NREL
Transforming ENERGY

Light Trapping, Enclosed Planar-Cavity Receiver for Heating Particles to Enable Low-Cost Energy Storage and Chemical Processes (LTPCR)

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Project #: CPS38896

Budget: $3M DOE + $0.75M cost share

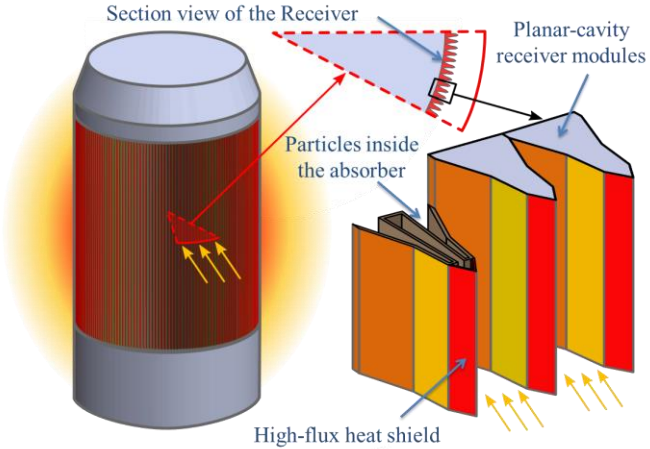
Performance Period: 01/2022–03/2025

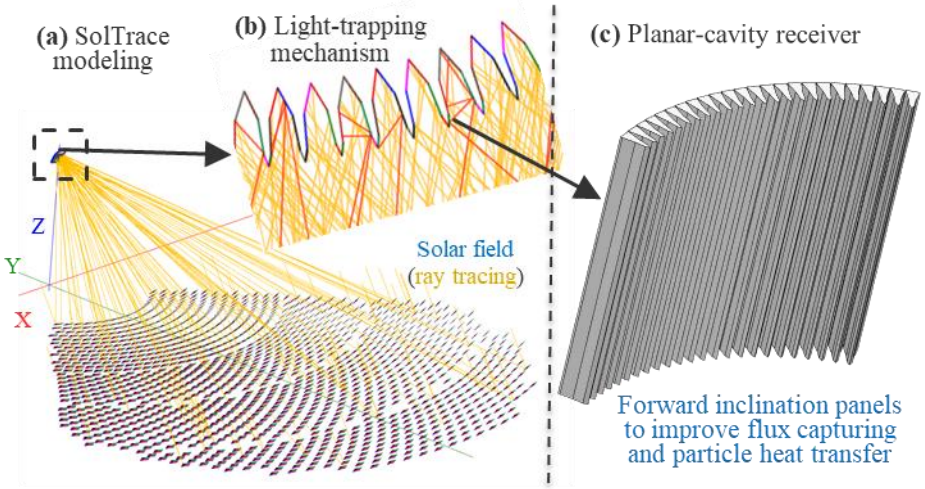
LTPCR Technical Objectives and Targets

Light Trapping Features:

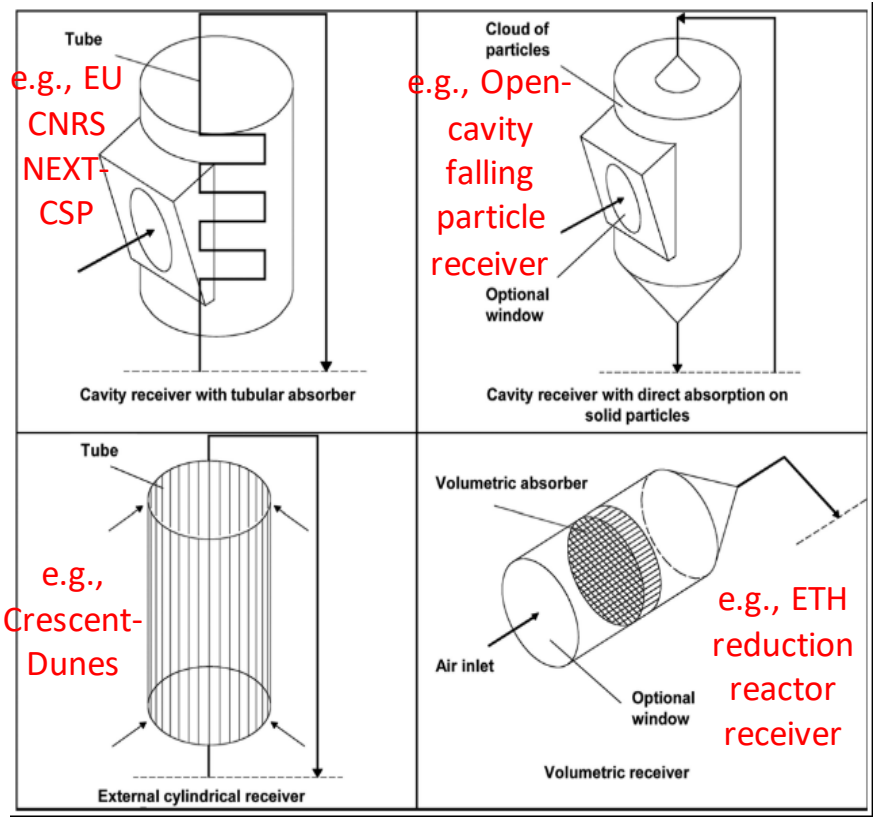
1. Use planar-cavity to capture and spread incident flux on receiver panel for high-temperature high-performance enclosed particle or gas media.
2. Enable solar thermochemical processes for fuel/chemicals and inexpensive non-black particles for low-cost thermal energy storage.
3. Demonstrate the LTPCR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

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





Advantages of Unique, Innovative LTPCR Design



Four conventional receiver configurations

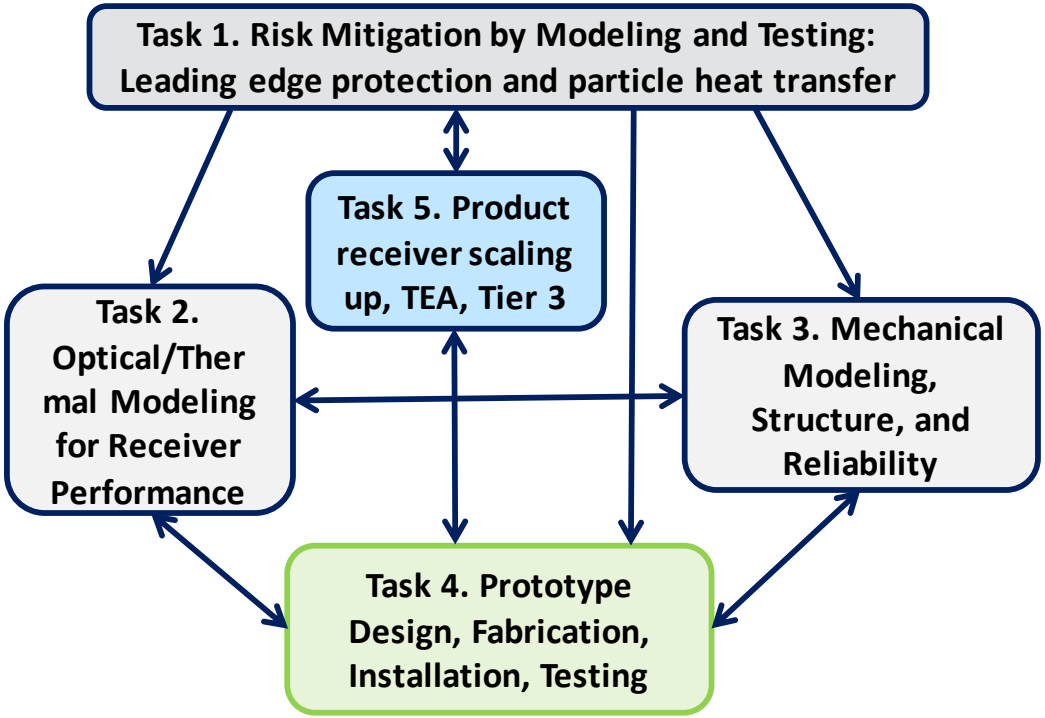
	Open-cavity falling particle receiver	Enclosed particle receiver
Pro	1. Direct illumination of black particles 2. Without intermediate heating surfaces	1. Support non-black low-cost particles and chemical processes. 2. No particle losses to environment.
Con	1. Uses expensive black particles at high cost. 2. Particle losses to the environment. 3. Unable to maintain atmospheric 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 surface from ambient loss, relieve stress.

LTPCR Development in NREL SETO Project

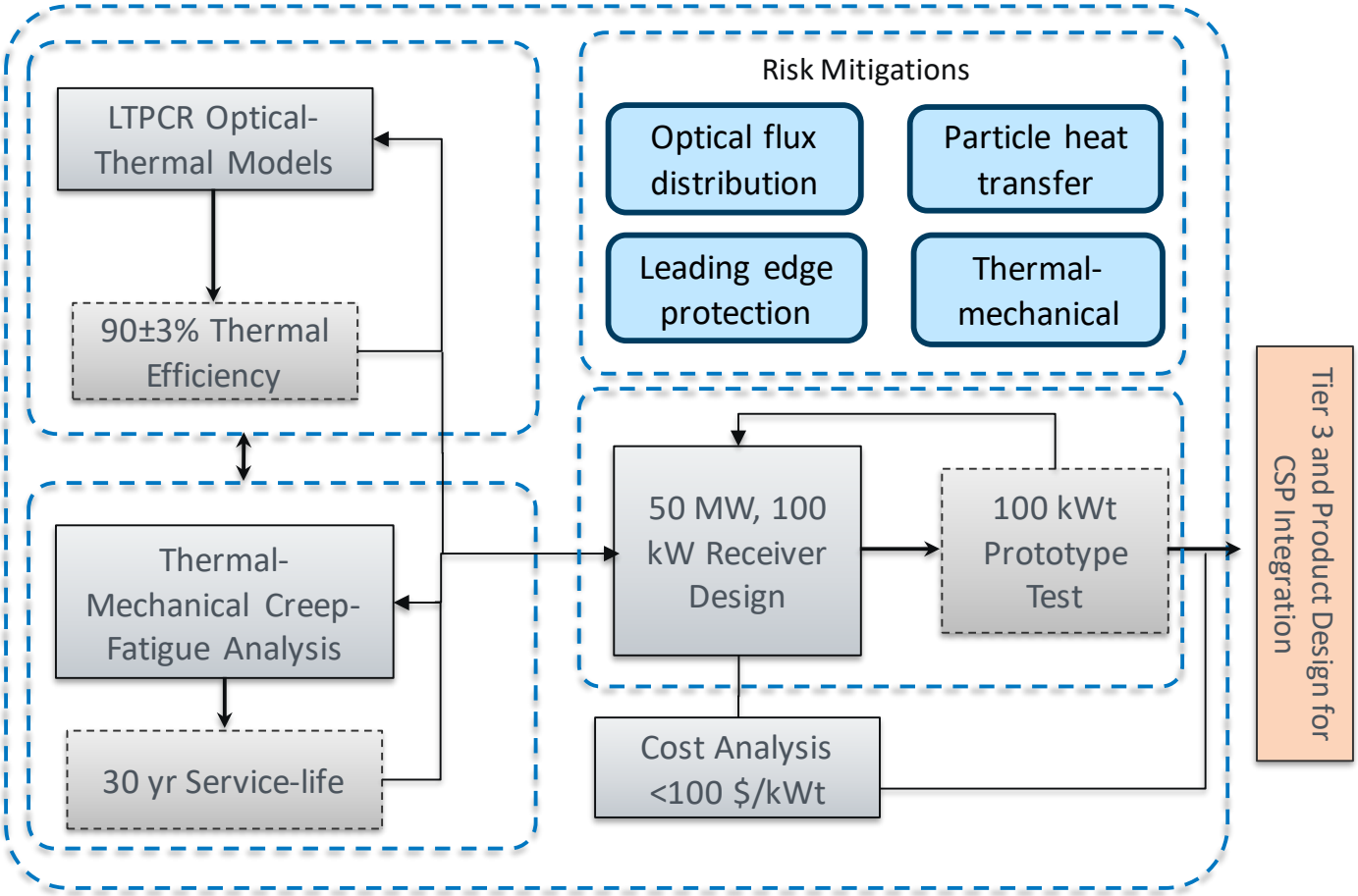
Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy



Project Objectives/Status:

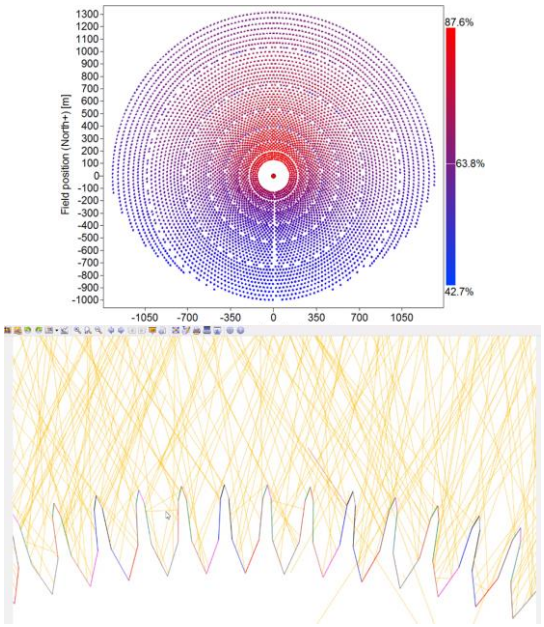
- Optical and thermal performance promising to 90% efficiency
- Mechanical reliability and 30-year service life realizable
- 100-kWt prototype development on path to test and project goals
- Cost of 50-MW <100 $/kWt
- Particle heat transfer >1000W/m^2-K
- Multiple leading-edge protections able to be implemented
- Scaling up to MW pilot and CSP integration in BP3.

Modeling, Testing, and Prototype Development



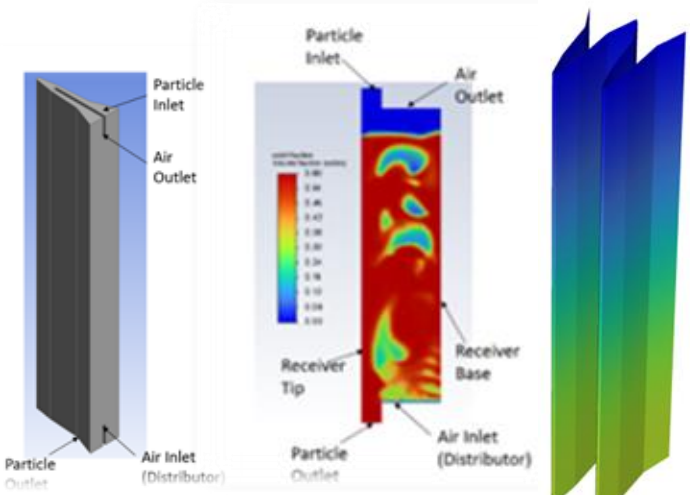
Comprehensive Models Predicting LTPCR Performance

Optical Modeling



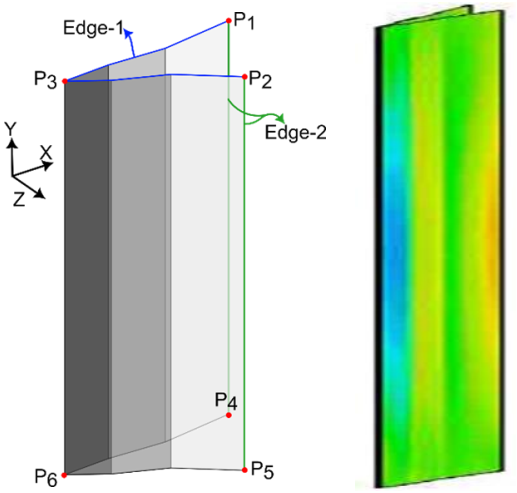
NREL SolarPILOT, SolTrace model to optimize flux distribution

Thermal Modeling



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

Mechanical Creep-Fatigue



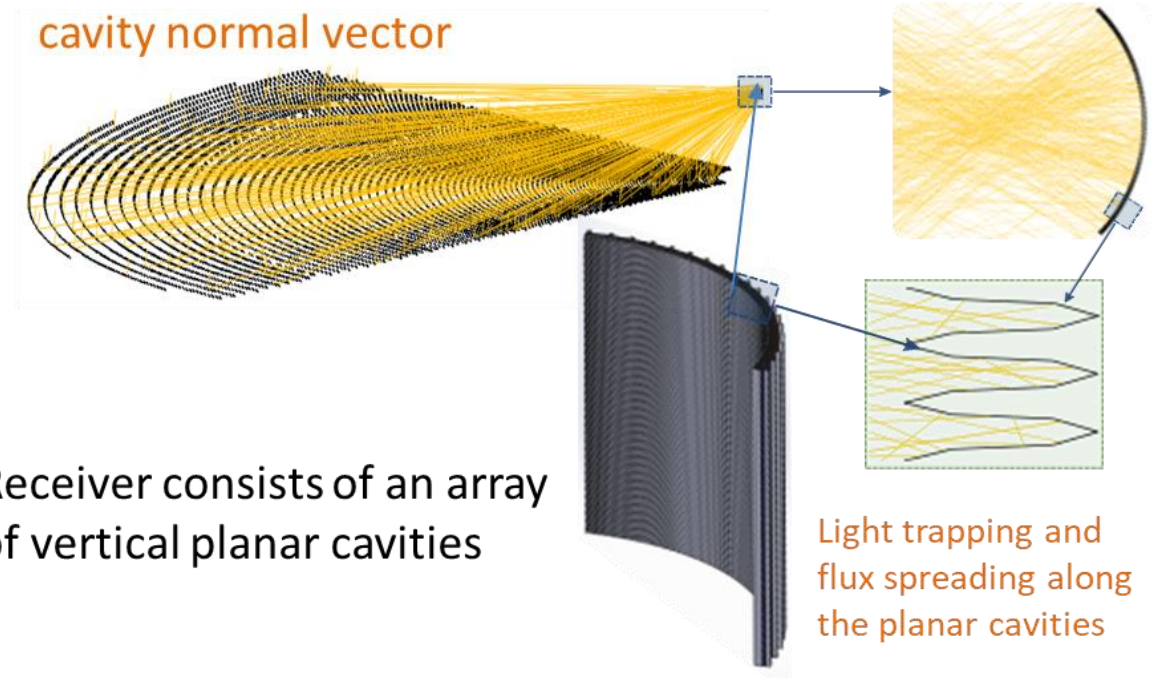
One side heating avoid thermal stress due to front heating on a circular tube receiver. It also allows implementing stress mitigation measures.

Strong modeling capabilities to predict performance for product designs.

Light Trapping Principle Modeled in SolTrace

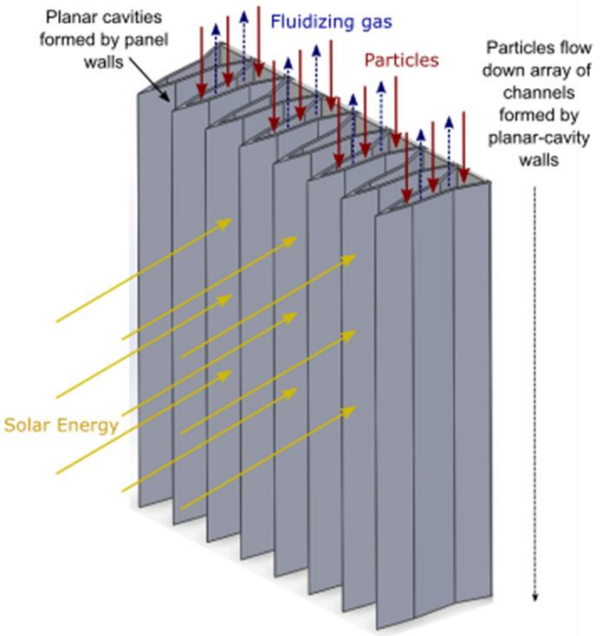
Heliostat aiming strategy to align with cavity normal vector

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

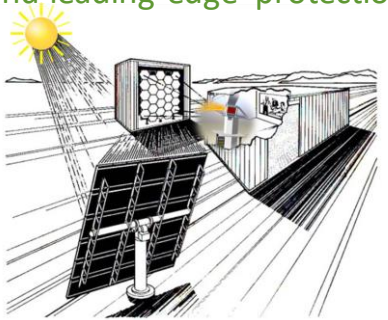


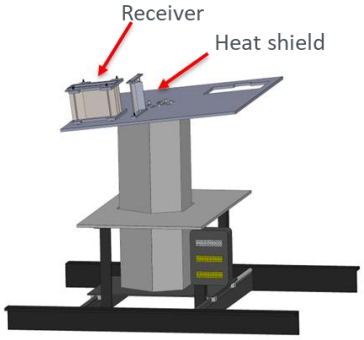
Receiver capable of high solar flux is key to its efficiency, cost, and life.

Testing Capabilities Applicable to LTPCR Development

Solar Furnace

NREL test of light trapping and leading-edge protection

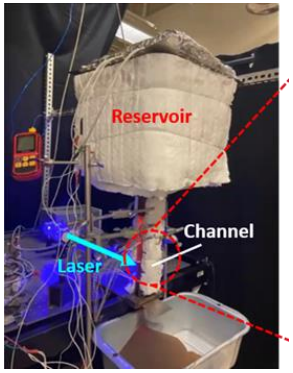


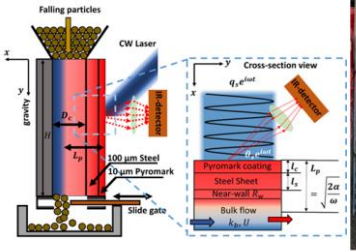


Particle Flow/Heat Transfer Test

CSM fluidization heat transfer test

UCSD heat transfer test

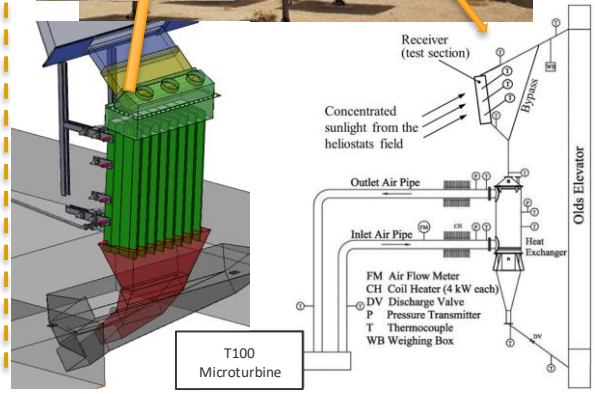




UTK test of flow visualization

100-kWt Prototype

Plug a 100kW prototype in KSU 300kW particle-CSP test facility



Verification tests and prototype test to prove key design needs.

Considerations Over Other Receiver Designs

1. Enclosed particle heating prevents particle loss and potentially negative environmental impacts.
   - Particle loss affected by wind limits cavity size.
   - Unable to accommodate chemical processes.
2. Moving parts of a rotating centrifugal receiver:
   - Complicates operation conditions to control.
   - Reliability and scalability issues for running large receivers.
3. Avoid cavity windows limiting performance and scaleup:
   - Window fouling and optical loss need to be resolved.
   - 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 constrains to be comprehensively considered.

Thank you!

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Alumina Energy: S. Braun

Summary

Receiver Technoeconomic Targets:

- Thermal efficiency: 90% at 750°C particle exit temperature
- Cost estimation: <$100/kWht
- Thermal-mechanical design modeling for 30-year life
- Looking for Tier 3 partners if prototype testing in the project BP3 is successful.

Major technical risks/challenges have been resolved:

1. Flux distribution and spreading for optimum optical, thermal, and mechanical performance
2. Particle heat transfer enhancement and leading-edge protection for high flux operation
3. Thermal-mechanical design and modeling to meet service life.

Innovation and Impact of LTPCR Development

1. Receiver Operating Principles and Solar Flux:
   - Systematic flux optimization will smooth thermal and stress distributions.
   - Leading-edge protection will be focused study to implement high flux operation.
   - Receiver cost will be investigated with design and fabrication.
2. Particle-Side Heat Transfer and Receiver Performance:
   - MFIX is capable of modeling "thermophoretic diffusion", but it is likely not the case.
   - Fin design will be optimized to enhance particle heat transfer.
   - Comprehensive measures will be studied to achieve >90% thermal efficiency.

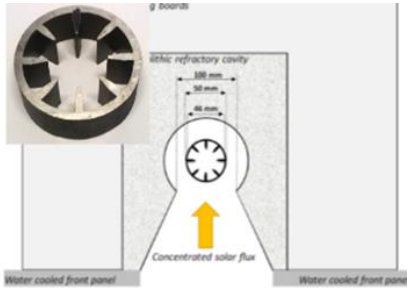
Major technical risks/challenges to be resolved:

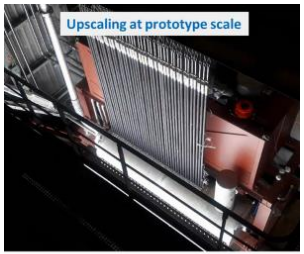
1. Flux distribution and spreading for optimum optical, thermal, and mechanical performance
2. Particle heat transfer enhancement and leading-edge protection for high flux operation
3. Thermal-mechanical design and modeling to meet service life.

The project outcomes can prove LTPCR technology for industry adoption.

Advancements over EU Next-CSP Tube Receiver

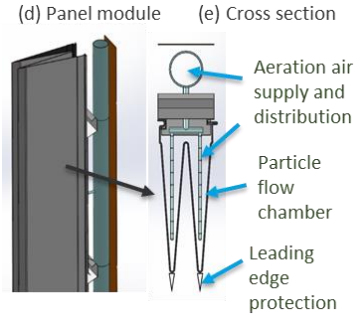
EU Next-CSP Fluidized Bed (FB) Receiver as a baseline





2.5 MW_{th} 3m-long solar receiver (40 tubes)

NREL LTPCR Approach

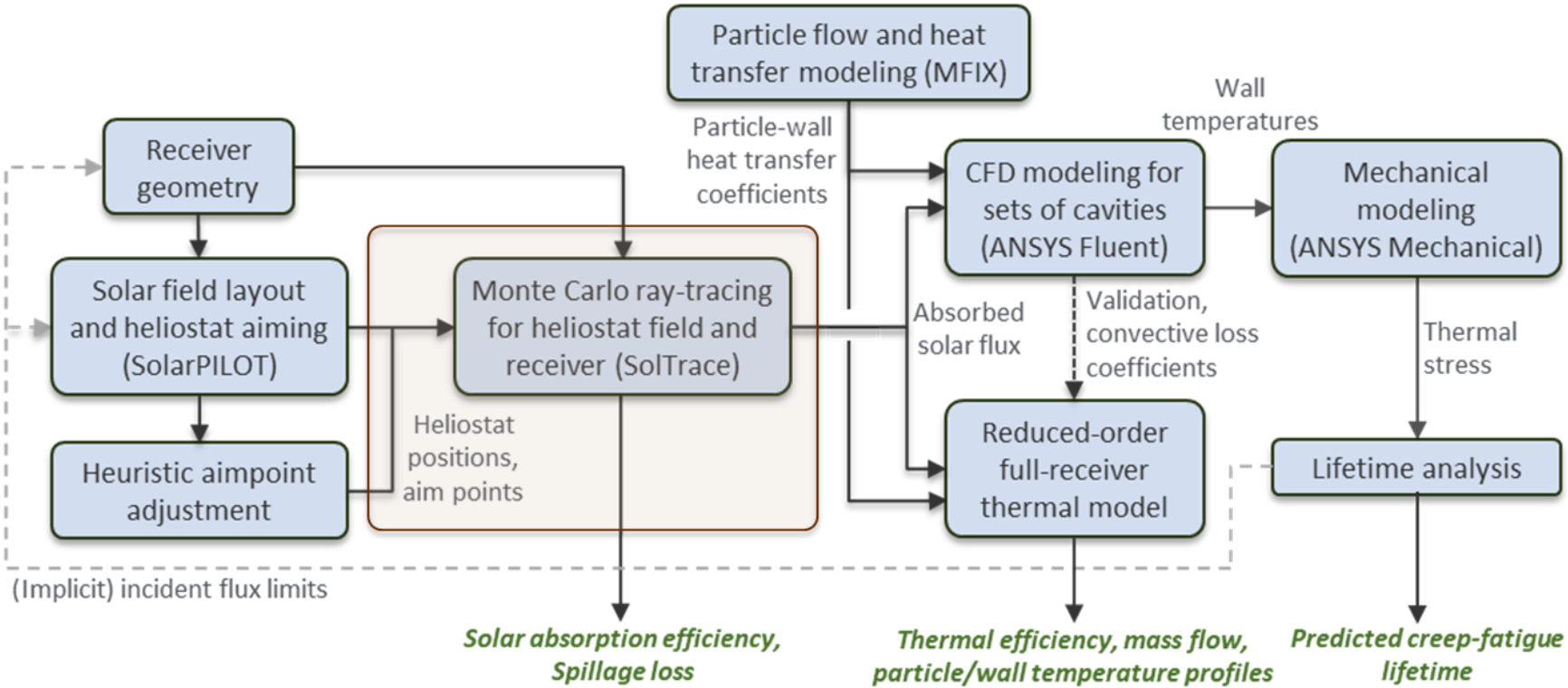


1. High solar flux through flux spreading.
2. Staged mild fluidization.
3. Panel shape optimization to lower stress and allow free thermal expansion.

CNRS FB Receiver Design	CNRS Design Issues	LTPCR Mitigation Strategies
Fluidization in 3–8 m tube	High ΔP, slug flow	Multistage dense-phase mild fluidization
Tubes with straight fins	Not effective fin use	Fins on tip and panel for high heat transfer
Circular tube	High thermal stress	Panel with optimum flux and stress relief.
Cavity enclosure	Flux and scale limit	Planar cavity open to scale up and flux access
Low flux (<500 kW/m^2)	Low receiver efficiency	Aiming strategy for flux spreading on panels

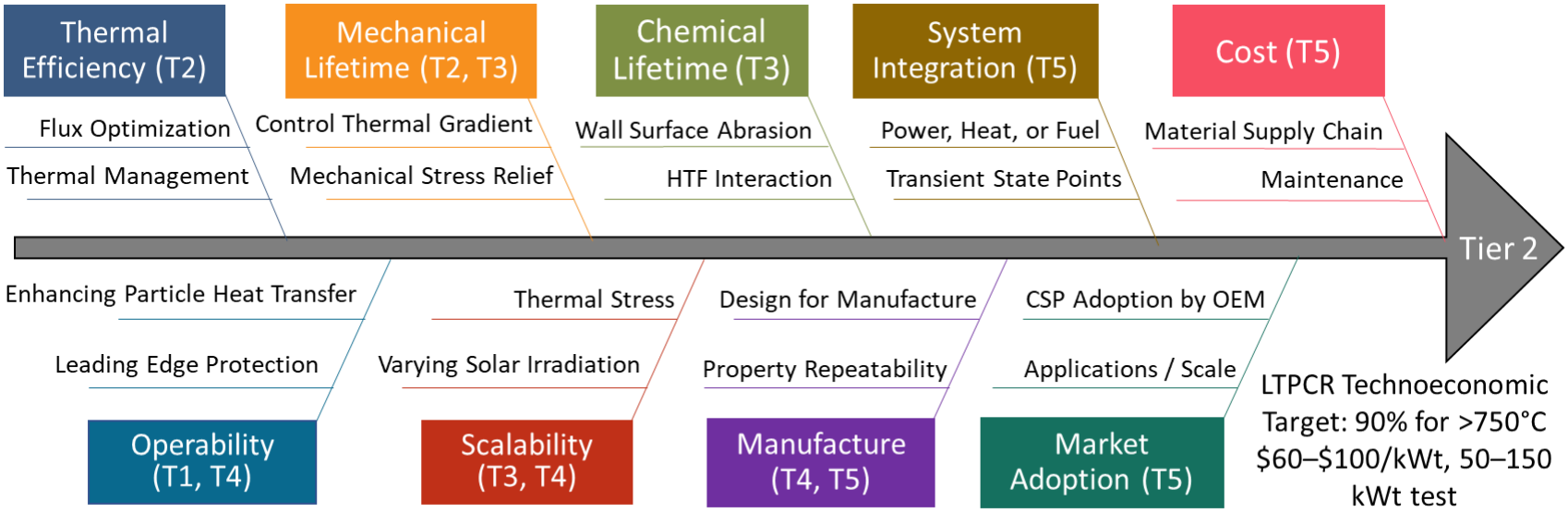
Receiver capable of high solar flux is key to its efficiency, cost, and life.

Advancements over EU Next-CSP Tube Receiver



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

Project Holistic Development Towards Pilot Scale



Major achievement and development outcomes:

1. Flux distribution and spreading for optimum optical, thermal, and mechanical performance
2. Particle heat transfer enhancement and leading-edge protection for high flux operation
3. Thermal-mechanical design and modeling to meet service life.