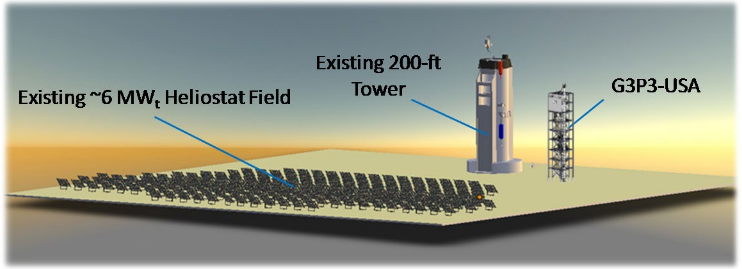
Gen3 Particle Pilot Plant (G3P3) Receiver Design and Testing



PRESENTED BY

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Others: Georgia Tech, King Saud U., DLR, ANU, CSIRO, U. Adelaide, CNRS-PROMES, CARBO Ceramics

SAND2020-11936 PE

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Overview

- Introduction and Objectives
- Receiver Design
- On-Sun Testing
- Lessons Learned

Background and Introduction

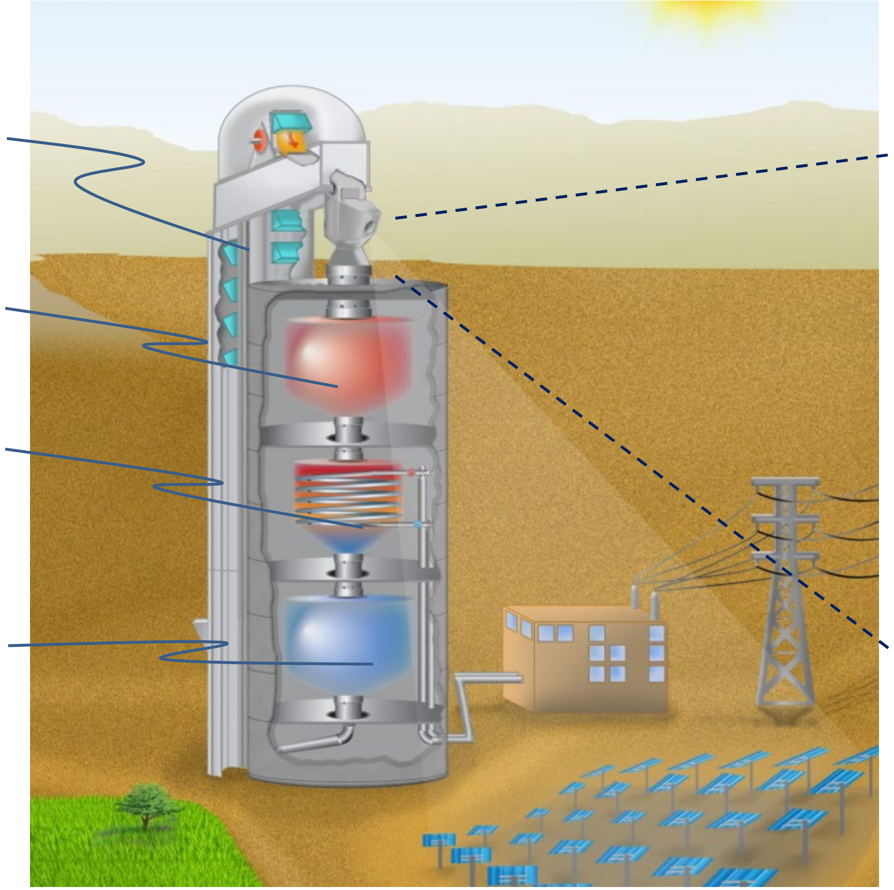
High-Temperature Particle-Based CSP

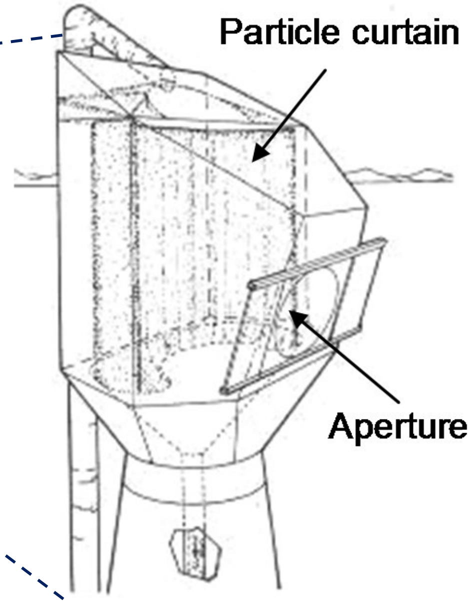
Particle elevator

Particle hot storage tank

Particle-to-working-fluid heat exchanger

Particle cold storage tank

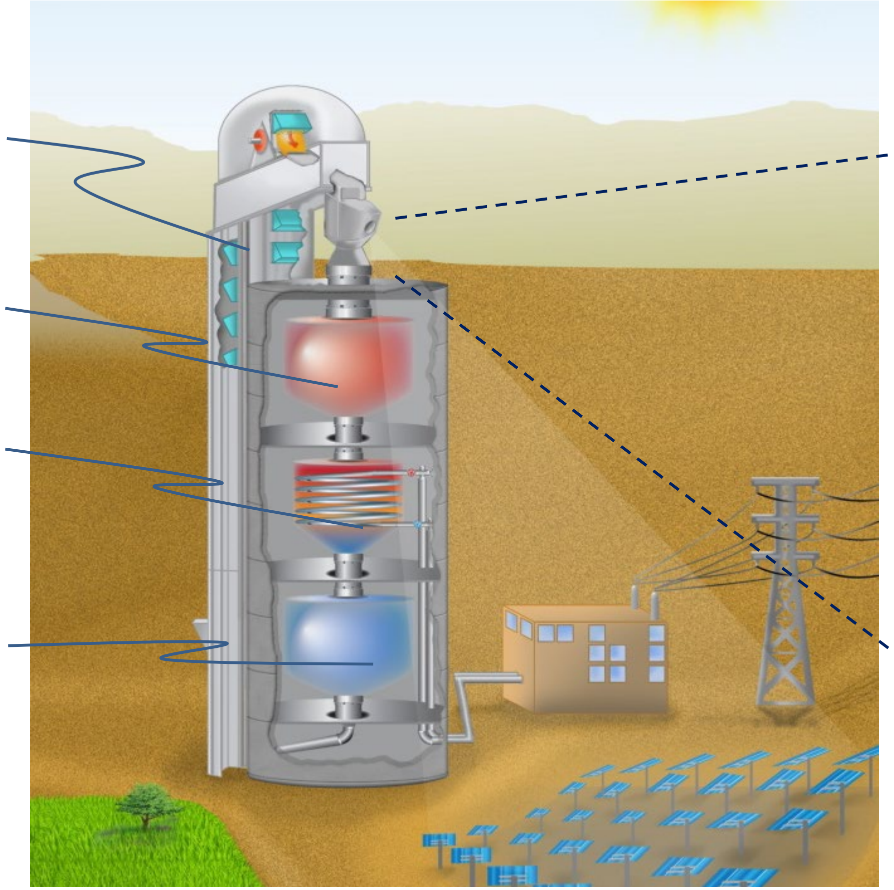


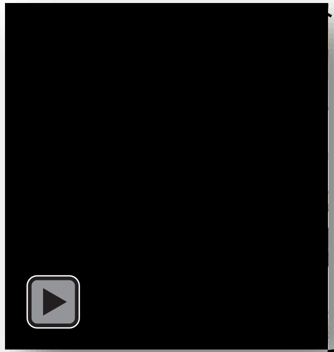


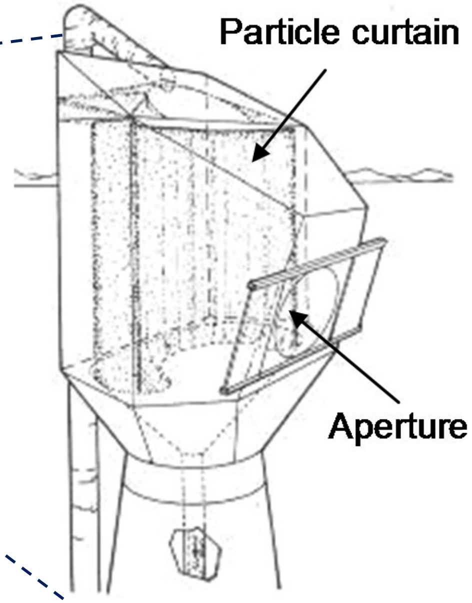
Falling particle receiver

Background and Introduction

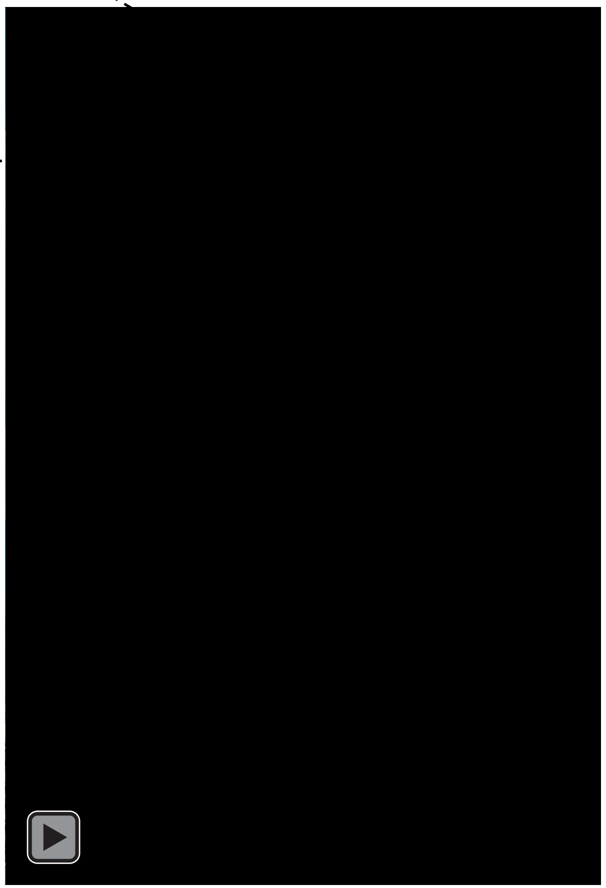
High-Temperature Particle-Based CSP







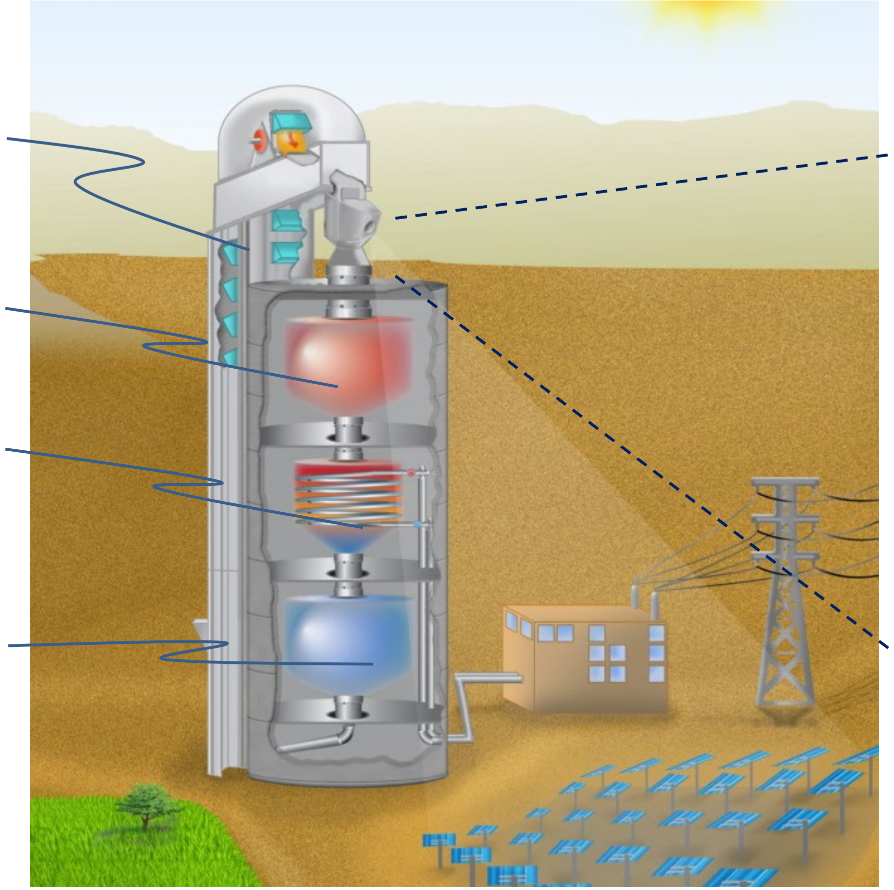
Falling particle receiver

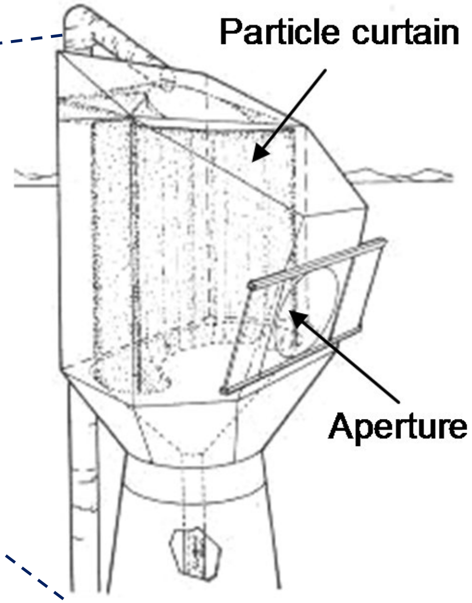


National Solar Thermal Test Facility
Sandia National Laboratories

Background and Introduction

High-Temperature Particle-Based CSP



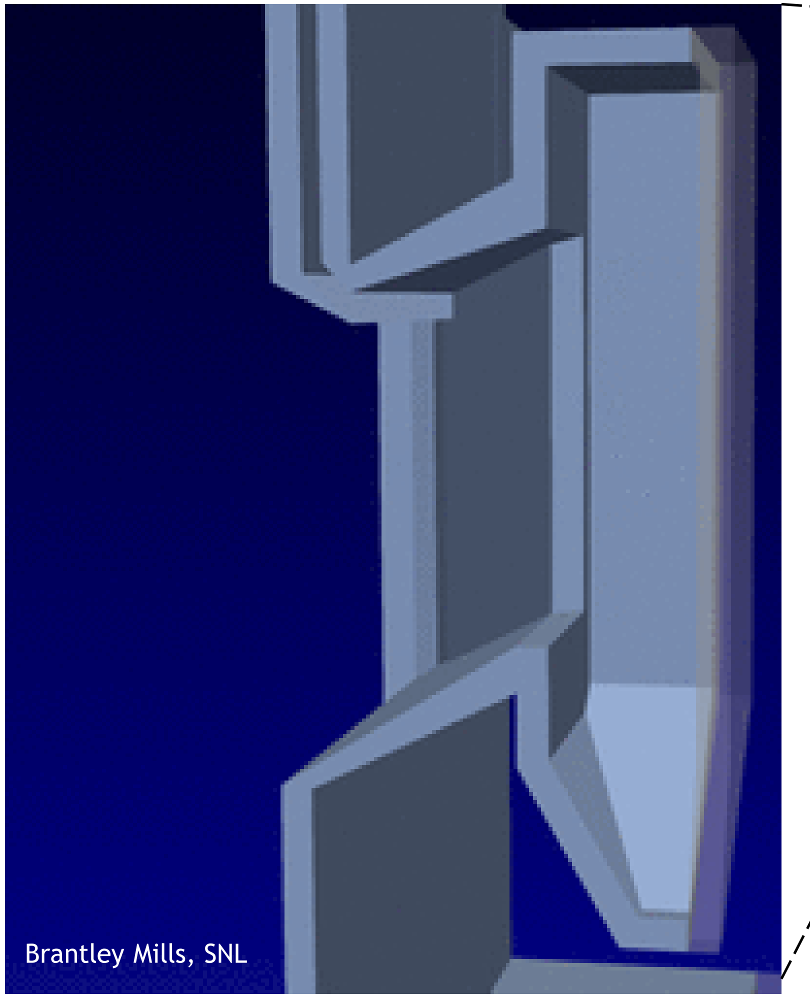


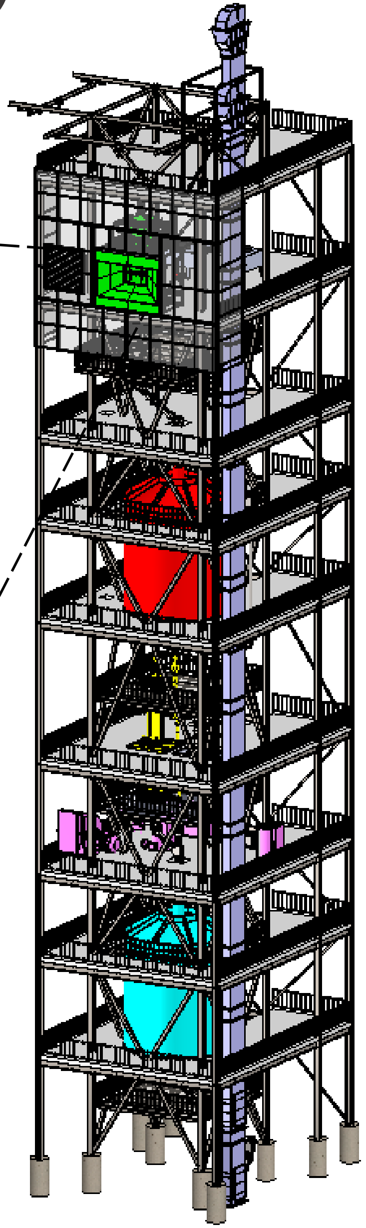
Falling particle receiver

- Higher temperatures (>1000 °C) than molten nitrate salts
- Direct heating of particles vs. indirect heating of tubes
- No freezing or decomposition
  - Avoids costly heat tracing
- Direct storage of hot particles

Gen3 Particle Pilot Plant (G3P3)

Next-Generation High-Temperature Falling Particle Receiver





K. Albrecht, SNL

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)

Objectives

- Present evolution of receiver design for G3P3
- Describe on-sun testing to evaluate performance of new design features and obtain operational experience
- Identify system interfaces, design challenges, and lessons learned

Overview

- Introduction and Objectives
- Receiver Design
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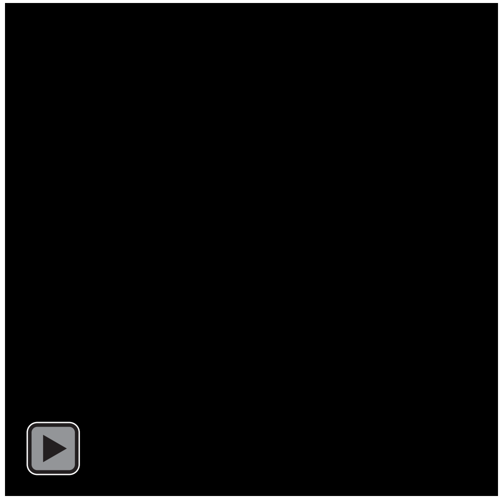
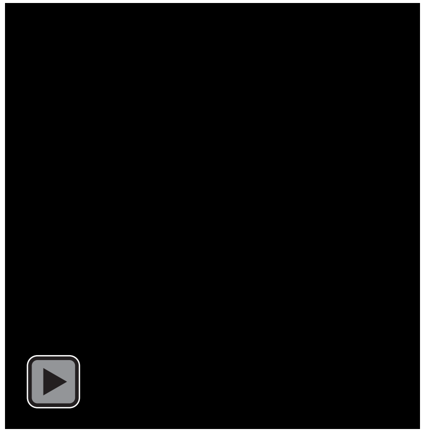
Alternative Particle Receiver Designs

Free-Falling (SNL)

Obstructed Flow
(Georgia Tech, King Saud U.)



Centrifugal (DLR)

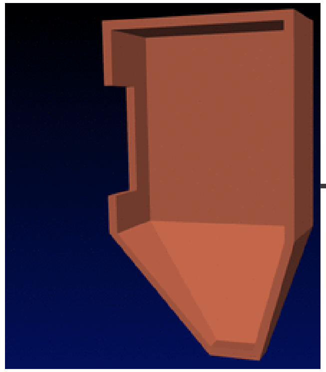


Fluidized Bed

G3P3-USA Receiver Design Evolution

2015 – 2018

NSTTF
1 MW_{th} FPR



Design Challenges
- Low thermal efficiency
- Sensitivity to wind

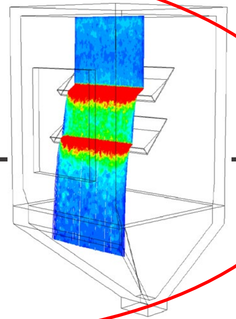
FPR = Falling particle receiver

Feature evaluation

- Hood/Tunnel
- Quartz Half Shells
- Active Air Flow
- Multistage
- Optimized Cavity

Reduced volume with SNOUT

StAIR Receiver



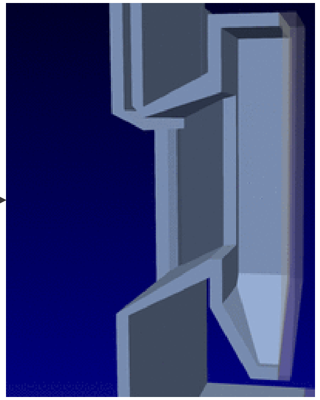
Design refinement

- Receiver Chimney
- Ray Tracing Analysis

2020

Design evaluation

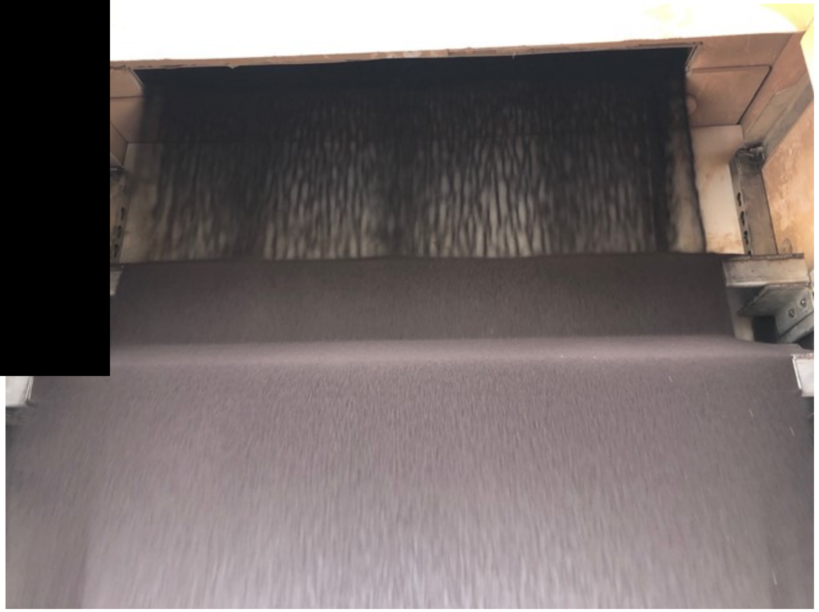
Optimized G3P3 FPR



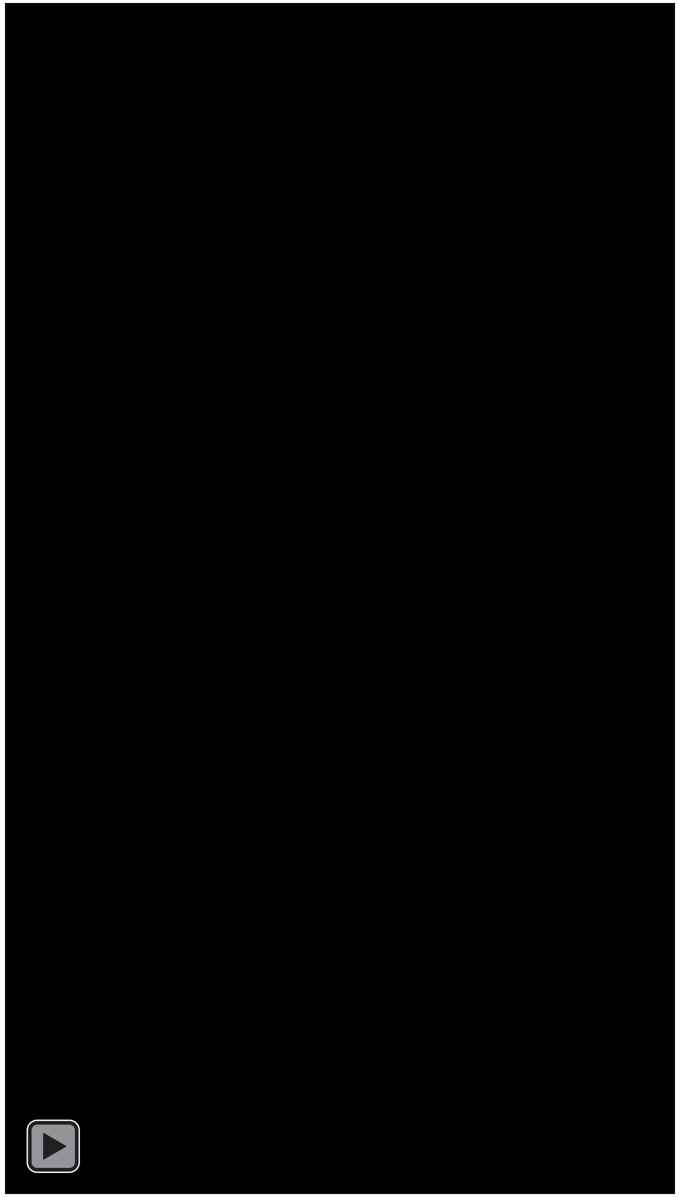
Pathway
- Wind Evaluation
- Ground Testing
- On-sun Testing
- Model Validation

StAIR (Staggered Angle Iron Receiver) Testing

Drawing of “stairs” in receiver cavity



Particle flow over two-stair configuration (5 – 10 kg/s)



StAIRS create a more uniform and opaque particle curtain for increased solar absorptance

G3P3-USA Receiver Design Evolution

2015 - 2018

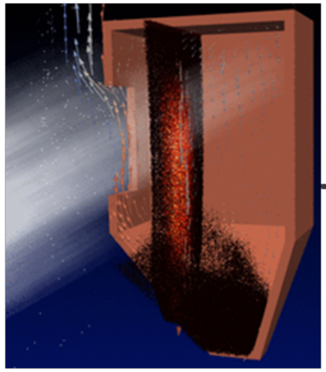
Feature evaluation

Design refinement

2020

Design evaluation

NSTTF
1 MW_{th} FPR



Design Challenges

- Low thermal efficiency
- Sensitivity to wind

FPR = Falling particle receiver

Hood/Tunnel

Quartz Half Shells

Active Air Flow

Multistage

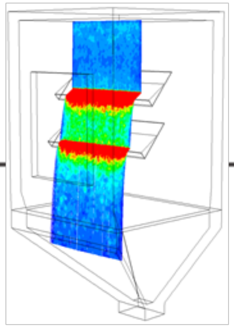
Optimized Cavity

Reduced volume with SNOUT

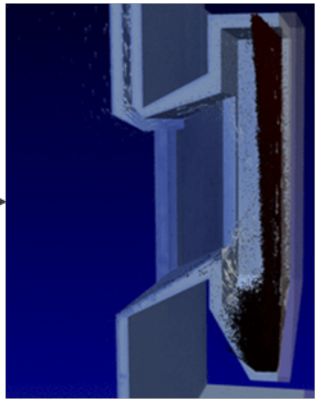
Receiver Chimney

Ray Tracing Analysis

StAIR Receiver



Optimized G3P3 FPR



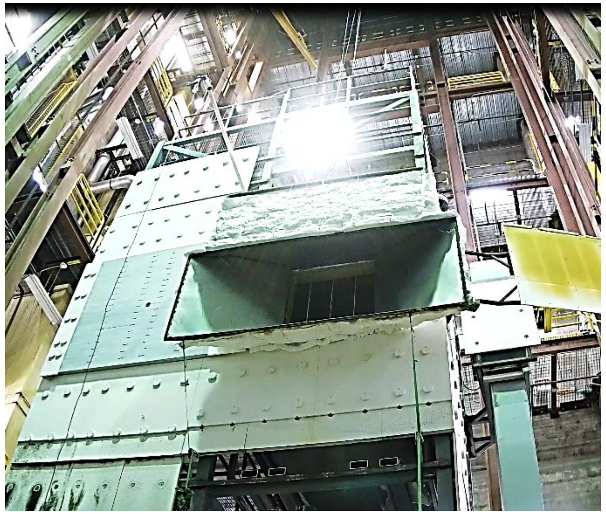
Pathway

- Wind Evaluation
- Ground Testing
- On-sun Testing
- Model Validation

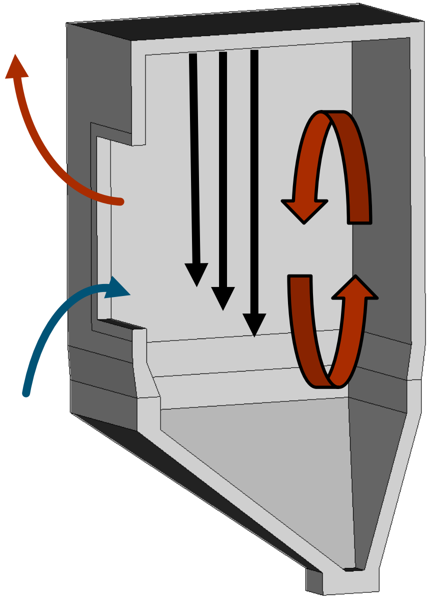
SNOUT and Reduced Volume Receiver

Baseline

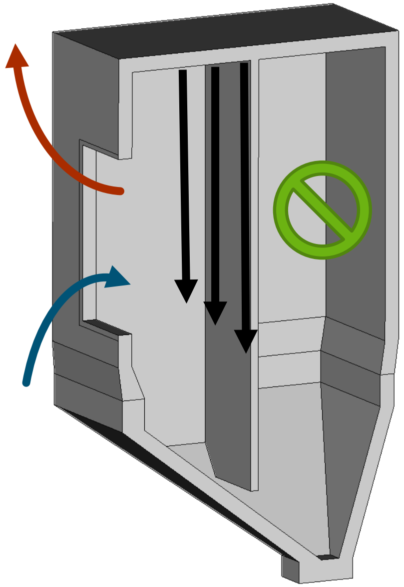
SNOUT

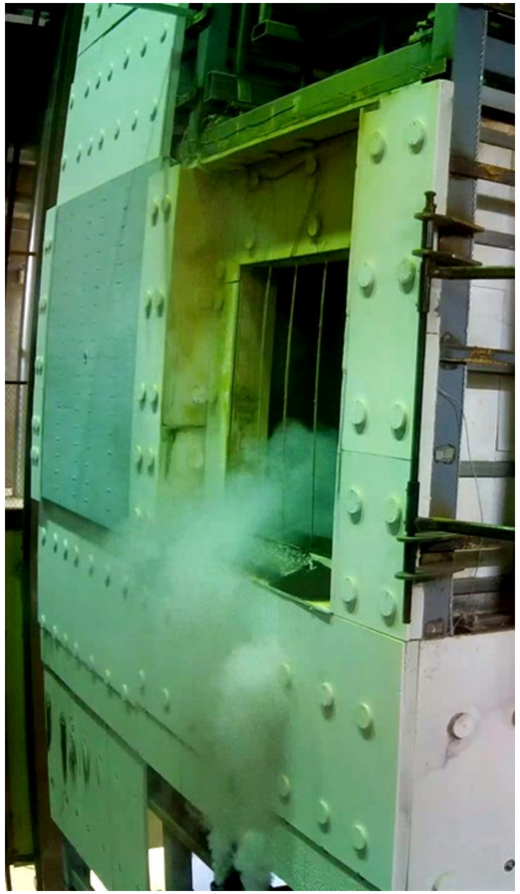


Baseline



Reduced volume receiver





Experiment

Simulation

SNOUT and reduced-volume reduced advective heat loss by ~20 – 25%

Overview

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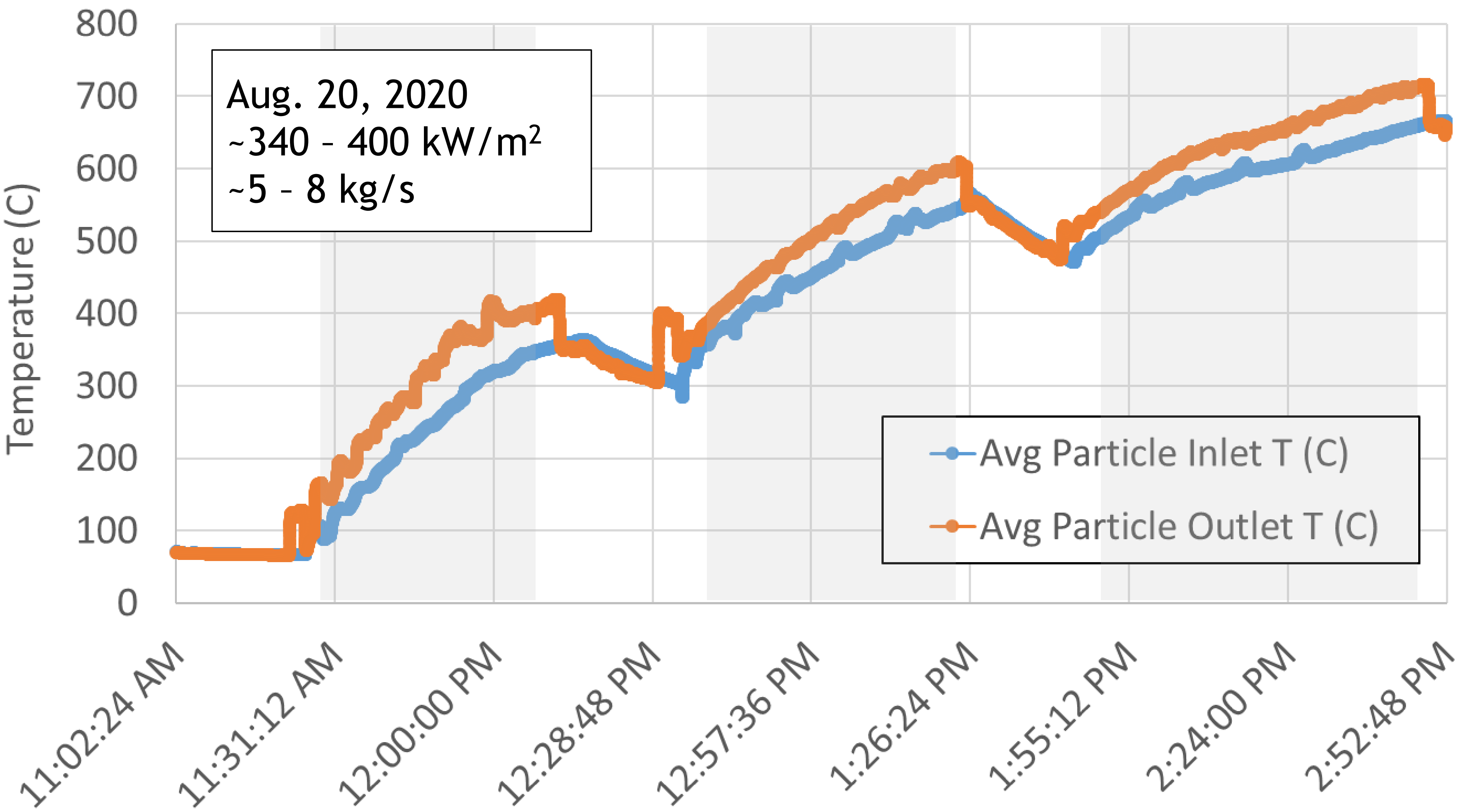
Control Room and On-Sun Testing

On-sun testing of particle receiver with StAIRs and reduced volume

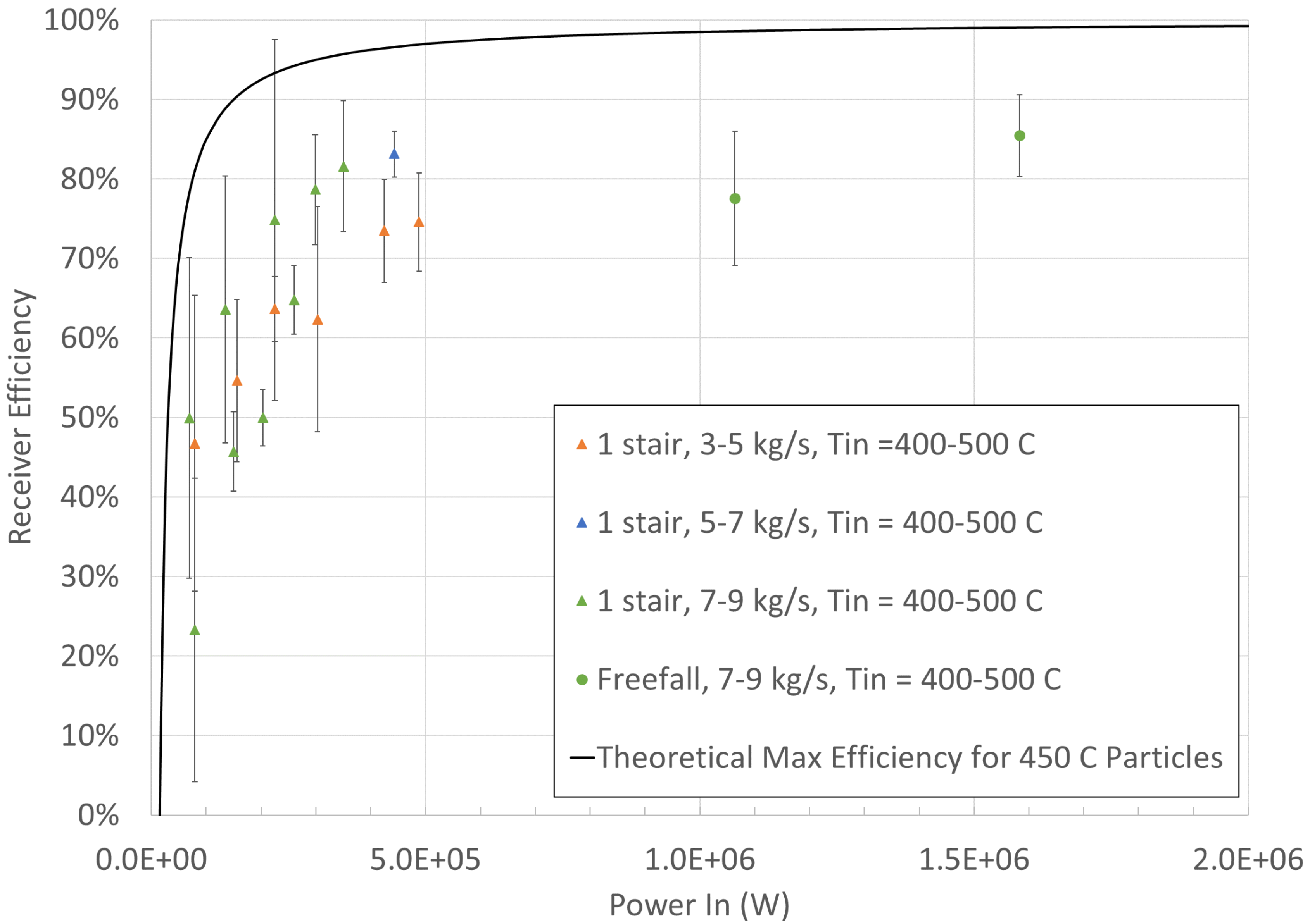
Sample of Test Log

Date	Start	End	Description	Weather
17-Aug-20	11h00	14h30	Receiver testing 500°C and 700°C, peak flux of 60 and 115 W/cm^2, two stairs	Very windy afternoon, Some clouds
18-Aug-20	11h00	14h30	Receiver testing 500°C and 700°C, peak flux of 60 and 115 W/cm^2, two stairs	Hazy from smoke
20-Aug-20	10h30	15h00	Test load cells, 50 W/cm^2, 500-600 °C, test single stair, top stair only	
21-Aug-20	10h30	14h00	Receiver testing, load cell troublehooting, single top stair	Hazy from smoke, low DNI
4-Sep-20	10h30	15h00	Receiver test day, 500C @ 5kg/s and 10 kg/s, with 50 W/Cm^2 700C @ ±5kg/s and 50 W/cm^2 700C at 108W/cm^2	Good DNI clear skies

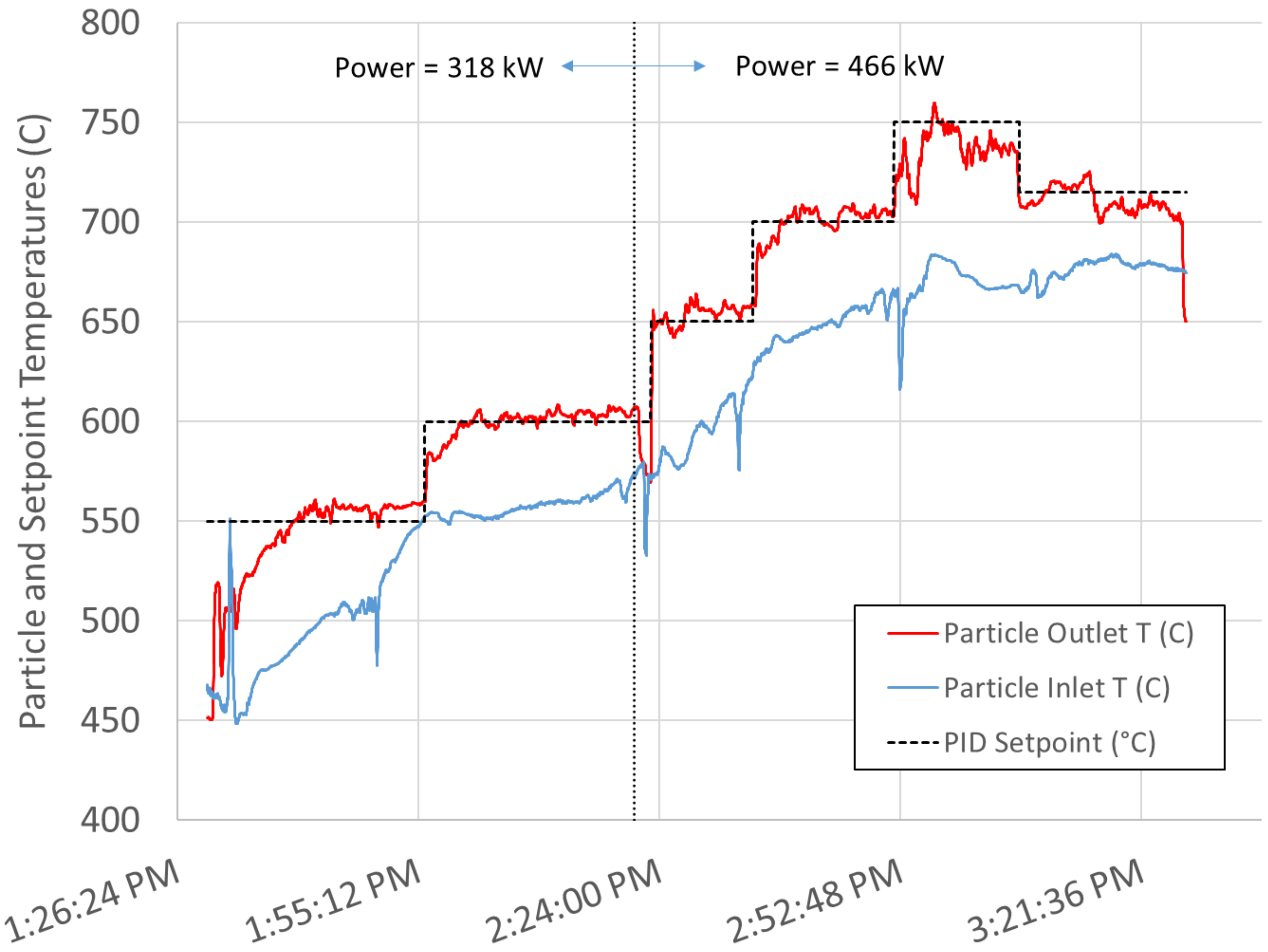
On-Sun Particle Temperatures



Receiver Efficiencies



Particle Temperature Control



- Automated particle outlet temperature control using closed-loop PID controller

Overview

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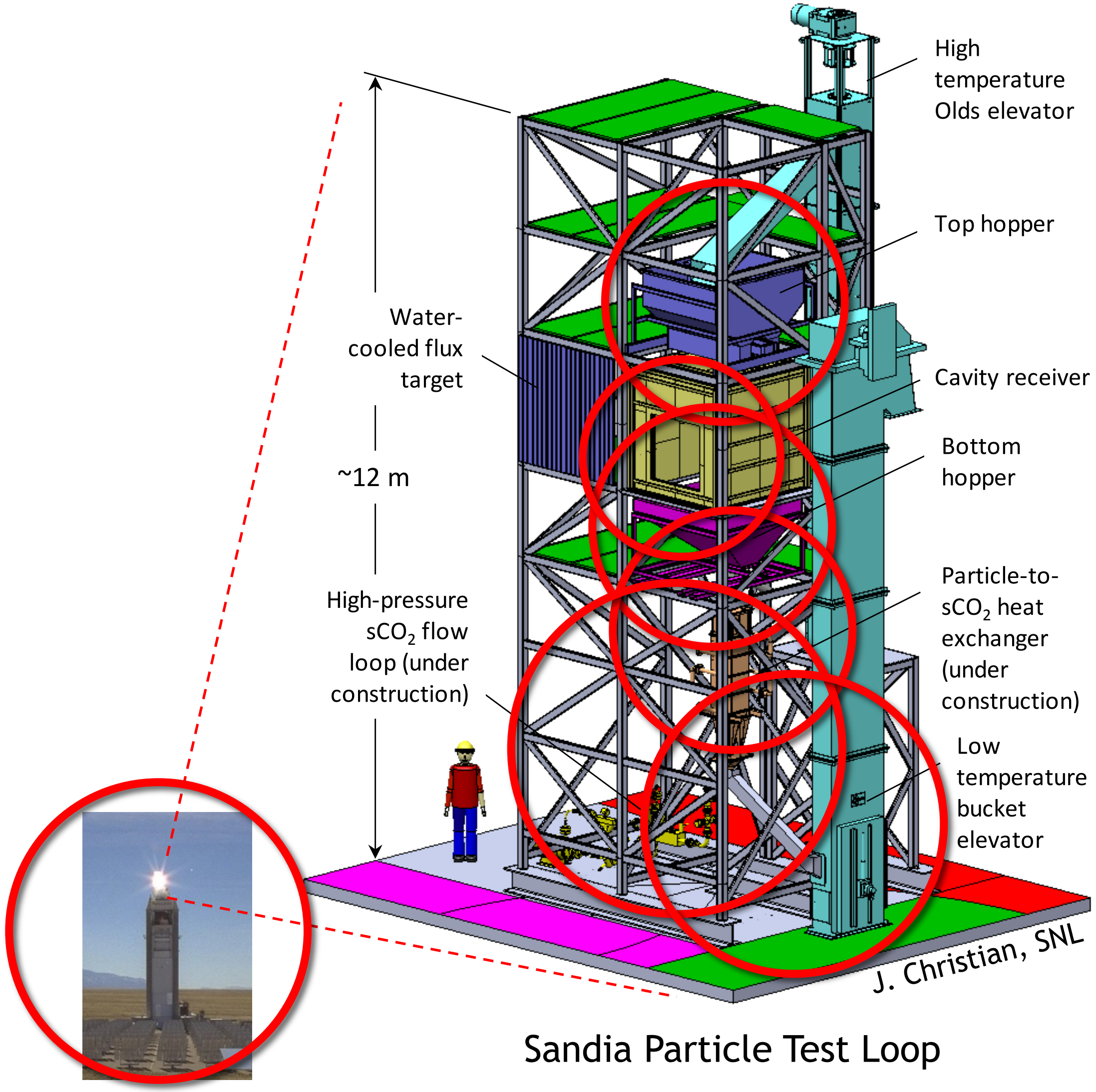
Mechanical Interfaces of System

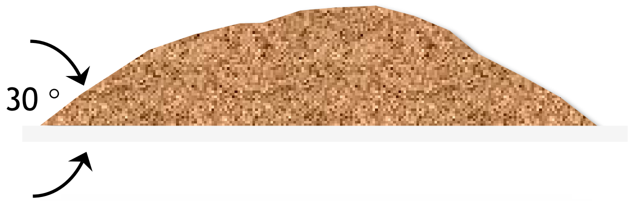
- Particle feed to the receiver
- Concentrated sunlight to particles
- Receiver to storage/collection bin
- Storage to heat exchanger
- Heat exchanger to sCO2 flow loop
- Heat exchanger to particle lift

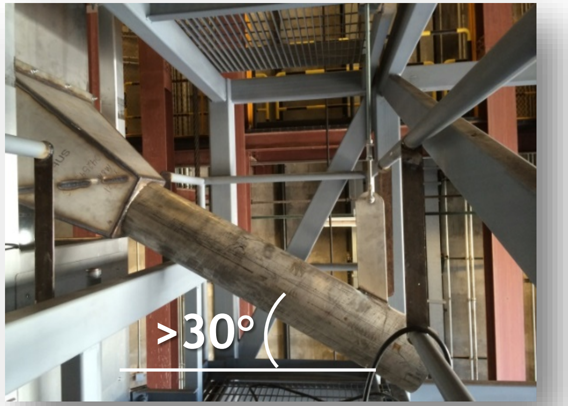


Sandia Particle Test Loop

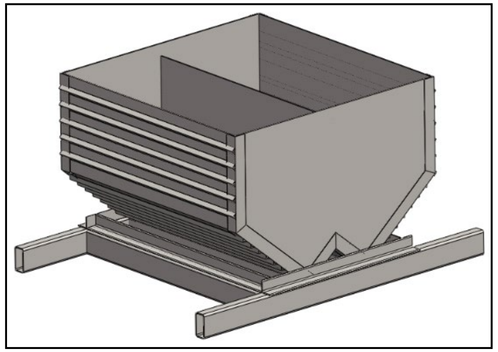
Particle Feed to the Receiver

- Sufficient pipe inclination angle for flow
  - Particle friction changes with temperature
- Funnel flow and avalanching in top hopper

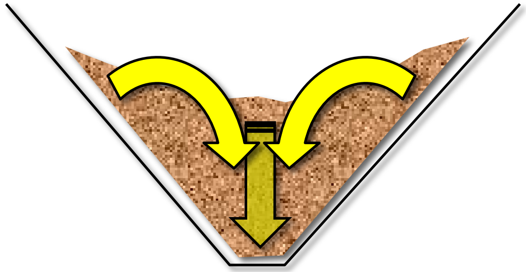




Pipe from particle elevator to top hopper



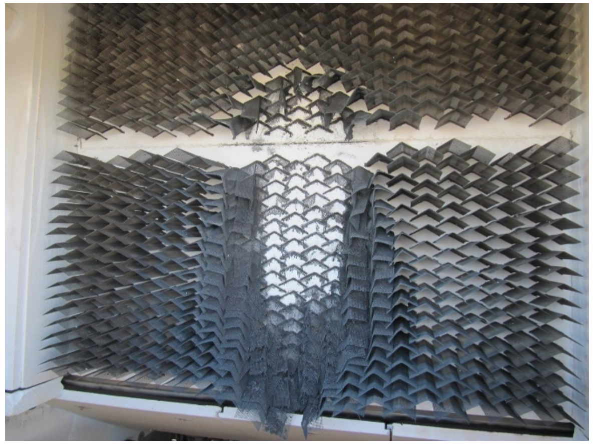
Top hopper



Funnel flow and avalanching

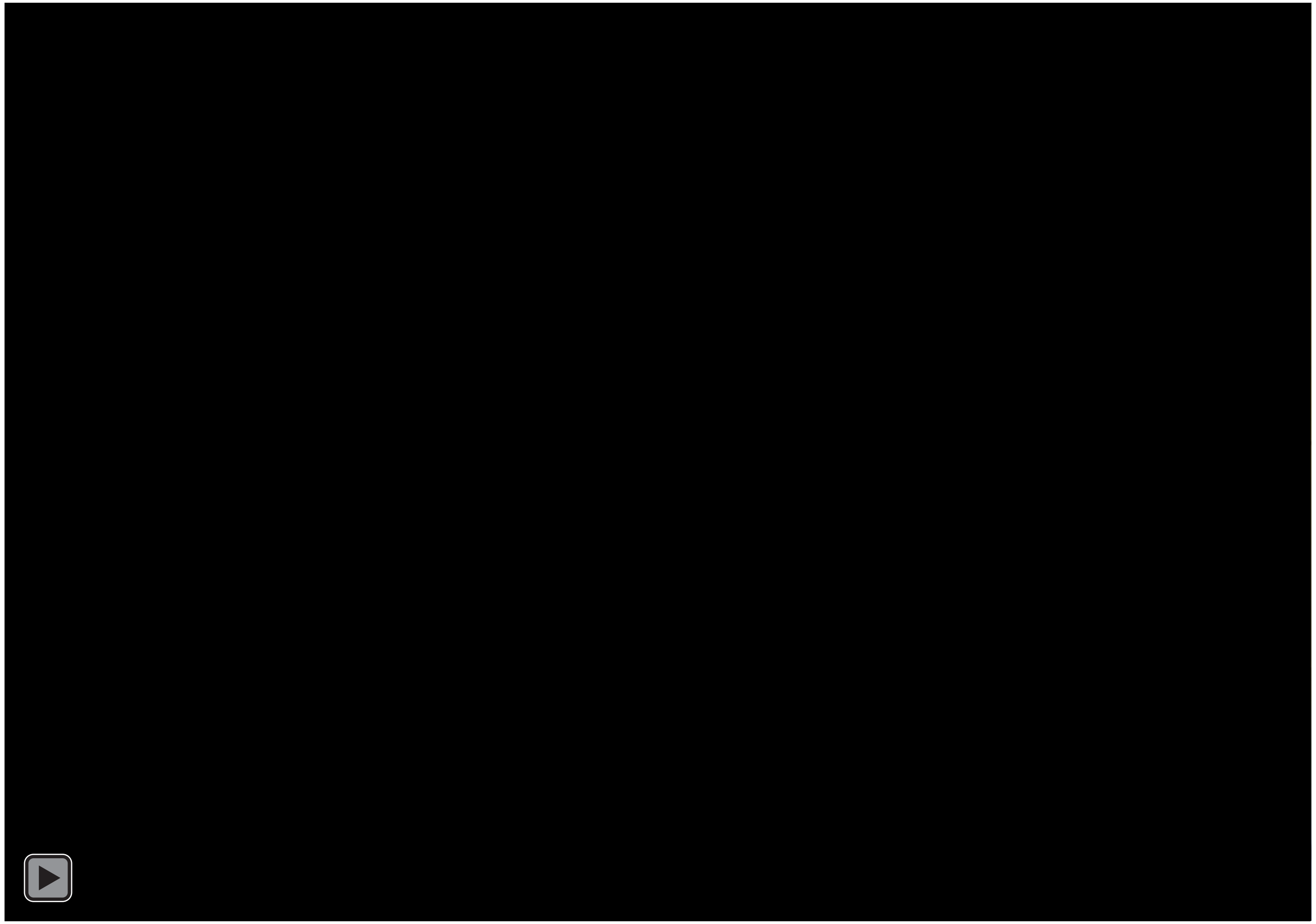
Particle Feed to the Receiver

- Initially used fixed-aperture plates to control mass flow rate into receiver
- Slotted plate deformed upon heating
- Reduction of particle mass flow rate led to melting of mesh structures
- Need automated particle mass-flow control to maintain constant particle outlet temperatures with varying irradiance



Staggered array of chevron-shaped mesh structures

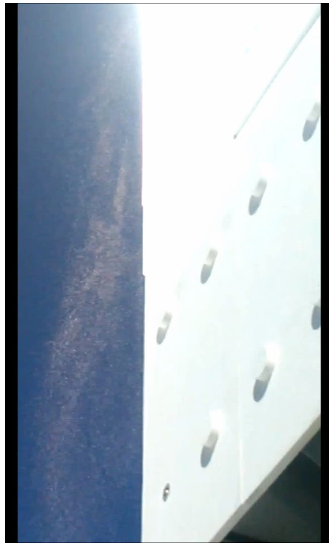
Particle Mass Flow Control - Demo



G. Peacock, K. Albrecht (SNL)

Concentrated Sunlight to Receiver

- Particle loss through open aperture
  - Trade-off between direct irradiance and particle losses
- Air curtains to reduce convective heat loss
- Light trapping with novel particle release patterns

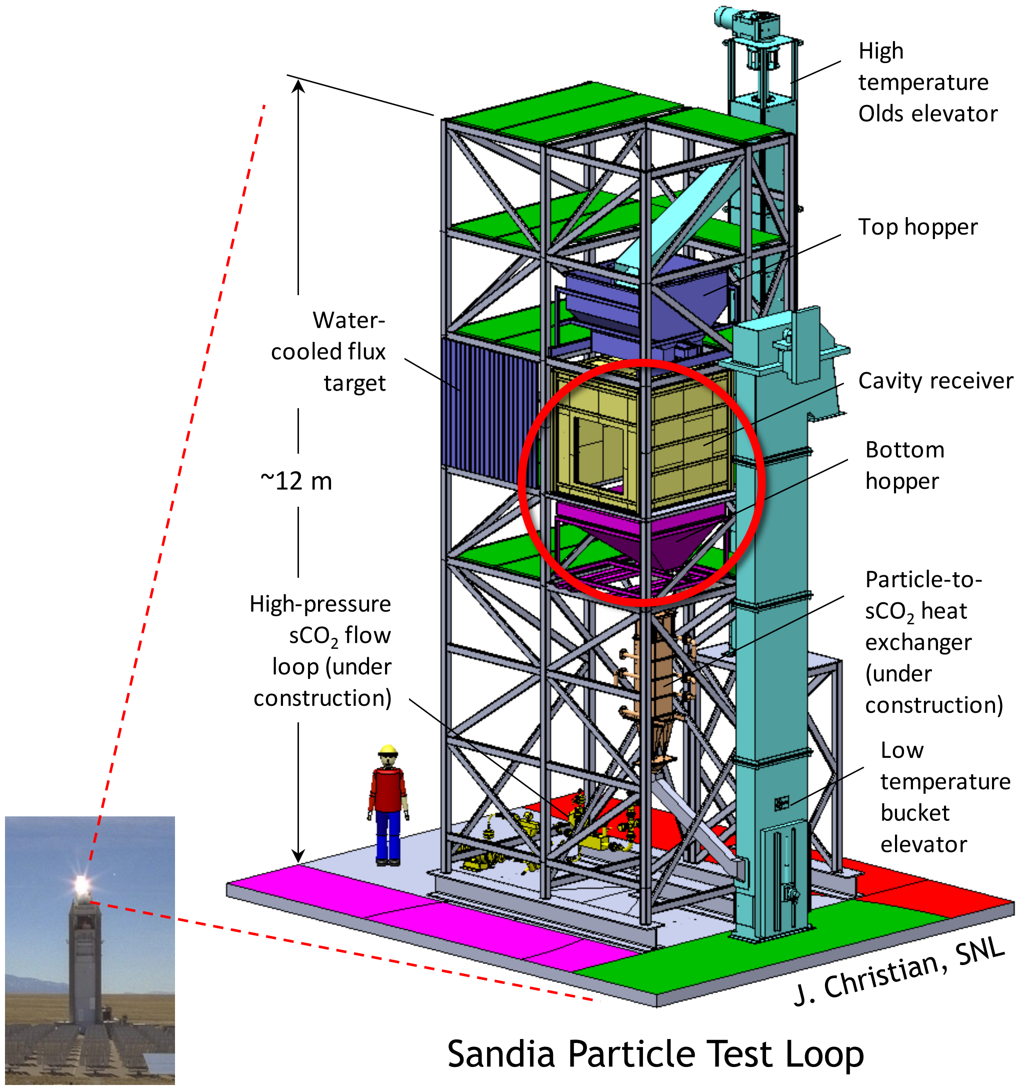


Nov. 2, 2015
3/8” slot - free fall
280 micron ACCUCAST ID50
10-15 mph south wind
500 - 1000 suns

Pump and nozzles to produce air curtain across aperture

Receiver to Storage Bin

- Reduce wear from direct impact on walls
  - Design for particle to particle impact
- Minimize opening to reduce heat loss from storage
- Design for filtration of debris and particle fines



Sandia Particle Test Loop

Summary

Summary

- Next-generation high-temperature particle receiver designed and tested
  - Optimized geometry to reduce advective and particle losses
  - SNOUT wind protection
  - Stairs to increase particle-curtain opacity and stability
- Lessons learned
  - Designs need to be scalable to large sizes (~1000 kg/s required)
  - High-flux, high-temperature environments are harsh on materials and sensors
    - In-situ measurements of temperature, mass flow, irradiance, wind
  - Thermal expansion
  - Mass flow control
  - Transient operation (start-up and shut-down)

Acknowledgments

SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

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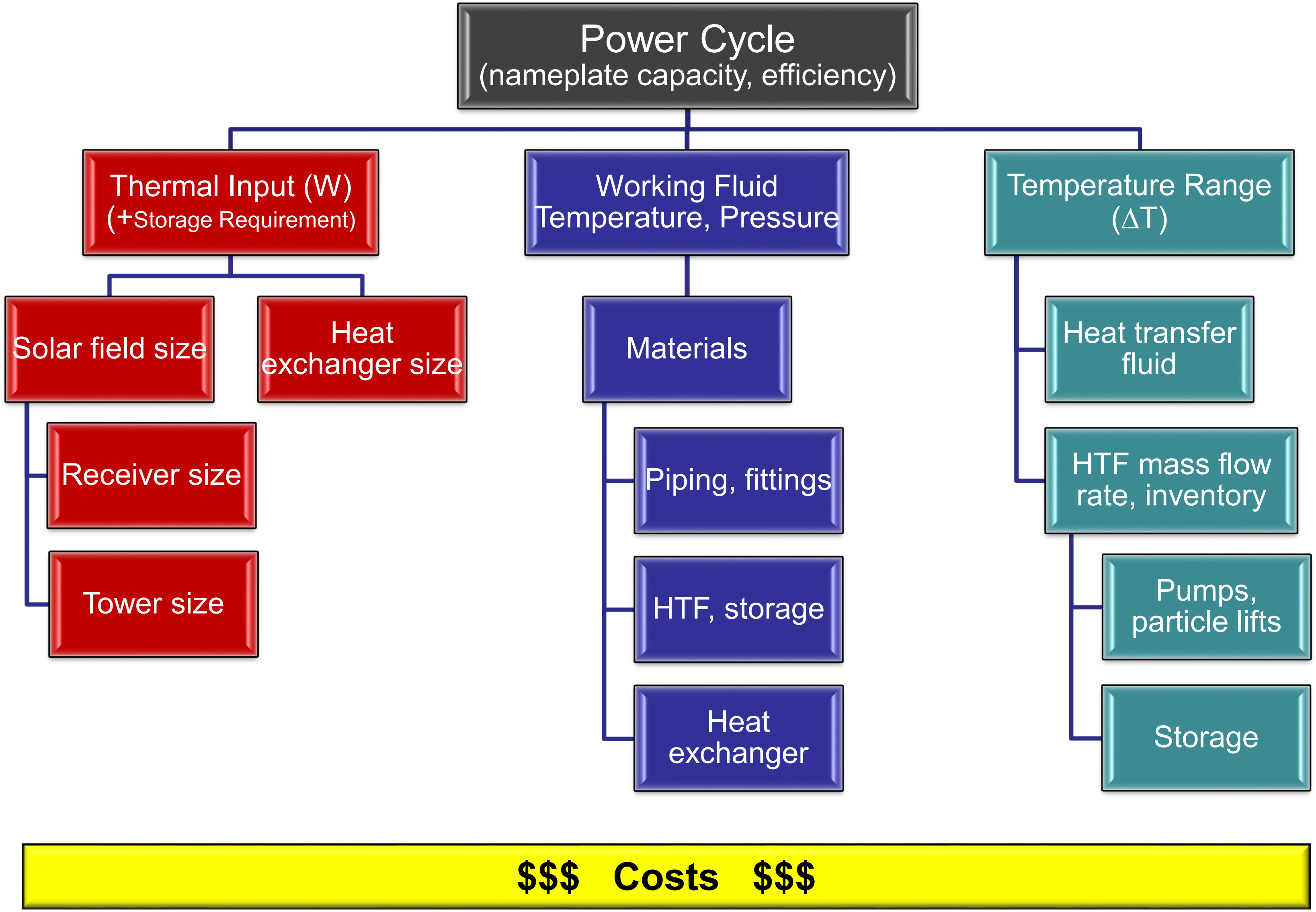
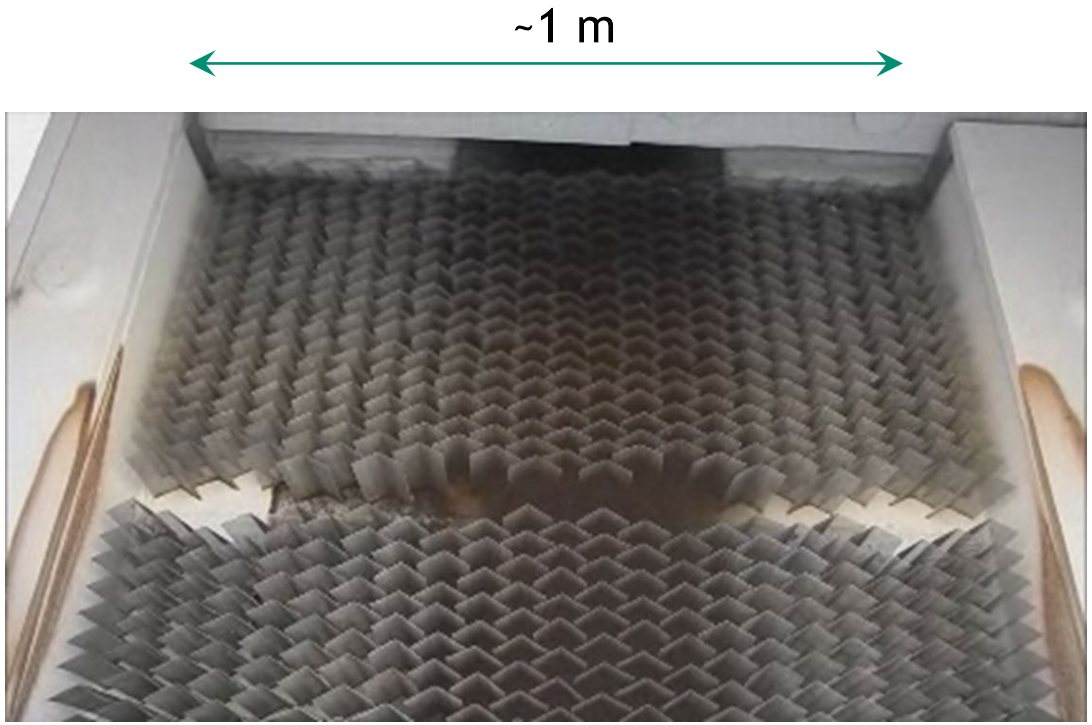
  - DOE Project Managers: Matthew Bauer, Vijay Rajgopal, and Shane Powers

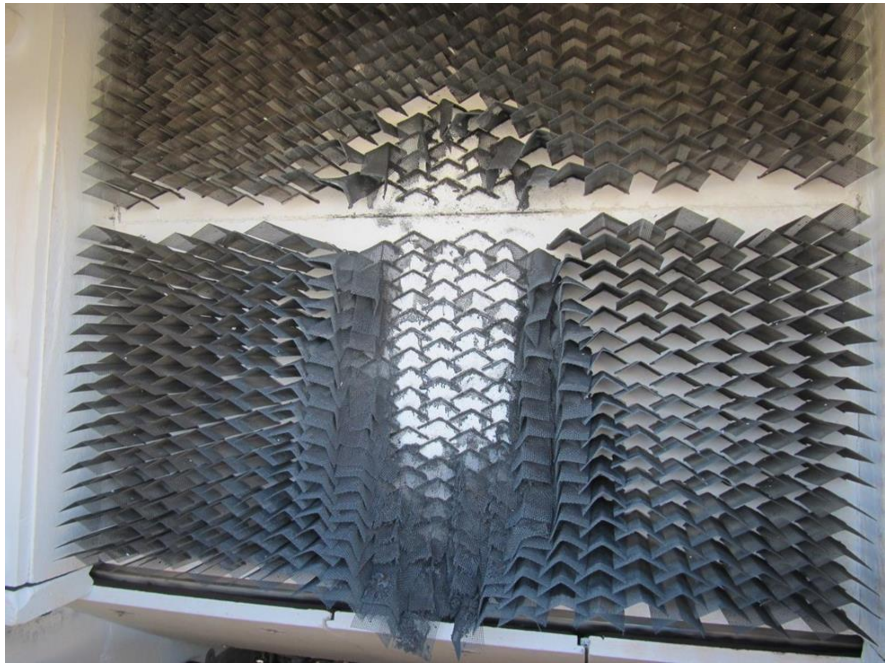
Backup Slides

Thermodynamic Interfaces



Overheating of Flow Obstructions





Failure of 316 SS mesh structures on July 24, 2015
~700 suns at ~1000 C (steel)

Uneven particle flow caused runaway heating and melting of obstructions