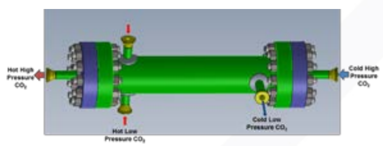
SunShot
U.S. Department of Energy

CSP Program Summit 2016



Development of a High Efficiency Hot Gas Turbo-Expander and Low Cost Heat Exchangers for Optimized CSP SCO_2 Operation

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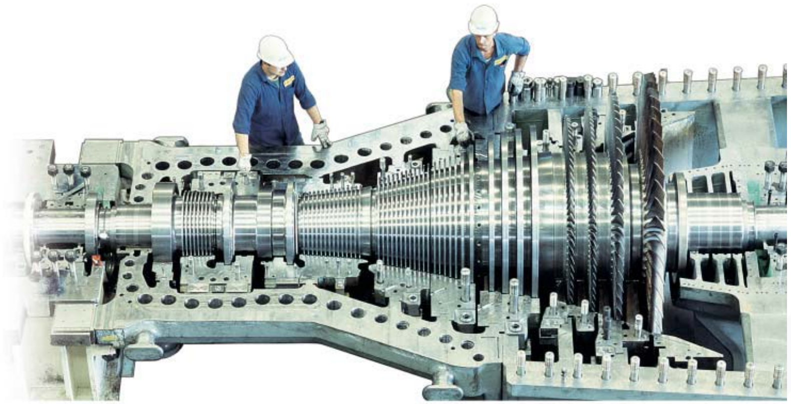
Project Objectives

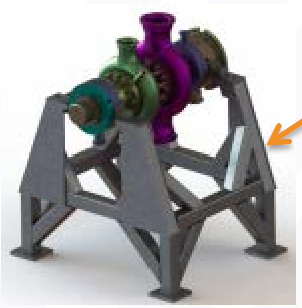
- To develop a novel, high-efficiency sCO_2 hot-gas turbo-expander optimized for the highly transient solar power plant duty cycle profile
  - This sCO_2 turbo-expander design advances the state-of-the-art from a current Technology Readiness Level (TRL) 3 to TRL 6
- To optimize novel recuperator technology for sCO_2 applications to reduce their manufacturing costs
- The sCO_2 turbo-expander and heat exchanger will be tested in a 1-MWe sCO_2 test loop, fabricated to demonstrate the performance of components along with the overall optimized sCO_2 Brayton cycle
- The scalable sCO_2 turbo-expander and improved heat exchanger address and close two critical technology gaps required for an optimized concentrating solar power (CSP) sCO_2 plant and provide a major stepping stone on the pathway to achieving CSP at $0.06/kW-hr levelized cost of electricity (LCOE), increasing energy conversion efficiency to greater than 50%, and reducing total power block cost to below $1200/kW installed

Motivation for SCO2 Cycles over Steam

20MW steam turbine

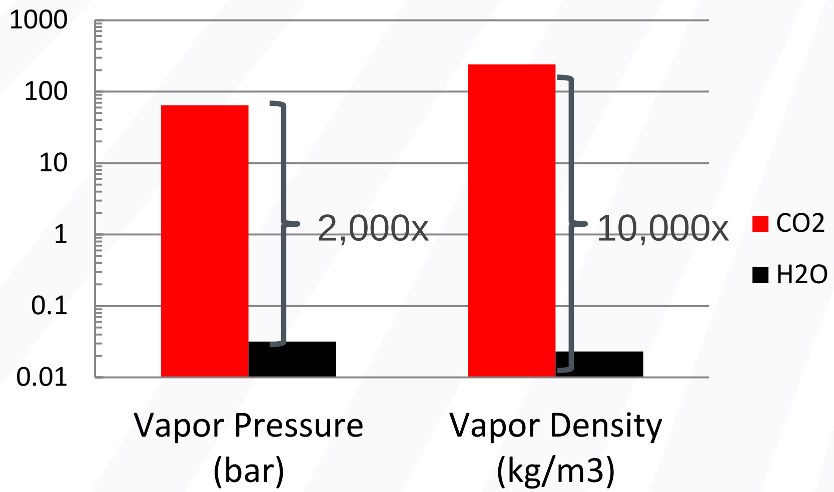


14MW sCO2 turbine



150 lb rotor
7” rotor tip diameter
27,000 rpm

Vapor properties at 25C (77F) condenser



Task 2.1: Heat Exchanger Fabrication

Completion Target Metrics:

- **Test Unit Size:** 50 kW scale up 100:1 for Phase 2
- **Capacity:** Design goal is minimum of 80% of 35 MW/m^3 (i.e., 27 MW/m^3. (Note: This only affects the size of the heat exchanger and not the amount of heat transferred. If a pressure containment envelope is used for prototype testing, the demonstrated power capacity may be lower.)
- **Pressure Drop:** Goal is to be < 1.5 times of bench-scale performance
- **Cost:** Goal is to not be more than 1.5 times \$50/kW (i.e., no more than \$75/kW)

5.5 MW Recuperator

1st Generation Design
sCO_2 Counter-current Micro-tube Heat Exchanger

Milestone Design Goals Met

- **Test unit size 50kW scale up 100:1 for Phase 3**
  - Design Requirement: 5 MW (5000 kW)
  - **Actual: 5.5 MW** (5500 kW)

- **Capacity:**
  - Design Requirement: 27 MW/m^3
  - **Actual** (Tube bundle dimensions): **89 MW/m^3**
  - **Actual** (Pressure vessel dimensions): **12.6 MW/m^3**

5.5 MW Recuperator

1st Generation Design
sCO_2 Counter-current Micro-tube Heat Exchanger

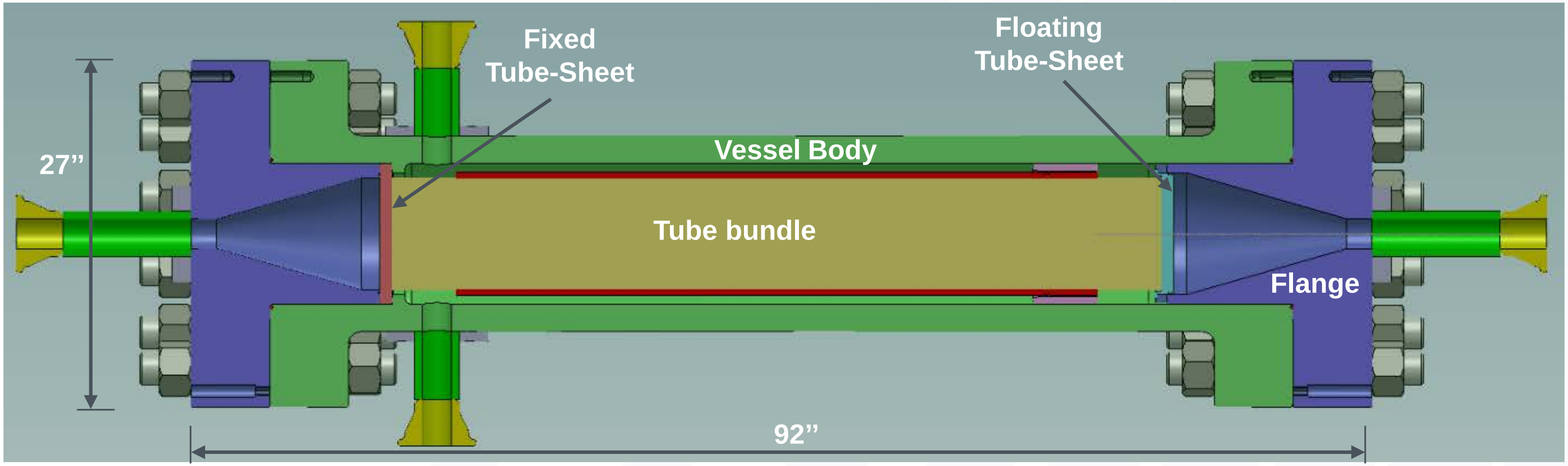
Milestone Design Goals Met

- **Delta pressure**
  - Design Requirement: 3 bar
  - **Actual** (Low Pressure Side): 1.4 Bar
  - **Actual** (High Pressure Side): 1.4 Bar

- **Fabrication cost:**
  - Design Requirement: Less than 75 $/kW
  - **Current Estimate: 72.2 $/kW**

5.5 MW Recuperator

sCO_2 Counter-current Micro-tube Heat Exchanger



Flanged Pressure Vessel:

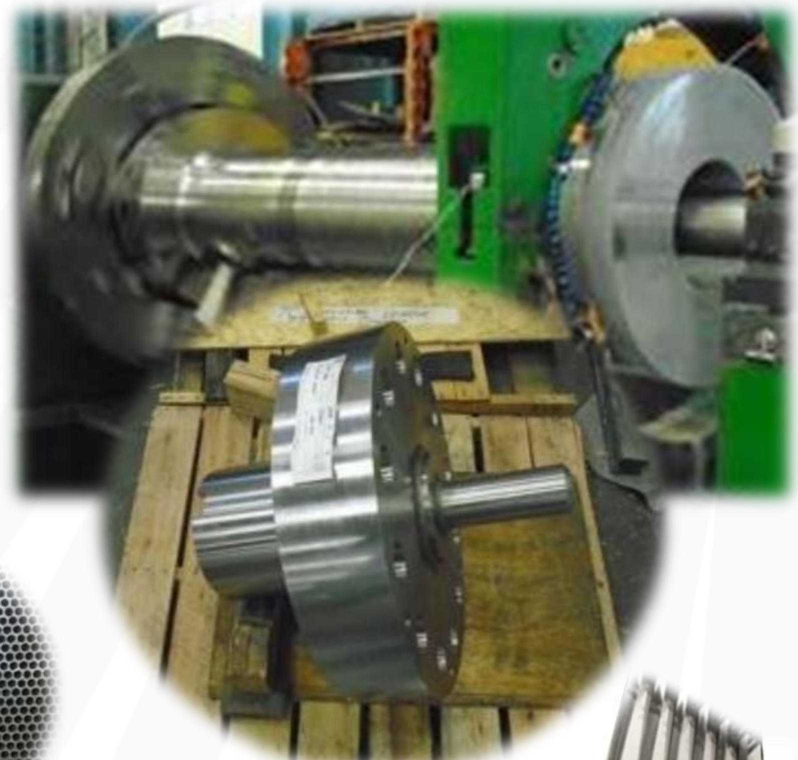
- Design per ASME Sec VIII, Div 1
- Design Conditions: 575°C @ 280 bar (1053°F @ 4116 psi)
- Body, Flange, & Bolts: 316H Stainless Steel

Features:
Floating Head Design
Replaceable Tube Bundle

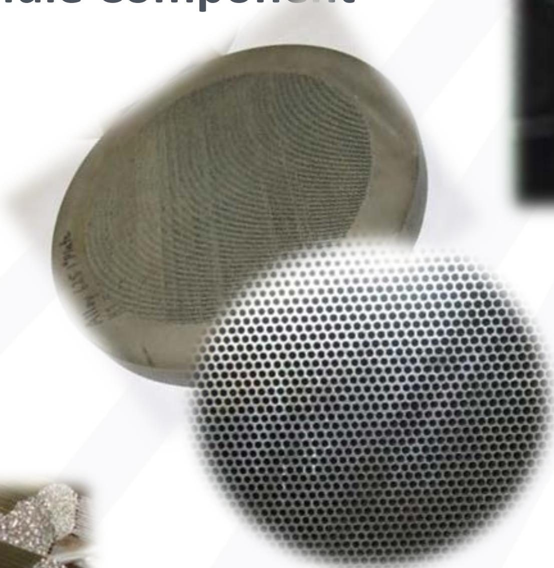
5.5 MW Recuperator

Recuperator Status

- Pressure Vessel Fabrication Completed
  - Hydro-test-ASME stamp complete



- Fabrication of Tube Bundle Component Completed
  - Tube sheets
  - Seals
  - Micro-tubes
  - Bundle supports
  - Braze fixtures



- Tube bundle assembly for brazing in process

Task 2.2: Turbomachinery Fabrication

SwRI will fabricate and assemble the complete turbo-machinery package, including skid, ancillary systems, and control system using in-house machine shops and contractors as necessary.

Completion Target Metrics:

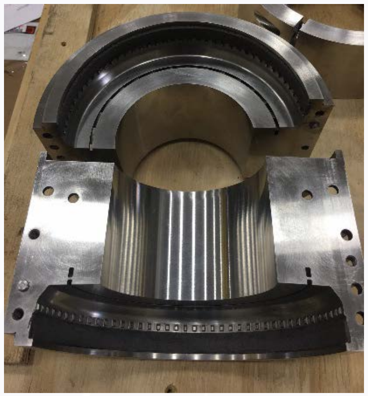
- Detailed design cross-sectional drawings, mechanical installation drawing, solid models, electrical drawings, and package drawings completed
- Detailed individual part drawings
- Bill of materials
- Material specification and quality certificates
- Major component inspection
- Turbine assembly
- Package assembly
- Package shipment
- Component testing to meet design specifications stated in design documents from Task 2.2:
  - Hydro testing of all pressure containing vessels meeting system design and safety factors
  - Over-speed spin test to 115% over-speed and progressive balance
  - Material and dimensional certification checks

Turbomachinery Fabrication

Parts that have been received:

Coupling Dummy and Housing

Operating Stand



Stator Nozzle

Exit Plenum Backing Ring

Balance Piston Seal

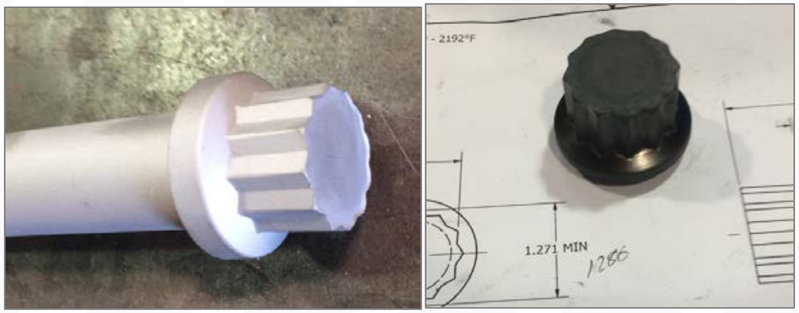
Turbomachinery Fabrication

Parts at vendor:

Rotor

Air Dyno

Cast Housings



Casing Nuts and Bolts

Turbomachinery Fabrication

At this time, the following metrics have been completed:

- Detail design cross-sectional drawings, mechanical installation drawing, solid models, electrical drawings, package drawings completed
- Detailed individual part drawings
- Bill of materials
- Material specification and quality certificates

Task 2.3: Test Loop Hardware Acquisition and Installation

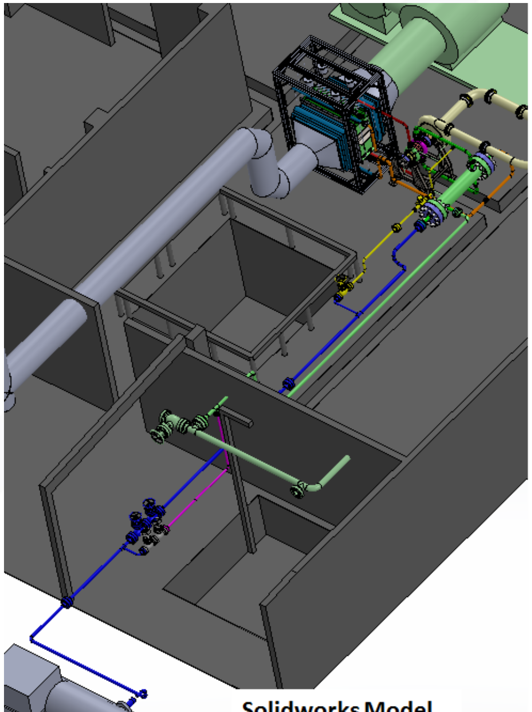
SwRI will acquire long lead time critical components required for the test loop and cycle demonstration. Installation of equipment and piping, plumbing, wiring, installation of instrumentation and control system, and system checks will be performed.

Task 2.3.1: Identify and acquire long-lead critical components required for test loop fabrication and commissioning

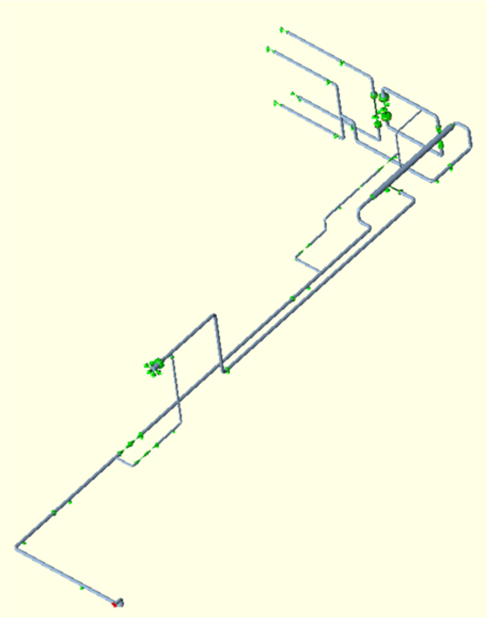
Task 2.3.2: Install subsystems and components into sCO_2 expander test loop

Thermal Pipe Stress Analysis

- Maximum stresses pass the B31.1 code stress compliance conditions
- Piping allowed to expand away from the rigidly-held turbine to keep the stresses as low as possible



Solidworks Model

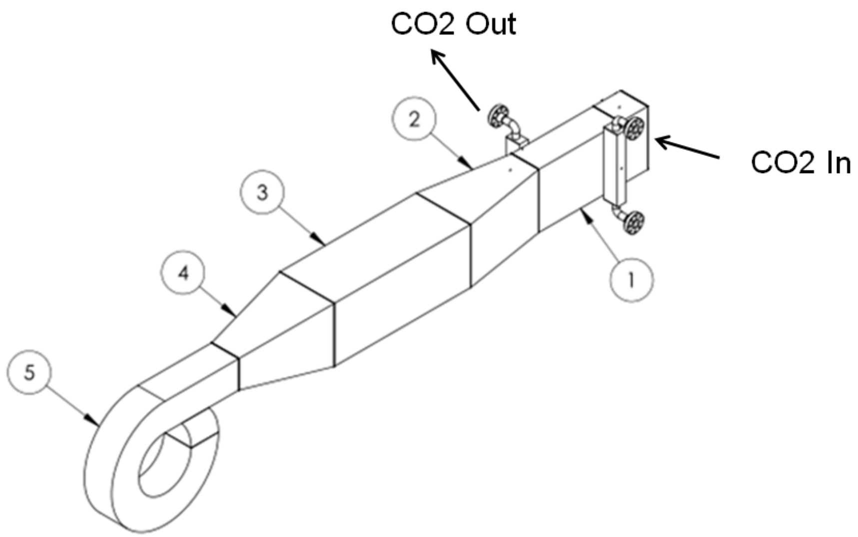


CAESAR II FE Beam Model

Primary Heater

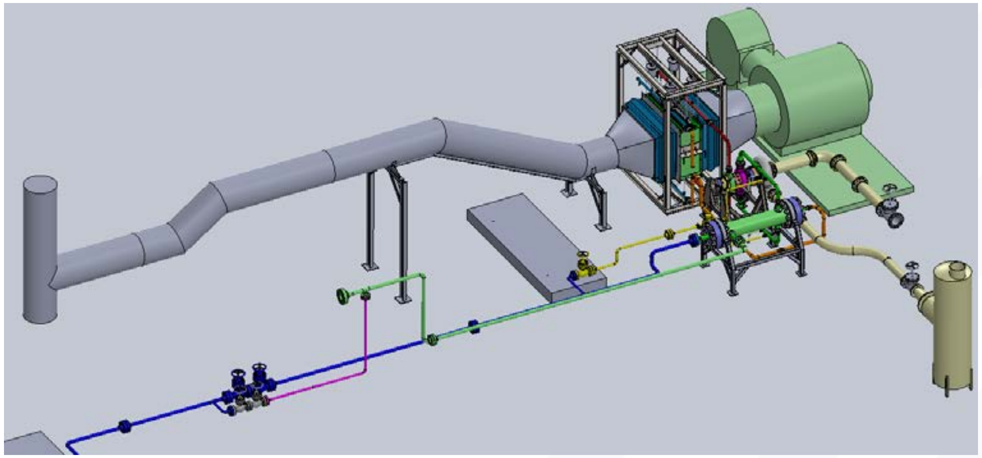
Heater Operating Conditions:

	Recuperator Outlet/ Heater Inlet	Heater Outlet/ Turbine Inlet
Temperature	470°C	715°C
Pressure	251.9 bar	250.9 bar
Mass flow rate of CO_2	8.410 kg/s	8.410 kg/s



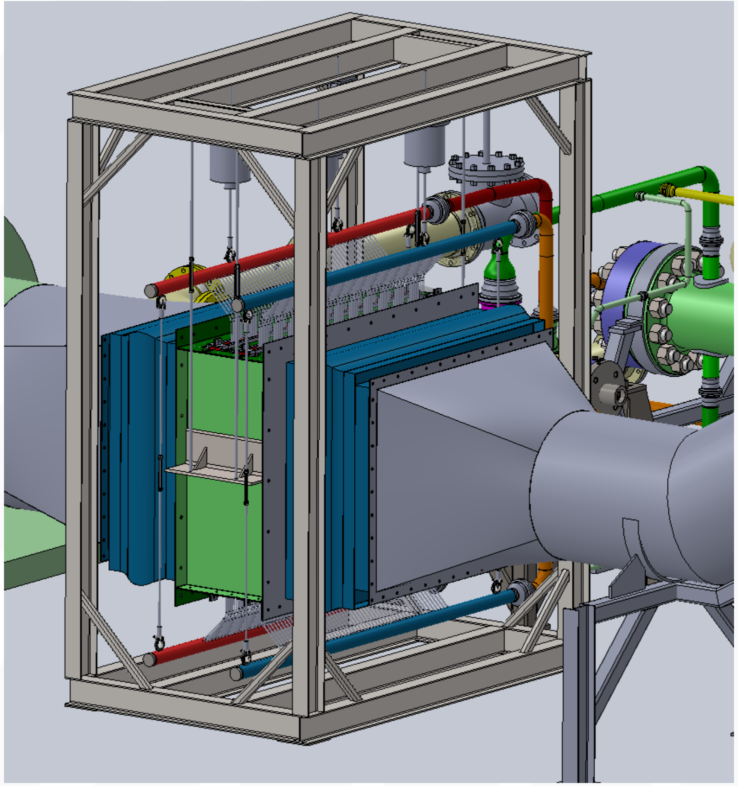
1) Duct surrounding the staggered tube bundle
2) Transition piece
3) Duct section containing the natural gas burners
4) Transition piece
5) Blower

Primary Heater



Overview of Burner/Blower, Heat Exchanger, and Exhaust Ducting in Relationship to the SunShot Turbine and Recuperator

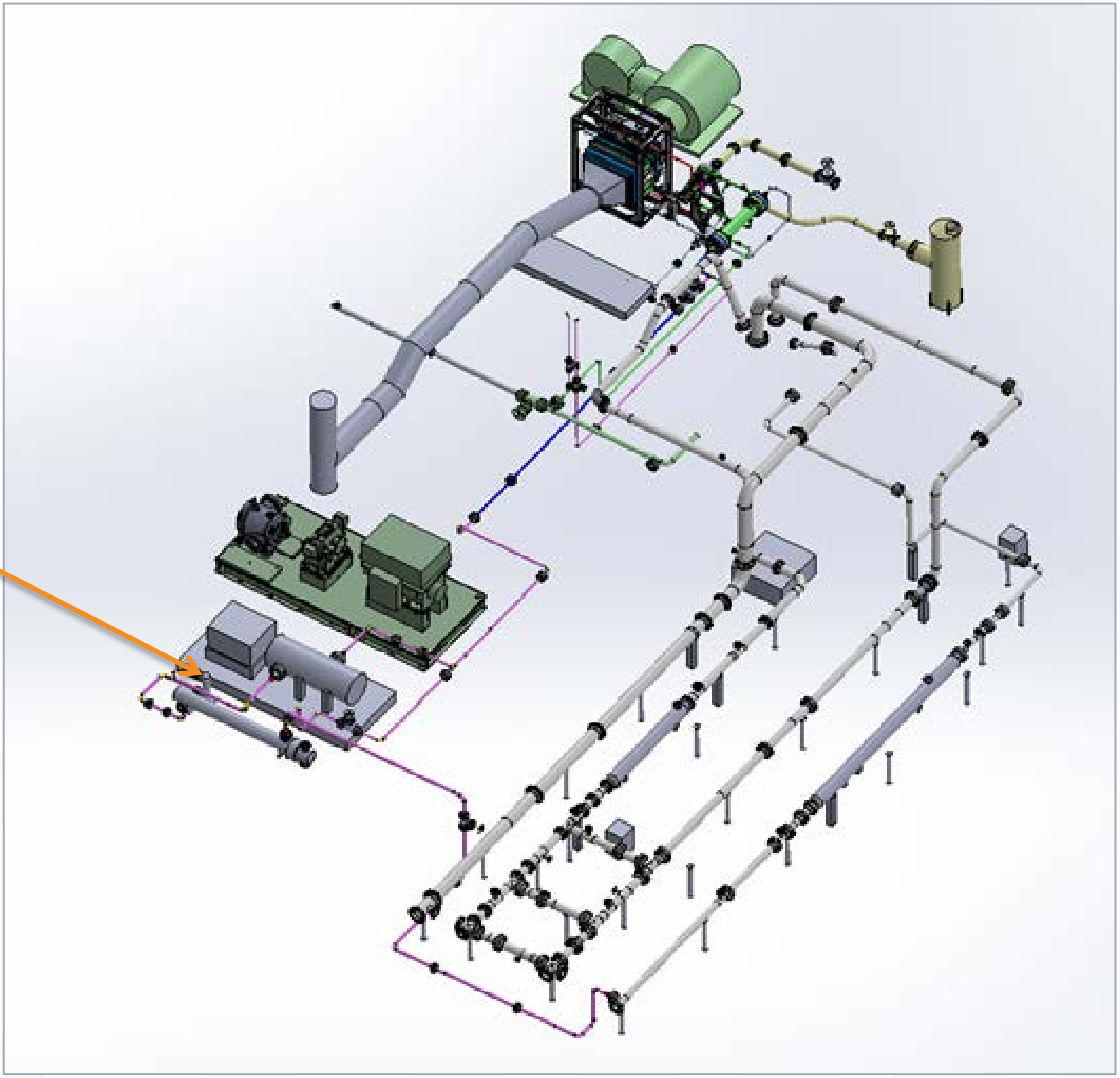
Dayco Heater



Close-up of the Heat Exchanger with the Associated Support Structure, Spring Can Supports, Expansion Joints, etc.

Test Loop Hardware Acquisition and Installation

Loop Filter



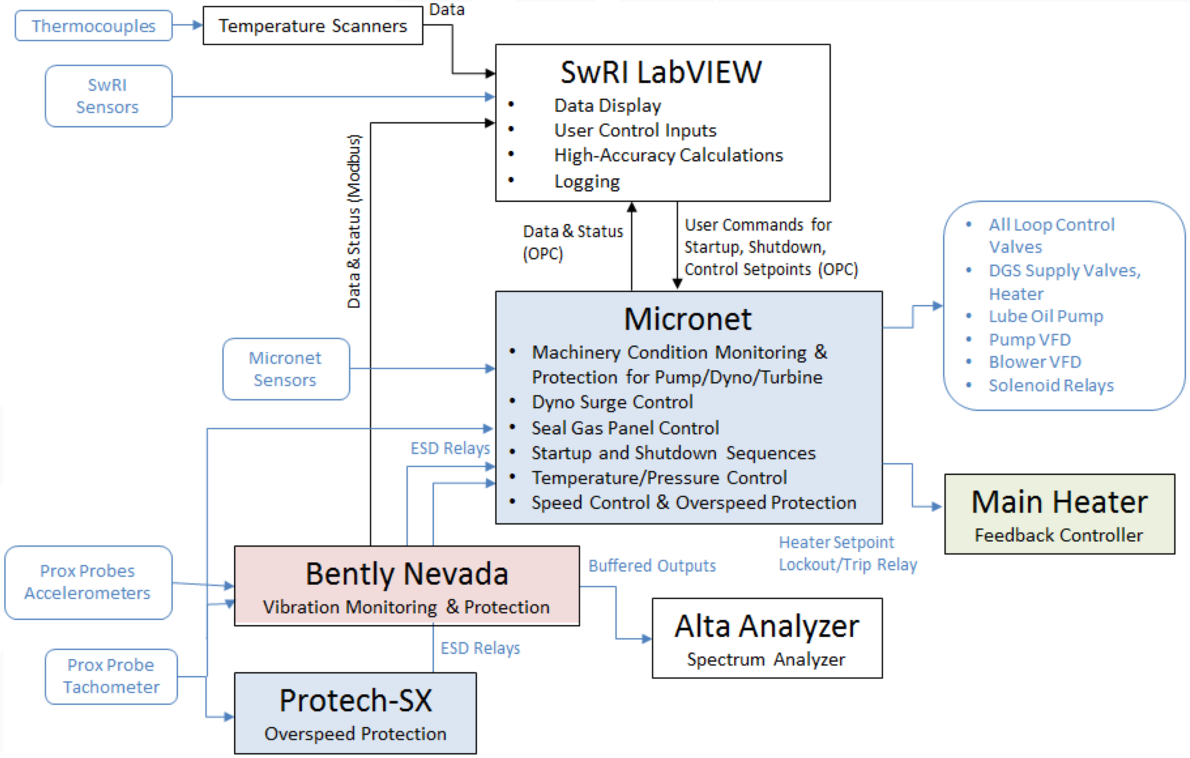
Overview of the sCO_2 Test Loop

Test Loop Hardware Acquisition and Installation

- Low and High-temperature piping designed and being manufactured.
- Pressure safety valves have been sized and PO placed
- Heat exchanger exit ducting is 80% installed
- Expansion joints that connect the heater to the heat exchanger and the heat exchanger to the exit ducting have been received

Instrumentation and Controls

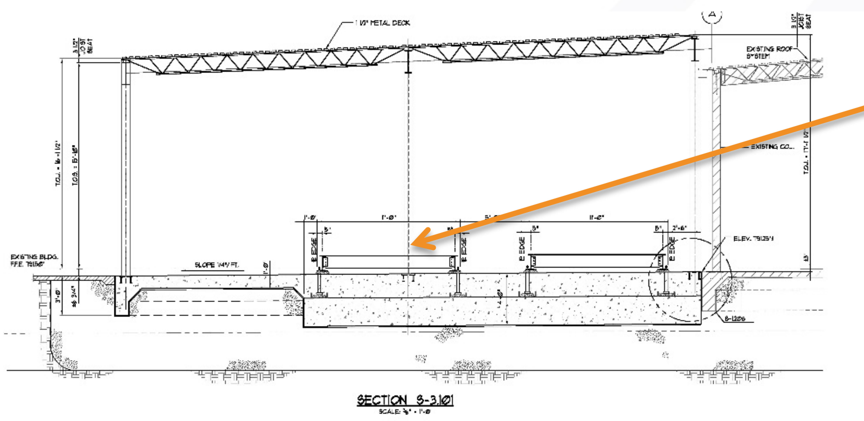
- The DAQ and control system design complete
- Health- and safety-critical parameters will be measured by a standalone microprocessor
  - Real-time, robust monitoring
  - Feedback control
  - Startup/shutdown sequencing



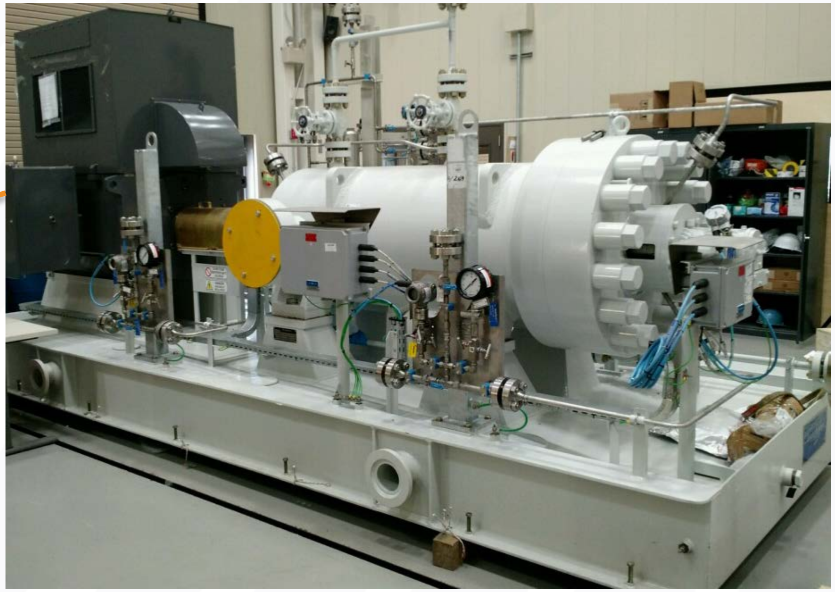
Data Acquisition and Control System Interface Diagram

Pump Procurement

- Pump procurement started over a year ago
- Lead time: 54 weeks
- Pump arrived on schedule



Schematic of Foundation for Pump Installation



GE Pump Package

Next Steps

- Complete procurement of major pieces of equipment and piping
- Complete facility upgrade that will house pump
- Begin installing, wiring, and plumbing equipment
- Install and wire control system
- Install piping and complete field welds
- Commission test loop

Discussion

Questions???