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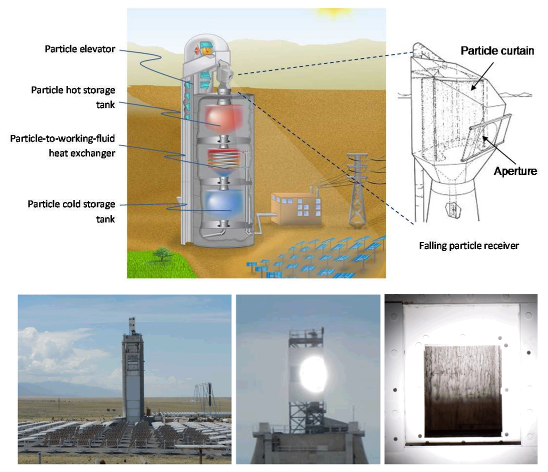
High-Temperature Particle Heat Exchanger for sCO2 Power Cycles

CONCENTRATING SOLAR POWER

PROBLEM STATEMENT

Next-generation solar-driven supercritical CO_2 (sCO2) Brayton cycles are being pursued to enable SunShot targets for concentrating solar power (CSP). New high-temperature heat-transfer media are being explored, including solid particles that can be efficiently and directly heated by concentrated sunlight. A particle-to-sCO2 heat exchanger is necessary to heat the sCO2 from the hot particles. However, a particle-to-sCO2 heat exchanger has not yet been developed.



Concentrated solar power using solid particles is being pursued to achieve higher temperatures and more efficient power cycles

PROJECT OVERVIEW

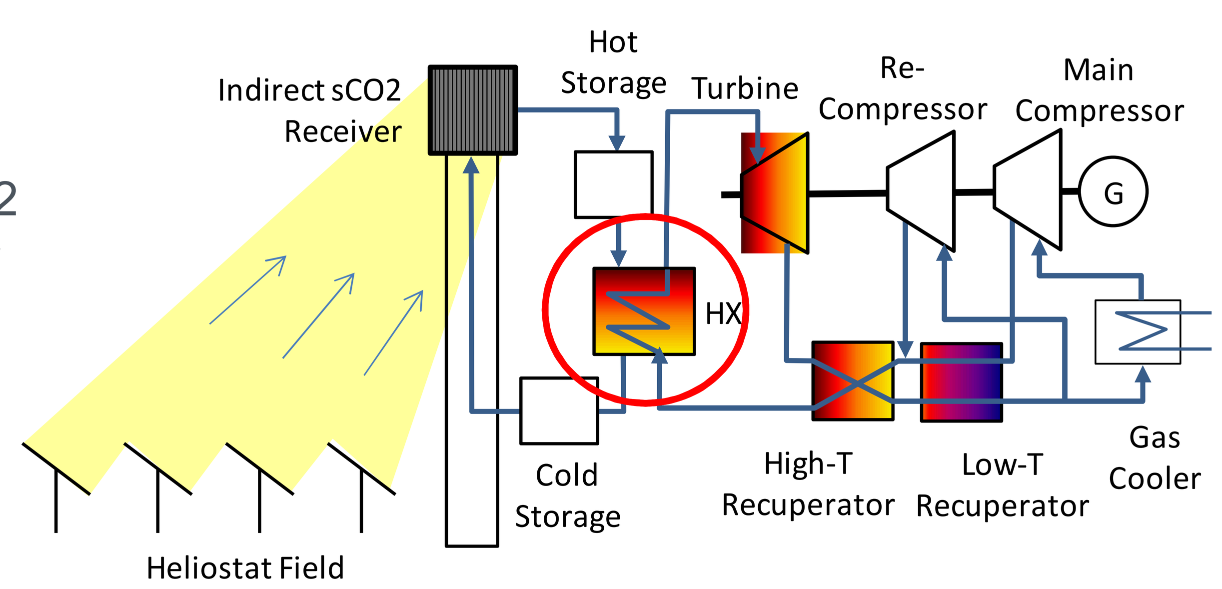
- ❑ Total Project Funding:
  - $4.6M (DOE)
  - $72K (cost share)
- ❑ Duration:
  - 3 years (10/1/2015 – 9/30/2018)
- ❑ Participants:
  - Sandia National Laboratories, National Renewable Energy Laboratory, Georgia Institution of Technology, Babcock & Wilcox, Solex Thermal Science, Vacuum Process Engineering

PROJECT OBJECTIVE

The goal of this work is to design, develop, and test a first-of-a-kind particle/sCO2 heat exchanger operating at sCO2 temperatures of ≥700 °C and pressures ≥20 MPa that will enable high-efficiency sCO2 power cycles. Moving packed-bed (shell-and-tube, shell-and-plate) and fluidized-bed heat exchanger designs will be investigated. The particle/sCO2 heat exchanger will be integrated with Sandia's falling particle receiver system for on-sun testing.

VALUE PROPOSITION

This work will develop the world's first particle-to-sCO2 heat exchanger for solarized sCO2 Brayton cycles to achieve $0.06/kWh



TECHNOLOGY OVERVIEW

Three particle heat-exchanger designs will be evaluated: (1) fluidized-bed, (2) shell-and-tube, and (3) shell-and-plate. The design that best meets the design criteria for cost and performance will be constructed and integrated with Sandia's falling particle receiver system.

Design Options	Pros	Cons	Risk Mitigation
B&W Fluidized Bed HX	• High heat transfer coefficient, low heat transfer area • Vast industry experience	Parasitic power requirements and heat loss from fluidizing gas	Minimization of fluidization velocity to reduce power requirements and heat loss through CFD modeling
Solex – Shell-and-Tube Moving Packed Bed HX	• Gravity-driven flow • Tubes can handle high-pressure sCO_2 • Lower pressure drop of sCO2 in tubes relative to plates	Particle flow stagnation area on top of tube and shadow area beneath tube may impede heat transfer	Improve particle/tube heat transfer via staggered tube arrangement with optimized spacing and/or extended surfaces
VPE/Solex – Shell-and-Plate Moving Packed Bed HX	• Gravity-driven flow • High potential surface area for particle contact • Higher heat transfer coefficient than shell-and-tube due to narrow channels and large surface area	Thermal gradients and warping of plates, numerous nozzles, potential for non-uniform particle flow	Use of multiple plate banks to minimize thermal gradient, proper spacing of plates, and adequate thermal insulation around nozzles

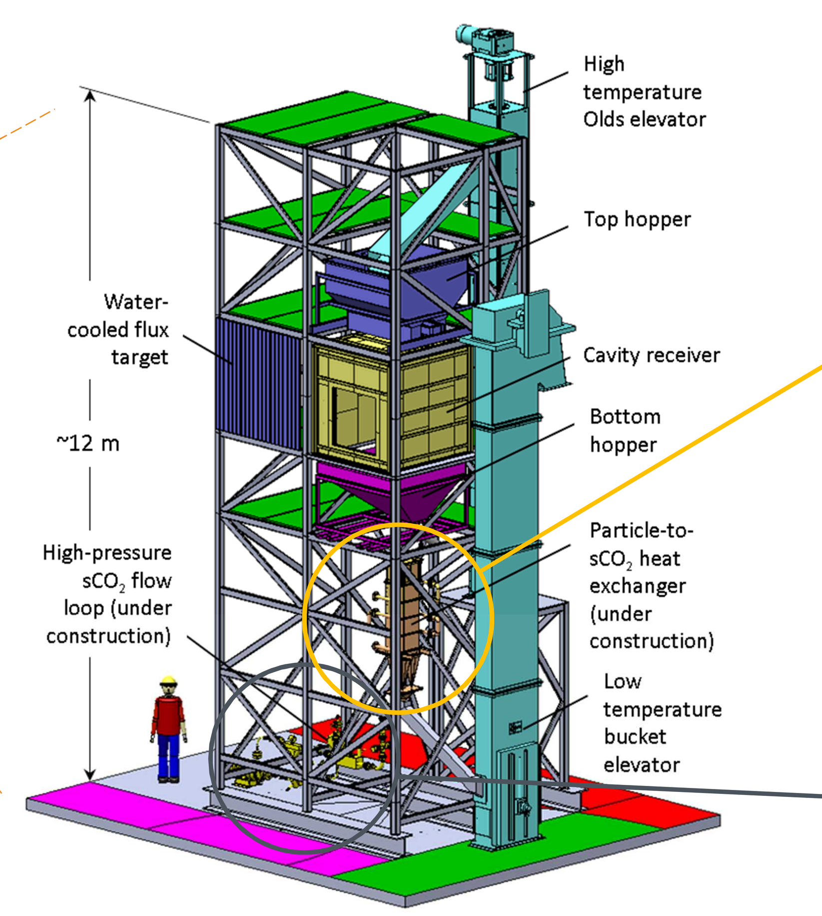
MILESTONES

- ❑ Phase 1
  - Work with industry to design fluidized-bed and moving packed-bed particle/sCO2 heat exchanger designs
  - Use analytical hierarchy process to downselect design
- ❑ Phase 2
  - Procure heat exchanger and sCO2 flow system and commission subsystem components
  - Develop models and tests to examine heat transfer and flowability
- ❑ Phase 3
  - Integrate heat exchanger and sCO2 flow system with particle receiver and perform on-sun tests

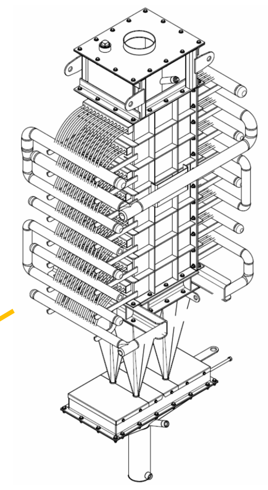
RESULTS

- Designed fluidized-bed and moving packed-bed particle/sCO2 heat exchangers with industry
- Measured particle/wall heat transfer coefficient at ~200 W/m^2-K for shell-and-plate design
- Performed particle flowability tests at 600 °C
- Designed and procured components for 100 kW$_t$ sCO2 flow system

Particle receiver testing at the National Solar Thermal Test Facility at Sandia National Laboratories, Albuquerque, NM

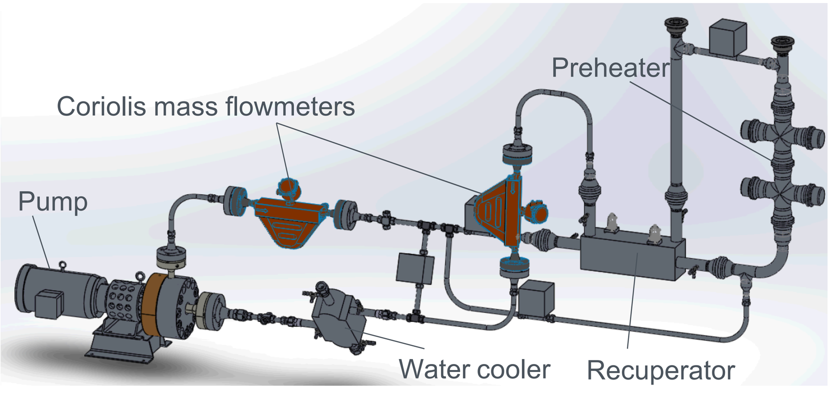


High-Temperature Particle Receiver



Solex/VPE particle/sCO2 shell-and-plate heat exchanger

- Heat duty = 100 kW
- $T_{particle,in}$ = 775 °C
- $T_{particle,out}$ = 570 °C
- $T_{sCO2,in}$ = 550 °C
- $T_{sCO2,out}$ = 700 °C
- $\dot{m}$ = 0.5 kg/s



sCO_2 flow system provides pressurized sCO_2 at 550 °C to heat exchanger for test and evaluation

Publications

- Ho, C.K., M. Carlson, P. Garg, and P. Kumar, 2016, Technoeconomic Analysis of Alternative Solarized s-CO2 Brayton Cycle Configurations, J. Solar Energy Engineering, 138, p. 051008-1
- Carlson, M.D. et al., 2017, Techno-Economic Comparison of Solar-Driven Sco2 Brayton Cycles Using Component Cost Models Baselined with Vendor Data and Estimates, Proceedings of the ASME 11th International Conference on Energy Sustainability, 2017
- Albrecht, K.J. and C.K. Ho, 2017, Heat Transfer Models of Moving Packed-Bed Particle-to-SCO2 Heat Exchangers, Proceedings of the ASME 11th International Conference on Energy Sustainability, 2017
- Albrecht, K.J. and C.K. Ho, 2017, High-Temperature Flow Testing and Heat Transfer for a Moving Packed-Bed Particle/sCO2 Heat Exchanger, in SolarPACES 2017, Santiago, Chile, September 26 - 29, 2017
- Ho, C.K et al, 2018, Evaluation of Alternative Designs for a High Temperature Particle-to-sCO2 Heat Exchanger, in Proceedings of the ASME 2018 Power and Energy Conference, PowerEnergy2018, Lake Buena Vista, FL, June 24 - 28, 2018

INDUSTRY IMPACT

- ❑ Teamed with leading industries to design particle/sCO2 heat exchanger: B&W, Solex Thermal Science, VPE
- ❑ Partnered with Solex Thermal Science and VPE to construct 100 kW$_t$ particle/sCO2 heat exchanger
- ❑ Worked with industry vendors to procure components for novel sCO2 flow system
- ❑ Teaming with industry on new proposals for next-generation (Gen 3) particle technologies for CSP

B&W thebabcock&wilcoxcompany
SOLEX THERMAL SCIENCE
VACUUM PROCESS ENGINEERING
Olds Elevator
CARBO INDUSTRIAL CERAMICS

SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy
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