Development of a Light-Trapping, Planar-Cavity Receiver for Enclosed Solar Particle Heating

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Outlines

- Principle of light trapping planar-cavity receiver (LTPCR) modeling the receiver flux distribution.
- Comparison of LTPCR vs. other receiver configurations.
- LTPCR receiver development:
  - Validation light trapping
  - Thermal performance modeling
  - Particle heat transfer
  - Prototype testing
  - 50 MWt commercial Design
- Summary

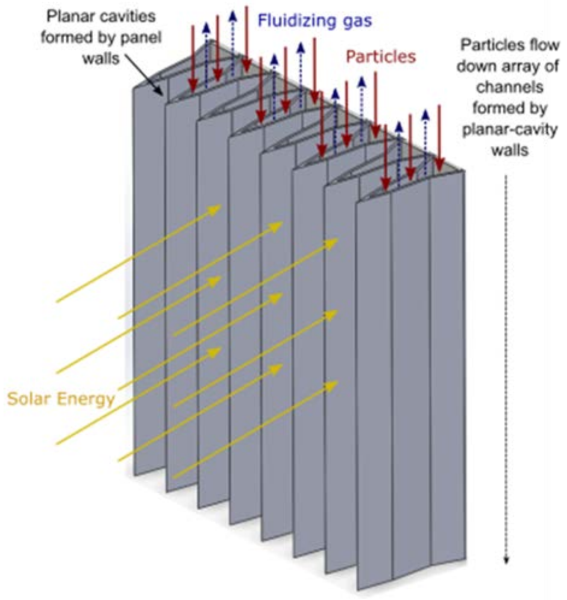
390-MWe Ivanpah Solar Electric Generating Plants

110-MWe Crescent Dunes Solar Plant with 10-hour Thermal Energy Storage

LTPCR Technical Objectives and Targets

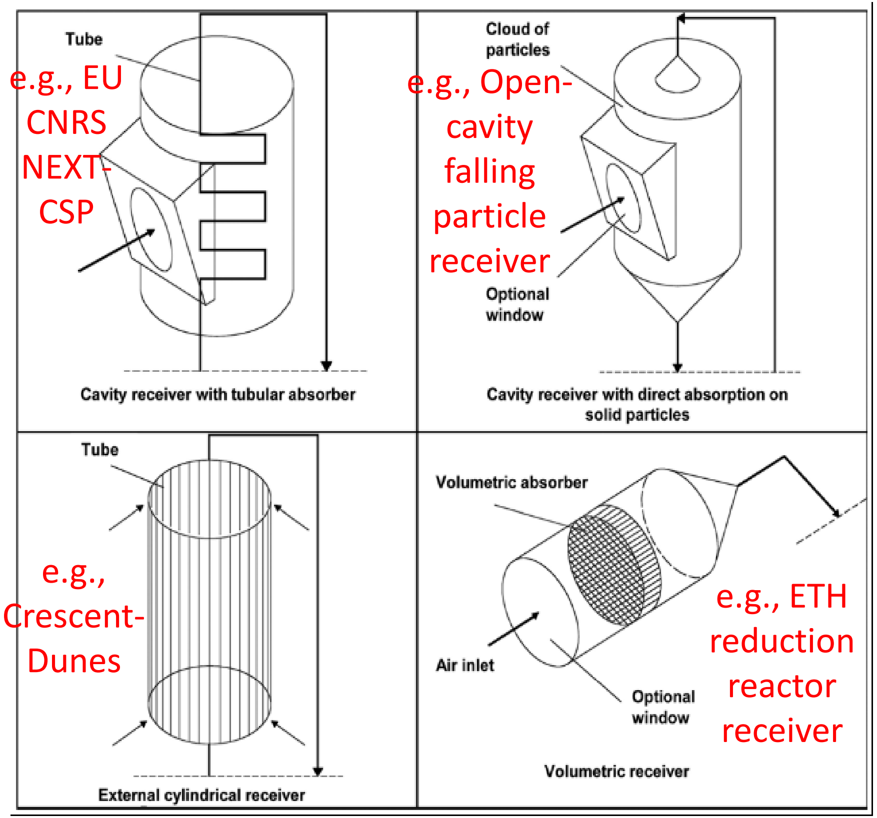
Light Trapping Receiver:

1. Use planar-cavity to capture and spread incident flux on receiver panel for high-temperature high-performance enclosed particle or gas media.
2. Enable solar thermochemical processes for fuel/chemicals and inexpensive non-black particles for low-cost thermal energy storage.
3. Demonstrate the LTPCR design through modeling, laboratory and on-sun testing.



10 years, multiple attempts to evolve the concept, Patent #10,422,552 B2 (2019).

Motivation: Inadequate Conventional Receiver Designs



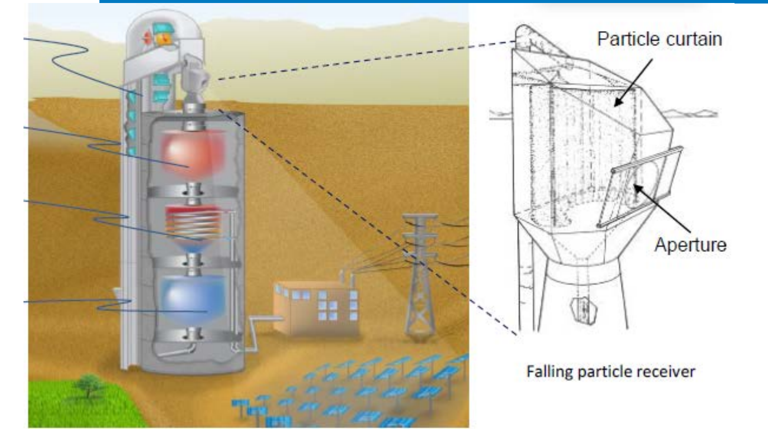
Four general receiver design configurations

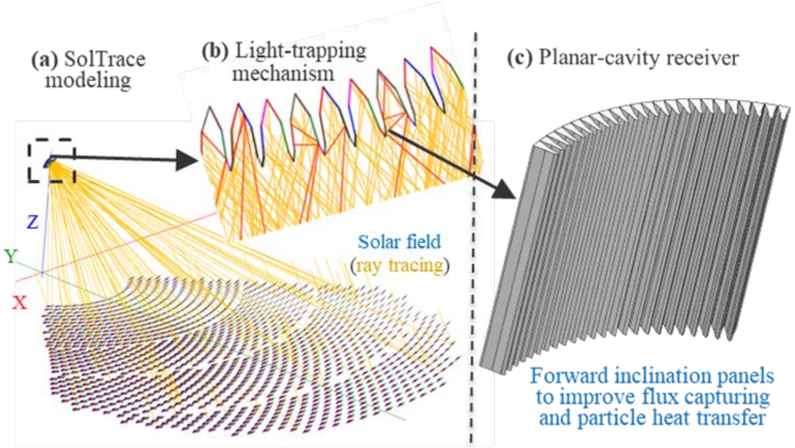
Needs of Receiver Designs:

1. High-temperature, high performance operation to support Generation 3 CSP and solar thermochemical processes.
2. Modular, scalability for various CSP-CST applications and scale of economics.
3. Effective interaction with solar heliostat field for high solar concentration and minimum thermal-optical losses.
4. Low maintenance and 30-year service life.

Current receiver configurations unable to address the needs of next generation CST-CSP.

Advantages of Unique, Innovative LTPCR Design





	Open-cavity falling particle receiver	Enclosed particle receiver
Pro	1. Direct illumination of black particles 2. No intermediate heating surfaces	1. Support non-black low-cost particles and chemical processes. 2. No particle losses to environment.
Con	1. Uses expensive black particles. 2. Particle losses to the environment. 3. Unable to support conditions for chemical processes.	1. Low particle heat transfer limits solar flux concentrations. 2. Indirect particle heating needs receiver enclosures.

LTPCR is scalable, reliable, and cost effective for next generation solar receiver.

LTPCR Innovations: Trap and spread solar flux, shield surfaces from ambient loss, relieve stress

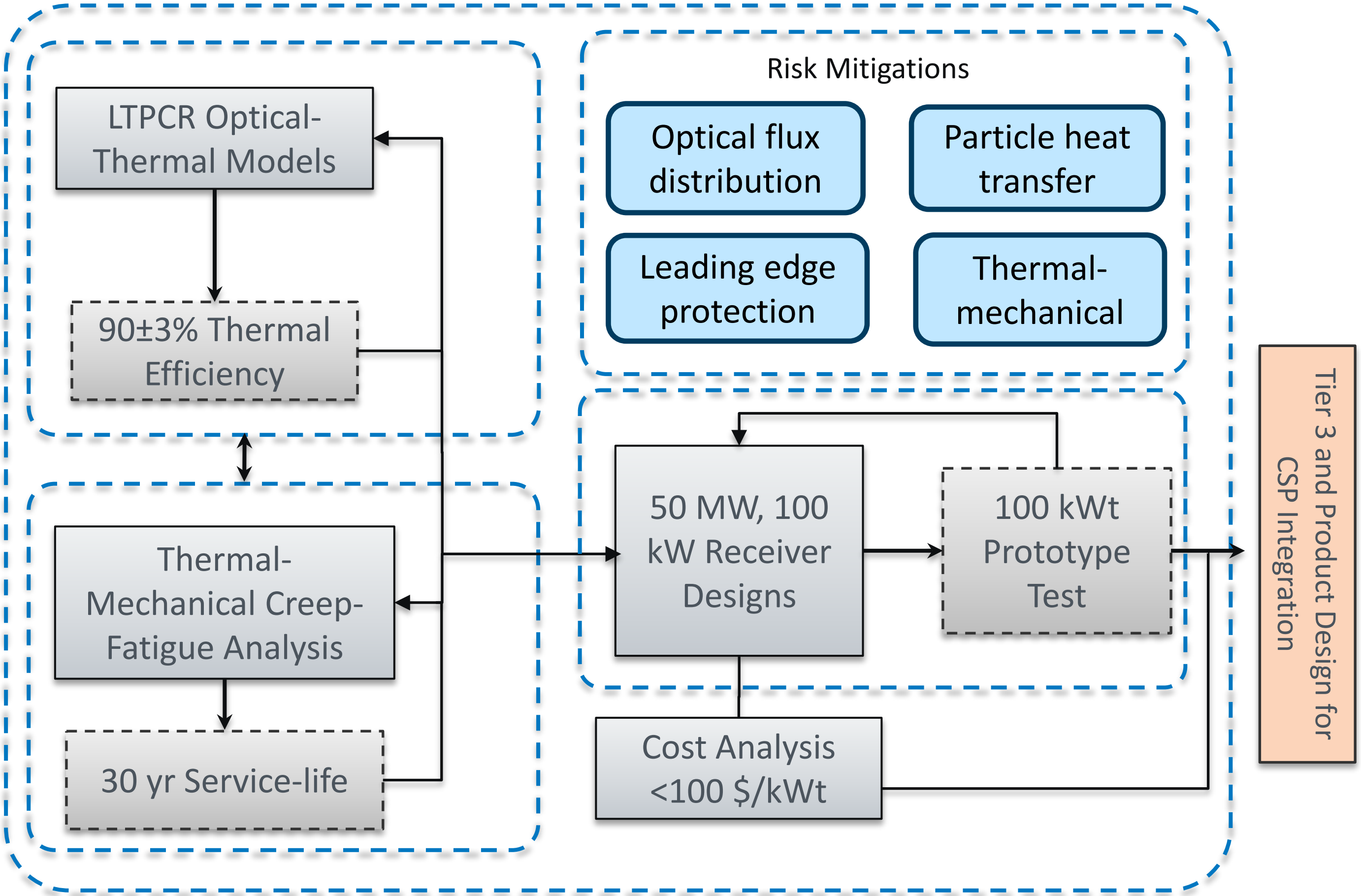
Objectives of the LTPCR Solar Receiver Design

LTPCR enclosed particle receiver avoids:

1. Particle loss and potentially negative environmental impacts:
   - Particle loss and wind effects are expected to limit open-cavity size.
   - Open cavity is unable to accommodate controlled ambient conditions for chemical processes.
2. Moving parts of a rotating centrifugal receiver:
   - Complicate operational conditions and control.
   - Reliability and scalability issues are expected for large receivers.
3. Cavity windows limiting performance and scaleup:
   - Window fouling and optical loss, thermal loss from window cooling
   - Window size restriction on flux spillage and capacity scaleup.
   - Reliability concerns with stress and thermal shock.

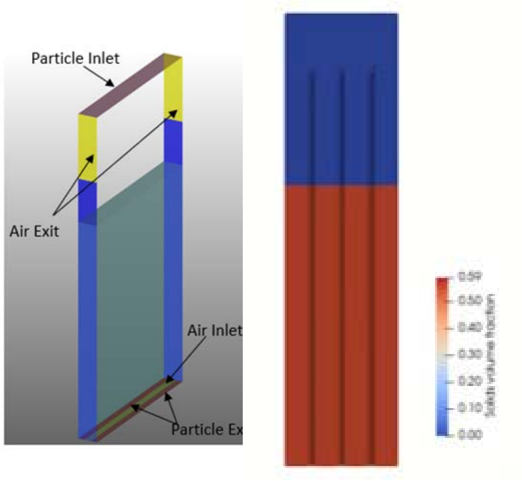
- ➢ **Solar receiver designs subject to environment, cost, capacity, performance constraints to be comprehensively considered.**
- ➢ **The LTPCR receiver design has potentials to support next generation CST-CSP.**

Modeling, Testing, Product and Prototype Development



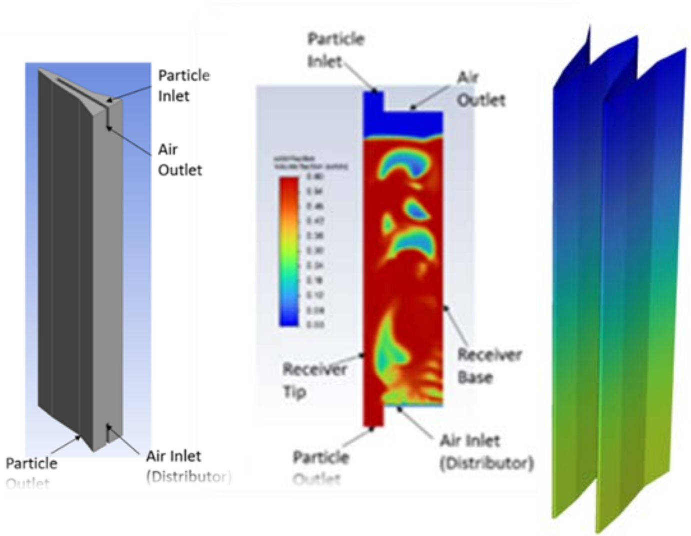
Comprehensive Modeling of LTPCR Performance

MFIX Modeling



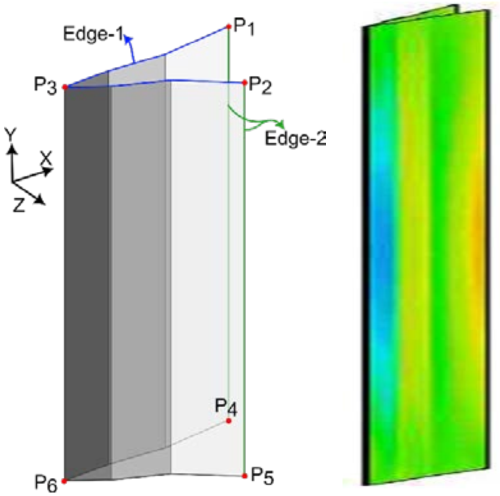
MFIX modeling of particle heat transfer and ANSYS/Fluent for thermal performance

ANSYS/Fluent Modeling



Integrating optical-thermal modeling with particle heat transfer predicts receiver performance for design iteration and service life analysis.

Mechanical Creep-Fatigue



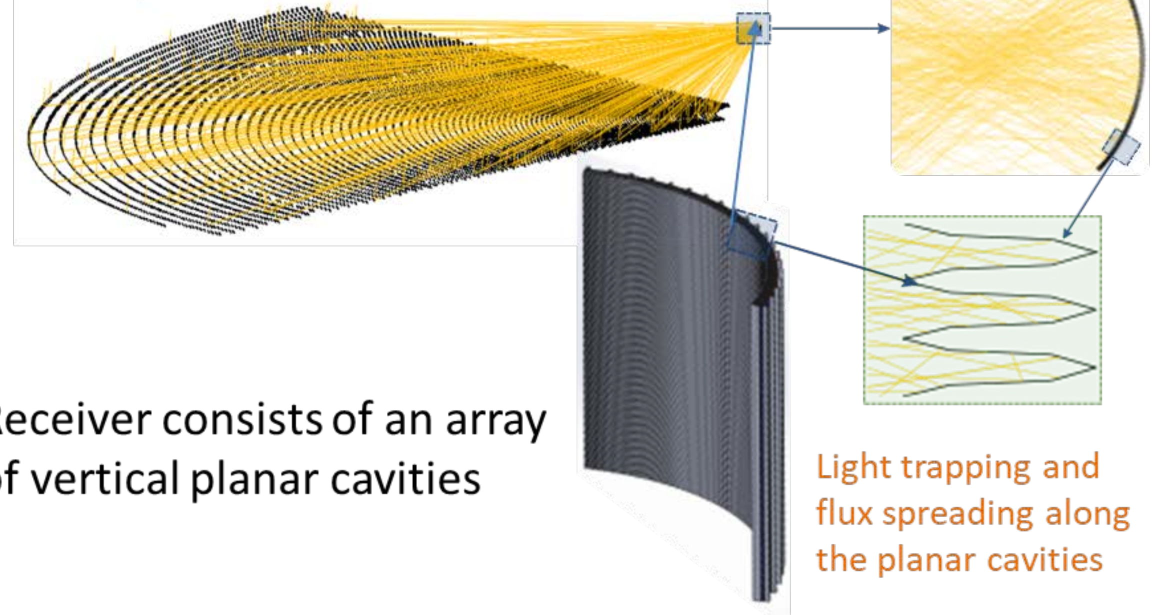
- Whole panel heating avoids thermal stress due to front heating on a circular tube receiver.
- Panel design allows implementing stress mitigation measures.

Modeling tools are used for all aspects of design and analysis.

Light Trapping Principle Modeled in SolTrace

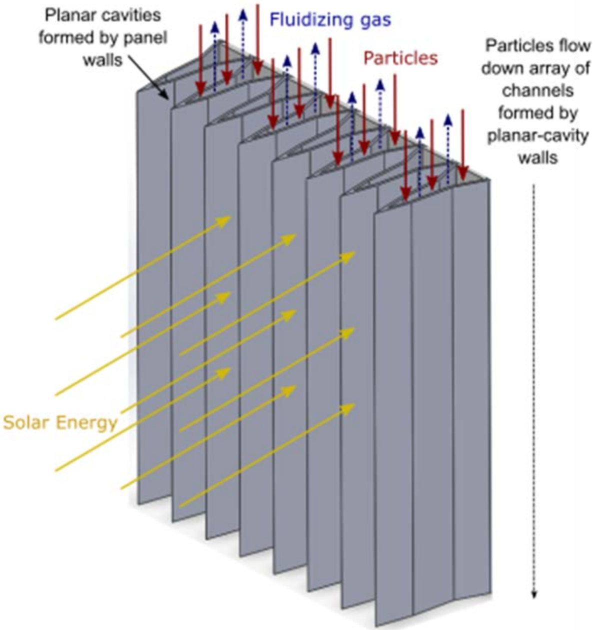
Heliostat aiming strategy to align with cavity normal vector

Flux beams aim at central axis of a cylindrical receiver envelope



Receiver consists of an array of vertical planar cavities

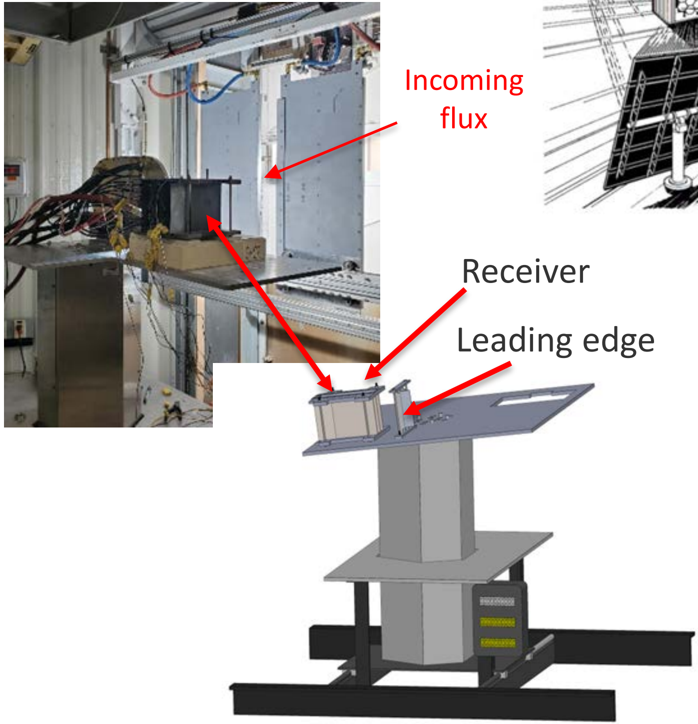
Light trapping and flux spreading along the planar cavities



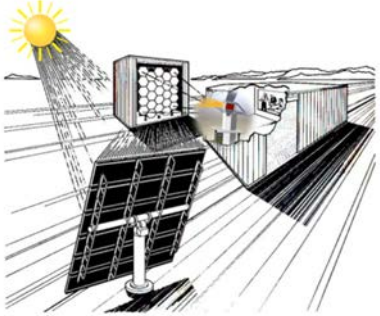
Receiver capable of high solar flux is key to its efficiency, cost, and life.

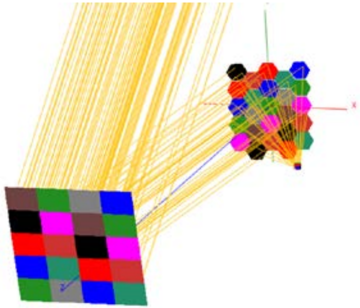
On-Sun Testing Verification of Light Trapping Effect

Prototype receiver panel flux-spreading test set up at the NREL High Flux Solar Furnace (HFSF)

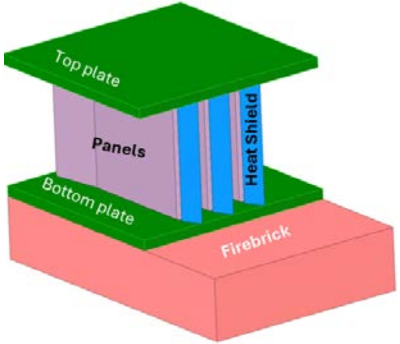


Ray tracing of the HFSF and receiver

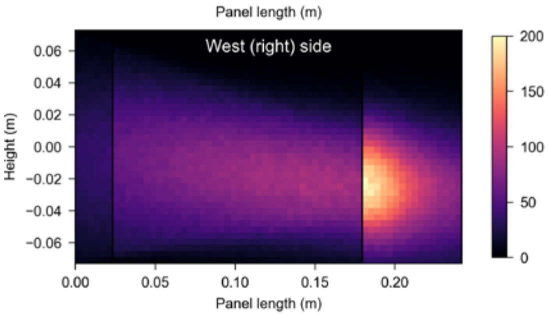




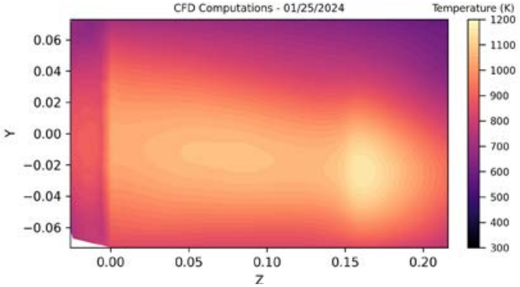
Heating model of receiver (natural convection, radiation, wall conduction)



Modeled panel flux distributions



Predicted temperature profiles

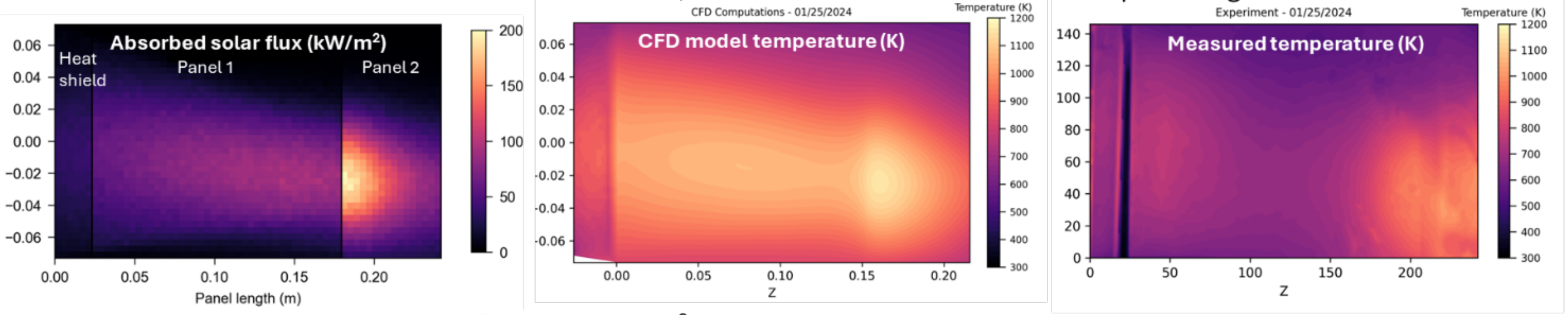


Consistent flux and temperature profiles

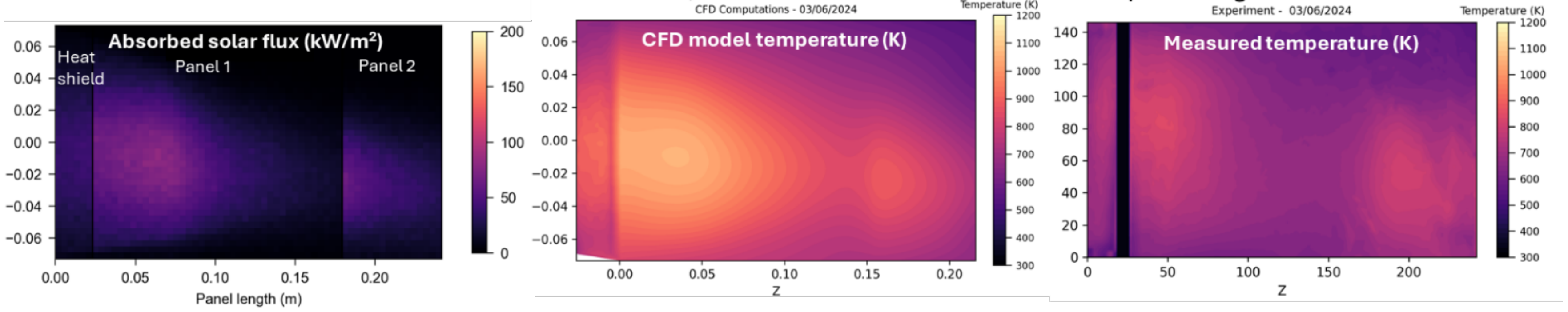
LTPCR HFSF model comparison

Flux, temperature distributions at west-side receiver surface, 100% open shutter/attenuator

1/25/2024: DNI = 956 W/m², insulation board 50mm from front panel edge



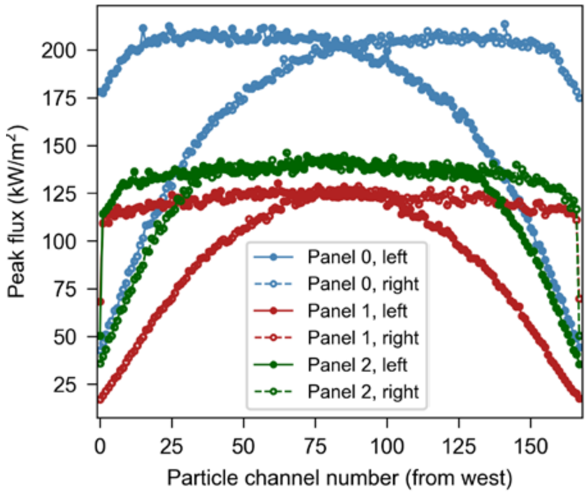
3/6/2024: DNI = 1007 W/m², insulation board 19mm from front panel edge



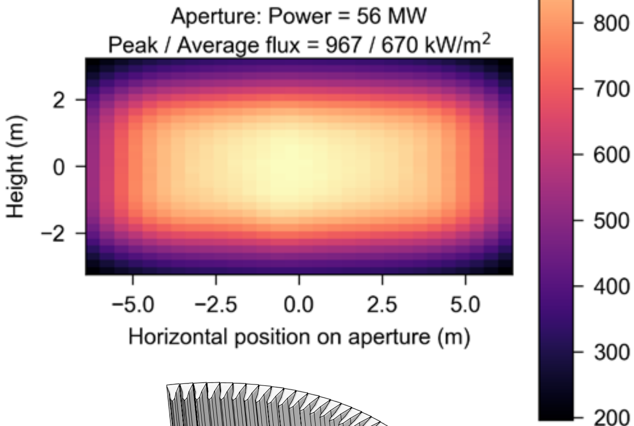
Models capture general trends and location of hot spots, but overestimate temperatures

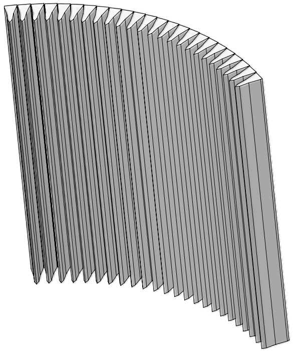
LTPCR SolTrace Modeling Results

Flux simulation by SolTrace

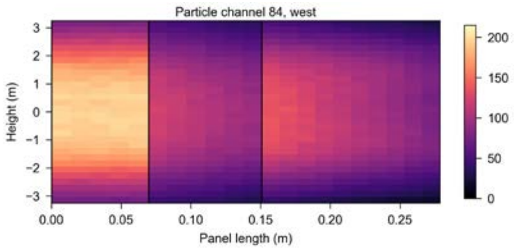


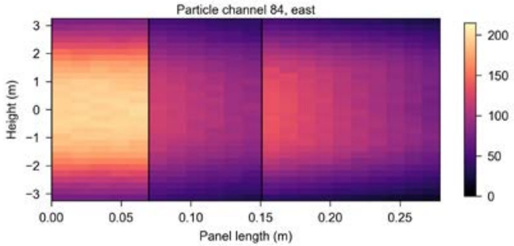
Flux on receiver aperture

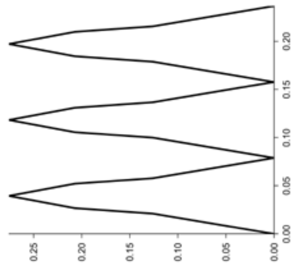




Flux on panel wall







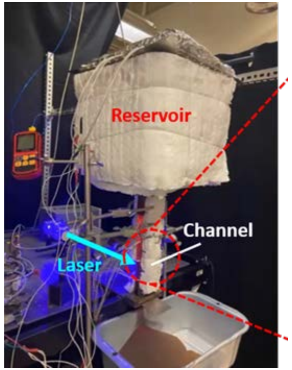
Particle thermal energy storage has potentials in many applications.

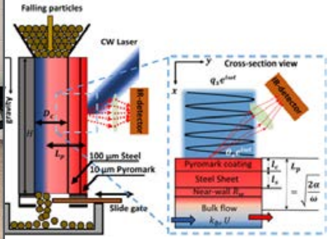
Substantial Particle Flow and Heat Transfer Test

Particle Flow/Heat Transfer Test

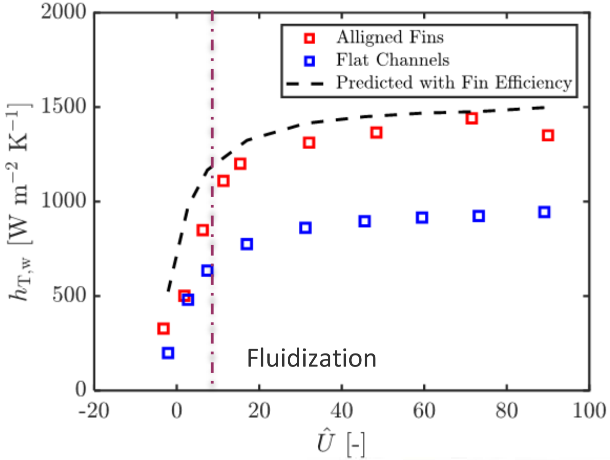
CSM fluidization heat transfer test

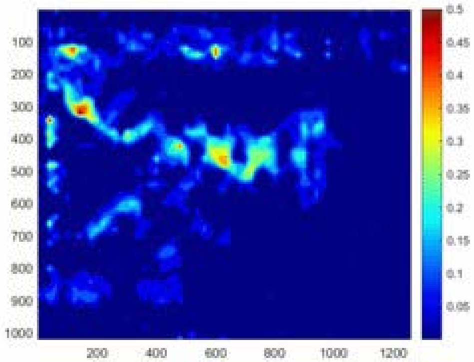
UCSD heat transfer test

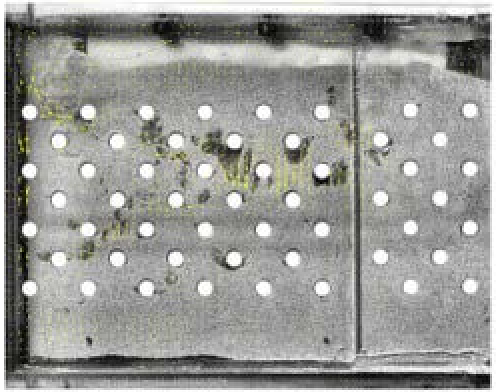




UTK test of flow visualization



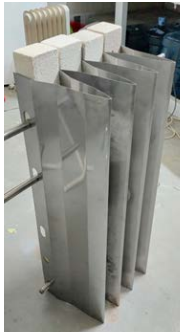


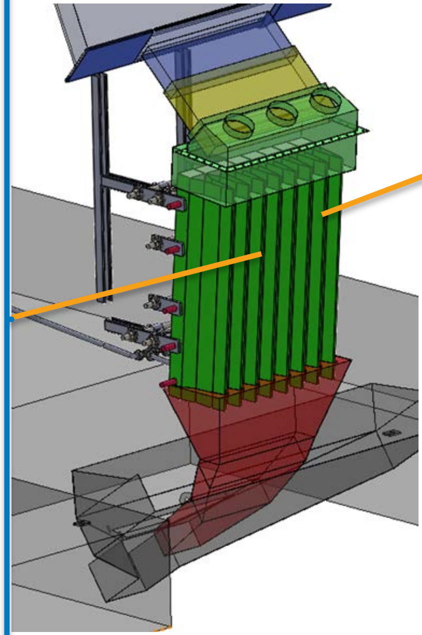


High particle/wall heat transfer coefficients were achieved.

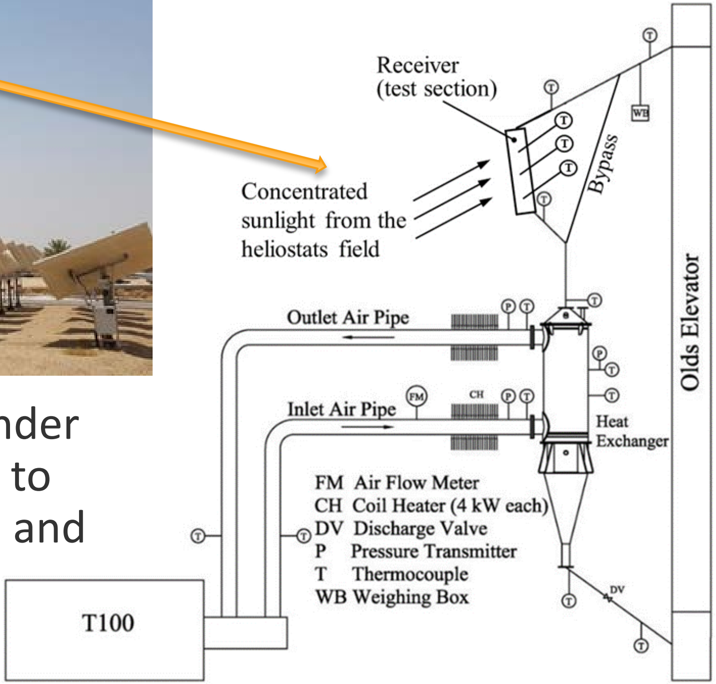
LTPCR Prototype Test Progress

LTPCR prototype is prepared at Kind Saud University (KSU) particle-CSP facility





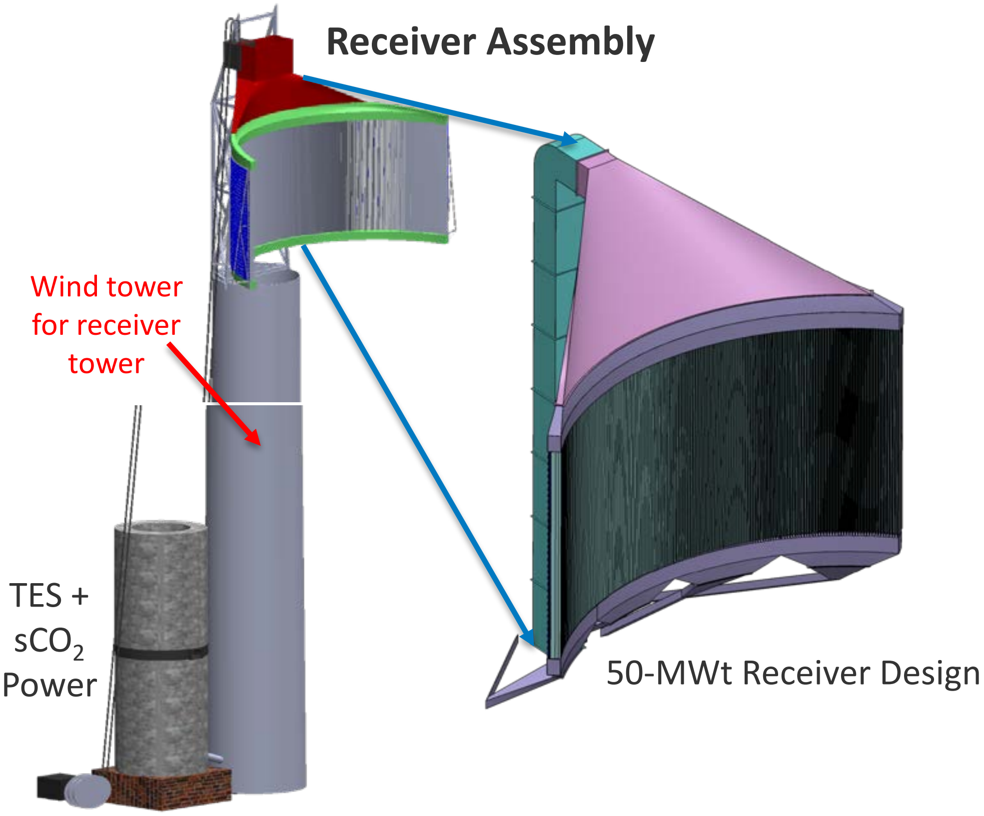
The prototype receiver is under installation at KSU field and to be tested to validate design and modeling methods.



Fabricated a 100kWt LTPCR prototype to be installed and tested at KSU in 2024.

Configuration of a 50-MW Receiver in Gen3CSP

- Tested prototype receiver will support commercial receiver design verification.
- Cost analysis of the receiver assembly including periphery components and a wind tower shows that bare-erect cost <$100/kWt.
- 110-m prefabricated wind tower costs a fraction of field erected concrete or steel tower.
- Wind tower also support skip hoister and skips travel inside the tower



LTPCR receiver and Gen3CSP integration will inform CSP industry.

LTPCR Development Summary

Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

- Optical and thermal performance shows promising pathways to 90% receiver efficiency for 750°C particle exit temperature.
- Prove realizable mechanical reliability and 30-year service life.
- 100-kWt prototype development on path to test and meet the project goal.
- Commercial receiver cost <100 $/kWt (50MWt receiver).
- Particle/panel wall heat transfer >1000 W/m^2-K.
- Multiple leading-edge protection strategies were implemented.
- Cost and performance support 50 MWt commercial receiver and Gen3CSP integration.

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Thank you!

Questions?

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NREL/PR-5700-90501

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This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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