U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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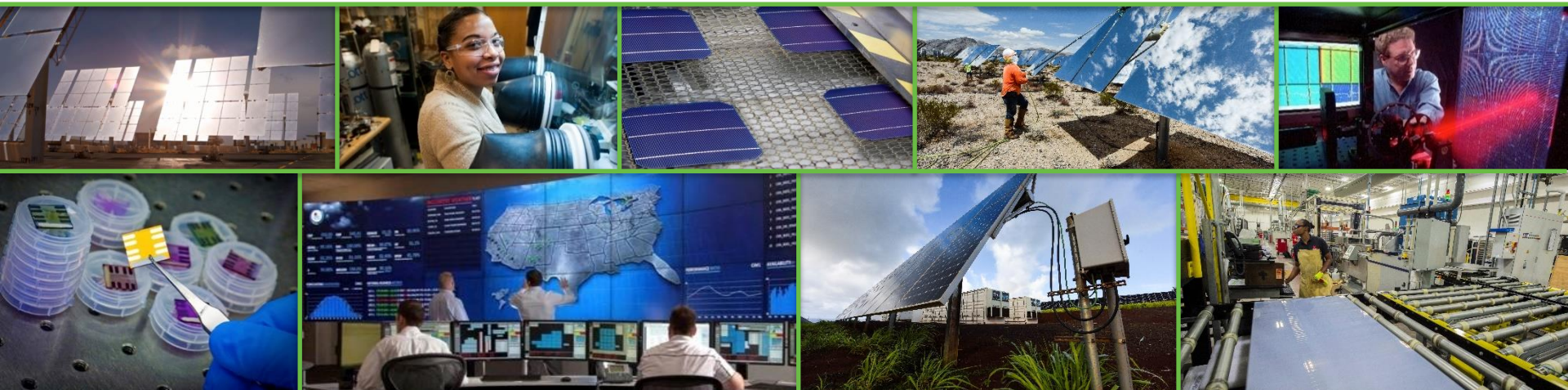
SETO Research on sCO_2 cycles 2014-2024

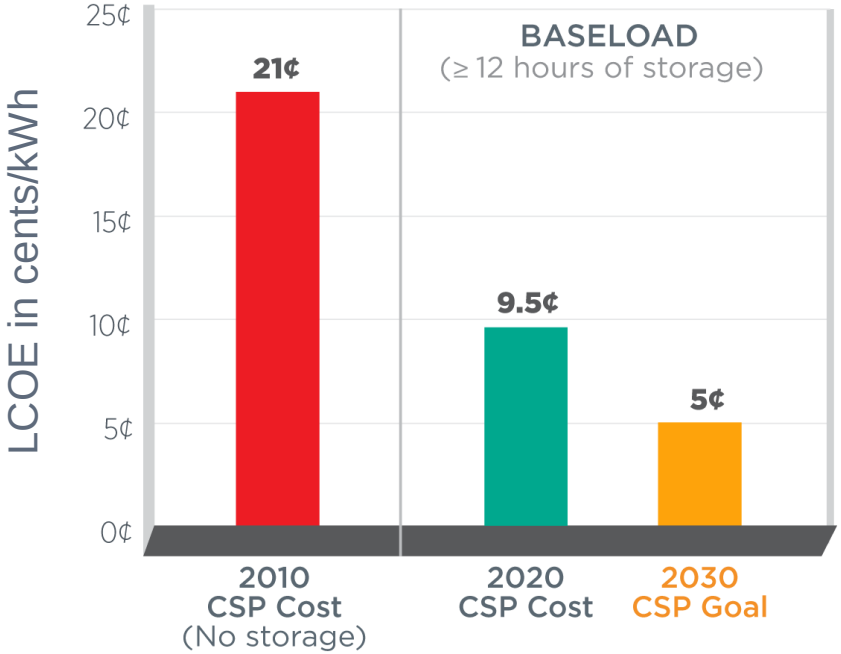
Rajgopal Vijaykumar, DOE Program Manager

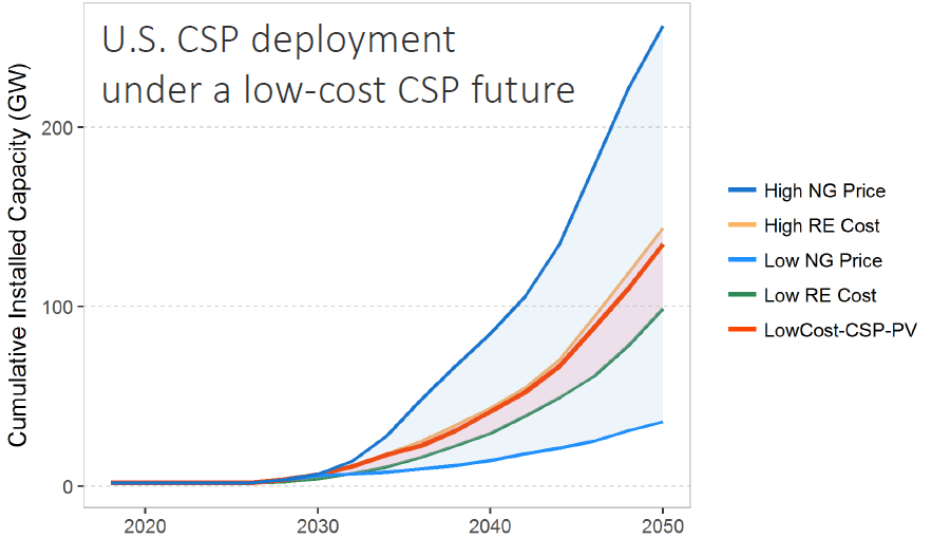
Solar Energy Technologies Office



2030 CSP Goal

The office's 2030 cost targets for CSP baseload (≥12 hours of storage) plants will help make CSP competitive with other dispatchable generators.



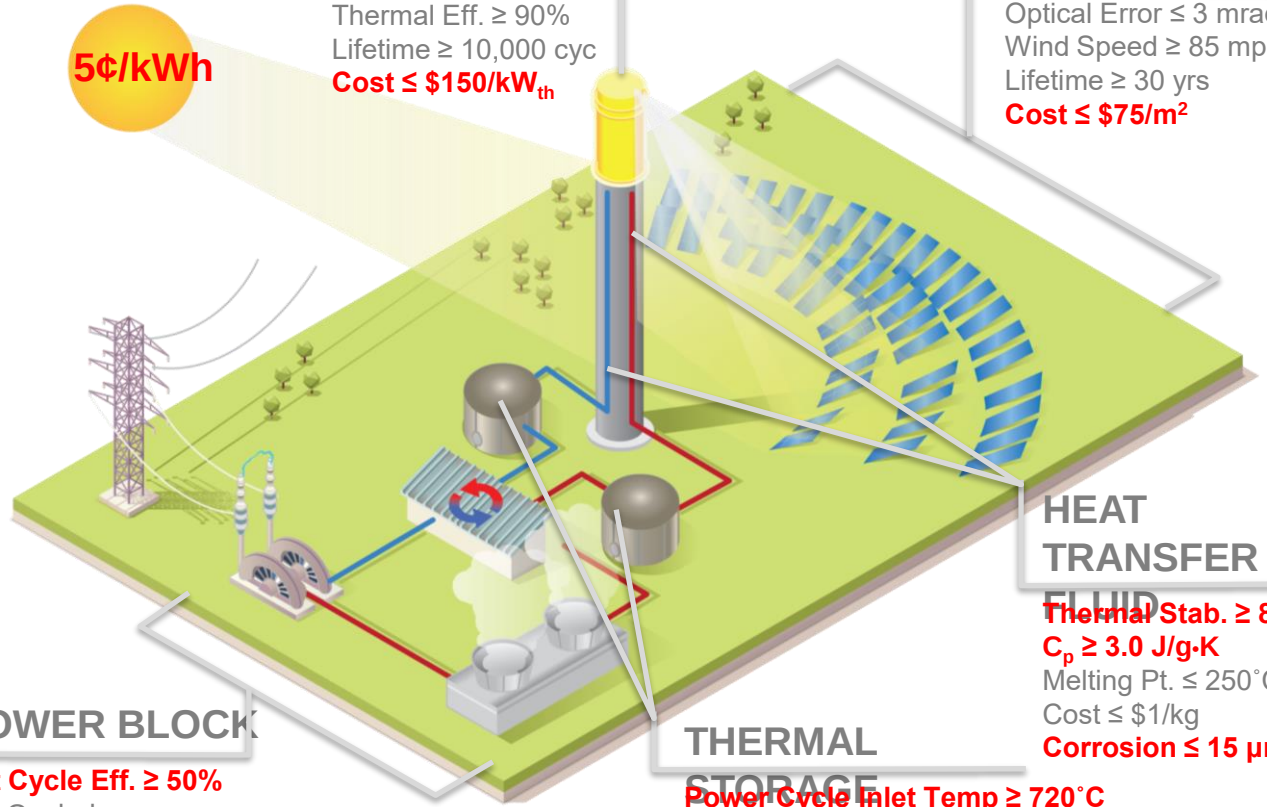


Murphy, et al. **2019**, NREL/TP-6A20-71912

*Levelized cost of energy (LCOE) progress and targets are calculated based on scenarios without federal tax credit or state/local incentives.

Study prior to passage of the Inflation Reduction Act

Highlighted targets are notable challenges



RECEIVER

HTF Exit Temp ≥ 720˚C
Thermal Eff. ≥ 90%
Lifetime ≥ 10,000 cyc
Cost ≤ $150/kW$_{th}$

SOLAR FIELD

Optical Error ≤ 3 mrad
Wind Speed ≥ 85 mph
Lifetime ≥ 30 yrs
Cost ≤ $75/m^2

HEAT TRANSFER FLUID

Thermal Stab. ≥ 800˚C
C_p ≥ 3.0 J/g·K
Melting Pt. ≤ 250˚C
Cost ≤ $1/kg
Corrosion ≤ 15 µm/yr

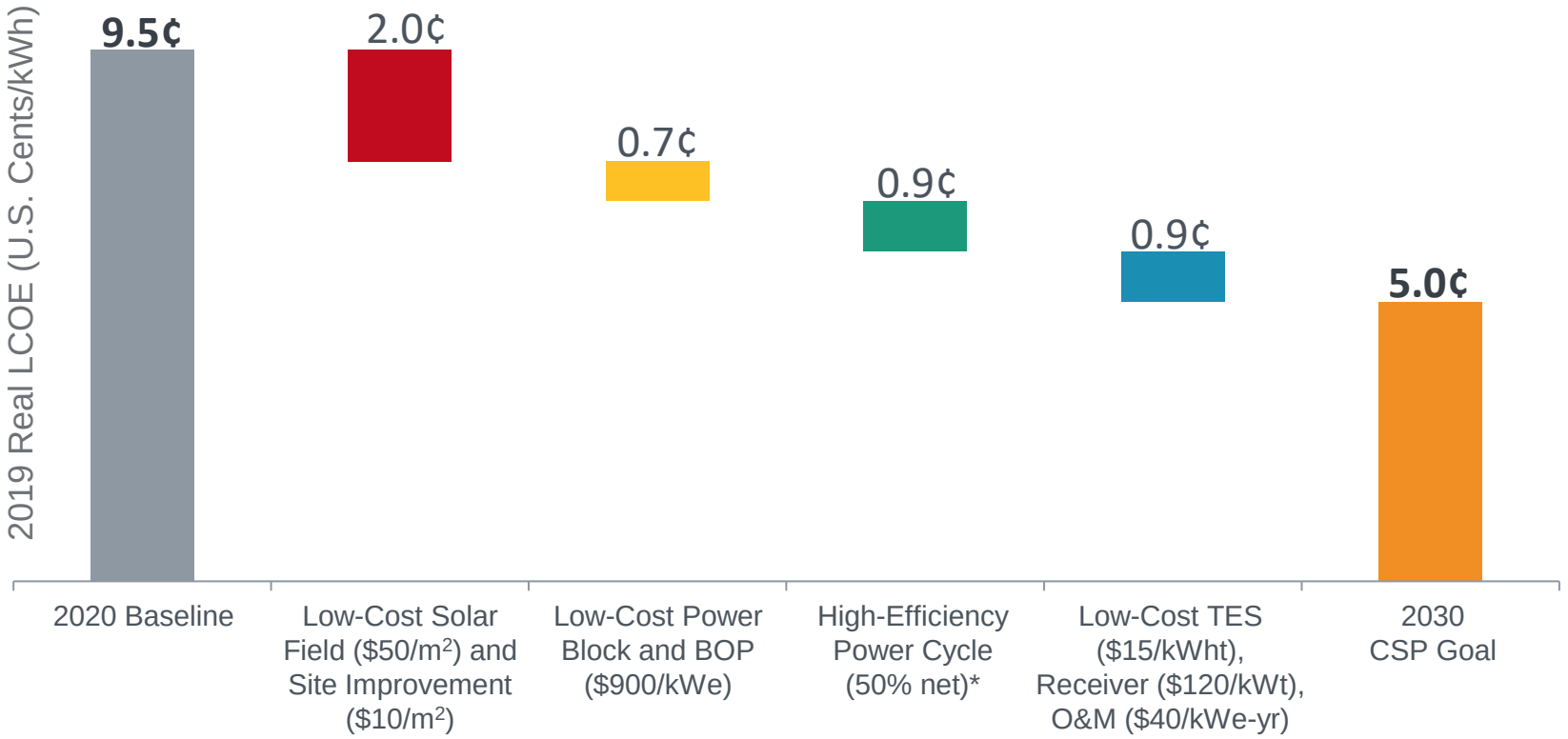
POWER BLOCK

Net Cycle Eff. ≥ 50%
Dry Cooled
Cost ≤ $900/kW$_e$

THERMAL STORAGE

Power Cycle Inlet Temp ≥ 720˚C
Energy Eff. ≥ 99%
Exergy Eff. ≥ 95%
Cost ≤ $15/kWh$_{th}$

A Pathway To 5¢ per kWh for CSP

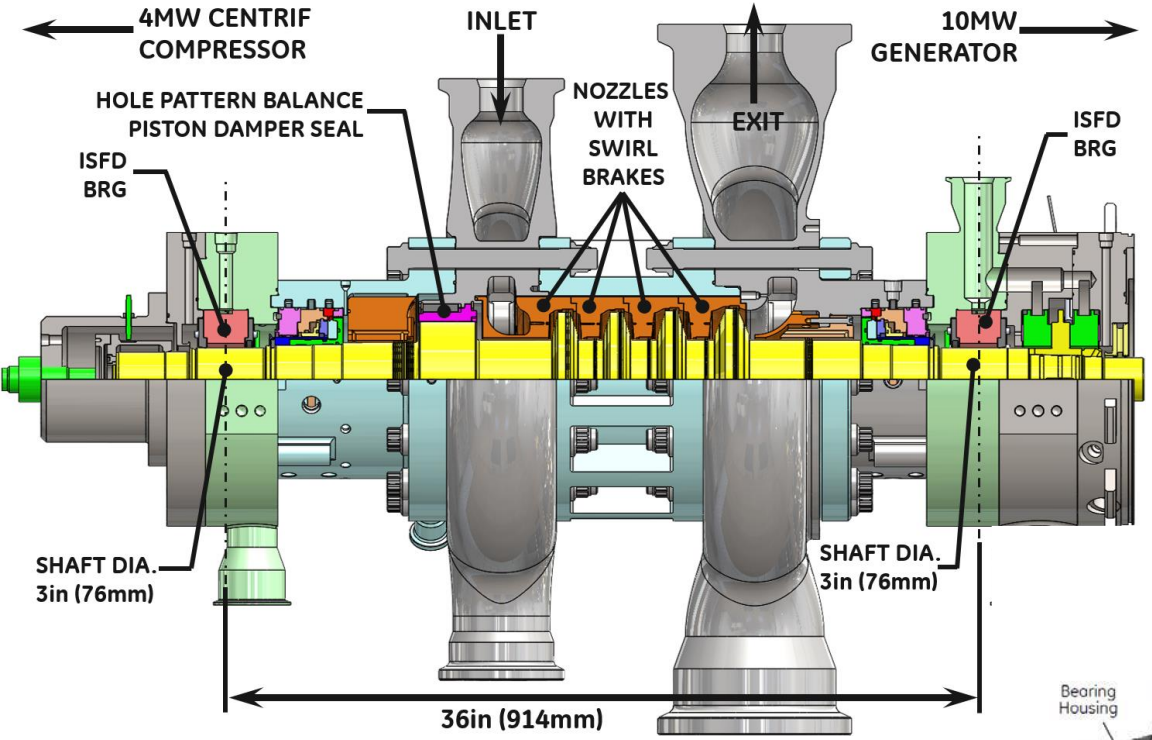


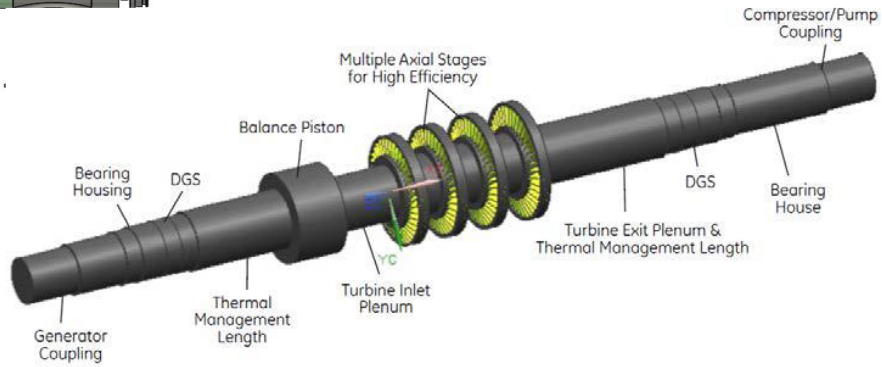
*Assumes a gross to net conversion factor of 0.9

SETO Research on sCO_2 Power Block

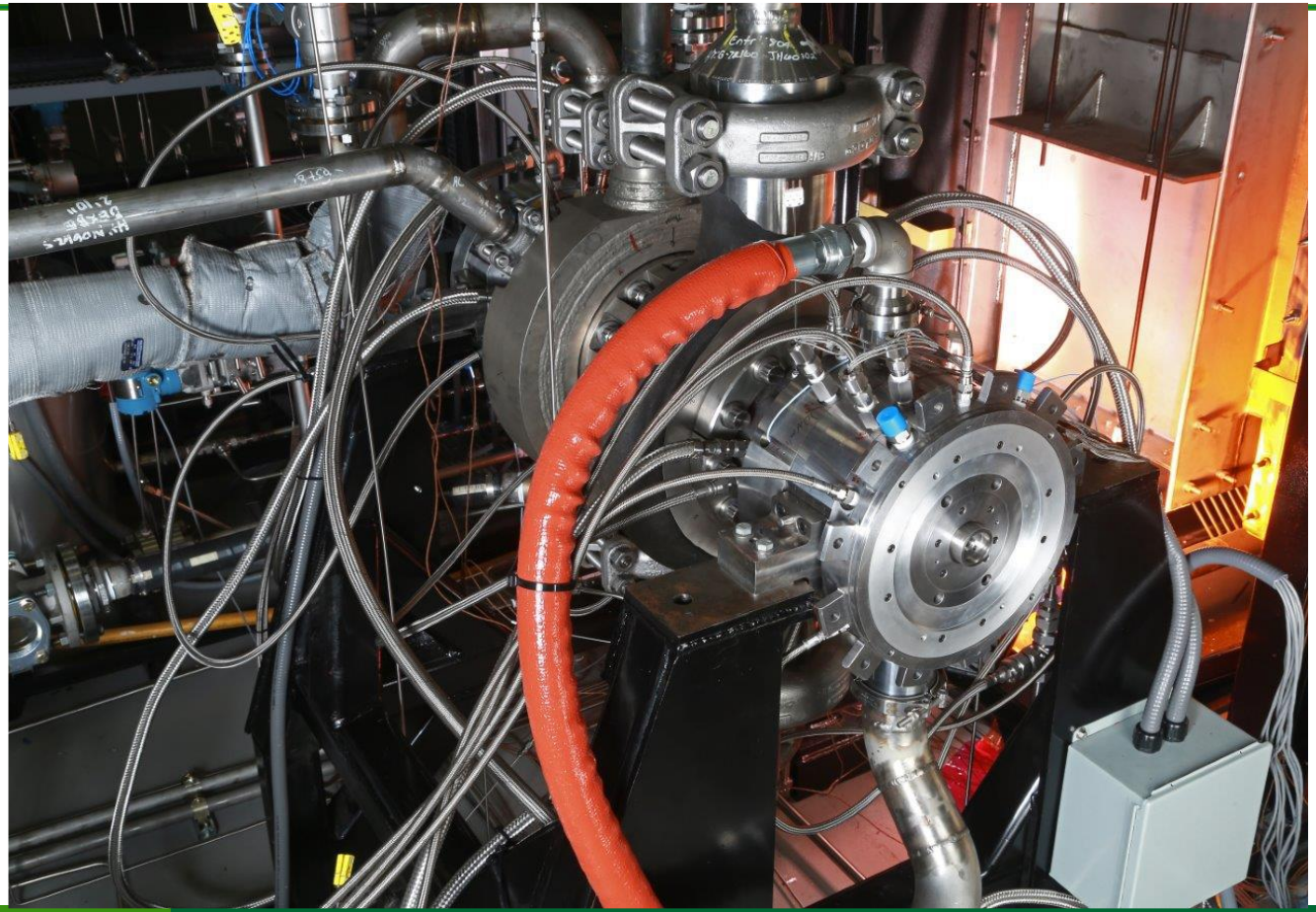
- SETO research started 2014 with Sunshot expander research in a gas-heated sCO_2 Loop; GE/Thar/SWRI (Cost including sCO_2 loop $9.8 M)
- Integral geared compander by Hanwha/SWRI in 2016(~$8.8 M)
- Apollo compressor (GE/SWRI) in 2016 (~5.4 M)
- sCO2 Corrosion and Creep Testing for Component Lifetime at ORNL ($2.4 M)
- Regenerator as cheap replacement of Recuperator UW/SNL ($2 M)

Sunshot Expander at 1 MWe Scale Testing

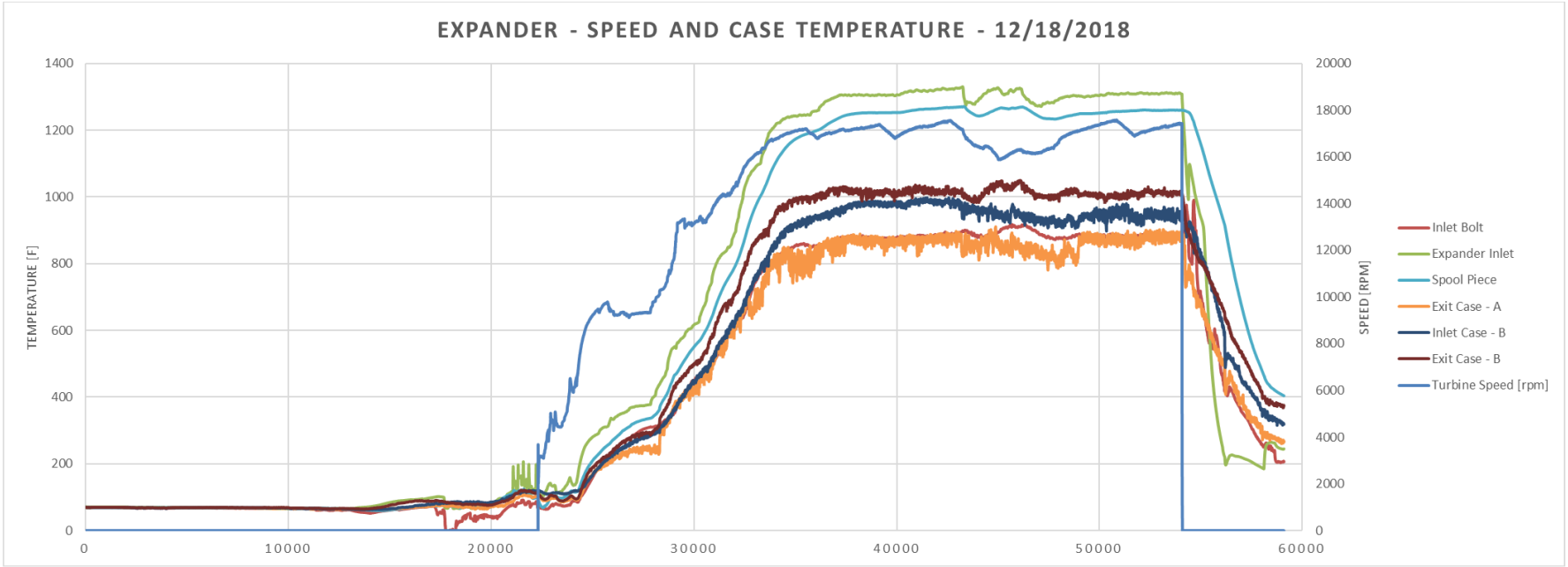




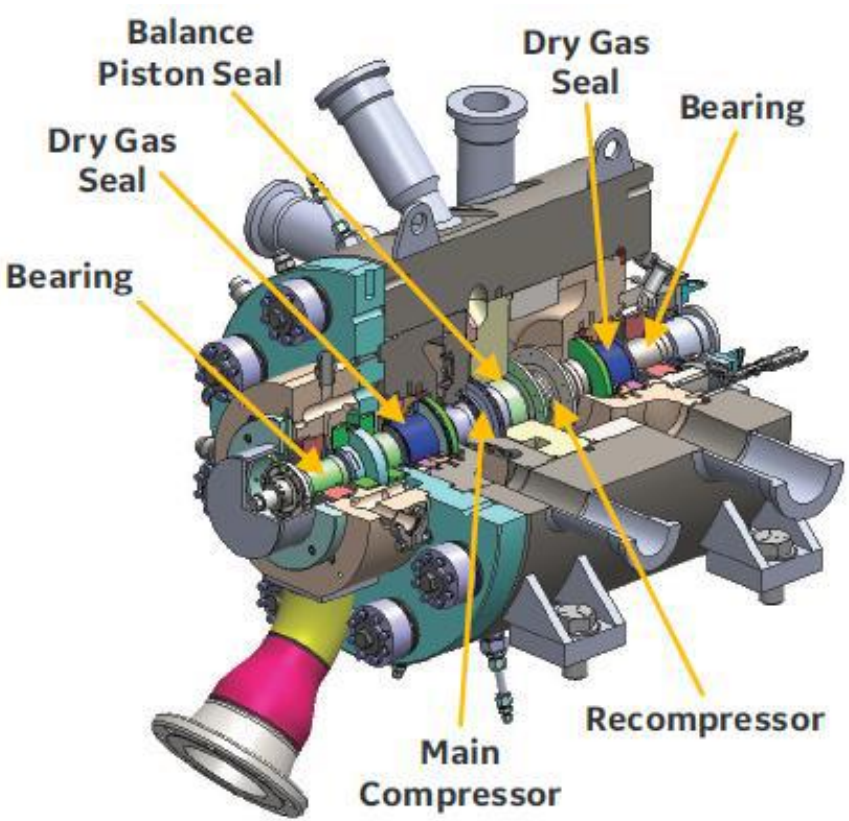
As Built Expander



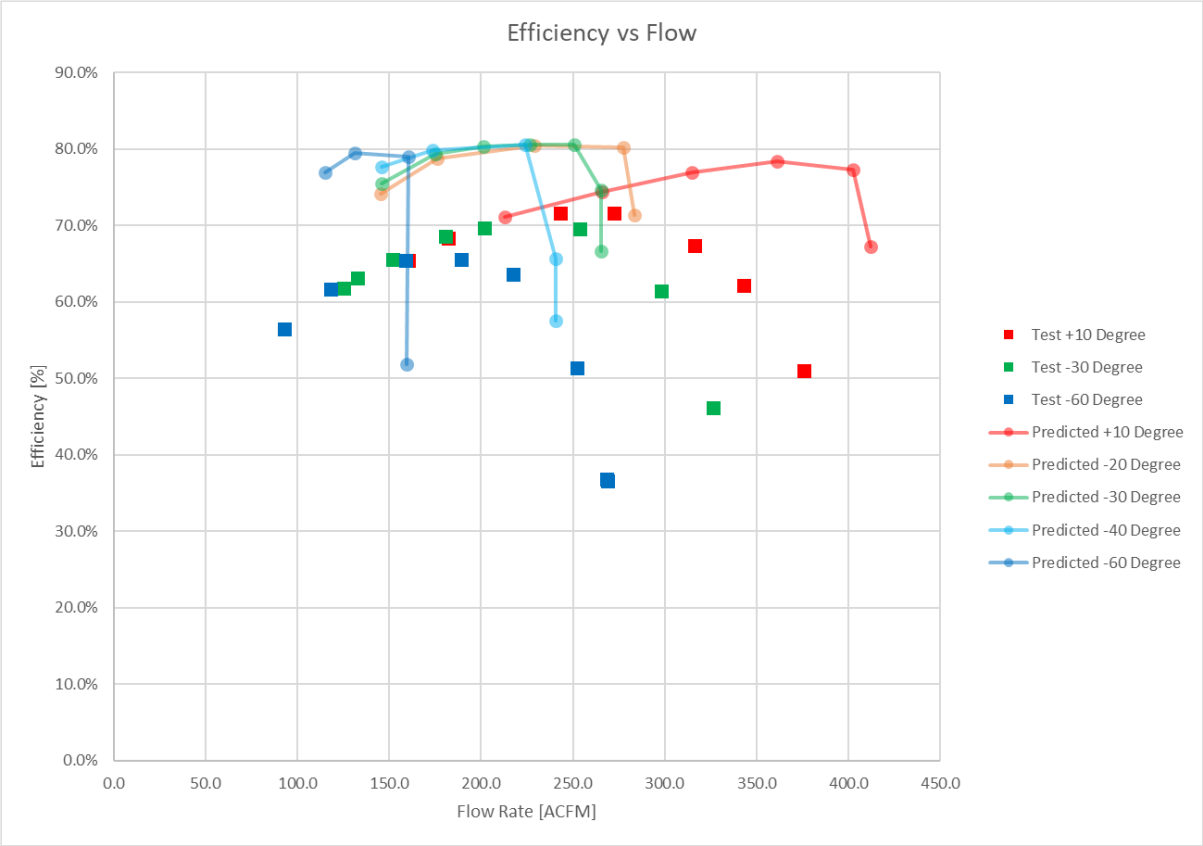
Temperature 700 ^{o}C and 255 bar Inlet for 5 hours



Apollo Compressor

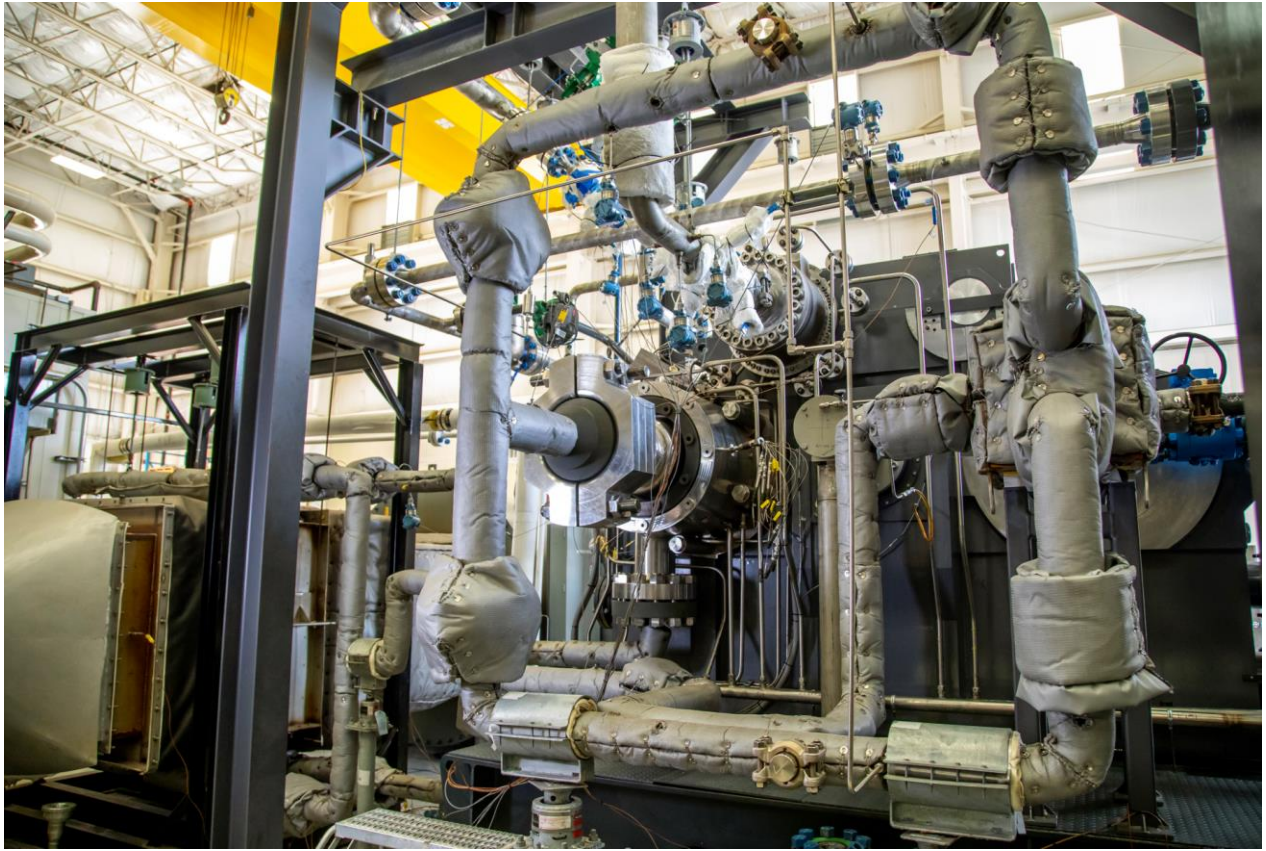


Apollo Compressor Testing

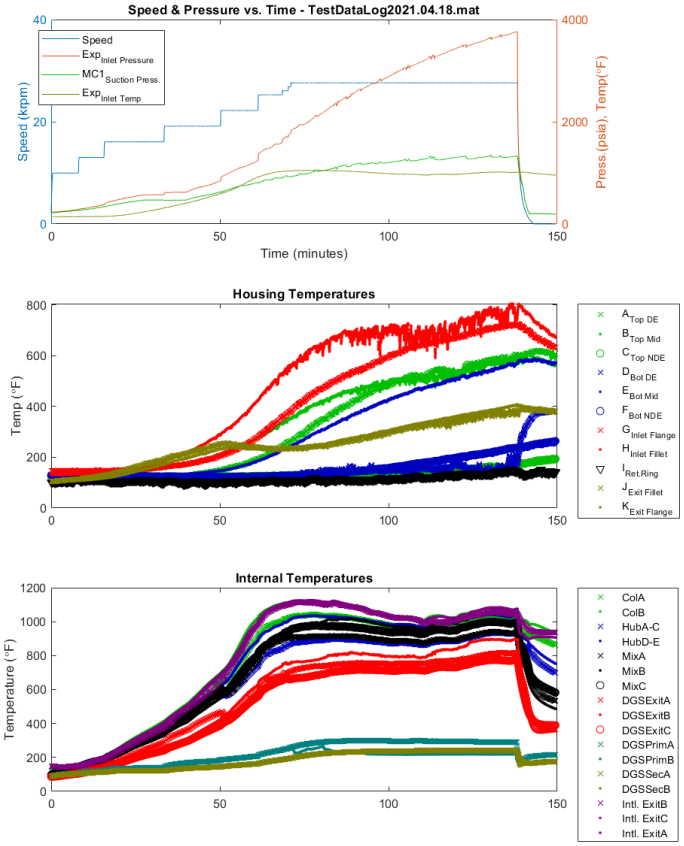


Results Further Improved by GE and SWRI using improved seals

Integral Geared Compander (Hanwha/SWRI)

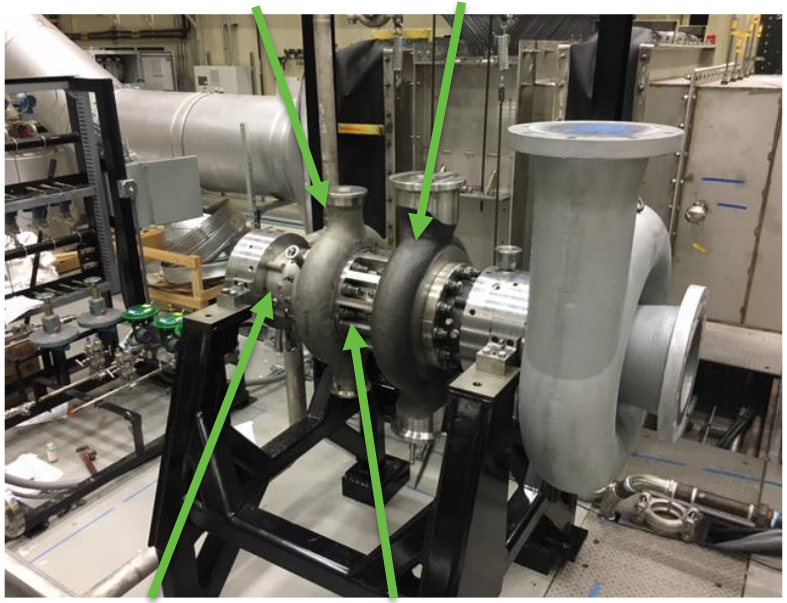


Sample Results



- Compressor Tested in a Separate Facility
- Compander Tested to 3765 psi and 1300 F although not together
- DGS Seal Problems Similar to Apollo Compressor/SunShot Expander suggests further R&D on High Temperature DGS
- Further Testing Conducted under Hanwha Funding Suggested Compander Ready for Demonstration

Casing Fabrication from H282



- Sunshot Expander made of 4 Pieces
- Cast from H282 by ORNL and Metaltek after Failure during Sunshot Project
- Single Piece Casing cheaper to Fabricate
- GE/Synertech fabricated a STEP-Casing using PM/HIP

Lessons Learned 2014-2020

- **Dry Gas Seal Failures Limited Testing**
  - Incorrect Integration of Seals
  - Commercial seals
- **Improvement of DGS Design Required**
  - Improved dry gas seals up to 500-700 C for 1.3-2% increase in compressor and expander efficiency
  - GE Tested Improved DGS in Compressor Loop
  - Eagle Burgmann Project Funded for 500 C DGS to be tested in a 700 C Ready Loop

Lessons Learned 2014-2020

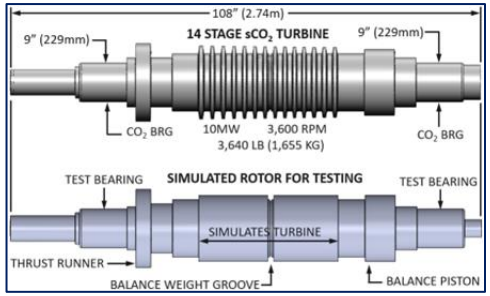
- **Fabrication of Turbine Casing**
  - Casting Nozzle Ring at ORNL using Haynes 282
  - Casing fabrication at GE/Synertech using PM/HIP
- **Recompressor not developed by GE for Apollo; developed separately by Echogen at NDTL**
- **Fabrication of Turbine Stop/Relief Valve using Sand Casting very expensive**
  - Shift TSV to 550 C Regime downstream of High Speed Train in a 2-Train Configuration

Gas Bearings for sCO_2 Turbomachinery

- **TSV using H282 too expensive to build and test**
  - IGV Compander design eliminates need for Stop Valve
  - Two-Speed Two Train system Proposed (GE IP)
- **Gas Bearings for Supporting High and Low Trains**
- **GE Completed air Testing of Gas Bearings 3,600 RPM, 3,800 lb casing for a ~10 MWe Turbine**
- **GE to continue Gas Bearing Testing in sCO_2 loop**
- **New Way Externally Pressurized Porous Bearing Tested on UNLV sCO_2 TAC to 700°C**

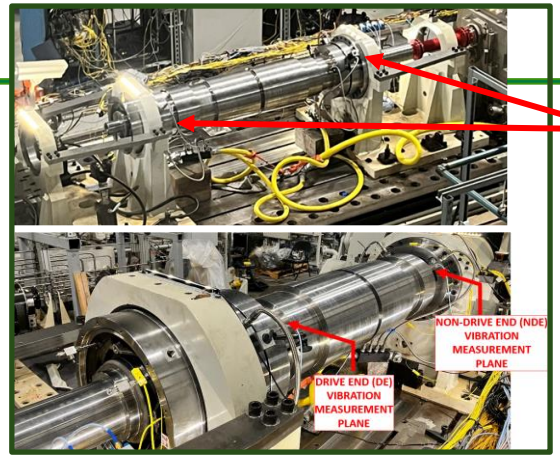
Simulated Oil-Free Rotor Testing

Additively manufactured air-bearing



Simplified Test Rotor
Rotor mass: **3640 lbs**
Bearing Dia: **9 in**

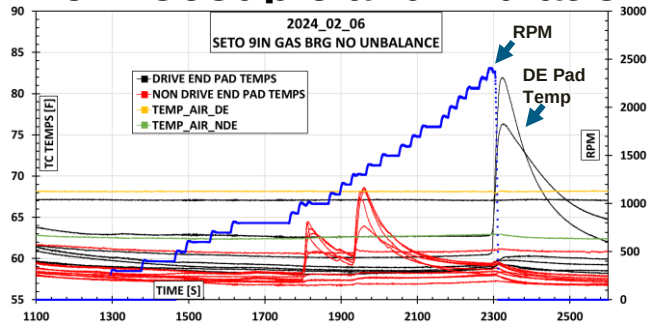
Test Bearing in housing with pad thermocouples



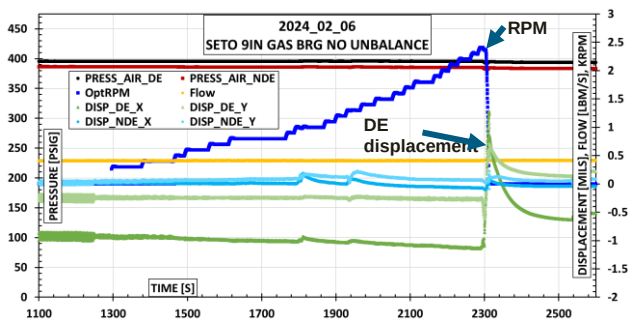
Rotor-bearing system installed in spin bunker test platform

High pressure air delivered to test bearings at 350-400psi to **float** the rotor

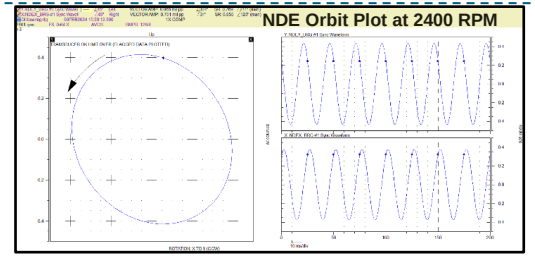
Thermocouple and Vibration

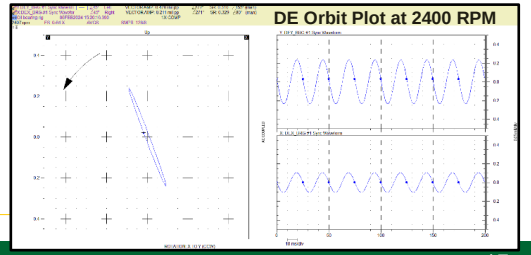


Pad temperatures with speed
Increase in DE pad temperature at 2400 RPM



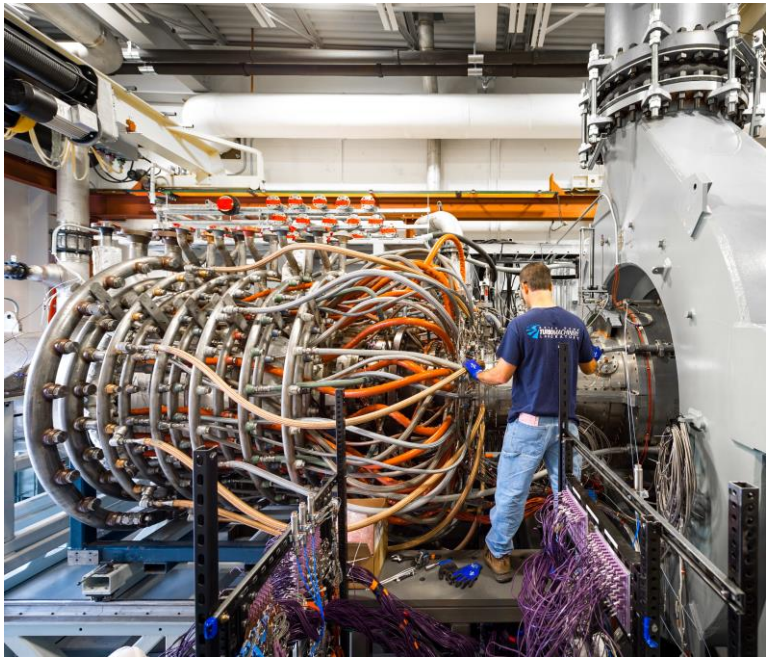
Displacement with speed
Increase in DE displacement at 2400 RPM





Successful Testing to 2400 rpm with Low Temperatures and Vibration

10 MWe Axial Compressor by Echogen/NDTL

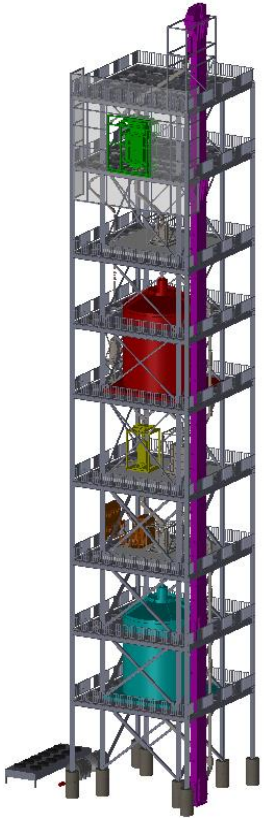


“sCO2 ReCompressor/Heat Pump Compressor” design under Testing at NDTL

G3P3-USA

- Particle based power tower with sCO_2 Loop for Cooling
- 7.3 MW heliostat field
- 2 MWth falling particle receiver, 6 MWth-hr TES, 1 MWth heat exchanger
- Heat exchanger located in a sCO_2 loop; supplies heat to {planned 400 kWe sCO_2 power block}
- Also integrated with a 600 kWe electric particle heater
- Air cooling as ultimate heat sink

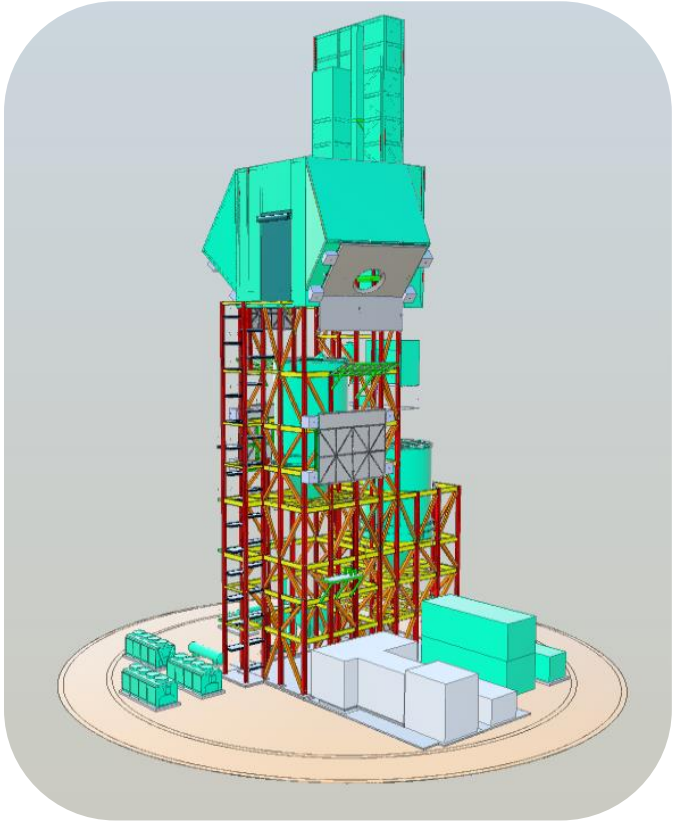
G3P3-USA



sCO_2 simple cycle loop to go here

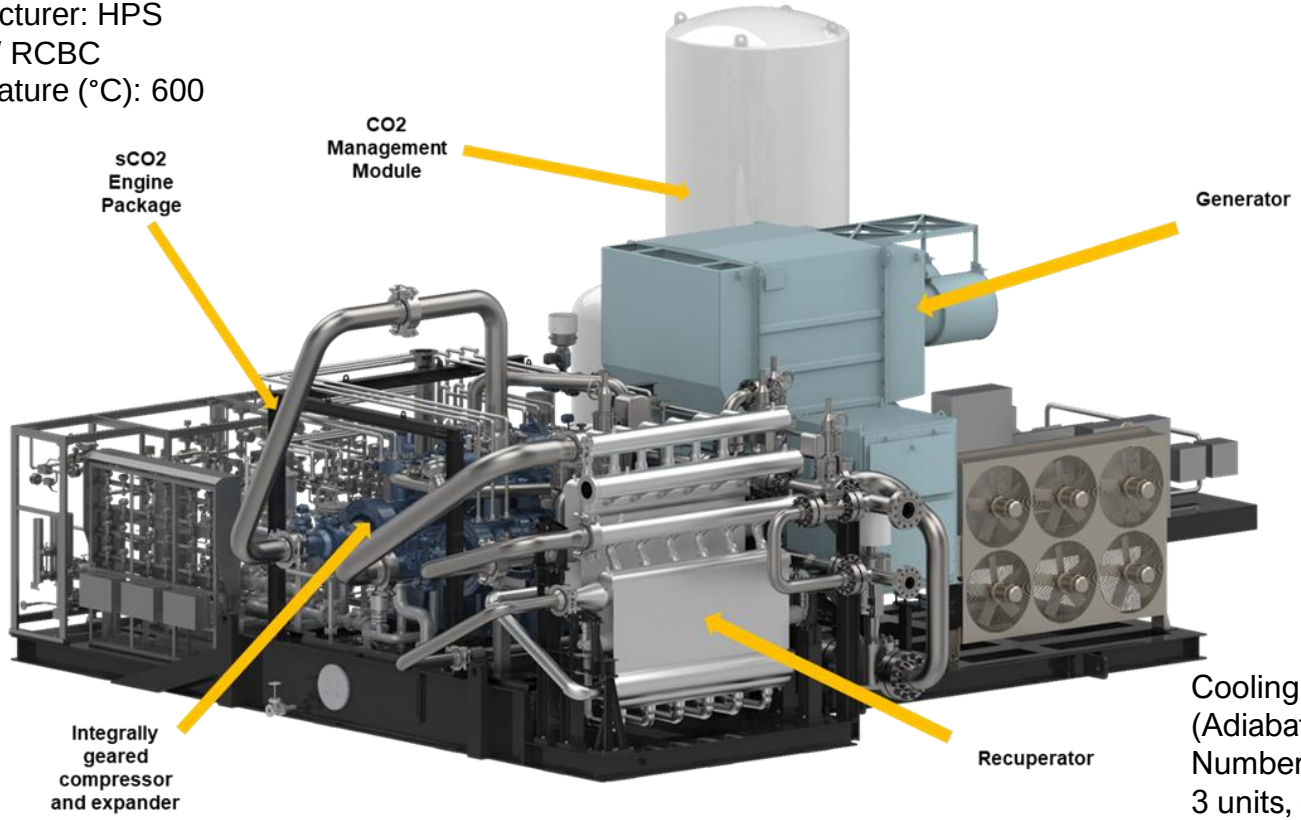
Project Overview

Project Name	Capella
Location	Kern County, USA
Technology	Particle Power Tower and sCO_2 Power Block (Gen 3)
Nominal Capacity	5 MWe
Status	FEED Complete
Break Ground	Q4 2024 (Forecasted)
Key Stakeholder	Woodside Heliogen U.S Department of Energy
Offtake Agreement	No Export (Test Facility)



Skid-based sCO_2 Power Block by Hanwha

Nominal Power Cycle Capacity: 5 MWe
Power Block Manufacturer: HPS
Power Cycle: sCO2 / RCBC
Turbine Inlet Temperature (°C): 600



Cooling Type: Hybrid (Adiabatic)
Number of Coolers: 3 units, 4 fans each

Image courtesy Hanwha Power Systems

3-D Rendition provided by PSM

Summary and Way Forward

- **Scaled Development and Testing of <1-10 MWe power block systems under various sources of DOE funding**
- **600^{o}-700^{o}C Testing at Various Scales from 1 MWe through 5 MWe with air cooling as ultimate heat sink planned**
- **Further Development and Scaleup to 10-30 MWe Planned:**
  - Small Business Innovation Research (SBIR) Topic Area "Supercritical CO_2 Cycles"
  - Open now Small Innovative Projects in Solar (SIPS) Academic FOA. (Apps due March 6th)
- **Notice of Intent Published: Concentrating Solar Flux to Heat and Power**
  - **Topic Area 2: Scalable Supercritical Carbon Dioxide (sCO_2) Turbomachinery**