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Construction and Commissioning of a 1 MW Thermal Supercritical Carbon Dioxide Cooling Loop

Francisco Álvarez

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Introduction

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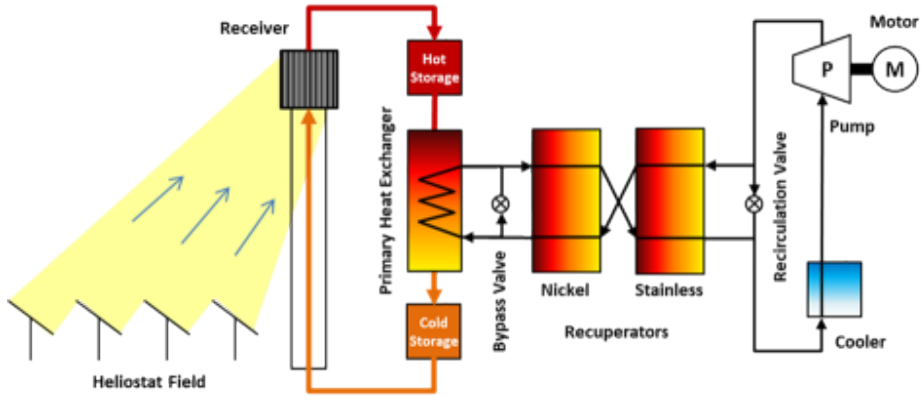
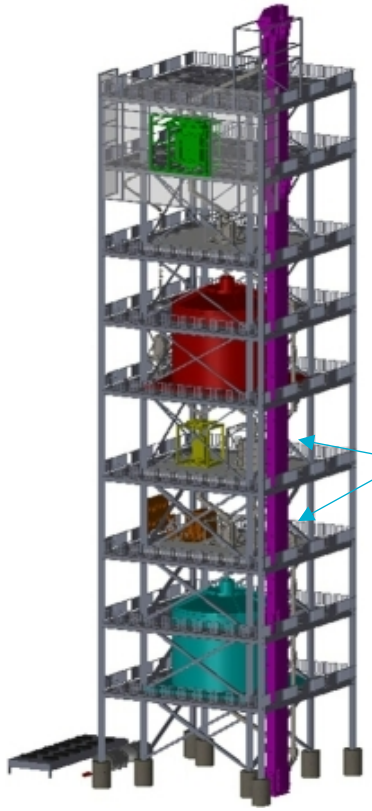
- The Generation 3 Particle Pilot Plant (G3P3) is currently in the construction phase at Sandia National Laboratories' National Solar Thermal Test Facility (NSTTF)
  - The pilot plant includes a supercritical carbon dioxide cooling system for the ceramic particles
- Supercritical carbon dioxide (sCO2) loop initial design was developed as part of the DoE's Solar Energy Technologies Office Generation 3 Program
  - Design was developed for the three parallel paths
    - Solid, liquid, gas
  - Solid/particle path team (G3P3) was selected to continue the construction of the pilot plant
    - sCO2 cooling loop is located on third and fourth levels of concentrating solar power tower



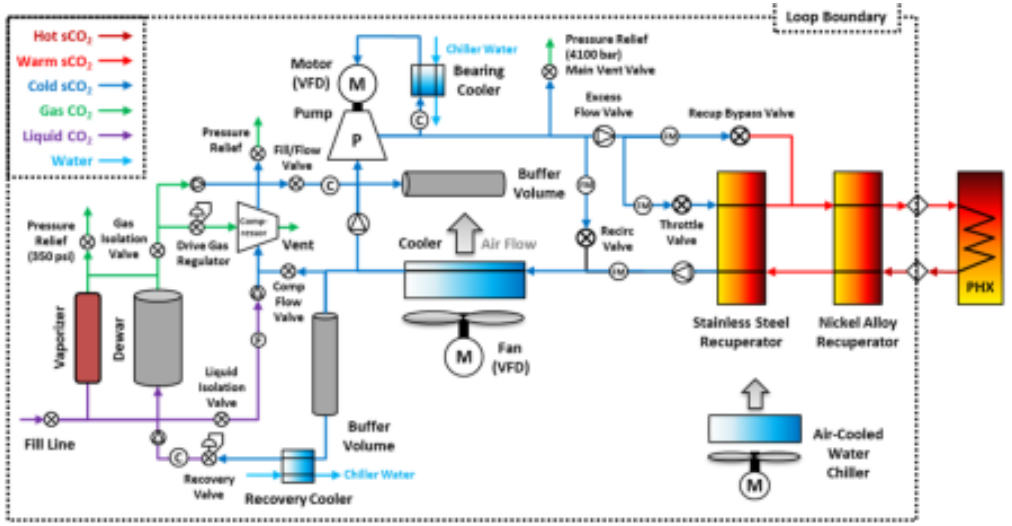


sCO2 loop located primarily on third and fourth levels

Overall Design

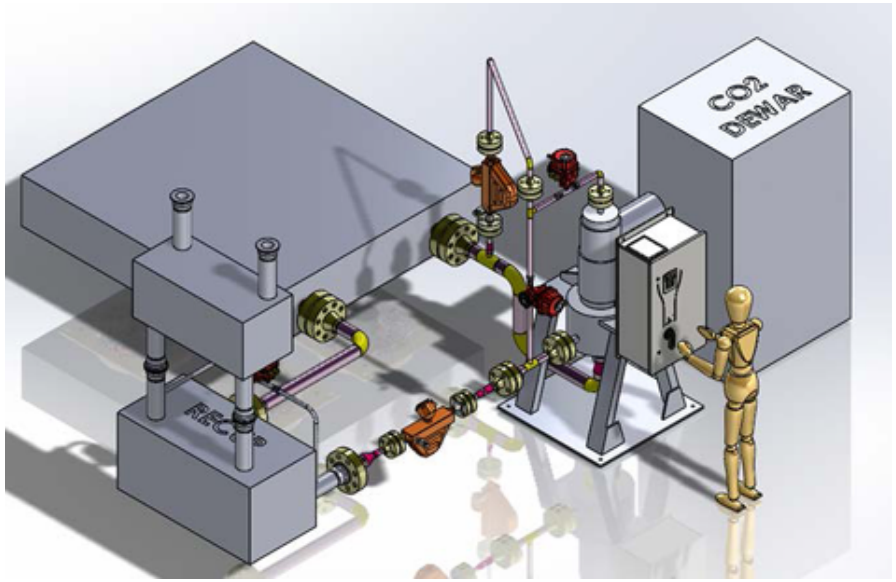
- Major requirements for the sCO2 cooling loop
  - 1MW thermal duty and 715°C PHX Outlet temperature bound the thermodynamic design of the system
    - Major components were designed to meet these requirements
- Major components include
  - Circulator pump
  - Air-Cooler
  - Recuperation system
    - Split into two recuperators; similar to a recompression Brayton cycle (RCBC)
  - Inventory System
- No turbomachinery is included in this system
  - Future implementation of turbomachinery in RCBC configuration is possible

Requirement	Value
Operating Fluid	Carbon Dioxide
PHX Outlet Pressure	250 bar
PHX Outlet Temperature	715 °C
Thermal Duty	≥1 MWth
Operational Time	16 hr/day
Allowable PHX Pressure Drop	≥5 bar (2%)
PHX Inlet Temperature	565 °C
Mass Flow Rate	≥5.3 kg/s

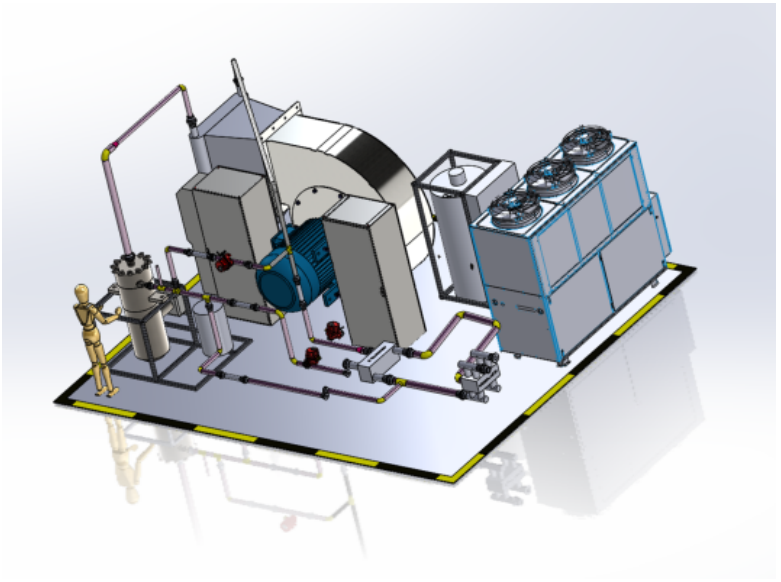


G3P3 Layout

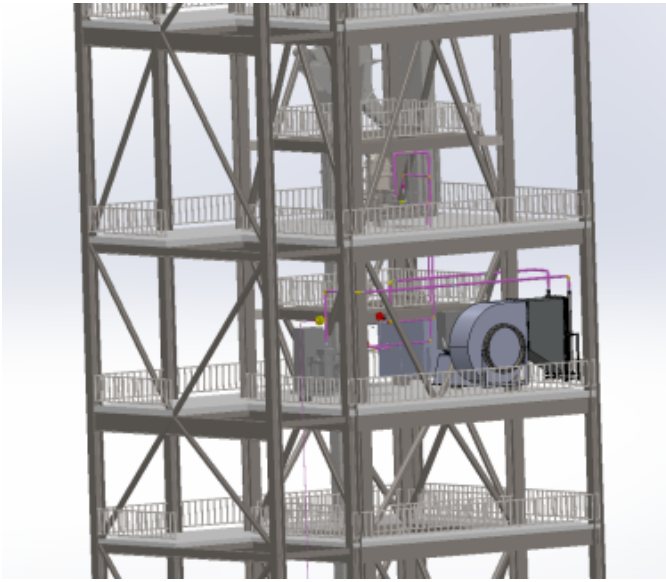
- Initial layout of cooling loop was developed for a single level configuration
  - Selection of G3P3
- Location of main components within third and fourth level of G3P3 tower
  - Third level: pump and air cooler
  - Fourth level: recuperation system
  - Ground level: inventory system



Initial Layout (single level)



Modified Layout

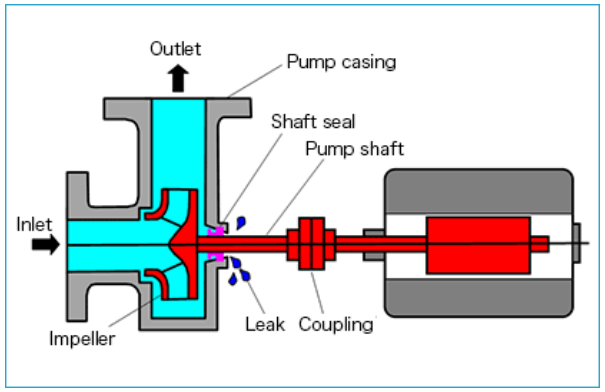


G3P3 Layout
In Tower

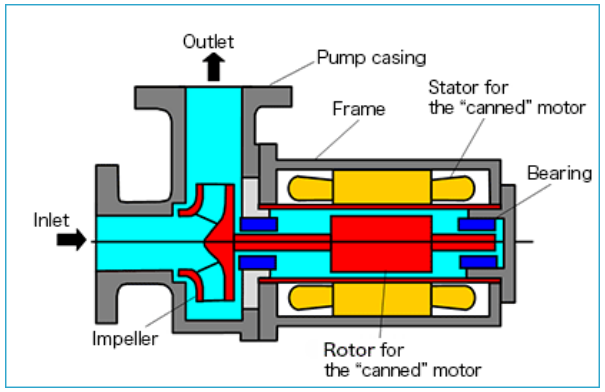
Major Components

Pump

- Seal-less Canned Motor Pump
  - “Can” prevents leakage since no seals between motor and pump exist
  - Pump bearings use process fluid for lubrication
  - High pressure
    - MAWP of 4100 psi (283 bar)
  - Centrifugal Pump
    - Single stage
  - Controlled by Variable Frequency Drive (VFD)

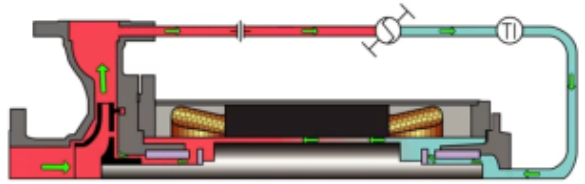


Standard Pump

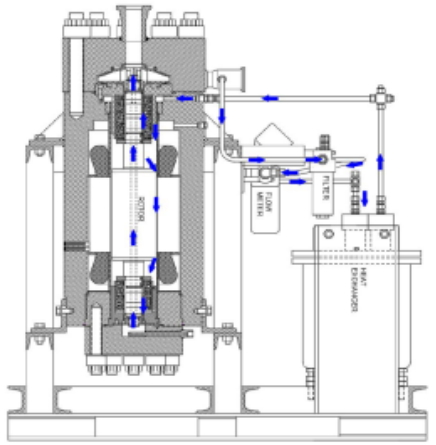


Canned Motor Pump

21-S External Circulation with Cooler



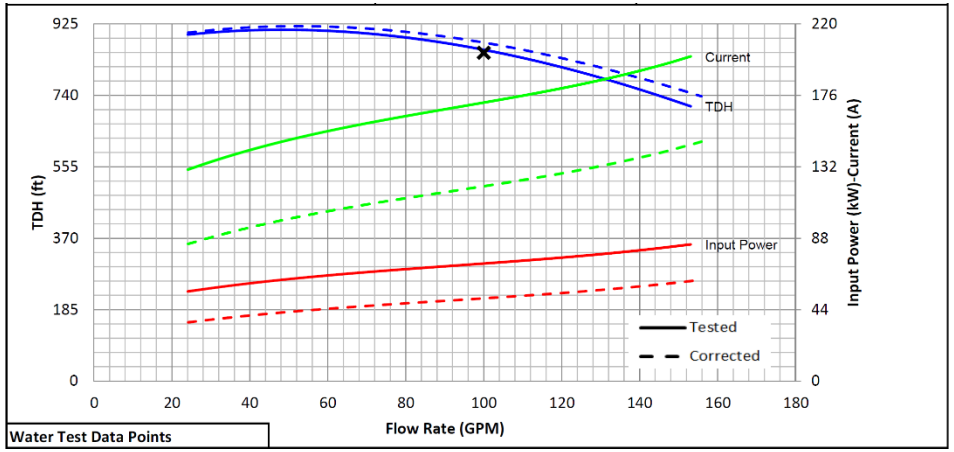
API685 Plan 21-S
Process fluid is diverted from pump Discharge, cooled down by external Cooler/chiller and reinserted at the back bearing

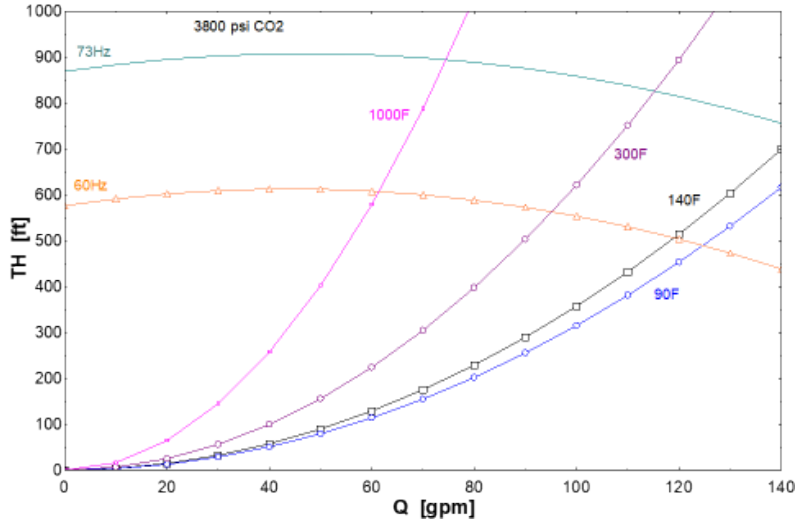


Pump Performance

- Pump performance was evaluated with water
  - Corrections for sCO2 were made and are shown in dashed lines (P. Anderson presentation at ASME ES2022)
  - To provide a flow of 5.3 kg/s of sCO2 to the system, a volumetric flow rate of 5.3 L/s (100 gpm) is provided by the pump
  - Design point for pump is a flow of 100 gpm and a head of 850 ft (achieved at 73 Hz)
    - Pump operation can range from 60-80Hz
  - Pump will be able to provide 100 gpm at different system temperatures causing a variation of pressure drop across the piping

Pump Curve at 73 Hz



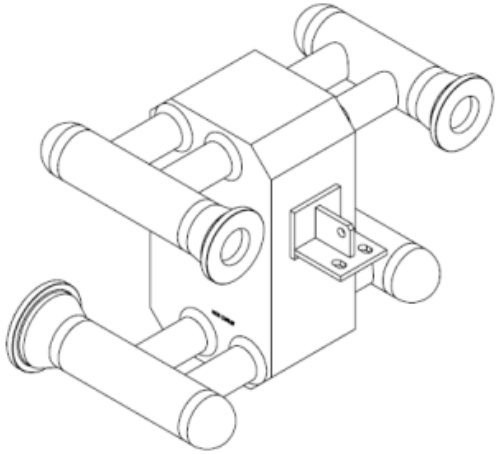


Air Cooler

- Air cooler is comprised of two subcomponents
  - Air Fan
  - Heat Exchanger
- Air fan is a commercial centrifugal fan capable of providing 64,000acfm of air flow and a static pressure of 8 in.water (power consumption 110 hp)
  - Air fan will be controlled by VFD to support different cooling needs for G3P3
- Heat exchanger is currently being built
  - Since system is single-pressure zone, the air cooler heat exchanger must be capable of supporting pressures up to 250 bar; stainless steel 316 was needed for this application
  - Thermal duty: design 1.03 MW (margin added that can provide up to 1.2 MW)

Recuperators

- The recuperation system is split into two recuperators
  - Nickel alloy recuperator (Inconel 617) – in construction
    - 1 MW thermal duty
    - Heat transfer area: 2.74 m^2
    - Design temperature: 735°C
    - Low Temperature Nozzles: SS316
    - High Temperature Nozzles: Inconel 625 and Inconel 740H
  - Stainless Steel Recuperator (SS316)
    - 3 MW thermal duty
    - Heat transfer area: 7 m^2
    - Design temperature: 590°C
    - Nozzles: SS316



Inventory System

- Inventory system will delivery sCO2 to the main piping system
  - Gas booster Maximator DLE 15-2
    - Pressures up to 300 bar (Pressure Ratio 1:30)
  - Coriolis flowmeters to quantify inventory delivered to main loop
  - Instrumentation including RTDs and pressure transducers
  - Filtration and pressure relief system

Additional Equipment

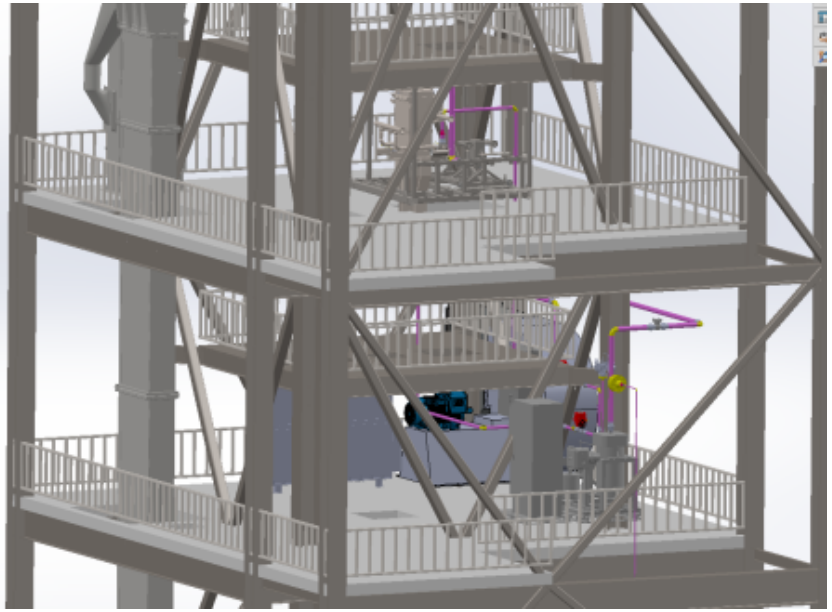
Design Details – Ancillary Equipment

- Connectors
  - Grayloc connectors used for most connections
    - ANSI flanges occasionally used for commercial equipment
    - Compactness and ease of installation
- Piping
  - Piping ranges from 1.5-3 NPS and SCH 160-XXH
  - Most piping is SS316
  - High temperature piping made from Inconel 625 and 740H
    - PHX inlet – Inconel 625
    - PHX Outlet – Inconel 740H
  - Piping built to ASME B31.1 Power Piping Standard
- Pressure Relief Valve
  - Pilot Operated Pressure Relief Valve
  - Set Pressure: 4060 psi (280 bar)
- Flowmeters
  - Venturi flowmeters
    - System is adaptable for Coriolis flowmeters
      - Current commercial availability in pressure containment and size is not sufficient for system needs

Integration and Commissioning

Location and Weights

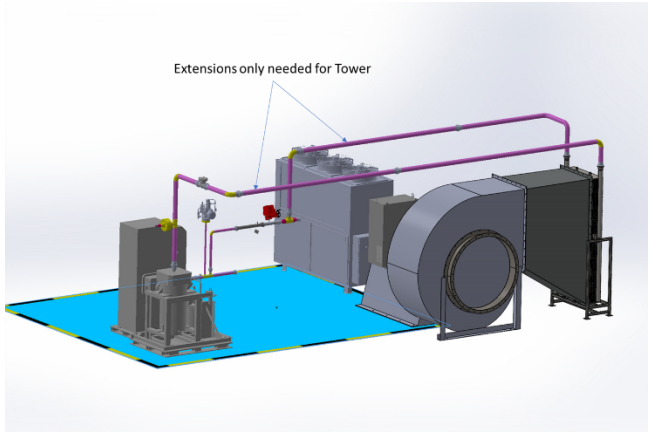
- Installation and commissioning in G3P3 tower will be started upon completion of tower construction
  - Overall, the air blower and pump are the heaviest items to install for the G3P3 system (above 2,700 kg)
  - The locations for the items are described in table to the right
  - sCO2 loop will be installed with consistent installation practices for G3P3

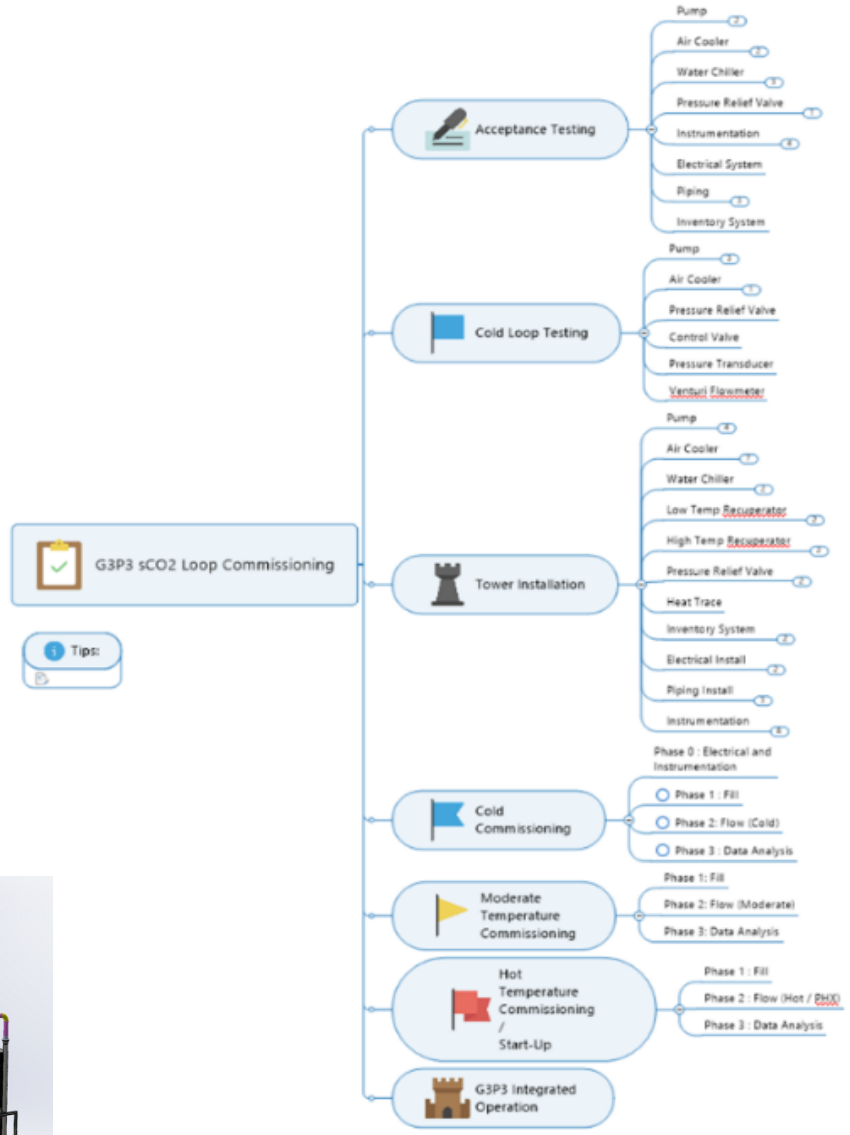


Component	Weight (lb)	Weight (kg)	Source	Location
Pump (skid)	6000	2722	Teikoku Drawing	3rd level
LT recuperator	1300	590	VPE Drawing	4th level
HT Recuperator	1160	526	VPE Drawing	4th level
Air Blower	6165	2796	AirPro Spec	3rd level
Air Cooler HX	4100	1860	VPE Drawings	3rd level
Air Cooler VFD	350	159	ABB Spec	3rd level
Piping	2000	907	Estimate	3rd level (most)
Pump VFD	825	374	ABB Spec	3rd level
Chiller	4710	2136	ThermalCare Spec	3rd floor
Dewar	1765	801	Chart Spec	Ground
Inventory System	500	227	Estimate from Aztech	Ground
Total	28875	13097		

Commissioning Planning

- Commissioning will be performed when sCO2 loop is installed in tower
  - Some preliminary testing will be completed at ground level to prove out the operation of the pump and the air cooler prior to installation in the G3P3 tower
  - Expected completion: Fall 2022
- After tower installation:
  - Cold commissioning
  - Moderate Temperature Commissioning
  - Hot Temperature Commissioning
  - Startup
  - Expected Completion Date for Commissioning: Winter 2024





Challenges

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- Material availability
  - Availability of high temperature materials (especially Inconel 740H) was challenging
    - One reason to move recuperators closer to PHX and reduce piping costs.
- COVID-19 delays and supply chain
  - Supply chain issues related to material availability caused by COVID-19 delayed completion of equipment manufacturing
- Development of new manufacturing techniques for high-pressure equipment (heat exchangers and pump)
  - Trial and error was involved in developing manufacturing techniques for the requirements imposed by the system
  - Trials required more time than expected and caused equipment delays

Conclusion

- G3P3 System Cooling Loop consists of a supercritical carbon dioxide, single pressure zone system
- Cooling loop installation will be split in different levels of the G3P3 tower
- Challenges have been encountered during the manufacturing and fabrication of major components and ancillary equipment
  - Delays caused by these challenges
- Commissioning of cooling loop is integrated with commissioning of G3P3 system
  - Some testing will occur on ground to prove out operation of some pieces of equipment
  - Experience from previous sCO2 loops at Sandia is being leveraged for the construction, commissioning, and operation of the G3P3 cooling loop