# Supercritical Carbon Dioxide Power Cycle Modeling and Additive Manufactured Turbine Experimentation

Anthony M. Grotjan[1], Gregory F. Nellis[1], Mark H. Anderson[1] (University of Wisconsin – Madison[1])

This work presents an integrated study of supercritical carbon dioxide power cycles, combining cycle-level modeling, turbomachinery loss prediction, and preparation for experimental validation. A detailed modeling framework incorporating empirical aerodynamic, windage, and leak-age loss correlations enables accurate system-level performance predictions across a range of power scales without relying on computationally intense methods. Multi-objective optimization and parametric studies reveal trade-offs between cycle efficiency and system compactness, showing how turbomachinery losses influence small-scale system performance and push optimal compressor inlet pressures below the critical point. Complementing the modeling, a test facility was designed and constructed to be capable of 800°C and 11 MPa operation, including management of complex auxiliary cooling flows. This facility was validated and will be used to test a 30 kW turbine-generator system additively manufactured from Haynes 282 to characterize and validate loss modeling predictions. This integrated approach provides pathways toward higher-efficiency, scalable cycles.

## Cycle Modeling

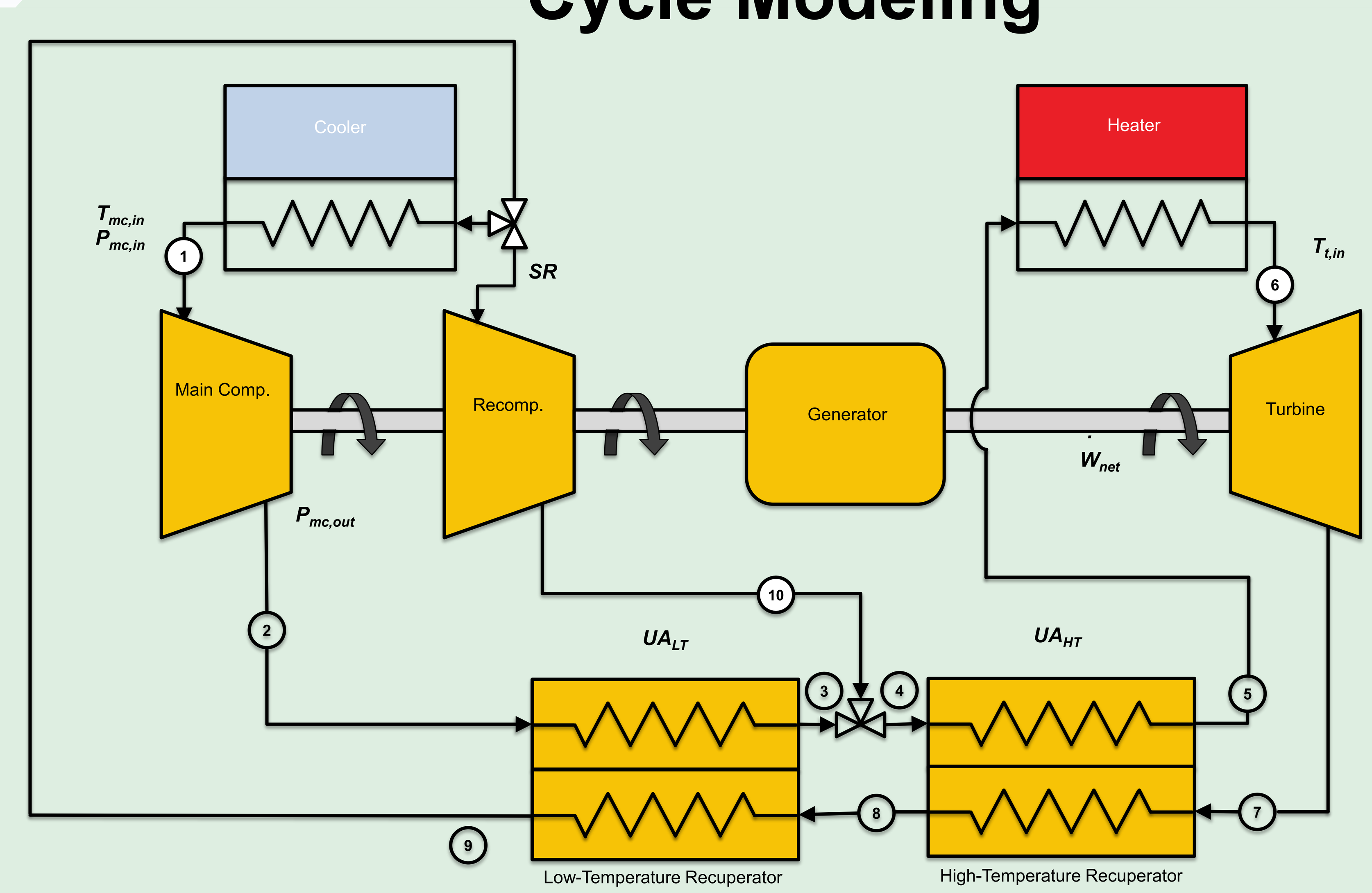


**Figure 1:** Schematic of RCBC with model inputs. Gold components integrate more sophisticated loss modeling than typical RCBC models in the literature.

### Integrated Loss Models

- Heat exchanger performance: discretized effectiveness-NTU model [3], [4]
- Heat exchanger sizing: analytical/empirical model [2] based on Blasius [5] and Dittus-Boelter [6] correlations
- Turbomachine aerodynamic losses: specific speed and specific diameter curves compiled by Balje [7] and digitized by Sondelski [8]
- Radial turbomachine leakage: Curve fit function of geometric clearances proposed by Qi [9] based on data from Futral and Holeski [10]
- Radial turbomachine windage: analytical model given by Vilim [11] with coefficients from Daily and Nece [12]
- Labyrinth seal leakage: empirical model developed by Egli [13] and Aungier [14],[15], and modified by Grotjan [2]
- Generator windage: empirical model developed by Aungier [14],[15]

See associated paper for list of references.

### Results

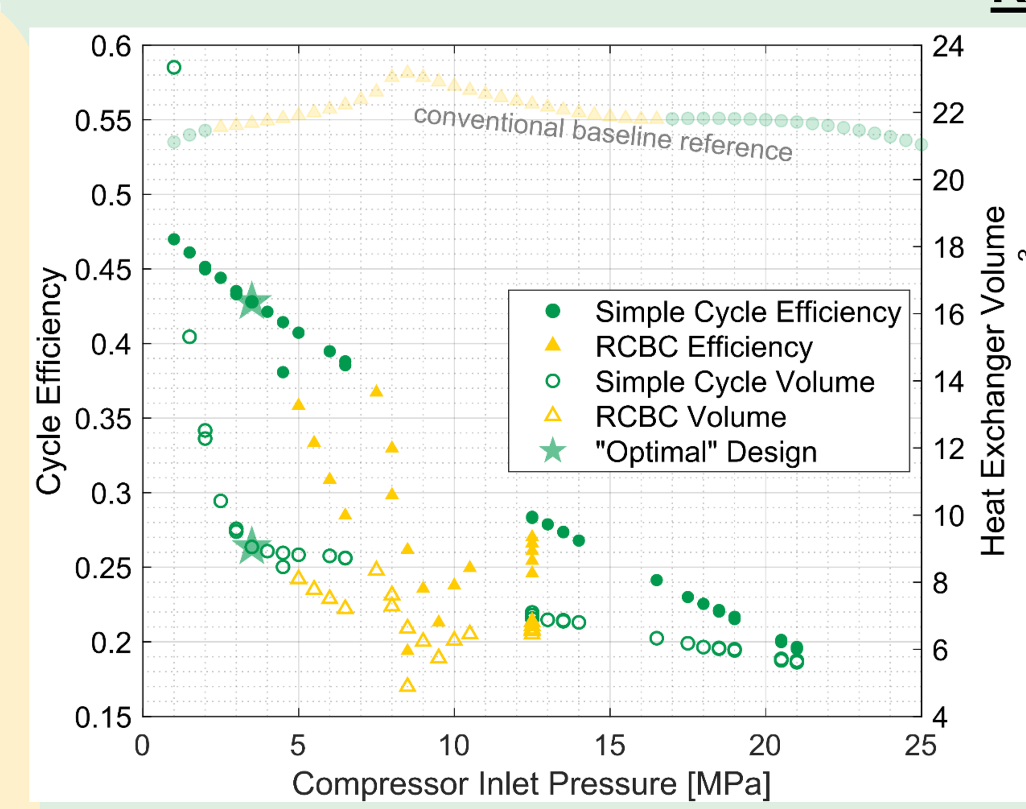


**Figure 2:** 500 kW power scale: Efficiency and normalized volume with loss models. Conventional baseline efficiency for constant turbomachine efficiency model is overlaid.

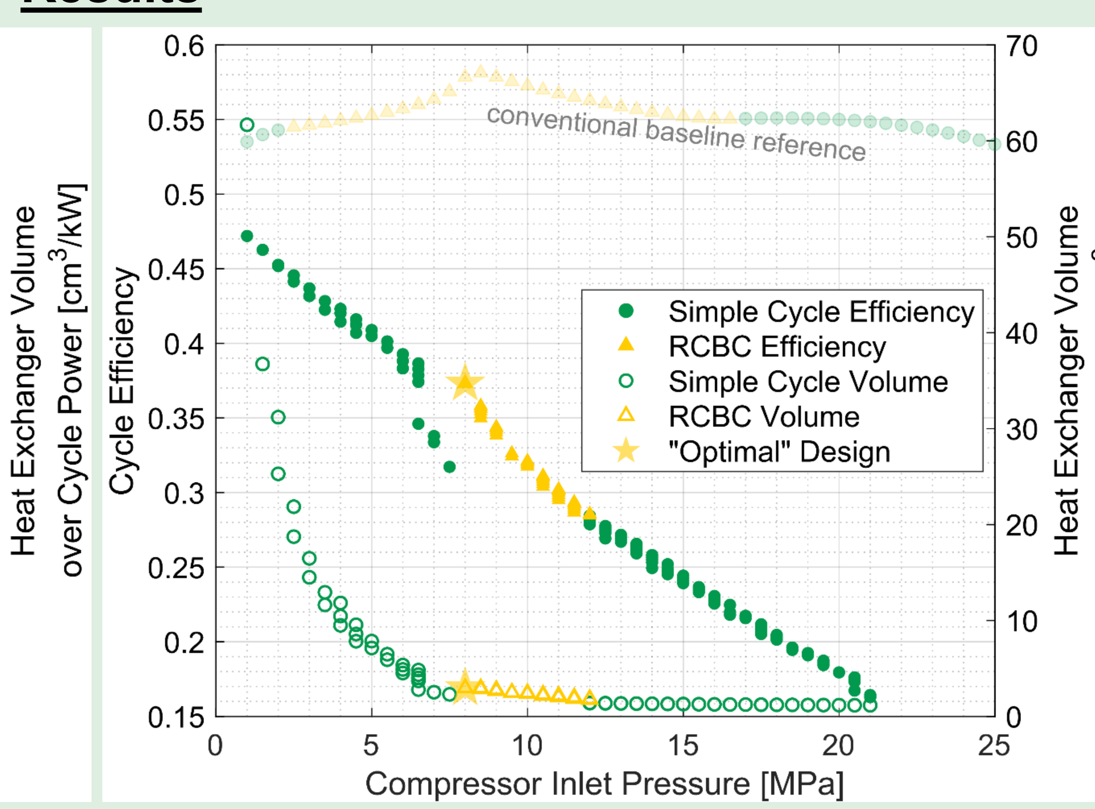


**Figure 3:** 50 kW power scale: Efficiency and normalized volume with loss models. Conventional baseline efficiency for constant turbomachine efficiency model is overlaid.

*Integrated loss models dominate at smaller power scales.*

*Conventional optimal operating conditions are still valid at large power scales, but simple, subcritical cycles are optimal at small power scales.*

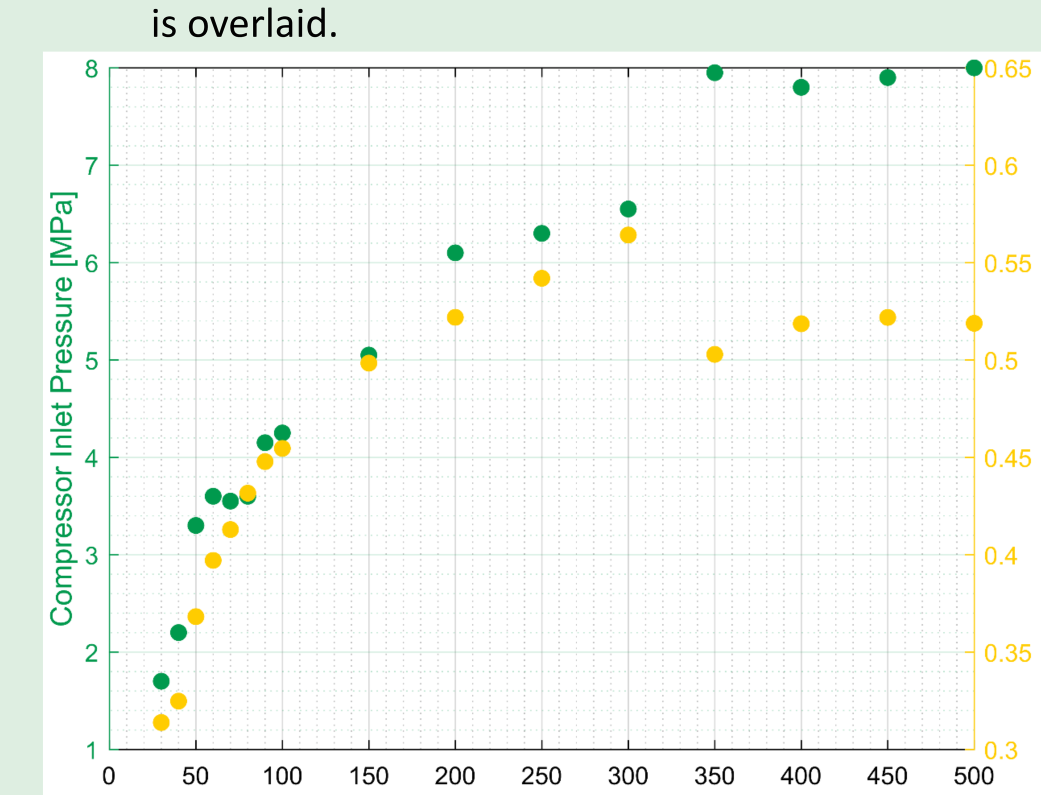


**Figure 4:** Optimal compressor inlet pressure and normalized cavity pressures as a function of power scale, derived from Pareto-optimal designs.

## Experimentation

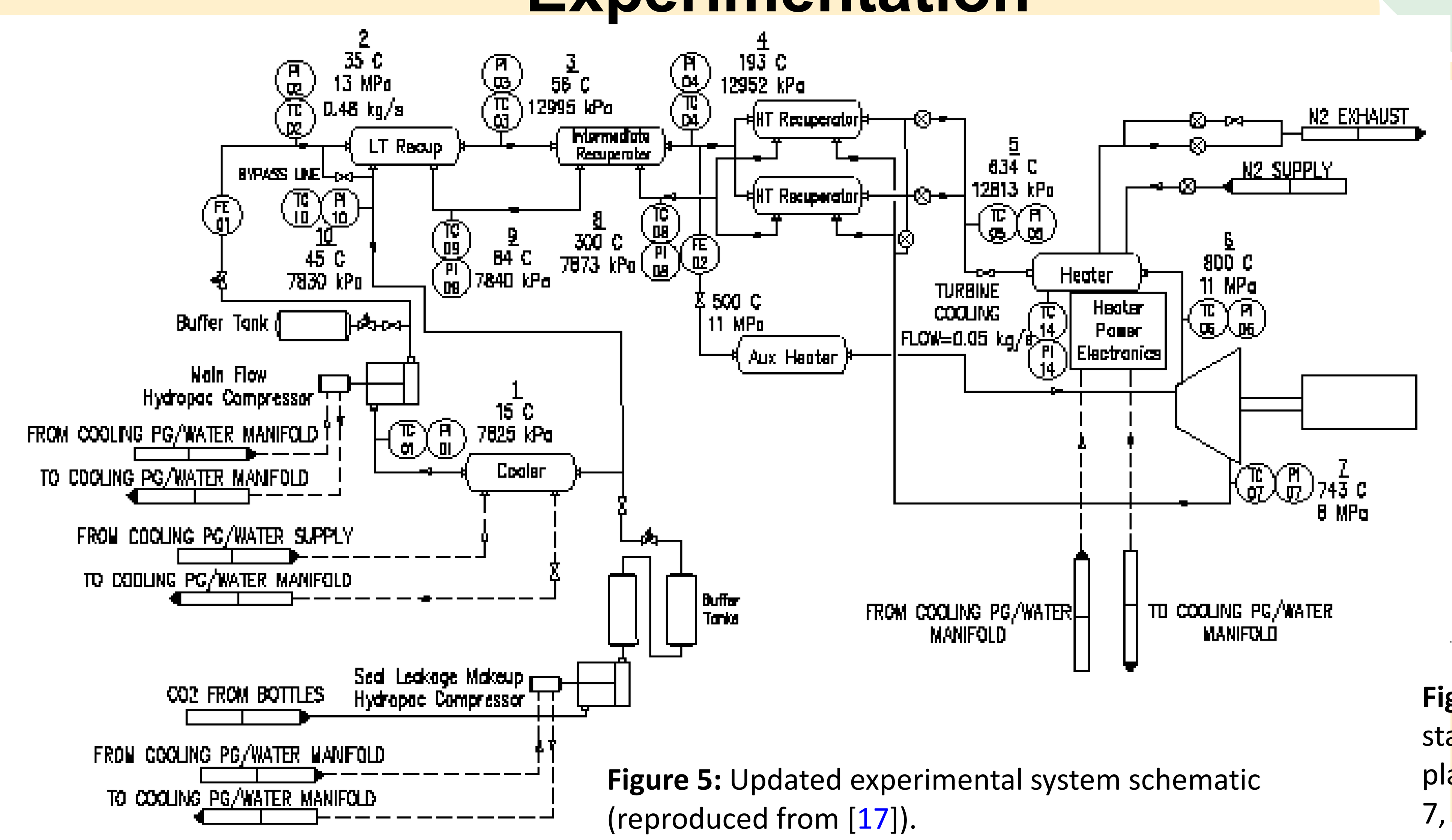


**Figure 5:** Updated experimental system schematic (reproduced from [17]).

### Results

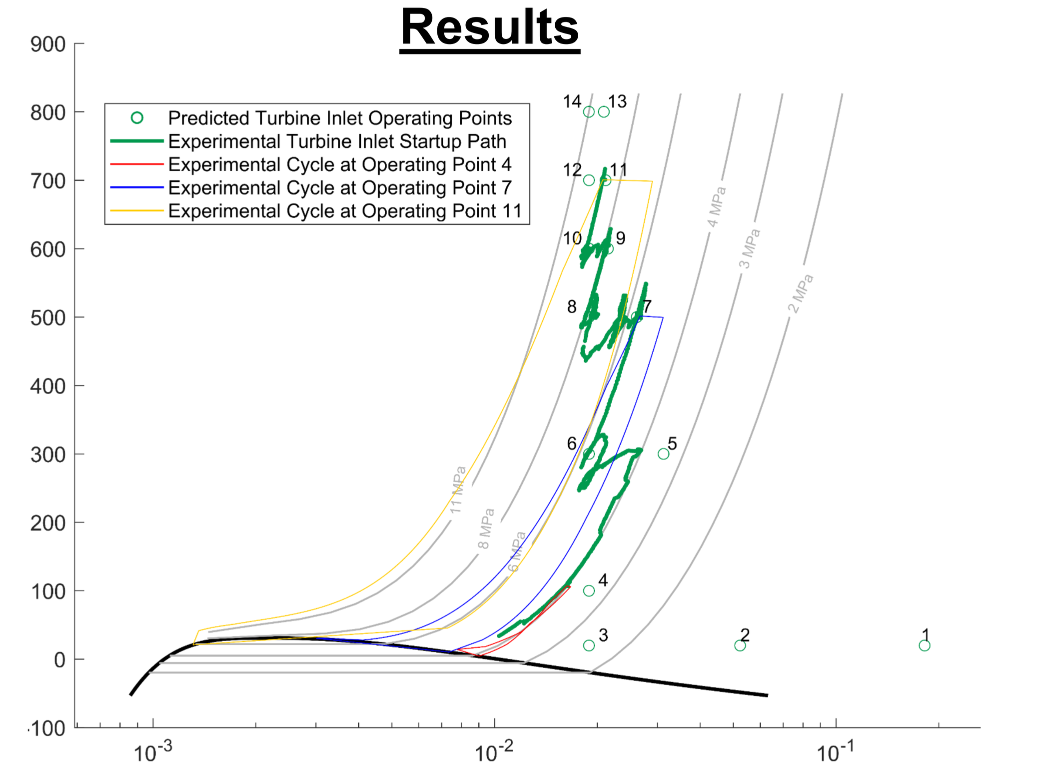


**Figure 8:** T–v diagram showing the proposed turbine-inlet start-up path, experimental data obtained using an orifice in place of the turbine, and full-cycle loops at operating points 4, 7, and 11.

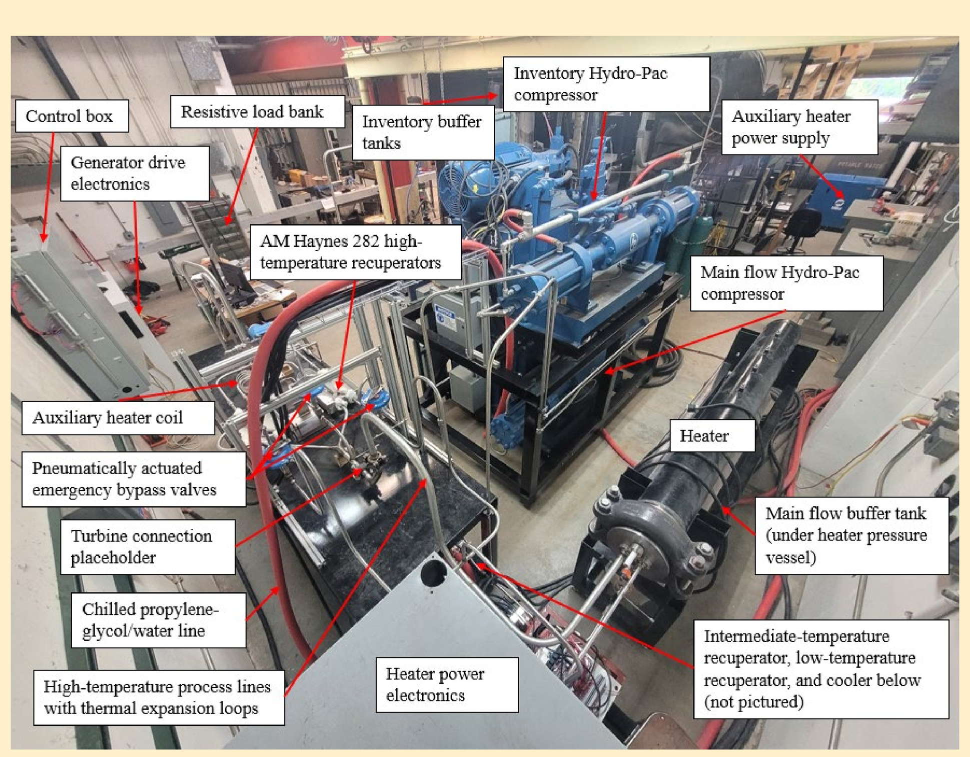


**Figure 6:** Constructed sCO2 turbine test facility (reproduced from [17]).

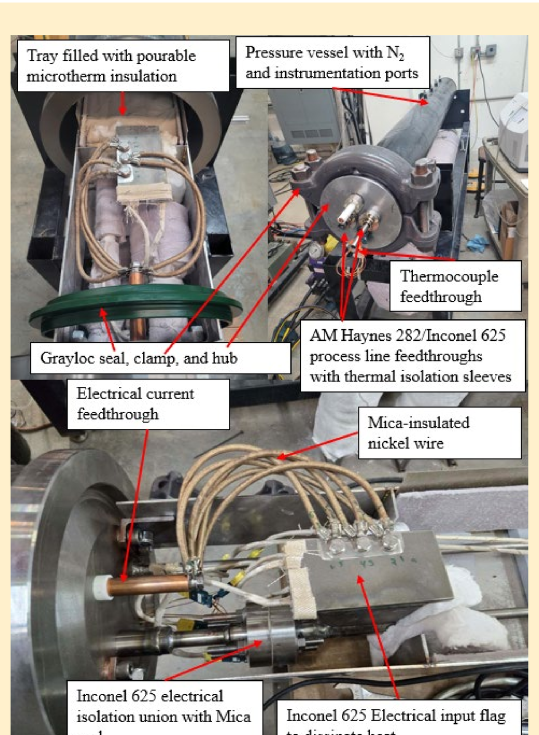


**Figure 7:** Constructed sCO2 heater assembly (reproduced from [17]).

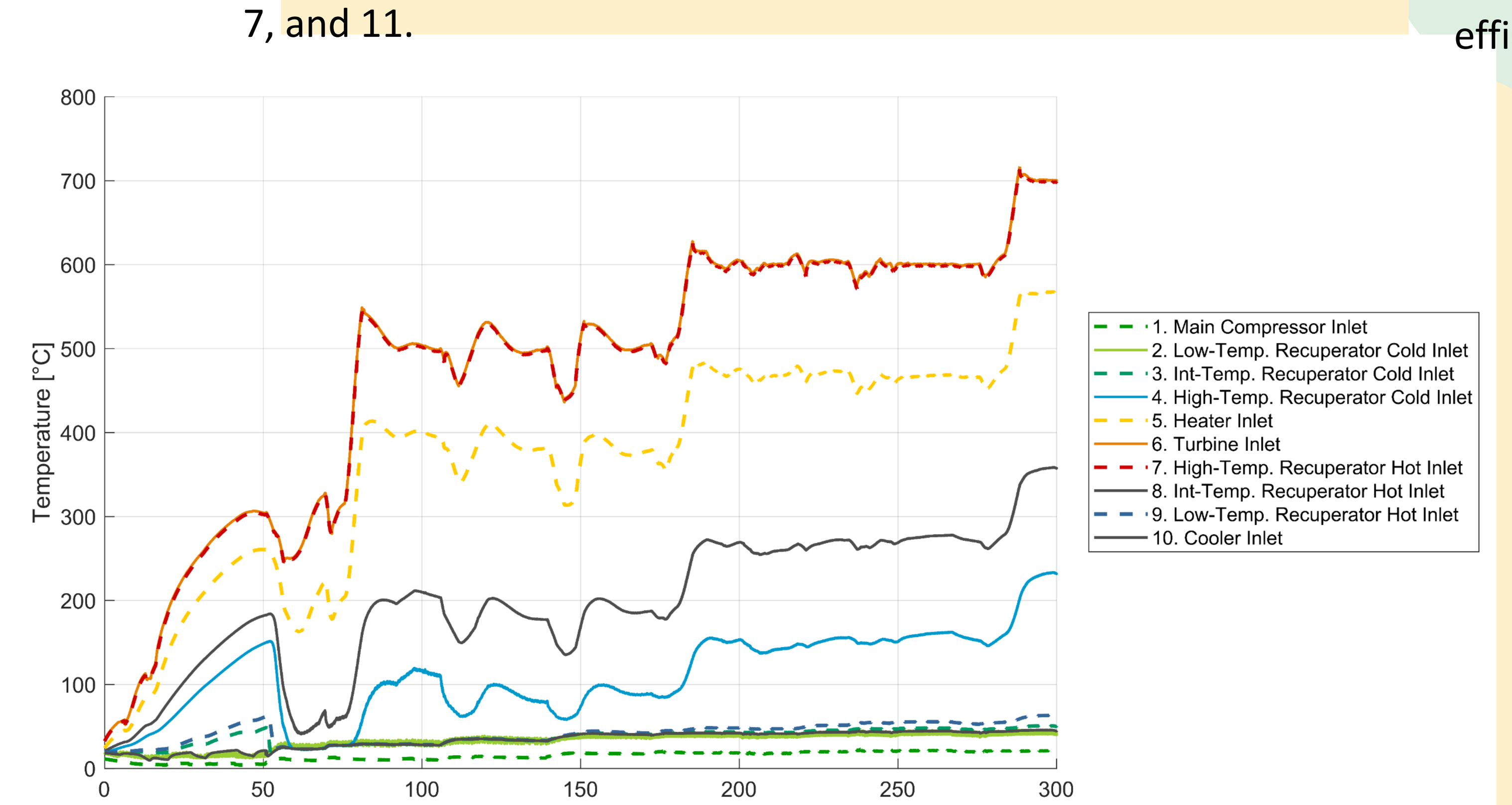


**Figure 9:** Measured temperature vs. time for all ten thermodynamic states during the validation campaign.