Supercritical Carbon Dioxide Pilot Plant Test Facility

DE-FE0028979

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2021 UTSR Project Review Meeting
November 9, 2021

Promise of sCO_2 Power Cycles

STEP DEMO

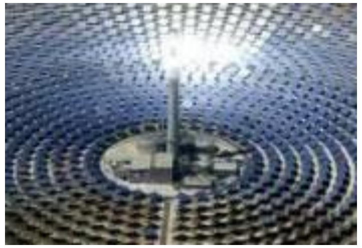
Promise:

> Efficient, Compact, Scalable, low water, low-carbon power generation

Plans to Demonstrate:

> Operability, Turbomachinery, Seals, Heat Exchangers, Durability, Materials, Corrosion, Cost

Versatile Technology – Broad Applicability:



Concentrated Solar

Fossil Fuel/Biomass

Geothermal

Nuclear

Energy Storage

Waste Heat Recovery

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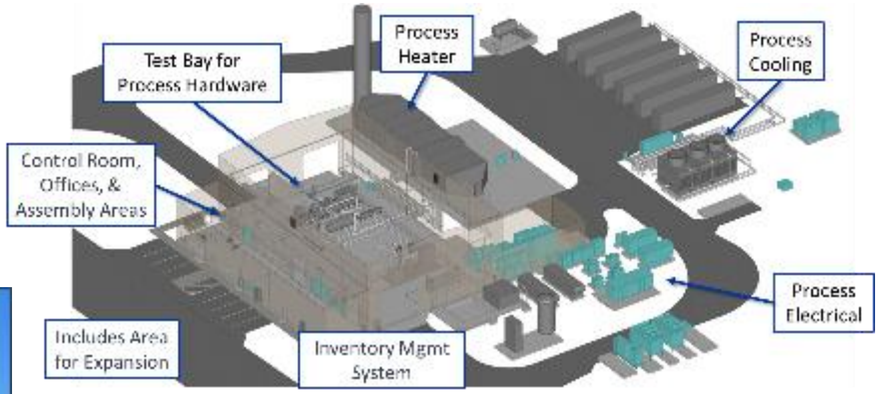
Supercritical Transformational Electric Power (STEP) Project DE-FE0028979

Scope: Design, construct, commission, and operate **10 MWe sCO_2 Pilot Test Facility**
Reconfigurable to test new technologies in the future

Goal: Advance state of the art for high temperature sCO_2 power cycle performance
Evolve Proof of Concept (TRL3) to operational System Prototype (TRL7)

Schedule: Three budget phases over six years (2016-2023)
Currently in Budget Phase 2 – Fabrication & Construction



Team: U.S. Department of Energy (**DOE NETL**)
Gas Technology Institute (**GTI®**)
Southwest Research Institute (**SwRI®**)
General Electric Global Research (**GE-GR**)

Industry Partners:

STEP Project Objectives

STEP Demo will demonstrate a fully integrated functional electricity generating power plant using transformational sCO2-based power cycle technology

Demonstrate pathway to efficiency **> 50%**

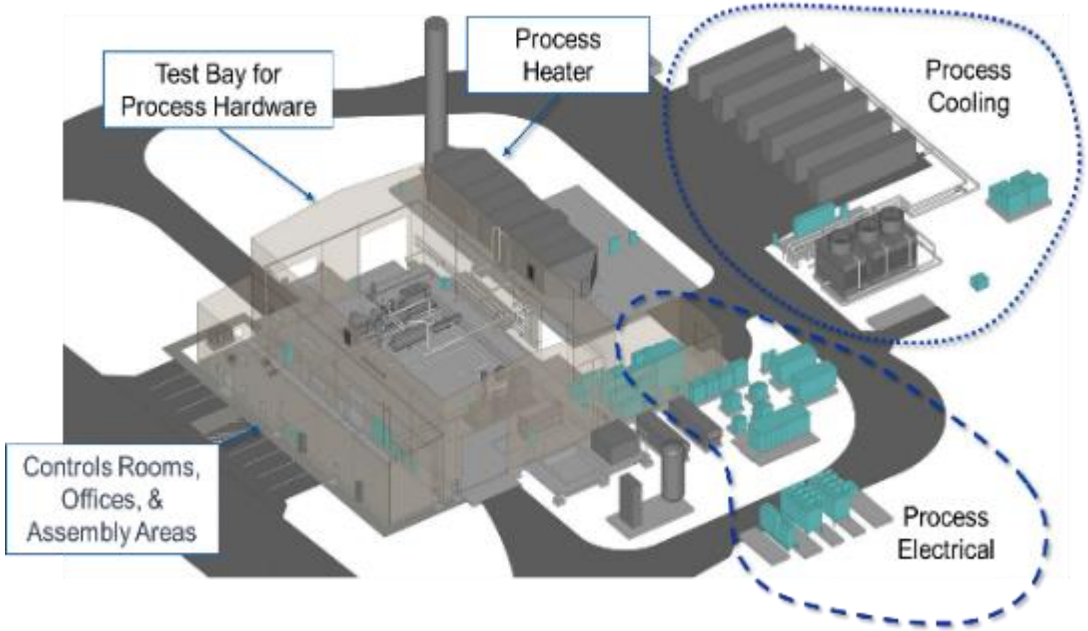
Demonstrate cycle operability **>700°C** turbine inlet temperature and **10 MW$_e$** net power generation

Quantify performance benefits:

- 2-5% point net plant efficiency improvement
- 3-4% reduction in LCOE
- Reduced emissions, fuel, and water usage

Demonstrate Reconfigurable flexible test facility

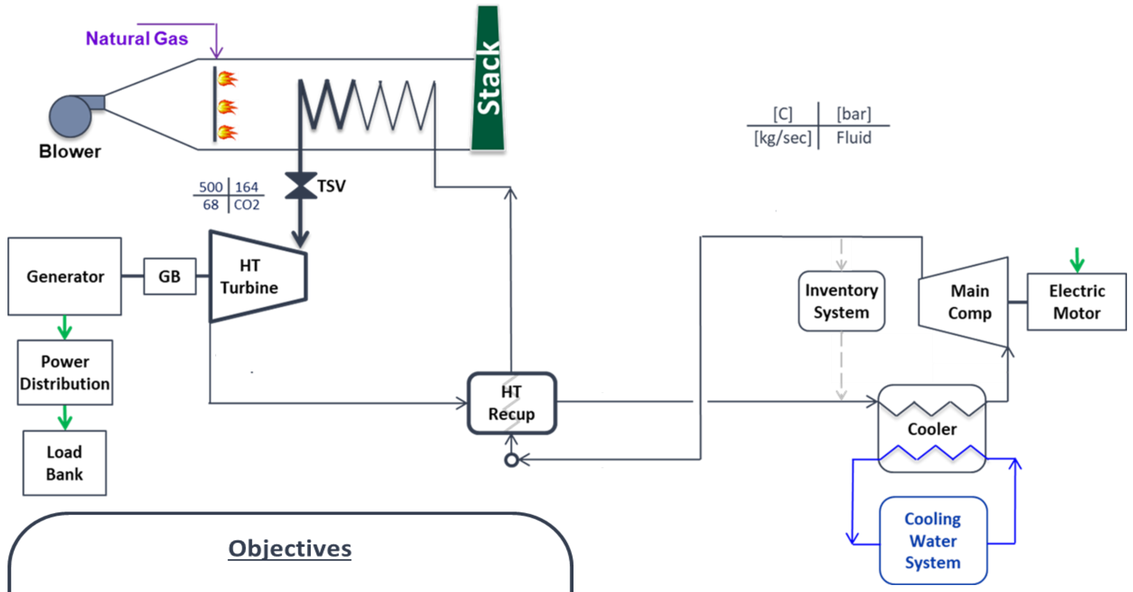
- Available for Testing future sCO_2 equipment & systems



STEP will be among the largest demonstration facilities for sCO_2 technology in the world

Simple and Recompression Brayton Cycle test configurations planned to achieve project objectives

Simple Recuperated Brayton Cycle

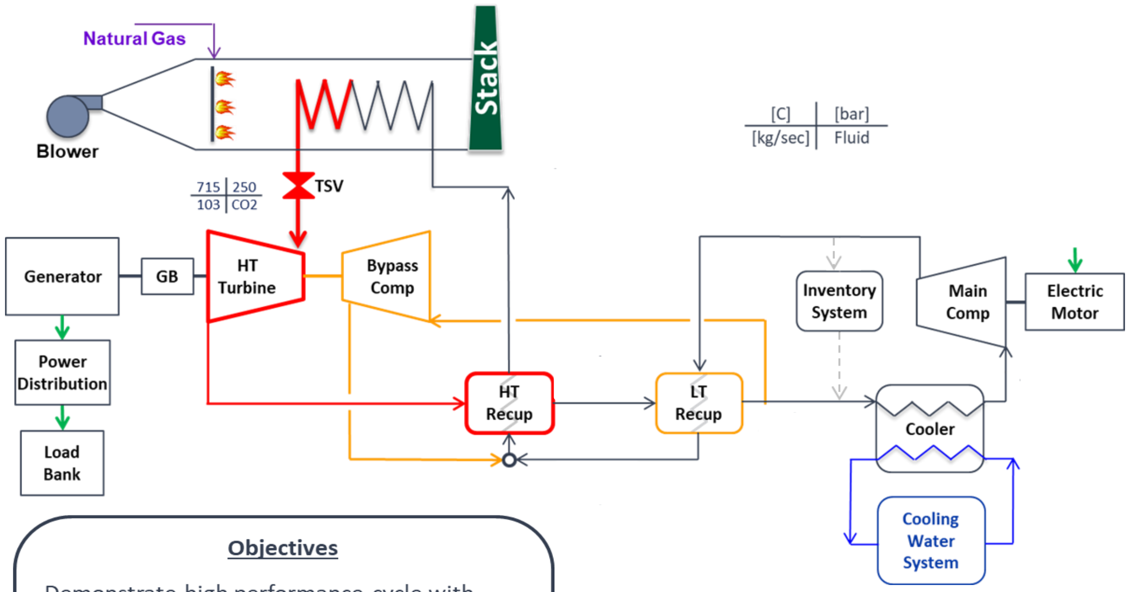


Objectives

Demonstrate initial cycle performance with reduced risk configuration

- Reduced Turbine inlet at 500°C similar to Waste Heat Recovery applications
- Single compressor configuration
- Provides Steady & Transient Cycle Performance Data used to predict RCBC performance and operations

Recompression Brayton Cycle (RCBC)



Objectives

Demonstrate high performance cycle with parallel compressors & multiple HEX

- Increase Turbine inlet to 715°C
- Measure Steady & Transient Cycle Performance Data, evaluate operability
- Demonstrate pathway to 50% thermal efficiency
- Supports application to in-direct coal, HT WHR Industrial sources, and CSP plants

STEP Project Status

- **Site Construction Progress Excellent**
  - Building Occupancy received in early June 2020 on schedule
  - Process Electrical, Primary Heater, Cooling Water, Compressor Installation progressing
- **Significant Achievements on Major Equipment Design & Fabrication**
  - Most Major Equipment delivered or near completion
  - Equipment deliveries to site started in Nov 2019 and new arrivals every month
- **Challenges with 'first of a kind' equipment**
  - High Temperature Recuperator Design Life
  - Fabrication of Turbomachinery, Primary Heater Fabrication, and Turbine Stop Valve
  - Resolved technical issues and progressing with final equipment manufacture and delivery
- **Developing supply chain for new materials and large-scale equipment**
- **Installation of equipment on-going with commissioning starting in Spring 2022**

STEP Demo Objectives – Technology Maturation

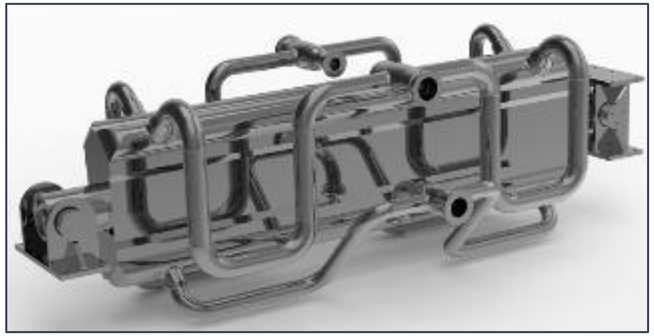
Advance state of the art for high temperature sCO_2 power cycle performance from Proof of Concept to System Prototype validated in an operational system (Technology Readiness Level 3 to 7)

INDIRECT-FIRED CYCLE

Recuperator Development

Compact, high efficiency designs for high T, high diff. pressure sCO_2

High Temperature Recuperator meets performance and life



High Temperature Recuperator fabrication nearing completion

STEP Demo Objectives – Technology Maturation

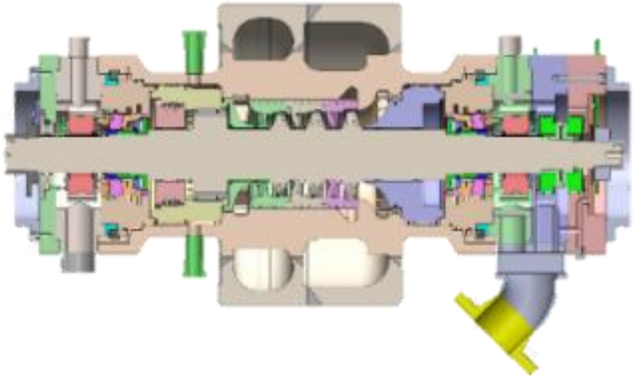
Advance state of the art for high temperature sCO_2 power cycle performance from Proof of Concept to System Prototype validated in an operational system (Technology Readiness Level 3 to 7)

STEP DEMO

INDIRECT-FIRED CYCLE

Turbine Technology

Low leakage seals, bearings; high temp, high power density sCO_2 turbine designs



Compact turbine assembly operates at >700°C

Turbine nozzle fabrication completed

Turbine rotor fabrication completed

STEP Demo Objectives – Technology Maturation

Advance state of the art for high temperature sCO_2 power cycle performance from Proof of Concept to System Prototype validated in an operational system (Technology Readiness Level 3 to 7)

STEP DEMO

INDIRECT-FIRED CYCLE

Materials

Development of compatible materials for high T sCO_2 conditions

Large-scale fabrication of sCO_2 heater coil – welded Inconel 740H tubes

First large-scale complex Inconel 740H tube heat exchanger installed
Heater coil operates at 265 bar and 700°C

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STEP Demo Objectives – Technology Maturation

Advance state of the art for high temperature sCO_2 power cycle performance from Proof of Concept to System Prototype validated in an operational system (Technology Readiness Level 3 to 7)

Large-scale cast Haynes 282 Turbine Stop Valve design and fabrication

First large-scale complex Haynes 282 Casting Turbine Valve operates at 265 bar and 700°C

STEP DEMO

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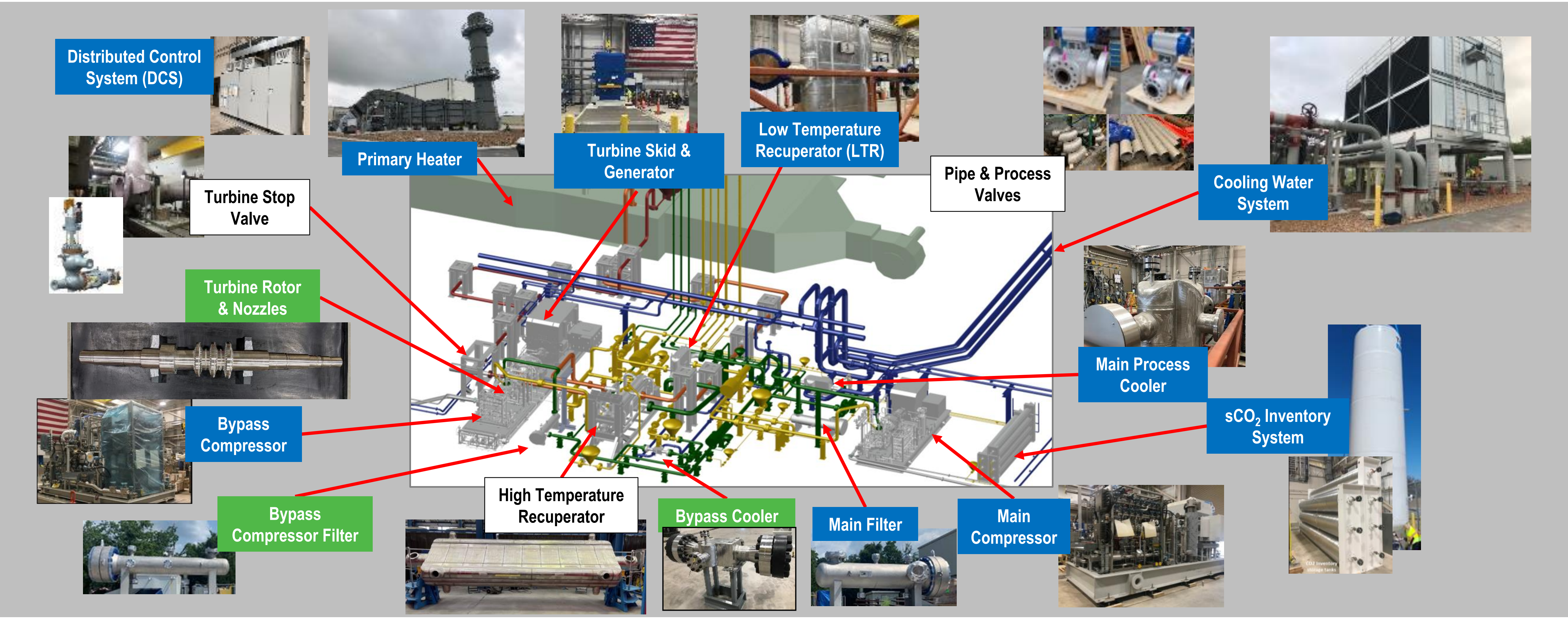
Process Equipment Progress



Blue – Received and Set, Green – Received, White – In Fabrication

Timeline to Test Operations

Jan. 2022	Complete Key Equipment deliveries
May 2022	Mechanical Completion – Simple Cycle
Sep. 2022	Complete Commissioning Simple Cycle
Dec. 2022	Complete Simple Cycle Tests
Apr. 2023	Complete RCBC Reconfiguration
Dec. 2023	Complete RCBC Tests (End Project)

STEP Test System Modeling

	Steady State	Transient
Software	Aspen Plus, Flownex	Flownex
Property Method	NIST REFPROP	NIST REFPROP
Cases Analyzed	2 Simple Cycle, 7 RCBC	Various operating scenarios such as start up, shut down, trips, and load level changes for both configurations
Purpose	Results used to define equipment requirements and specifications	Results supported system requirements and operational analysis of facility

Data generated will be used to validate the steady state and transient models, which will be used to project performance at the commercial scale and be valuable tools for other sCO_2 systems in the future

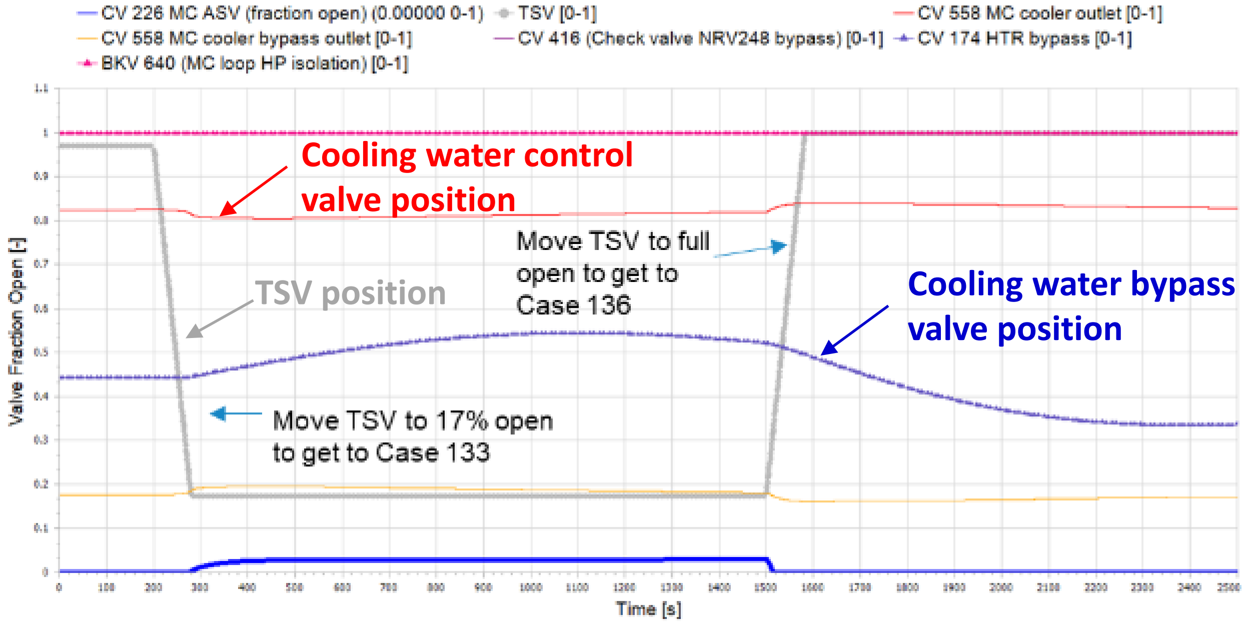
Steady State Modeling Initial Results

Model Names	Cycle Configuration	Description	Load %	Net Power Level (MWe)	Cooler Exit Temperature	Turbine Inlet Temperature	Cycle Efficiency
133	Simple	Simple cycle minimum load case	Min	2.5	35°C	500°C	22.6%
136	Simple	Simple cycle maximum load case	Max	6.4	35°C	500°C	28.3%
151	Recompression	Baseline case	100%	10.0	35°C	715°C	43.4%
152	Recompression	"Hot" Day Case	70%	6.6	50°C	675°C	37.4%
153	Recompression	"Cold" Day Case	100%	9.9	20°C	525°C	36.8%
154	Recompression	Partial load case using inventory control	40%	4.0	35°C	715°C	37.0%
155	Recompression	RCBC at 500°C turbine inlet temperature	70%	6.9	35°C	500°C	32.5%
157	Recompression	Partial load case using TSV throttling (transient condition)	40%	4.2	35°C	715°C	30.8%
157a	Recompression	Partial load case using TSV throttling	40%	3.9	35°C	675°C	29.6%

Simple Cycle Power Level Transient Sample Results

> Max Load (6.4 MWe) → Min Load (2.5 MWe) → Max Load (6.4 MWe) by throttling the Turbine Stop Valve (TSV)

- TSV (gray line) closes to 17% open at 200s and reopens fully at 1500 seconds
- As a result:
  - The HTR bypass valve (purple triangle) opens to maintain a 7°C approach temperature to protect the HTR
  - The 3-way valve of the cooler (red and yellow lines) adjusts flow through and around the cooler to maintain a 35°C inlet temperature to the MC
  - The ASV opens slightly to allow minimal recycle



TSV = Turbine Stop Valve
ASV = Anti-surge valve
MC = Main Compressor

HTR = High Temperature Recuperator
HP = High pressure

Transient Modeling Key Findings

- Control valve schedules during start-up were evaluated and determined
- Sequence approaches to manage component temperatures within specification
- Determined timing to enable heater ignition/firing at minimum system flowrate.
- Determined if liquid formation occurs during loop filling.
- Determined start up and interactions of two parallel compressor loops for RCBC
- Evaluated fast ramp scenarios and identified limiting capabilities of other sub-systems

STEP Simulator

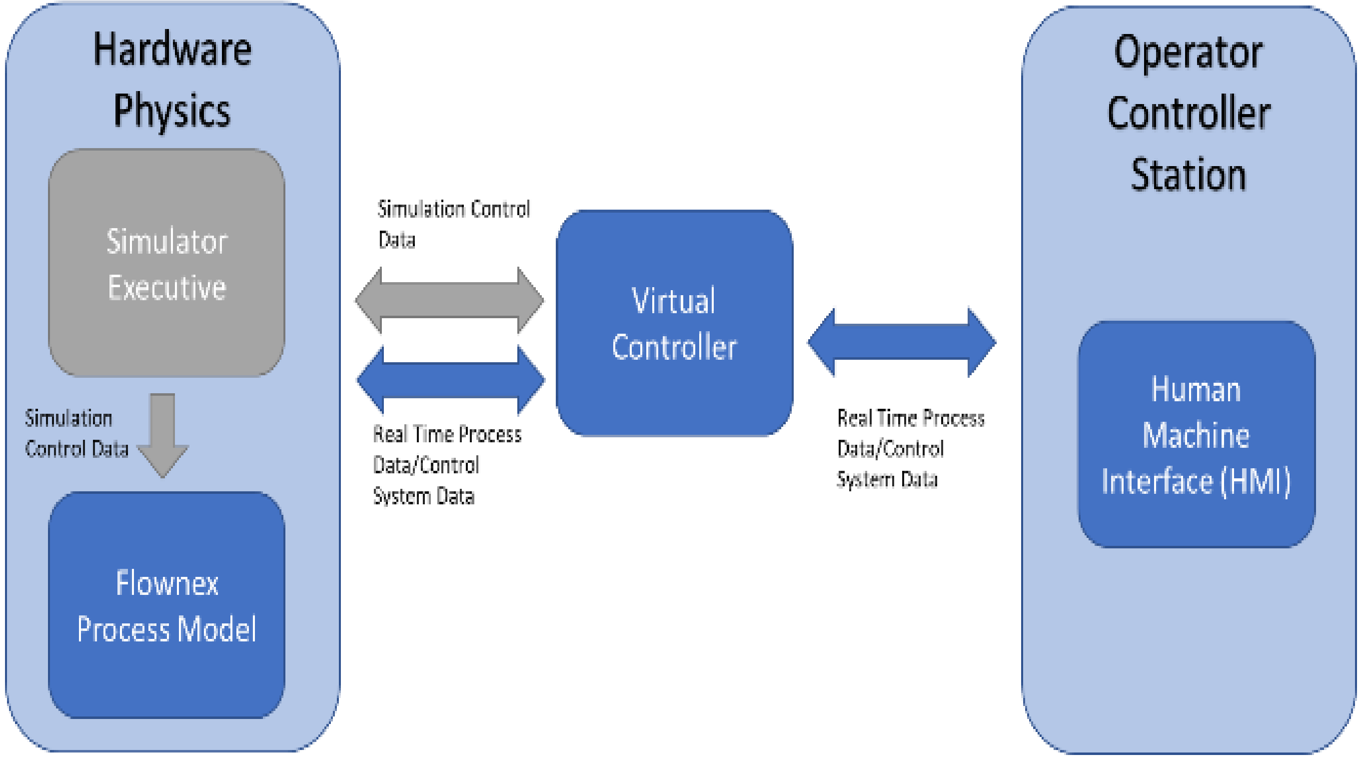
> A virtual simulator will be built of the facility

> Flownex will represent the hardware physics

> Mark VI controller will be used for the virtual controller

> Operators will use this simulator

  – Training to gain familiarity with test system dynamics
  – Practice various control strategies
  – Assess “What if” scenarios



Summary & Conclusions

- Facility Significant Progress on Major Equipment Fab/Installation
- Challenges with low TRL equipment which is educating the industry engineers and supply chain
  - Turbomachinery, High Temperature Recuperator, Primary Heater, and Turbine Stop Valve
- Commissioning to Initiate in Spring 2022
- Modeling of System Operation in Simple and RCBC configurations completed
  - Continue to Anchor Model to Commissioning and Simple Cycle/RCBC Test Data
- Digital Simulator using those System Models being developed to train operators and potential commercial system developers
- STEP Project Status can be followed at *www.STEPdemo.us*

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