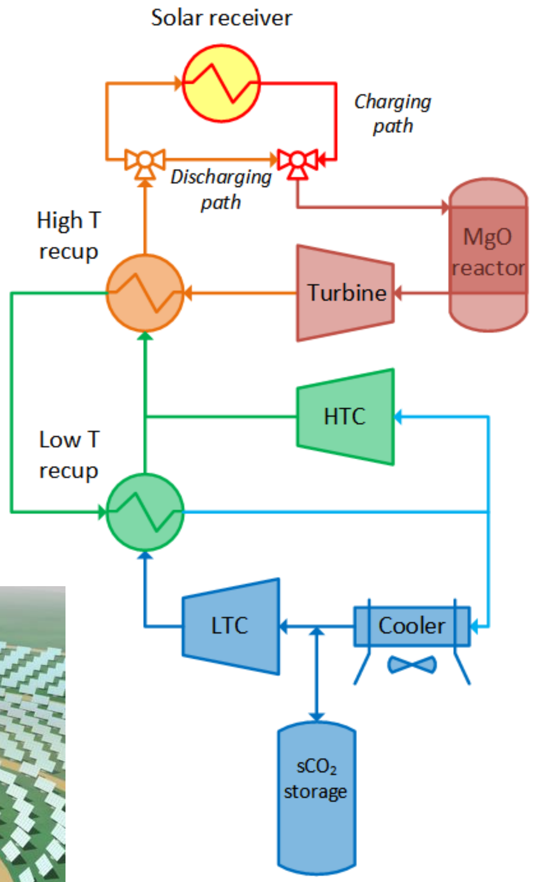
sCO_2 Power Cycle with Integrated Thermochemical Energy Storage Using an MgO-Based sCO_2 Sorbent in Direct Contact with Working Fluid

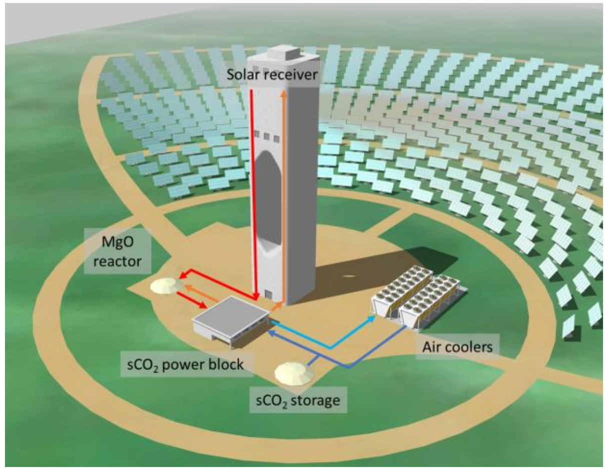
DE-EE0008126
CSP Program Summit
Oakland, CA
March 18-19, 2019

ECHOGEN
power systems

Program summary

- Thermochemical energy storage using $MgO+CO_2=MgCO_3$ reversible reaction with sCO_2 power cycle
- CO_2 generated/consumed stored by sCO_2 inventory control system (ICS)
- Reactor and ICS storage in underground pressure vessel
- Overall technology requirements:
  - >50% cycle thermodynamic efficiency
  - >95% exergetic storage efficiency
  - Storage system cost < $15/kWth





Program goals

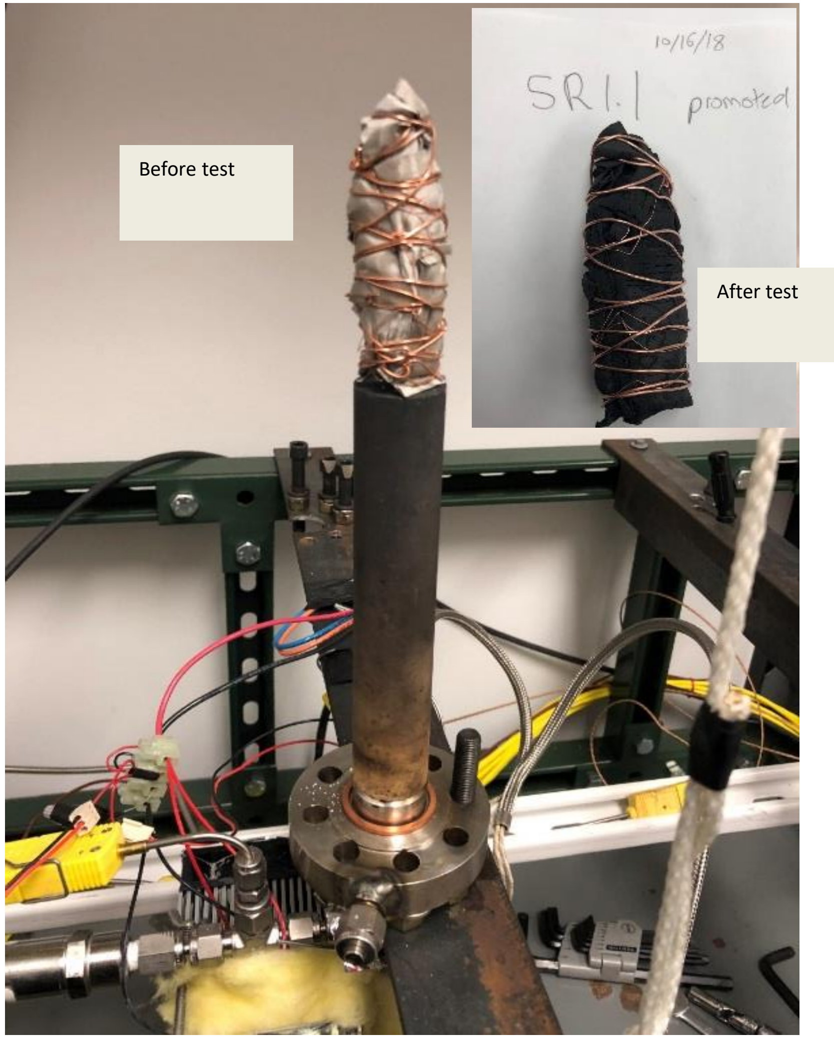
- Refine/improve MgO sorbent performance, complete design of commercial-scale reactor / storage system
- Conduct lab-scale test of integrated sCO_2 loop / TCES system
- Complete techno-economic analysis of full-scale (100MWe) power block + TCES system

MgO Sorbent Development

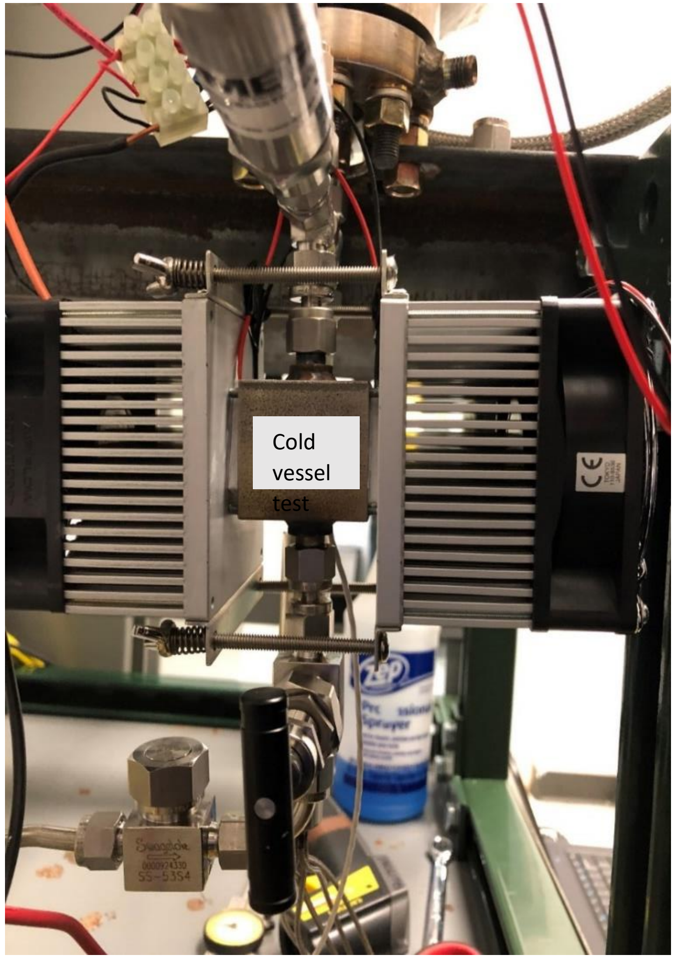
- SR tested 26 MgO based lab-scale sorbents in HTR for capacity, durability and production cost.
  - Absorption capacity: 2-6 hr charge/discharge cycles at pressures of 100-300 atm (600-670°C), > 0.25 g CO_2/g sorbent
  - Degradation: < 1% loss in capacity over 25 cycles
  - Cost of sorbent material (including processing) plus containment less than 9$/kWh$_{th}$.
- Identified "MgO coated with 40wt% Na_2CO_3 promoter (MC30P_coated_40wt%)" for large batch sorbent production (~100kg) for lab prototype system testing

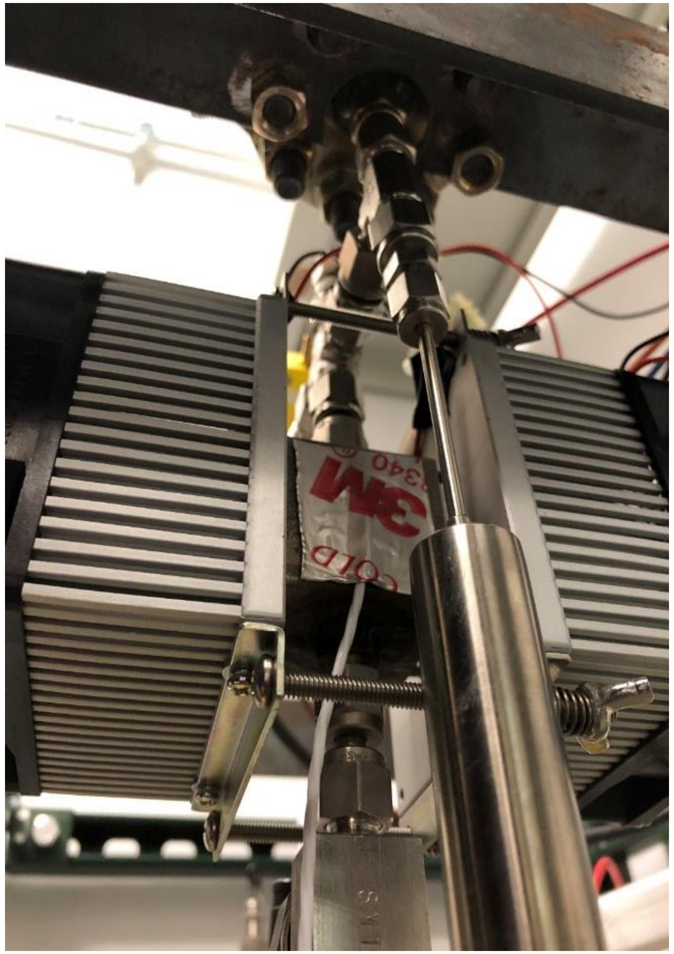
			cost ($/kWh_th)		
sample name	weight gain (≥0.25 g/g)	Energy density (≥500 MJ/m^3)	sorbent	containment	total (<9)
E13 pellet 0% promoter	0.125	398	5.89	3.21	9.11
E13 pellet 10% promoter	0.165	581	4.98	2.20	7.18
E13 pellet 20% promoter	0.228	872	3.95	1.47	5.42
E13 pellet 22% promoter	0.188	733	4.85	1.74	6.60
E13 pellet 40% promoter	0.211	941	4.84	1.36	6.19
E19(older) pellet 40% promoter	0.330	1474	1.23	0.87	2.10
SR1.1 powder 0% promoter	0.717	1139	1.02	1.12	2.15
SR1.1 pellet 0% promoter	0.351	761	2.09	1.68	3.77
SR1.1 powder 10% promoter	0.833	1537	0.99	0.83	1.82
SR1.1 pellet 10% promoter	0.574	1424	1.44	0.90	2.33
SR1.1 powder 20% promoter	0.825	1282	1.09	1.00	2.09
SR1.1 pellet 20% promoter	0.615	1204	1.46	1.06	2.52
SR1.1 powder 40% promoter	0.826	865	1.23	1.48	2.71
SR1.1 pellet 40% promoter	0.723	1299	1.41	0.98	2.39
E3 pellet 20% promoter	0.149	500	6.03	2.55	8.59
E4 pellet 20% promoter	0.300	778	3.00	1.64	4.64
E5 pellet 20% promoter	0.069	163	13.04	7.86	20.90
E6 pellet 20% promoter	0.149	293	6.05	4.36	10.41
E19(new) pellet 20% promoter	0.245	420	3.68	3.04	6.72
E26 pellet 20% promoter	0.255	437	3.54	2.92	6.46
SR1.1Pcal_coated_40wt%	0.772	2081	1.32	0.61	1.93
MC30P_coated_40wt%	0.735	1968	1.39	0.65	2.04
Mg-citrateP _coated_ carbon _sintered_40wt%	0.731	1735	1.39	0.74	2.13
Mg-citrateP _coated_ carbon _40wt%	0.789	1699	1.29	0.75	2.04
Mg-citrateP_carbon_sintered _40wt%	0.668	1586	1.52	0.81	2.33
Mg-citrateP_carbon__40wt%	0.739	1739	1.38	0.73	2.11

MgO Sorbent Development



Samples are individually wrapped in steel mesh and binded with copper wire, after test the meshed is substantially oxidized

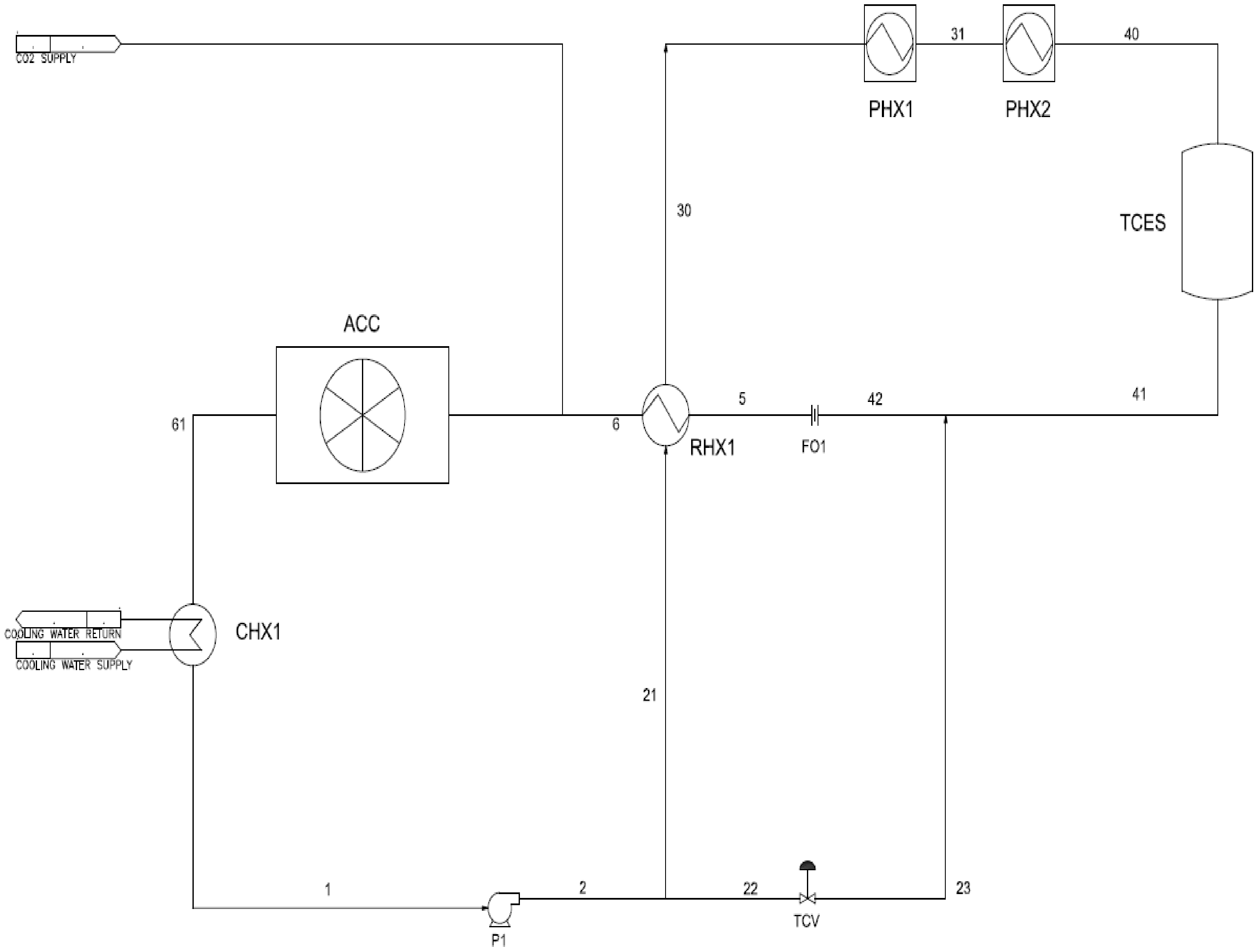




Cold side including pressure transducer, two thermocouple probes, RTD, fill valve and cold vessel with thermoelectric modules and heat sinks.

Lab Scale sCO_2/TCES Test Loop

- Lab scale test loop design is complete
- Design Target: 700°C, 20 MPa, 0.2 kg/s CO_2 flow rate
- Stage-I testing and commissioning (without HTR and TCES) of sCO_2 test loop is complete.
  - Max CO_2 Temperature= 522°C (Stage 1 heater design point)
  - Max Coil Temperature=594°C
  - Max Heater Element Temperature=942°C
  - Max Pump Discharge Pressure=11.5 MPa (fixed-orifice limit)



Lab Scale Testing: sCO_2 Radiant Heaters

- Material: TP316H
- Size:1”OD x 0.120”wall
- Spec: B31.3 A269
- 4-pass Config. approx. 27 linear ft
- Max Coil Temperature YTD: 594°C
- CO_2 Outlet Temp: 522°C

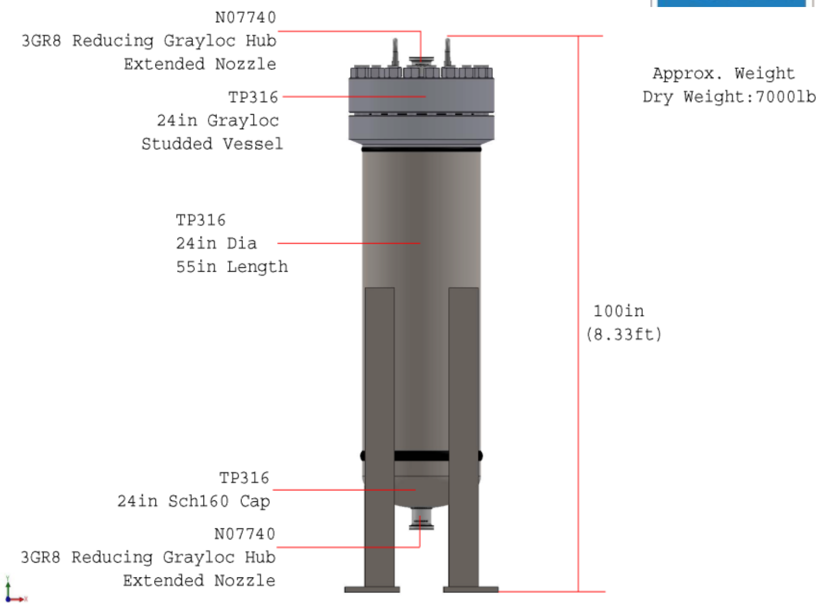
Low Temperature Radiant Heater (PHX1)

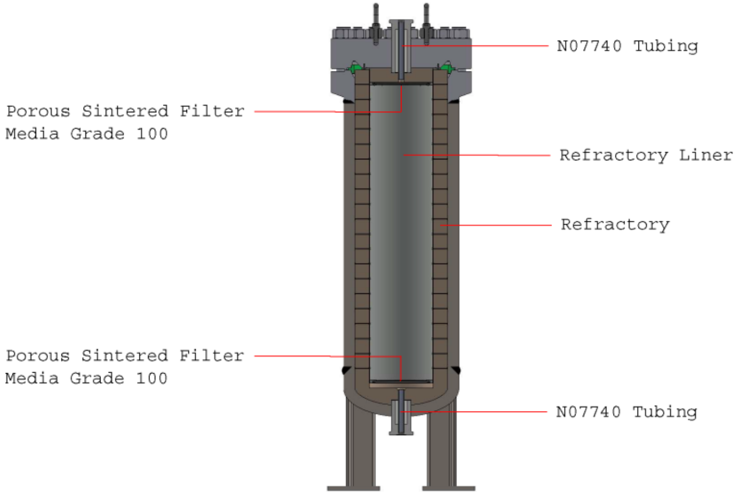
- Material: N07740
- Spec: B31.1 Code Case 190
- Size:1.25”OD x 0.156”wall
- Coil Config. Approx. 72 linear ft
- Max conditions
  - Max Temp= 759°C
  - Max Pressure= 20.68MPa
  - Design Flow= 0.2 - 0.3kg/s

High Temperature Radiant Heater (PHX2)

Lab Scale Testing: TCES Reactor Design

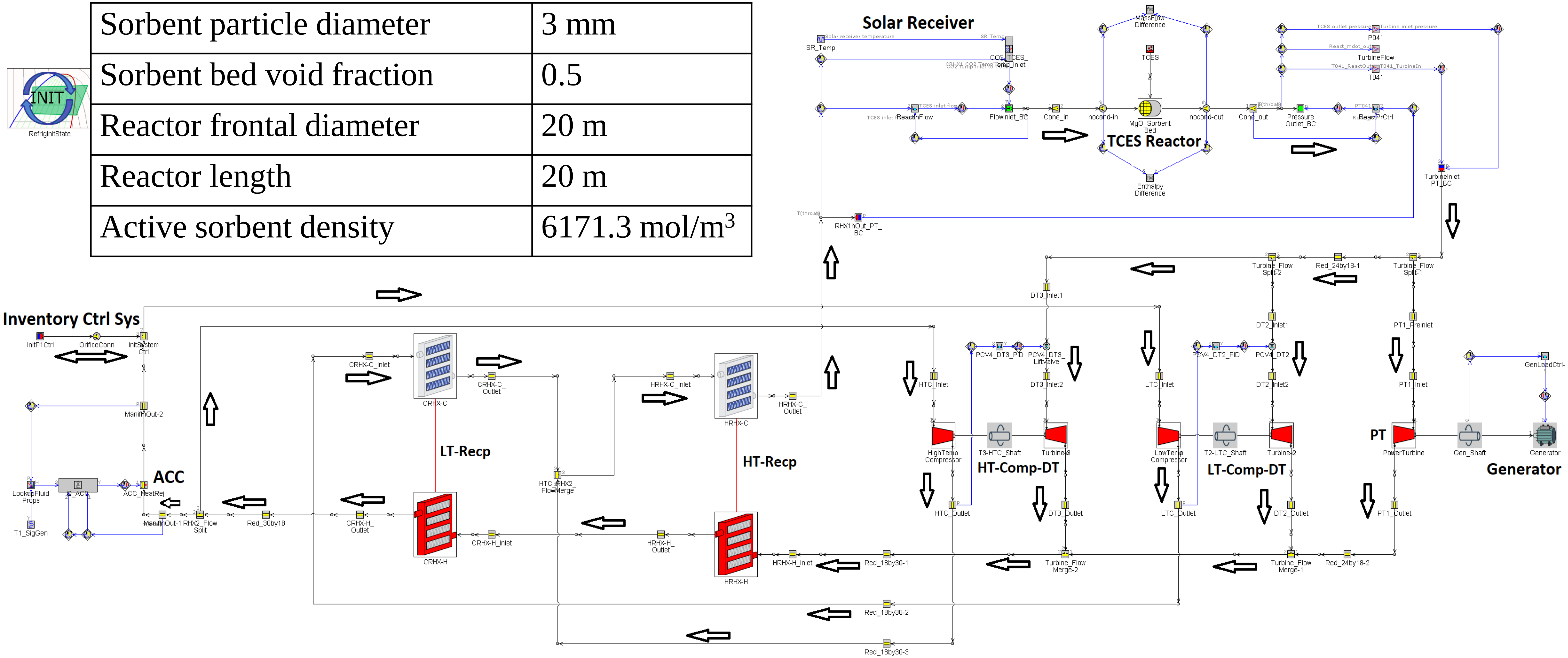
- Lab scale reactor design is complete for phase-II testing
- Design based on planned charging/ discharging rate of 20kW with a cycle time of approximately 2 hours
- Reactor Body
  - 24” Schd. 160 A106 Gr. B Pipe
  - Design pressure 20 MPa
  - Approx. Dry Weight: 7000lb





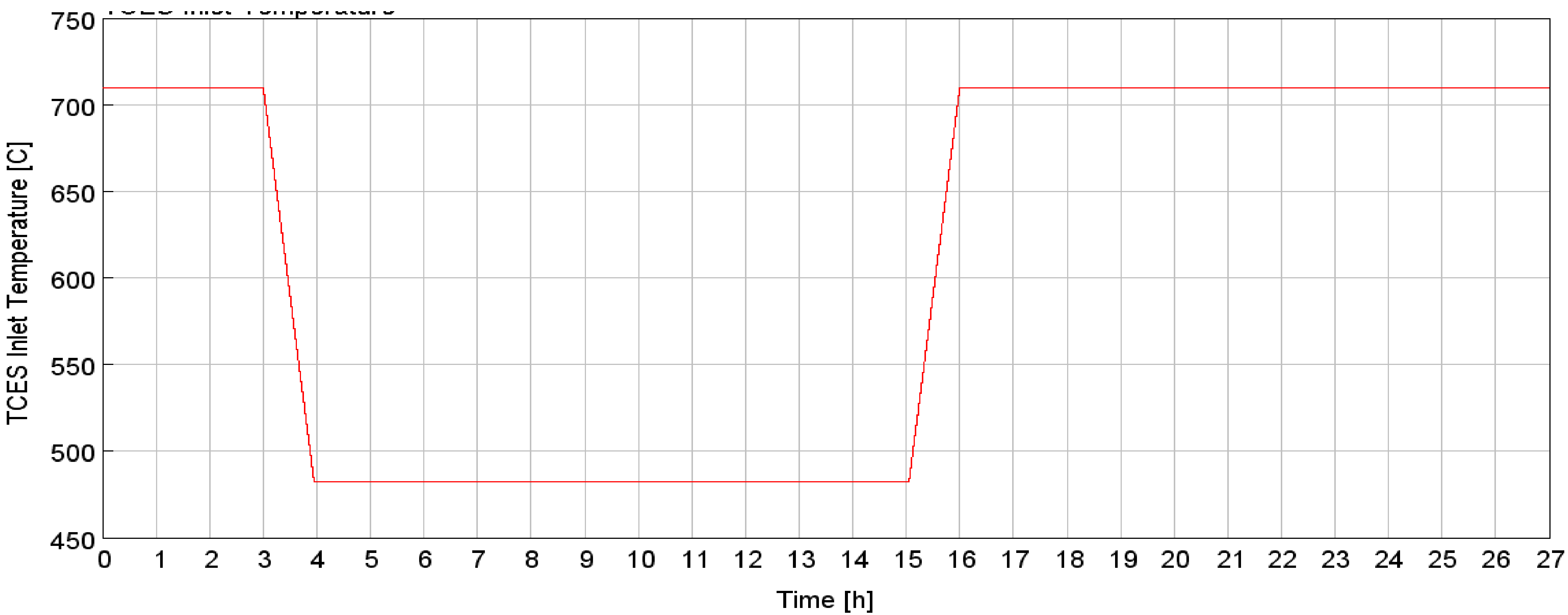
Full-scale (100MWe) TCES + sCO_2 Power Cycle Transient Modeling

Sorbent particle diameter	3 mm
Sorbent bed void fraction	0.5
Reactor frontal diameter	20 m
Reactor length	20 m
Active sorbent density	6171.3 mol/m^3

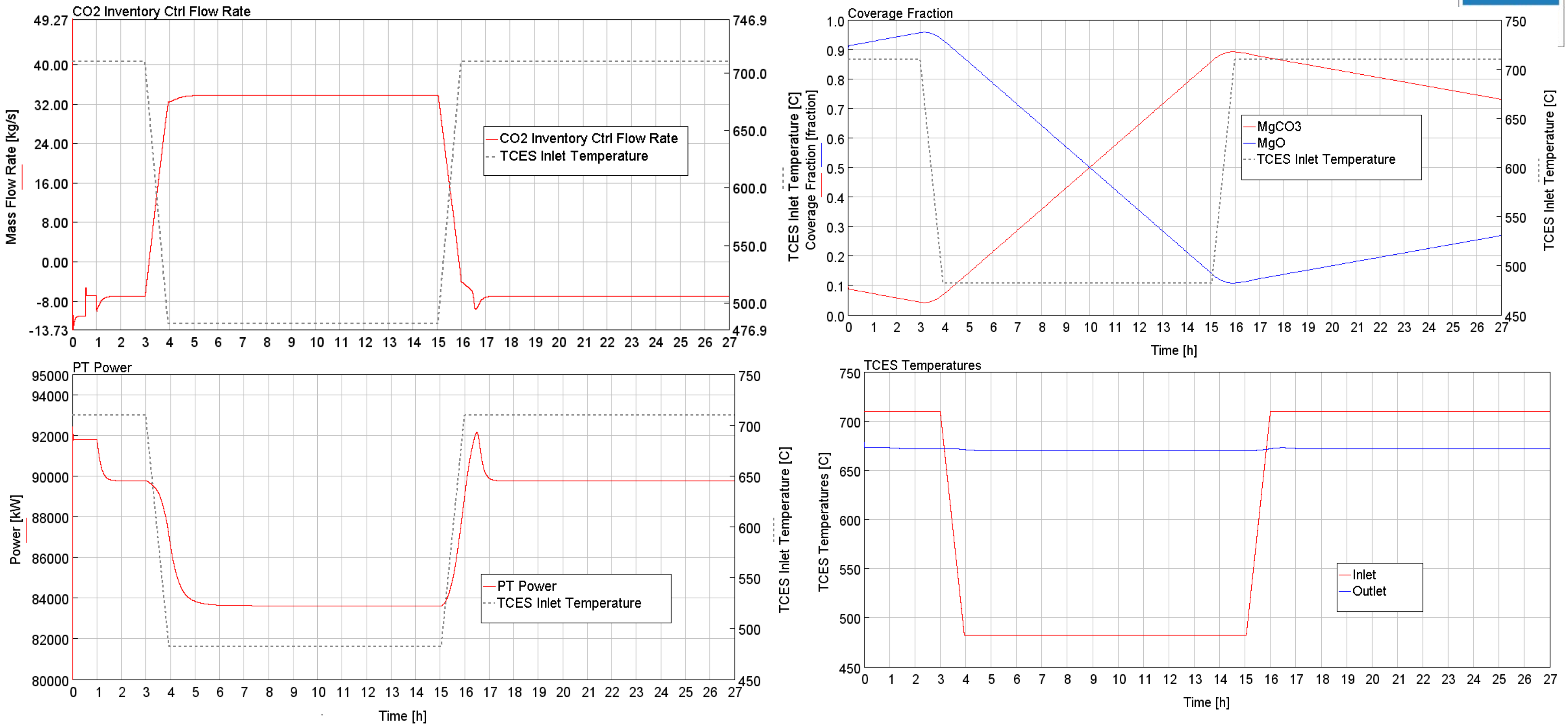


TCES + sCO_2 Power Cycle Transient Modeling

- Drive turbine throttle valve CO_2 high pressure control = 30.4 MPa
- System low pressure controlled using inventory control system = 10.21MPa



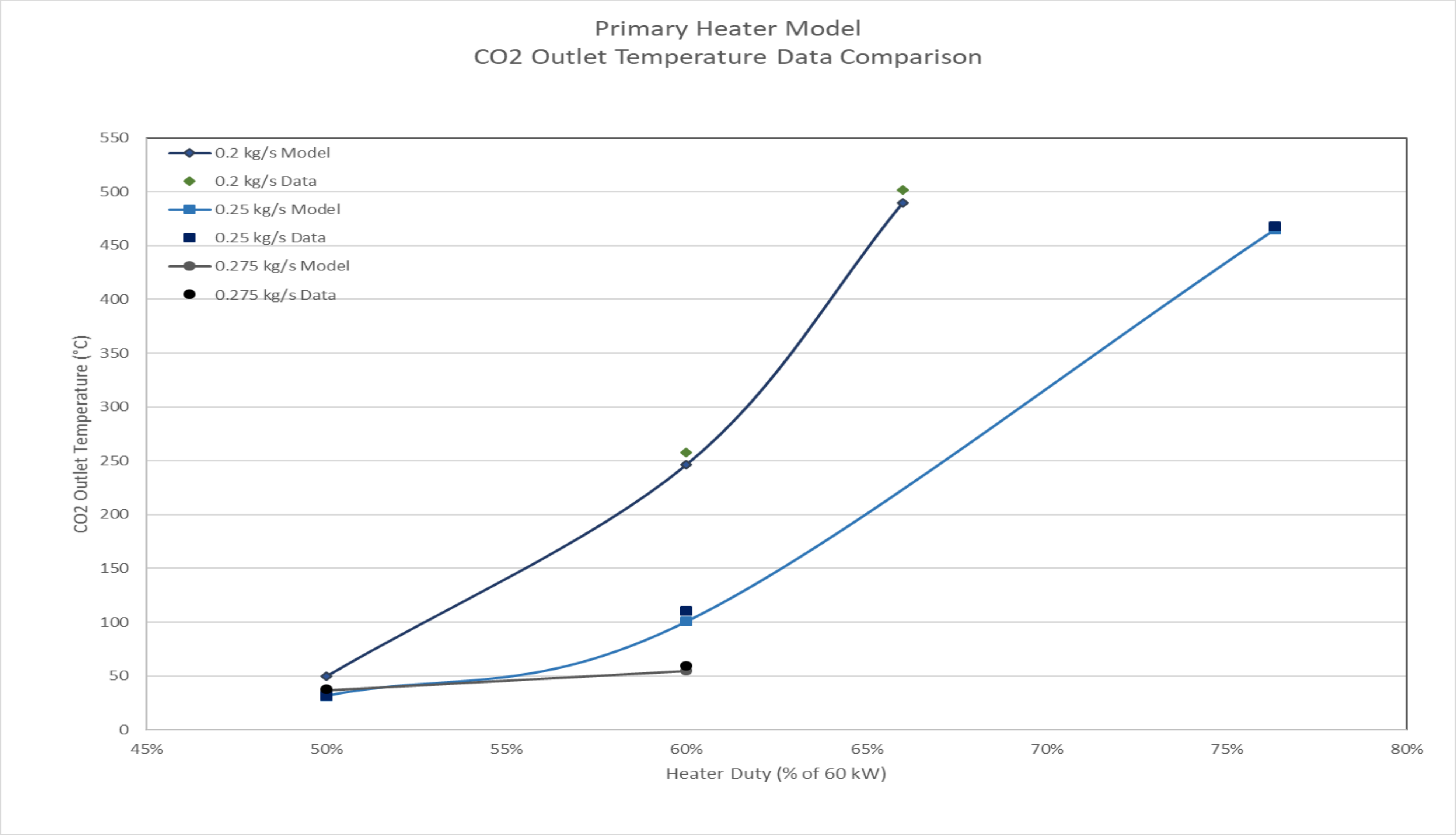
TCES + sCO_2 Power Cycle Transient Modeling



Summary

- During BP1, SR tested and identified a MgO based sorbent for large-batch production (100kg) for lab scale testing of integrated sCO_2/TCES system in BP2.
- Stage-I testing and commissioning of sCO_2 test loop is complete.
- Stage-II testing of high temperature heater is slightly delayed due to manufacturer delay in Inconel 740H tube supply.
- Stage-III testing during BP2 involves complete testing of lab scale integrated sCO_2 loop/TCES reactor test loop.
- The result of the transient simulation indicated that with proper cycle design, and TCES reactor capacity, the SunShot targets of 100MW capacity, and 10hours storage could be met.
- Operation and control of the cycle appears feasible, and based on the kinetics of the sorbent/CO_2 reaction, adequate charging and generation rates are achievable.

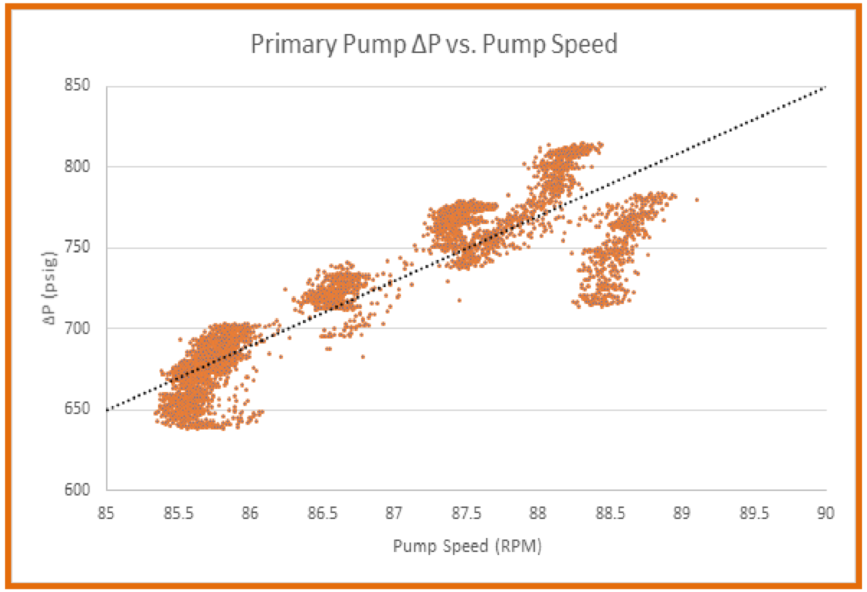
Stage-I sCO_2 Loop Testing: PHX1

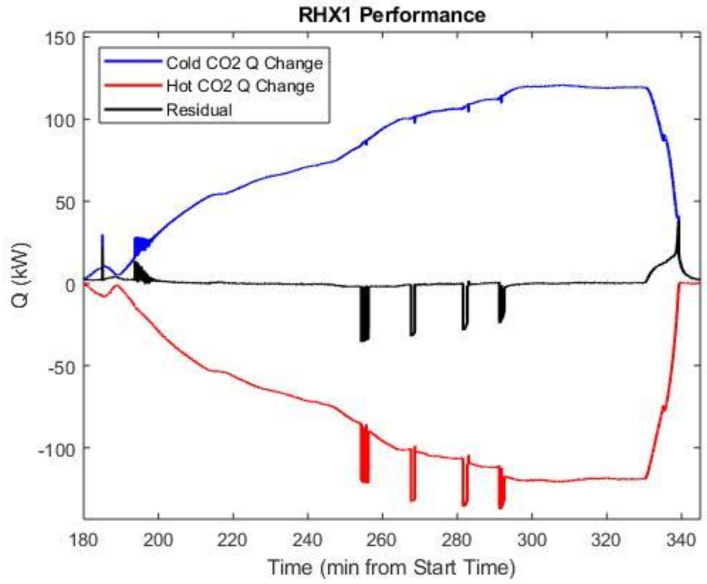


Stage-I sCO_2 Loop Testing: Pump and Recuperator

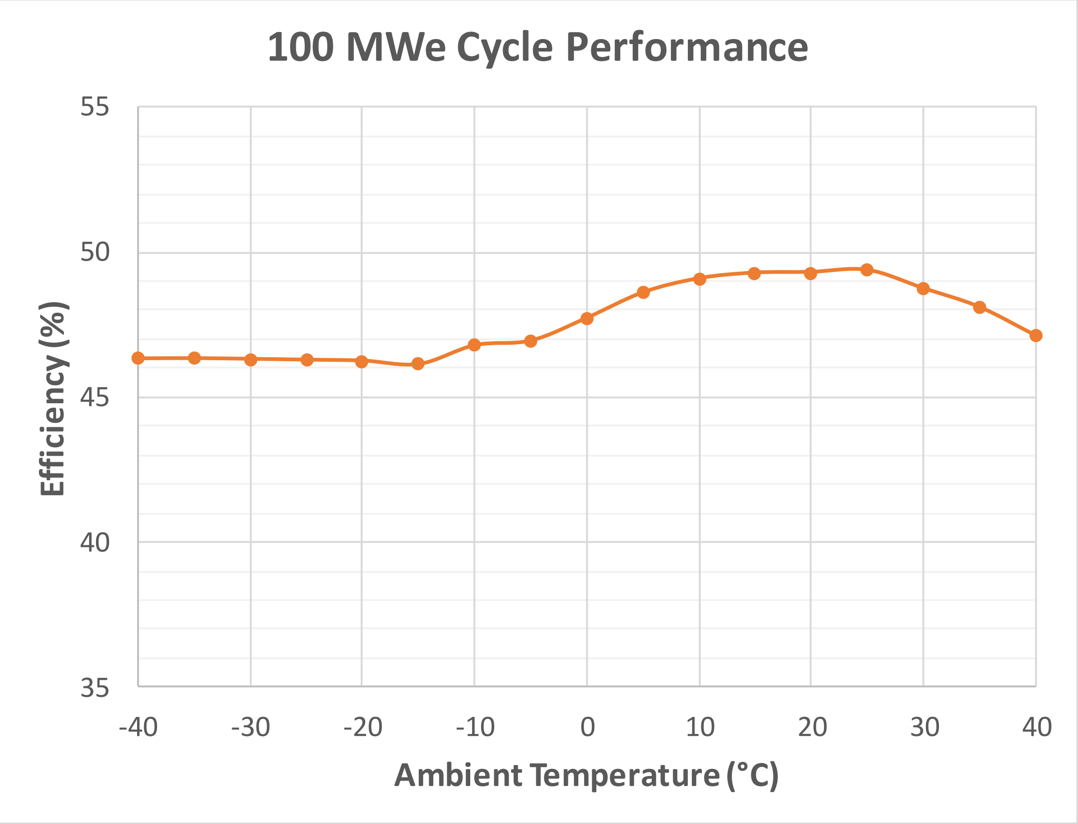
- CAT Pump
- Model:6821K.CO2
- Rated Flow: 25GPM
- Max Discharge Pressure: 20.7 MPa
- Motor Size: 30HP

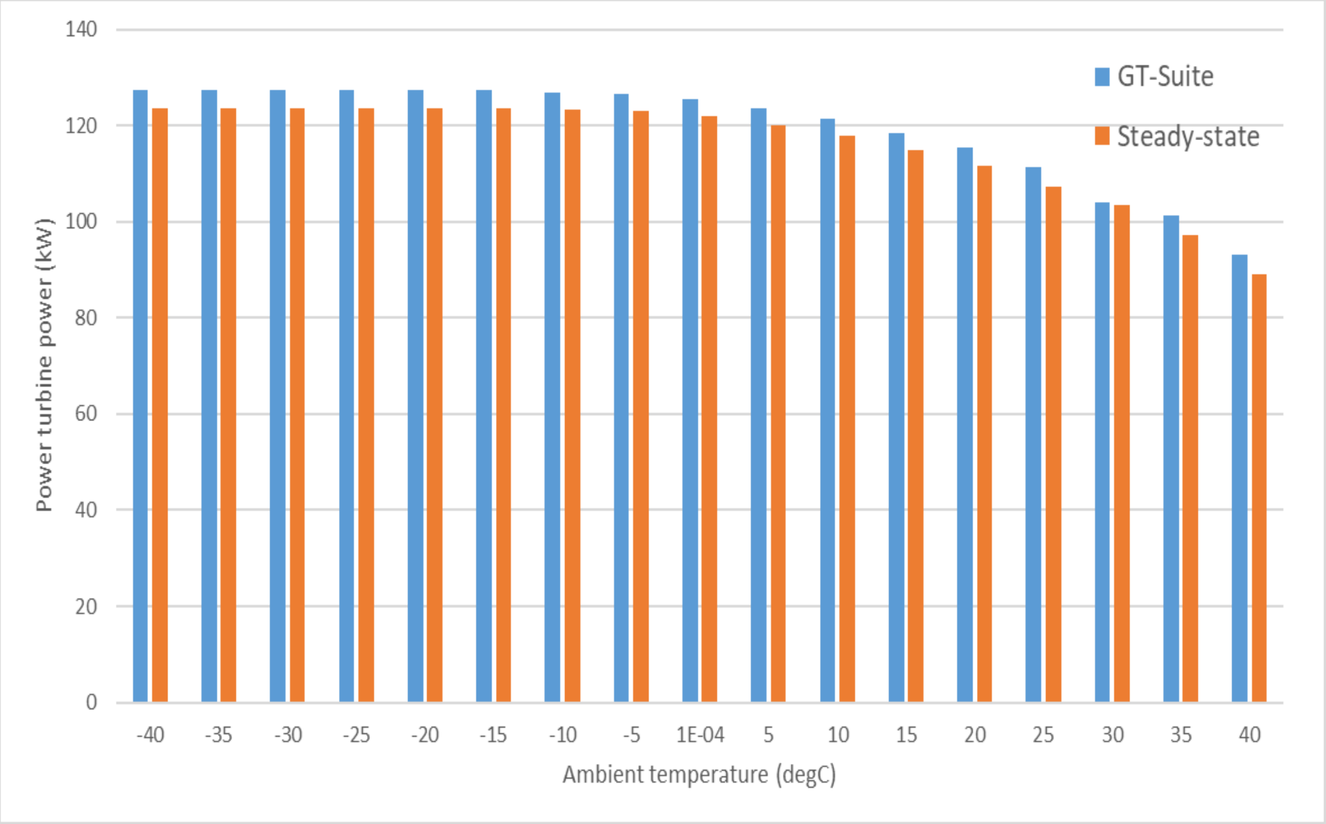
- Manufacturer: VPE
- Microchannel heat exchanger
- Design Code: ASME BPV Code Section VIII Div I
- Core/Nozzle Material: SS 316L
- Design UA=3kW/K
- Design dP=0.3MPa





TCES + sCO_2 Power Cycle Transient Modeling





TCES + sCO_2 Power Cycle Transient Modeling