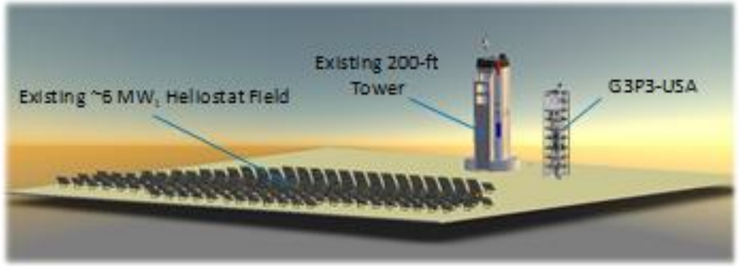
Sandia National Laboratories

Evaluation of Particle-to-sCO_2 Heat Exchangers and On-Sun Testing



PRESENTED BY

Clifford K. Ho

Sandia National Laboratories, Albuquerque, NM, ckho@sandia.gov

Contributors:

SNL (K. Albrecht, M. Carlson, H. Laubscher, F. Alvarez), Solex, VPE, Babcock & Wilcox, National Renewable Energy Laboratory, Georgia Tech

SAND2021-10299 PE

Objectives

- Evaluate alternative particle heat exchanger designs that can heat sCO_2 to 700 °C at 20 MPa for 100 kW prototype
  - Define design criteria
  - Use quantitative Analytic Hierarchy Process
  - Construct and integrate final design with Sandia's falling particle system

Heat Exchanger	Advantages	Disadvantages
Fluidized Bed	High heat-transfer coefficients	Energy and mass loss from fluidization
Moving packed bed (shell/tube)	Gravity-fed particle flow; low erosion	Low particle-side heat transfer
Moving packed bed (shell/plate)	High potential surface area for particle contact; low erosion	Potentially higher costs

Analytic Hierarchy Process

1. Identify a goal
2. Identify criteria to achieve goal and weight criteria
3. Define alternative designs or options to achieve goal
4. For each criterion, perform pairwise comparison of each design option
5. Obtain a final score for each design option

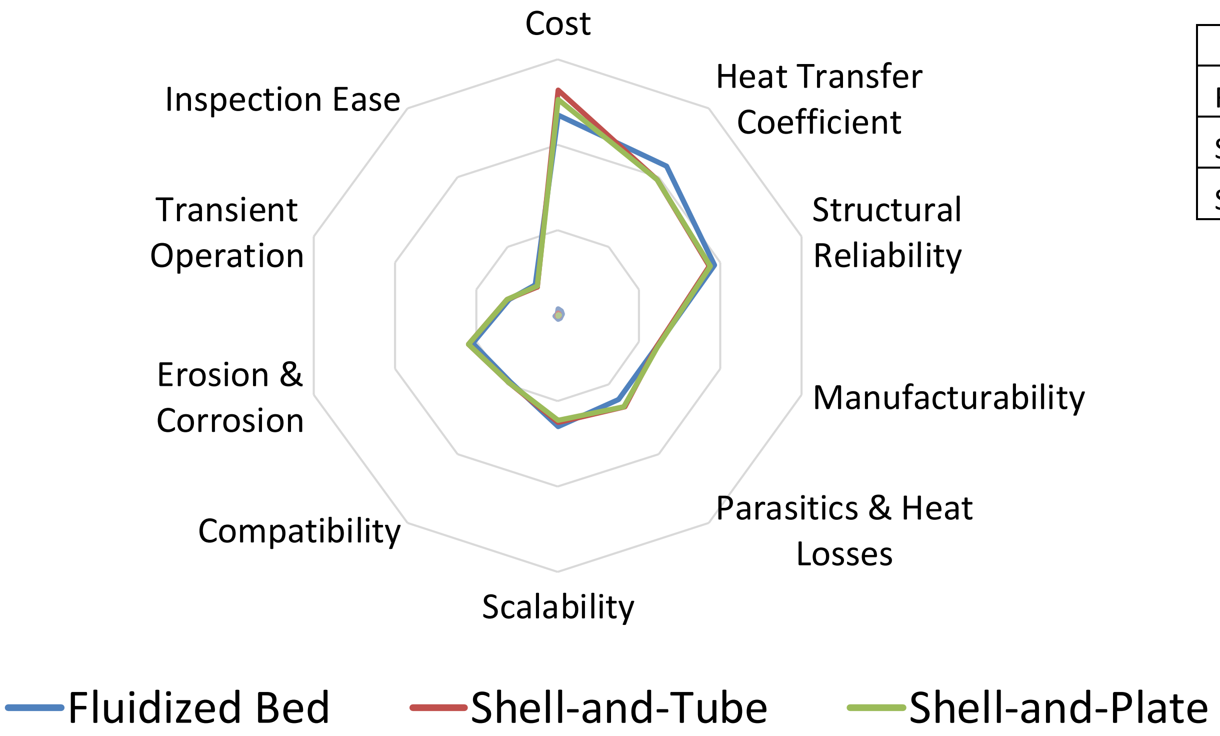
A team of researchers and heat-exchanger vendors independently assigned ratings to each pair of criteria and to each pair of design options

Final Criteria Weightings

Criteria	Weight
Cost	0.19
Heat Transfer Coefficient	0.15
Structural Reliability	0.14
Manufacturability	0.09
Parasitics & Heat Losses	0.10
Scalability	0.09
Compatibility	0.07
Erosion & Corrosion	0.08
Transient Operation	0.05
Inspection Ease	0.03

Final weighted scores for each design

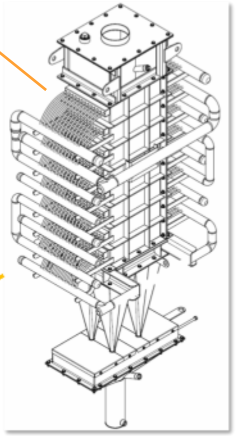
Final Scores	Cost	Heat Transfer Coefficient	Structural Reliability	Manufactur-ability	Parasitics & Heat Losses	Scalability	Compatibility	Erosion & Corrosion	Transient Operation	Inspection Ease
Fluidized Bed	0.2495	0.2817	0.2702	0.2634	0.2509	0.2732	0.2616	0.2577	0.2599	0.2780
Shell-and-Tube	0.2806	0.2574	0.2615	0.2639	0.2748	0.2632	0.2666	0.2683	0.2676	0.2577
Shell-and-Plate	0.2693	0.2579	0.2633	0.2673	0.2731	0.2591	0.2666	0.2697	0.2676	0.2607



Design	Final Weighted Score
Fluidized Bed	0.2219
Shell-and-Tube	0.2245
Shell-and-Plate	0.2225

Shell-and-plate was selected for final design and procurement

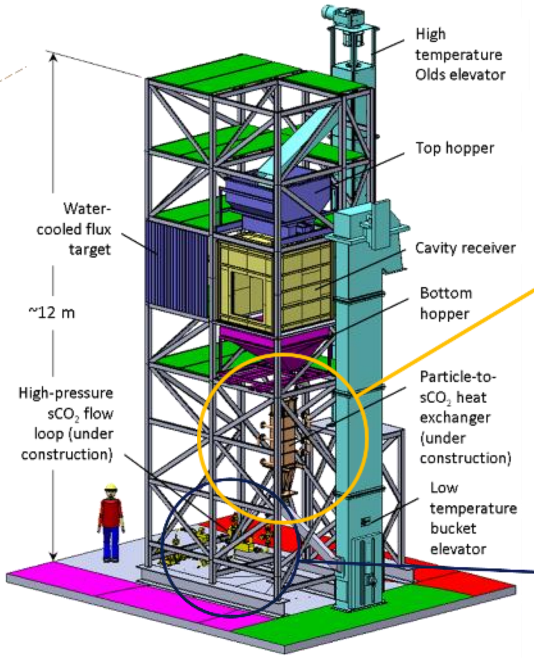
Integrated Shell-and-Plate Particle-to-sCO_2 System

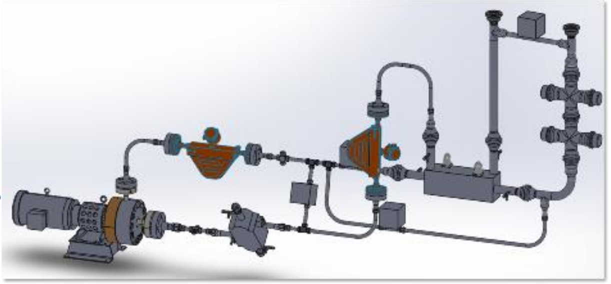


Solex/VPE/Sandia particle/sCO2 shell-and-plate heat exchanger

- 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

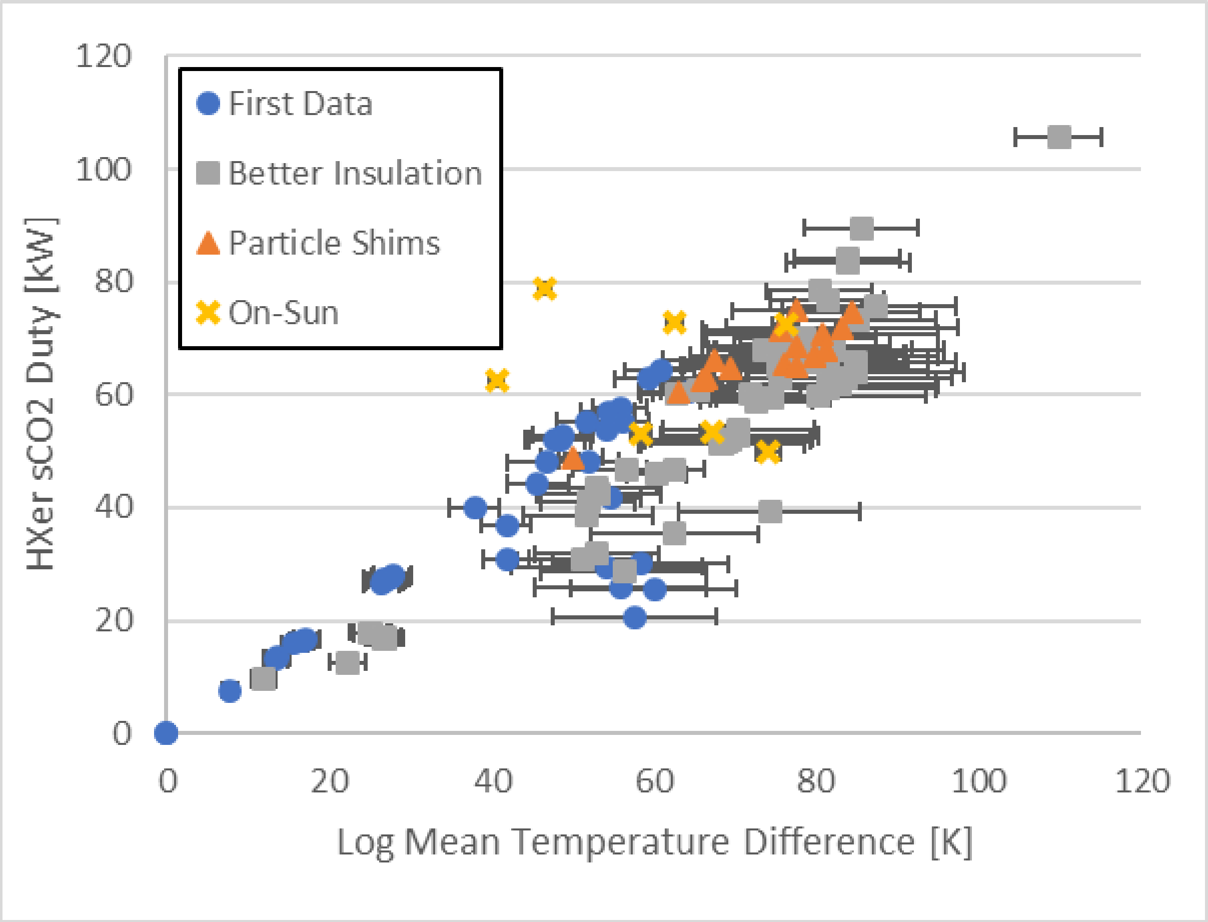
Particle receiver testing at the National Solar Thermal Test Facility at Sandia National Laboratories, Albuquerque, NM

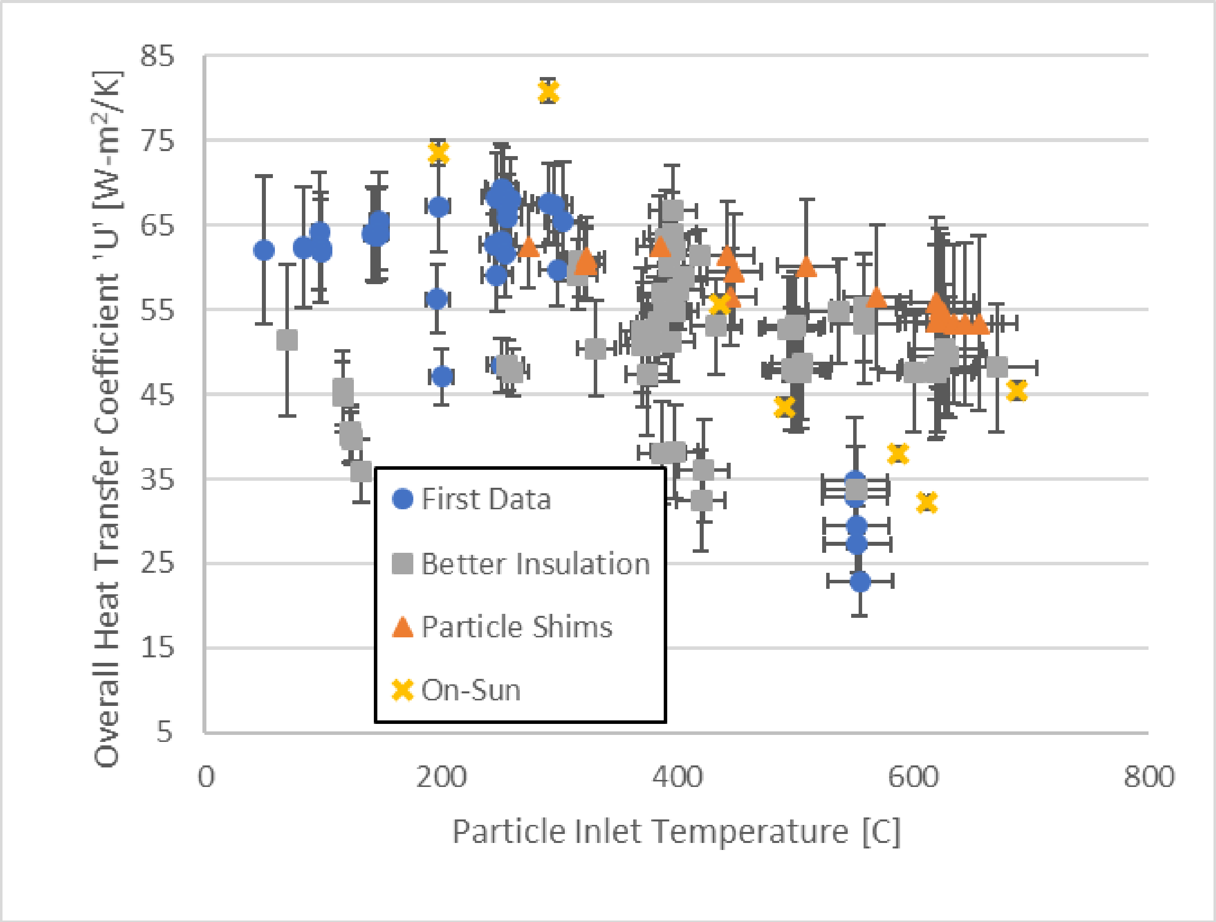




sCO_2 flow system provides pressurized sCO_2 at 550 °C to heat exchanger for test and evaluation

100 kW$_t$ Shell-and-Plate Prototype HX Test Results



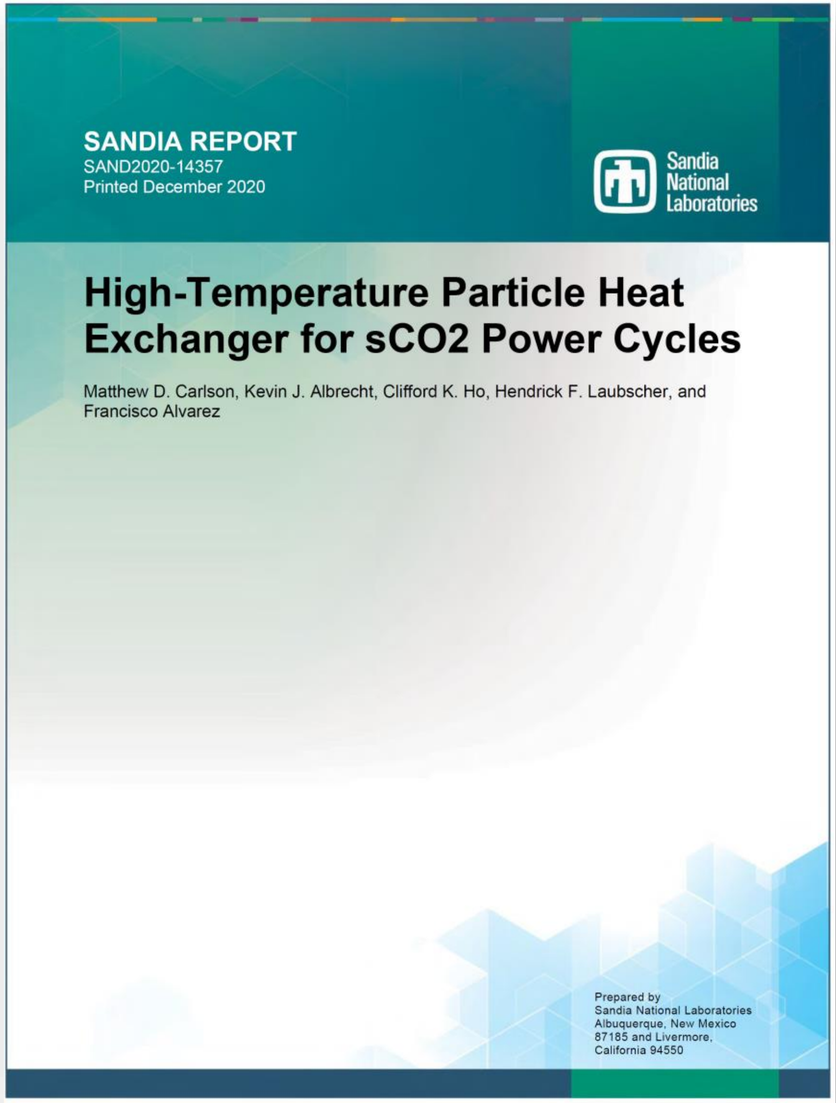


Carlson, Albrecht, Ho, Laubscher, and Alvarez (SAND2020-14357)

Summary

Recommendations for Next-Generation Particle/sCO_2 HX

- Manufacturing techniques that enable closer plate spacing for enhanced particle side heat transfer
- Heat exchanger geometry for pure counter flow arrangement to reduce thermomechanical stress and improve thermal performance
- Heat exchanger geometry and manufacturing that eliminate any internal ledges causing stagnant particle regions
- Pipe and sCO2 channel networks that reduce pressure drop and improve flow uniformity
- Heat exchanger particle feeder design that eliminates parallel particle flow paths causing maldistribution
- Geometries that reduce thermal mass and allow for large temperature ramp rates for reduced startup time



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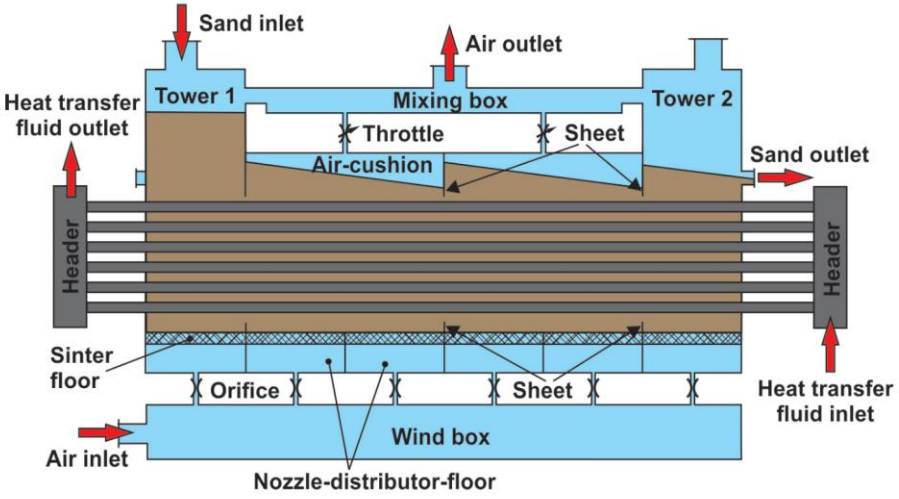
High-Temperature Particle Heat Exchanger for sCO2 Power Cycles

Matthew D. Carlson, Kevin J. Albrecht, Clifford K. Ho, Hendrick F. Laubscher, and Francisco Alvarez

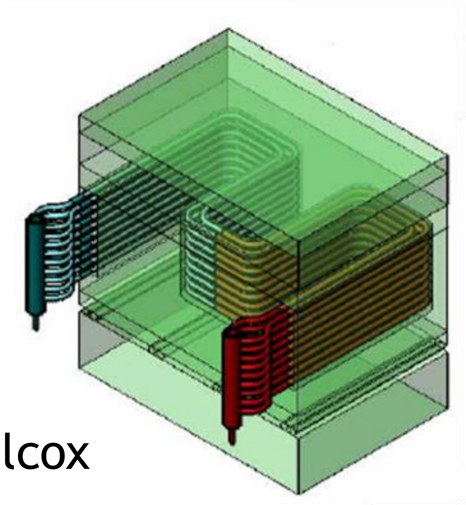
Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550

Fluidized-Bed Heat Exchangers Being Considered for Gen3



Scheme of the SandTES heat exchanger

SandTES pilot plant at TU Wien

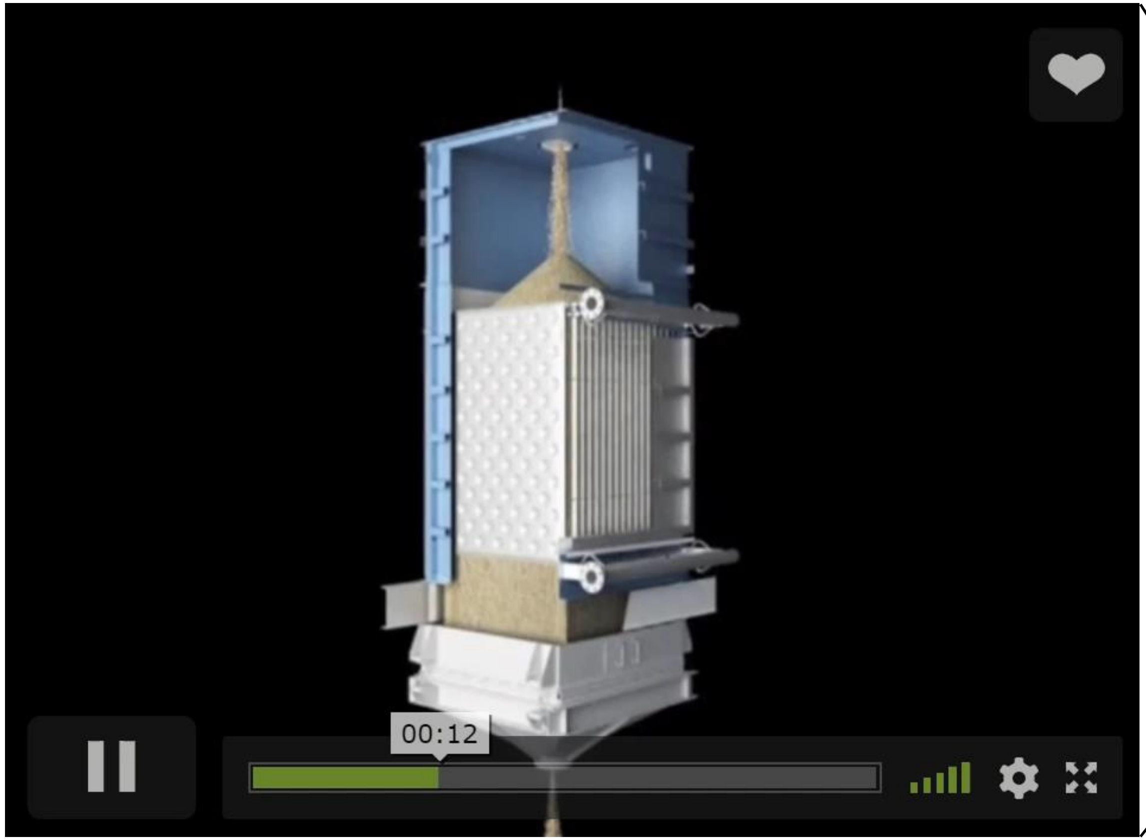


Babcock & Wilcox

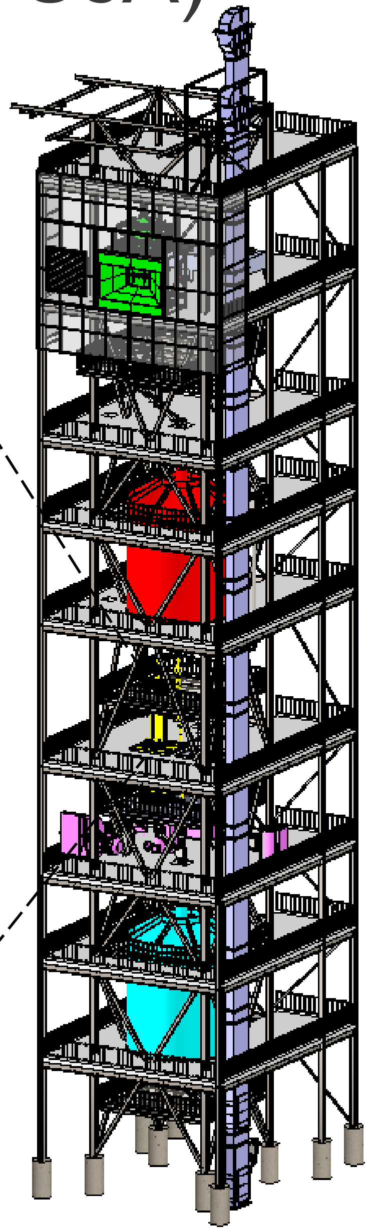
	Inlet	Outlet
Pressure:	20 MPa (2900 psi)	20 MPa (2900 psi)
Temperature:	561 °C (1042° F)	732 °C (1350° F) and 800 °C (1472° F)
Material:		
Header	SA335 P91	SB167 Seamless (UNS N06617)
Header Stubs	SA213 T91	SB167 Seamless (UNS N06617)
Safe Ends	SA213 TP347H	
Section Tubes	SA213TP304H	SB167 Seamless (UNS N06617)

Gen3 Particle Pilot Plant (G3P3-USA)

High-Temperature Particle-to-sCO_2 Heat Exchanger
(VPE, Solex, Sandia)



https://www.solexthermal.com/our-technology/cooling/



Gen 3 Particle Pilot Plant

- ~1 – 2 MW_t receiver
- 6 MWh_t storage
- 1 MW_t particle-to-sCO_2 heat exchanger
- ~300 – 400 micron ceramic particles (CARBO HSP 40/70)

K. Albrecht, SNL

Acknowledgments

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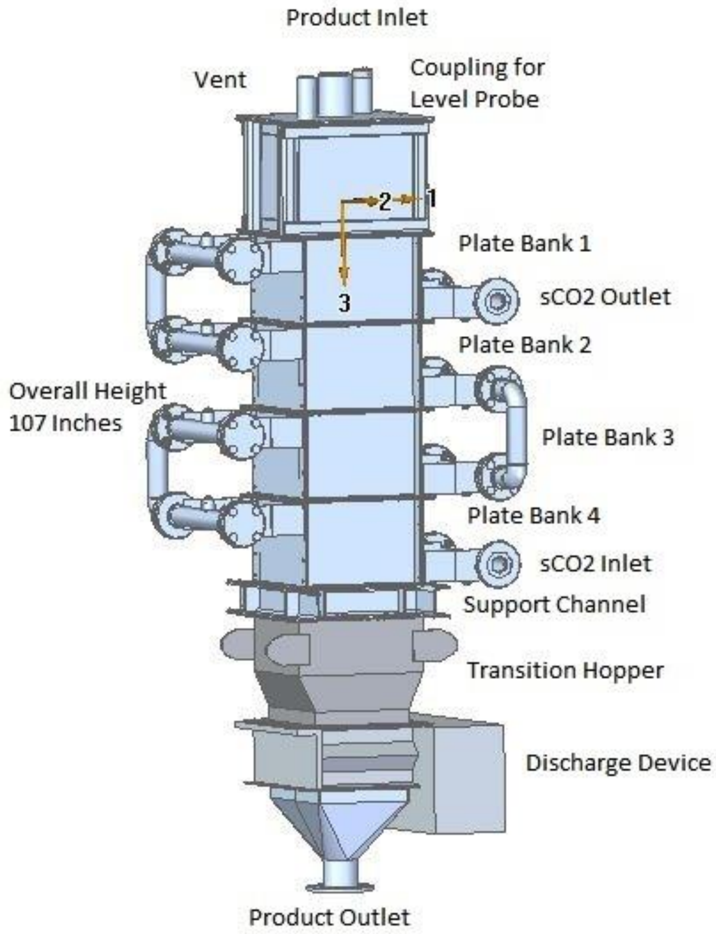
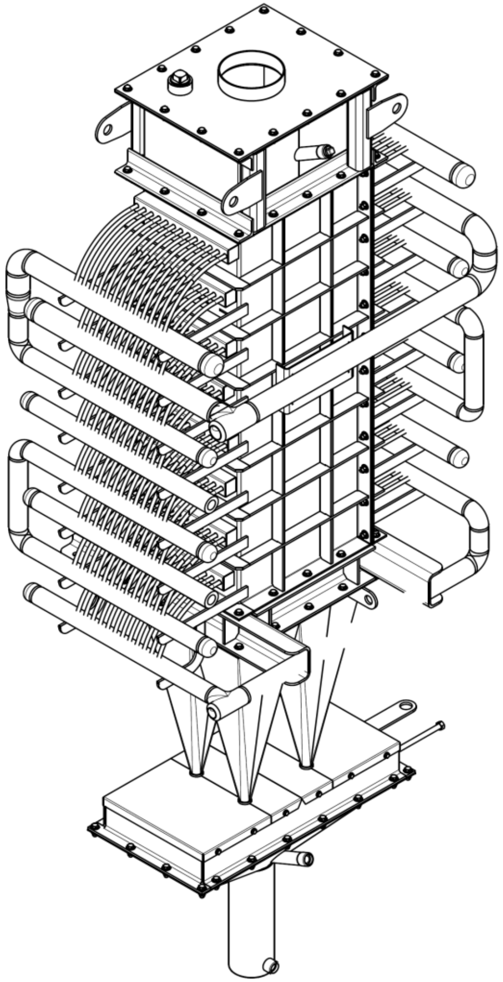
  - DOE Project Managers: Matthew Bauer, Shane Powers, Vijay Rajgopal, Levi Irwin, Andru Prescod, Mark Lausten, Avi Shultz

Backup Slides

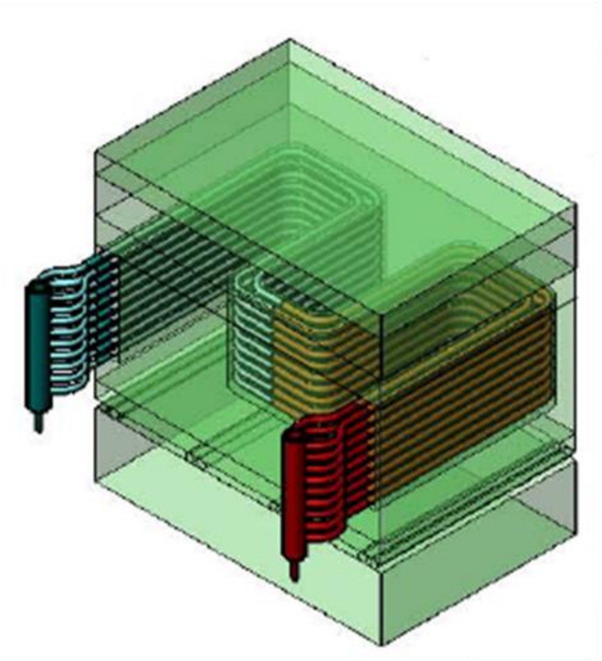
Shell-and-Plate Heat Exchanger Design (Solex, VPE, Sandia)

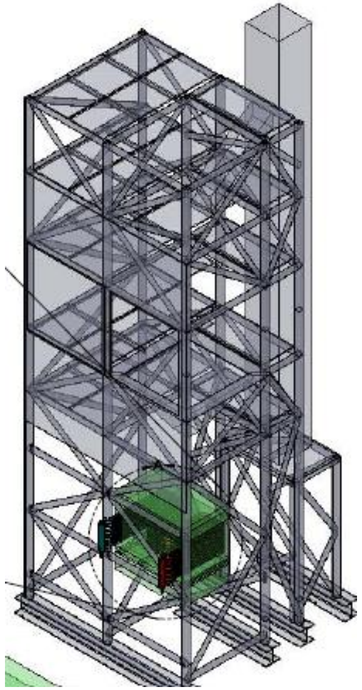




Product Flow Rate (kg/h)	1476
Product T in (°C)	775
Product T out (°C)	570
sCO_2 Flow Rate (kg/h)	1944
sCO_2T in (°C)	550
sCO_2T out (°C)	700
Heat Duty (kW)	100

Fluidized-Bed Heat Exchanger (B&W, NREL, Sandia)





- Tube size:
  - 1 inch OD tubes with 2.5 inch side spacing and 2.5 inch back spacing
- Submerged Tube bundle:
  - Two columns of nine tubes each
  - Tube length: 19-21 feet within the heat exchanger
  - Height: 21 inches
  - Sits approximately 8" above the air distributor
  - Six inches of fluidized solids is provided above the top of the tube bundle to cushion the top of the tubes from the incoming hot solids
  - Total depth of fluidized solids is 35 inches
  - Partition walls are tall enough to exceed the height of the expanded bed i.e., minimum 40 inches high
  - Width of the bundle channel, wall-to-wall excluding the dummy tubes, is 7.5 inches

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Bed-to-OD heat transfer coefficient: 477 W/m^2-K

Bed-to-CO_2 overall heat transfer coefficient (OD-based): 261(W/m^2-K)