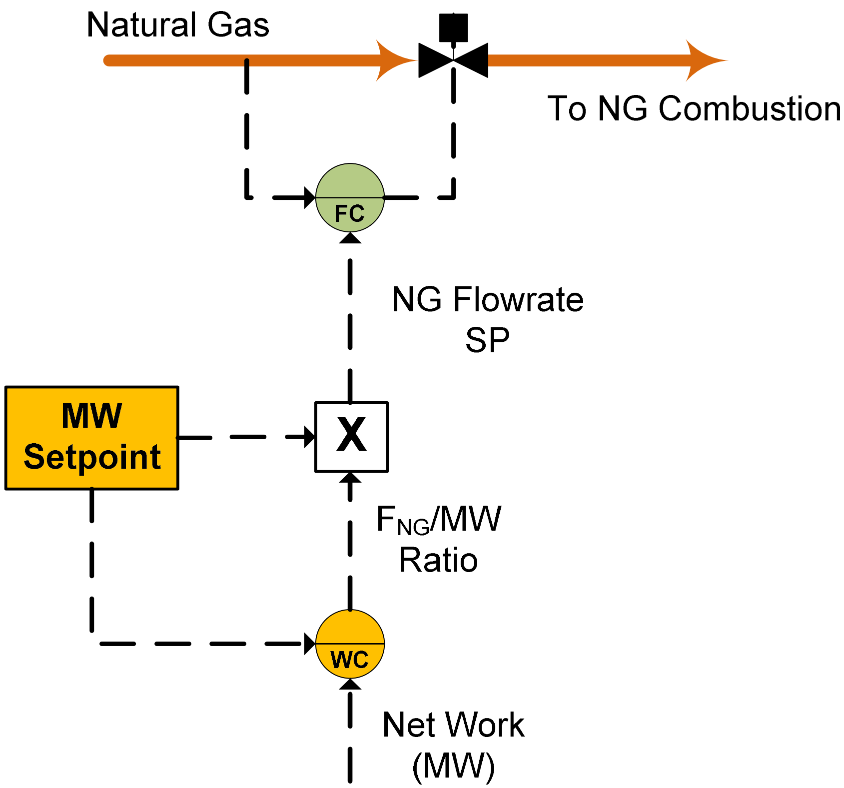


- **TIT-C design using Inventory Pressure Control**
- **Split Range Control (SRC)**
  - Pressure dead-band to prevent jittering



Controller Design

Work Controller (Ratio control augmented w/ feedback trim)

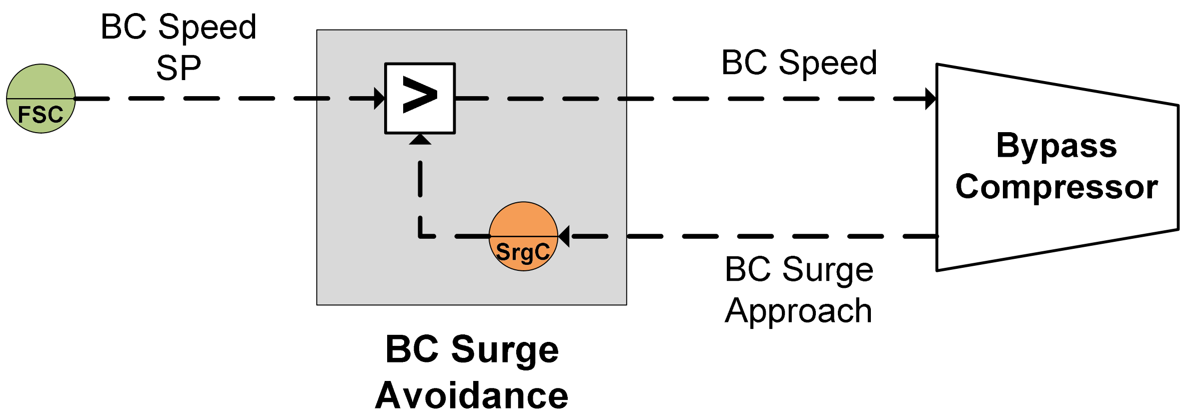


- F_{NG}/MW ratio block acts as a fast feedforward-type control
- WC controller provides feedback from actual net MW measurement – offset-free load following

Note: Combustion TC utilizes similar Ratio/FB-trim Control

Controller Design

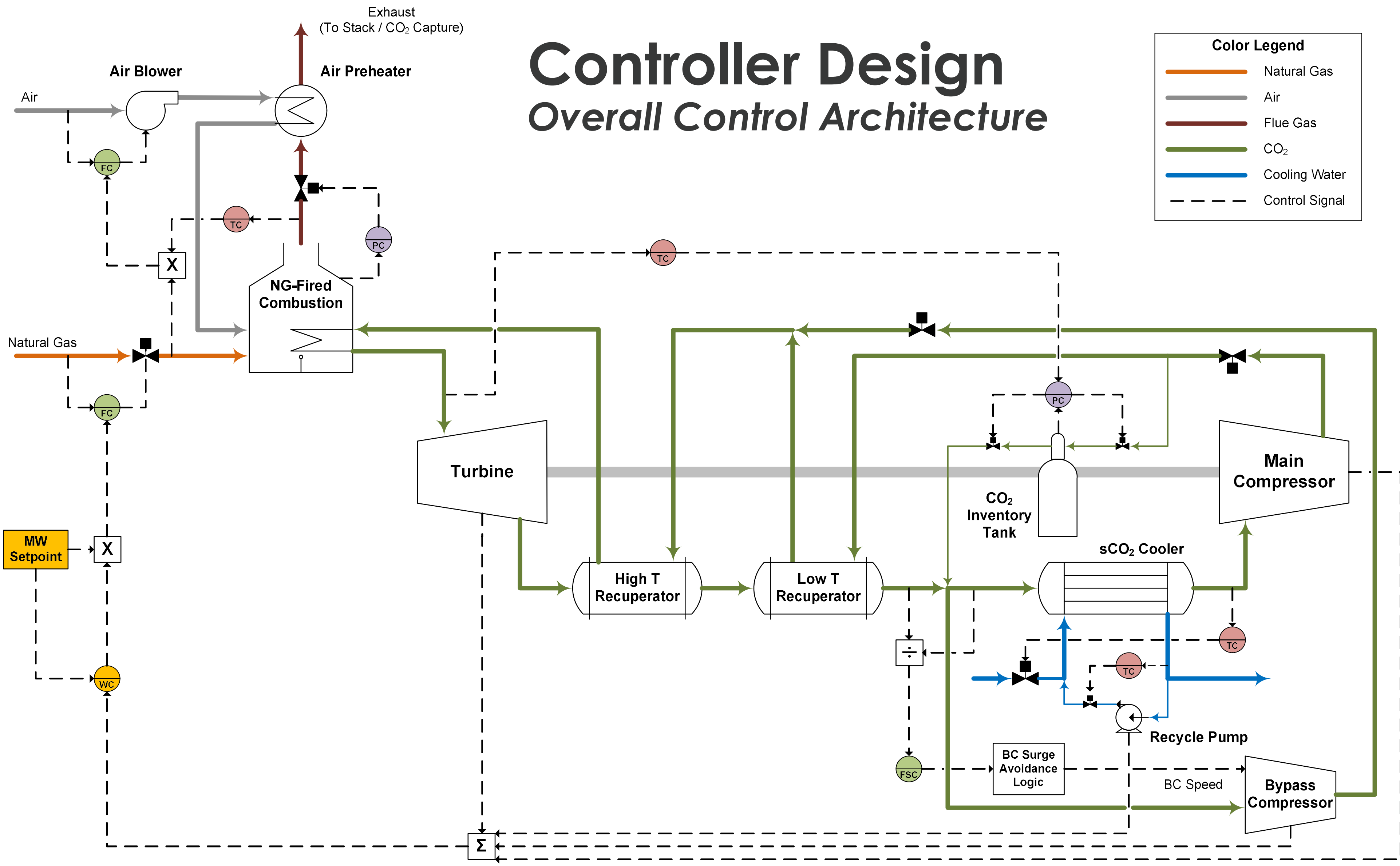
Bypass-Compressor Surge Avoidance



- Disable FSC once BC Surge approaches 10%
- Aggressive controller tuning for SrgC

Controller Design

Overall Control Architecture



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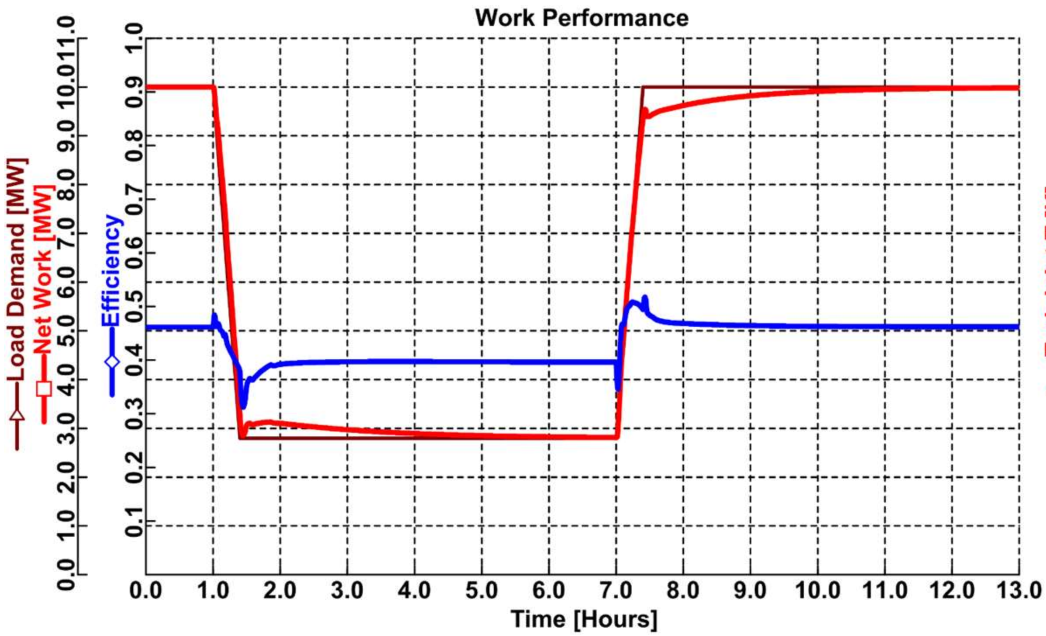
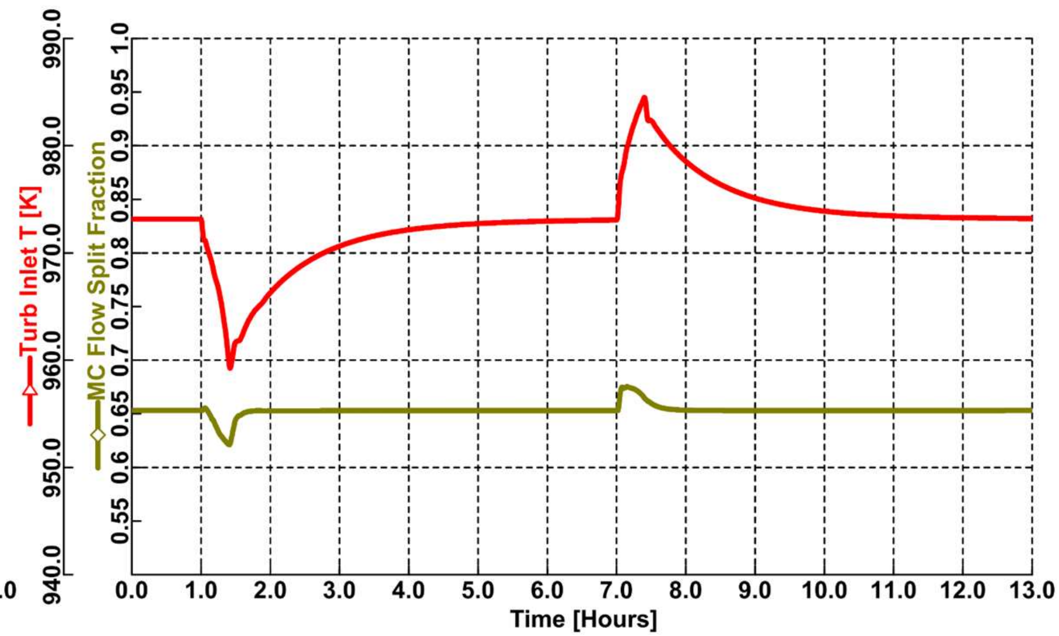
Control Response – Results

Large-ramps in MW demand (72% turn-down @3%/min)





- **Actual Net-Work closely following MW Demand throughout ramp**
- **TIT well controlled (± 15K) within limits**
- **Minor offshoots in efficiency adherent to TIT response**
- **Main-Bypass flow-split tightly controlled**

Control Response – Results

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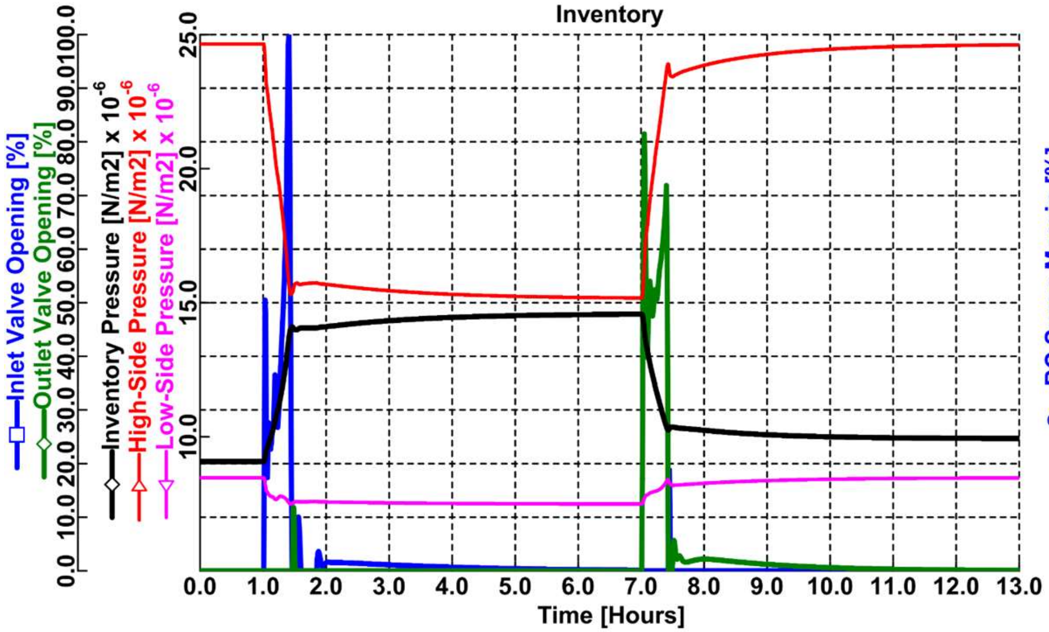

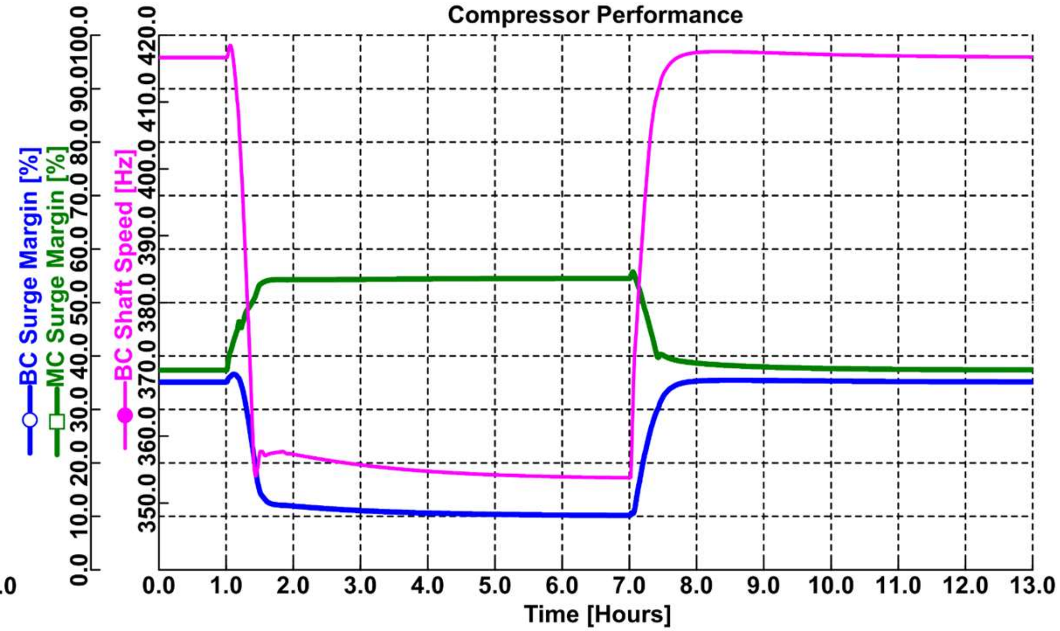

- **Bypass Compressor remains above 10% surge-limit**
- **BC Shaft Speed decreases to maintain flow-split**

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Conclusions

- Identified primary control objectives for "fast" and efficient control performance during rapid transients
- Developed advanced regulatory control-strategies to meet control objectives
- Demonstrated controller responses utilizing above strategies within a rigorous process simulation platform
- May serve as an use-case example and initial guide toward STEP's RCBC control development effort

Future Work
10MWe sCO_2 Recompression Brayton Cycle

- **Numerous scenarios to investigate**
  - Startup, Shutdown, Trips…
  - Simple cycle
- **Numerous control approaches to try**
  - E.g., switch TIT and load control signals
  - More advanced control approaches
- **Dedicated compressor surge-control for complete shutdown**
  - Spill-back streams on main & bypass controllers
- **Non-grid connected operation**
  - Turbine speed control using Turbine Inlet Control/Throttle Valve
  - Agent-based control compared to PID control for turbine speed control
- **Improve simulation robustness**

Websites and Contact Information

Office of Fossil Energy: www.energy.gov/fe/office-fossil-energy

NETL: www.netl.doe.gov/

sCO_2 Technology
Program: www.netl.doe.gov/research/coal/energy-systems/sco2-technology