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DOE Virtual Receiver and Reactor Workshop

Gen 3 Particle Pilot Plant (G3P3) Update

Sandia National Laboratories

Award # DE-FOA-0001697-1503

CPS# 34211

February 15, 2024

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Other Contributors: King Saud University, Saudi Electricity Company

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Presentation Overview

- G3P3 Overview
  - Overall Design and Construction Status
- Particle Receiver Background
  - Falling Particle Receivers (FPR)
  - Effect of Wind on FPRs
  - Features to Improve Performance
- Scaling FPR Technology
  - Commercial-scale FPR Size
  - Considerations at Commercial Scale

G3P3 Overview

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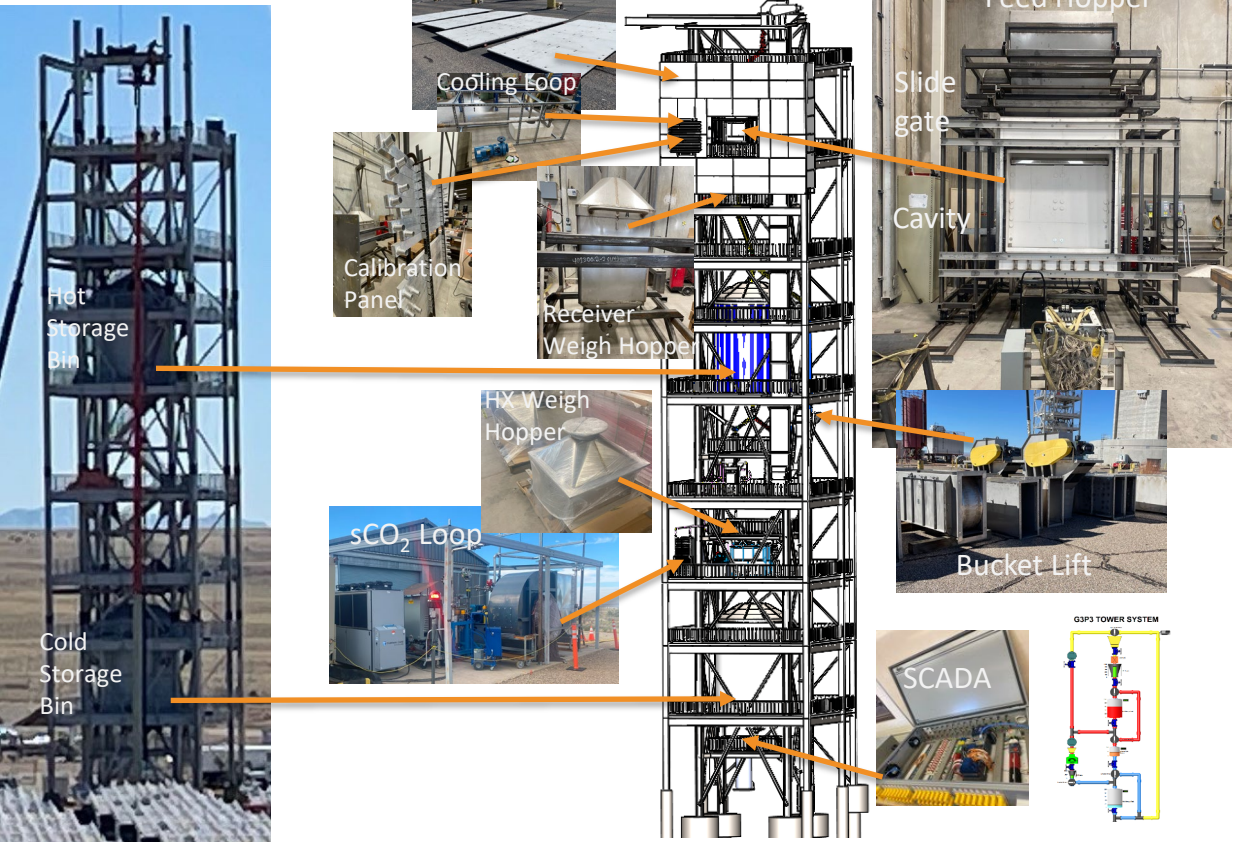
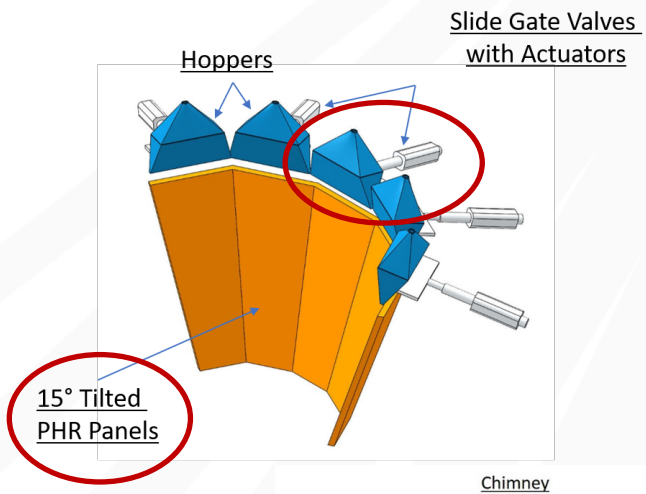
G3P3 Project Status Overview

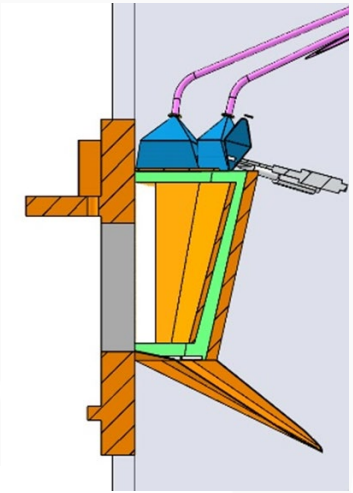


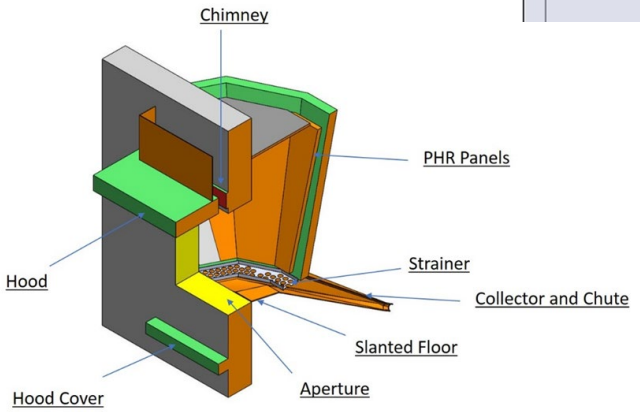
- Tower steel top-out 2/15/24
- Concrete slabs and electrical will resume through March
- Storage bin insulation will start in May
- Ductwork and equipment load-in TBD

Particle Heating Receiver

- Aperture size: 2.3 m (H) x 2.7 m (W)
- Nominal Thermal Power Incident on the PHR Aperture: ~7MW
- Cavity design
- Design derives from SNL's concept
  - **Minimizes advective heat losses**
- Receiver consists of 5 panels (Duraboard)
- 15° backward tilt
- Geometry similar to SNL/CSIRO's design
- Inherent SNOUT feature
- Dedicated hopper/slide gate for panels
- Flow regulated by feedback control system
  - **Based on SNL's design**

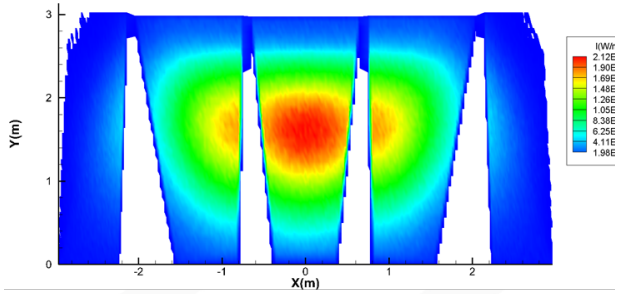




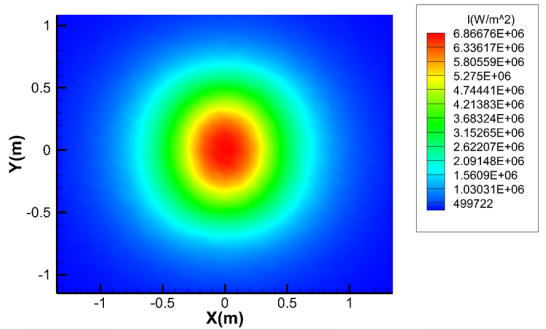


Particle Heating Receiver

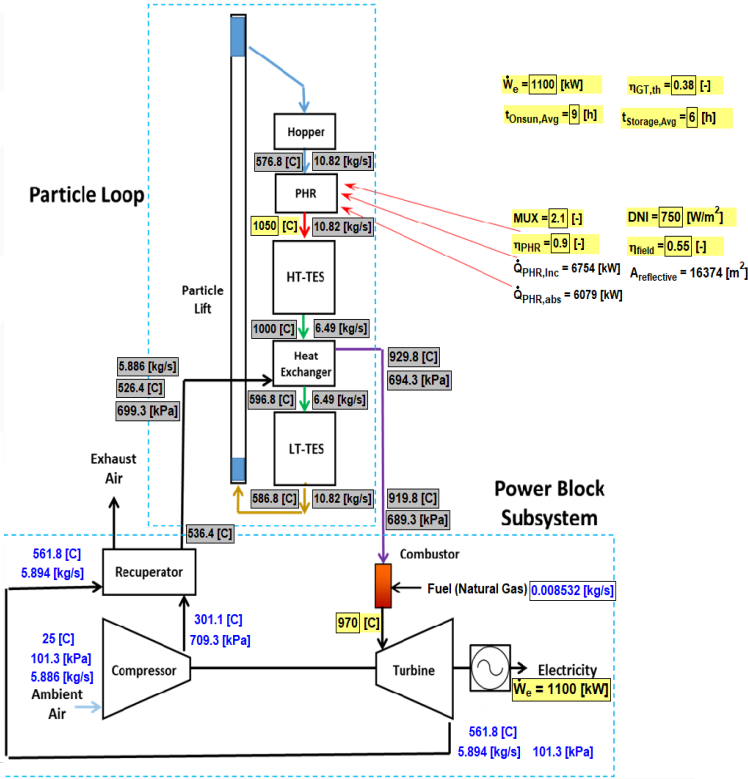
- Particle flow range 12-9.0 kg/s
- Max Particle temperature 1050 ˚C
- Residence time ~4.0 - 6.0 sec
- Obstruction Material: Inconel 800h, WHIPOX
- Average flux on aperture: 1340 kW/m^2
- Average flux on the receiver: 429 kW/m^2



Receiver flux map (noon)



Aperture flux map (noon)



Particle Receiver Background

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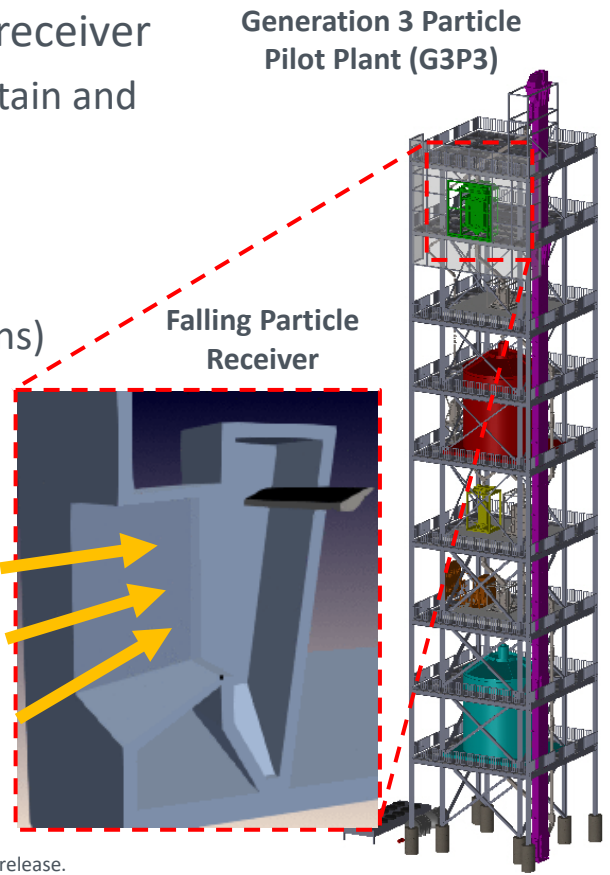
Falling Particle Receivers

- Falling particle receivers (FPRs) are one type of particle receiver
  - Cavity-type receivers where particles are released in a curtain and fall via gravity past the beam of concentrated light
- Advantages of FPRs:
  - Direct irradiance of the particles (absence of flux limitations)
  - Experimental evidence of high temperatures (> 800°C)
  - Low parasitics; only a single slide gate for control
  - Conceptually simple and inexpensive
- Disadvantages of FPRs:
  - High advective losses through the aperture
  - Open aperture increase susceptibility to wind
  - Particles can escape through the aperture (fines)



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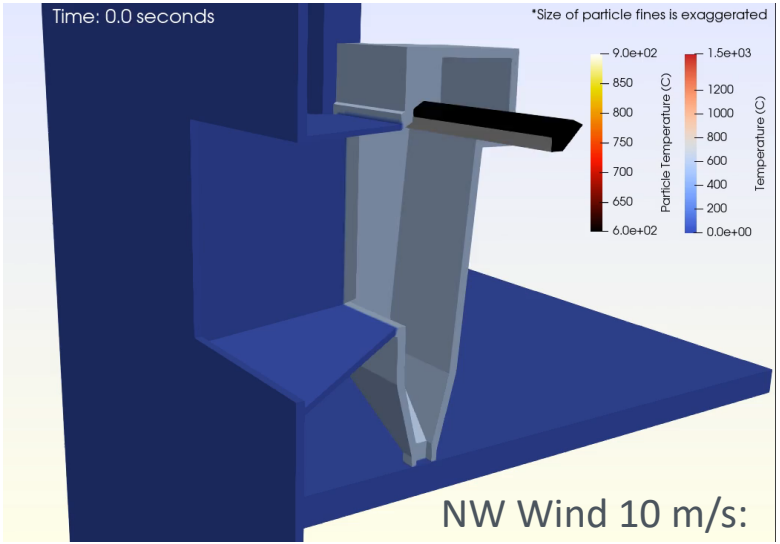
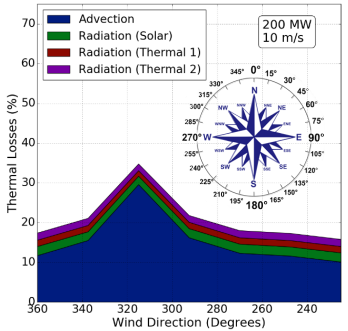
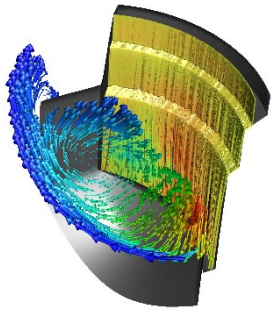
Wind on Falling Particle Receivers

- Wind can significantly affect receiver performance especially at scale
  - Increases advective losses and particle attrition
  - Adds difficultly in designing passive features
- The G3P3 FPR included several new features to improve performance/resilience:
  - "SNOUT"
  - Optimized cavity
  - Multistage obstructions (stAIRs)
- These features were pursued for their <u>ability to scale with receiver size</u>



Losses at Commercial Scales





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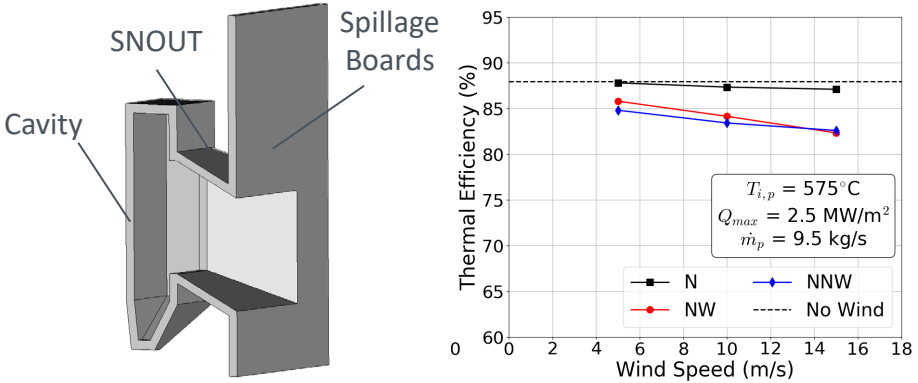
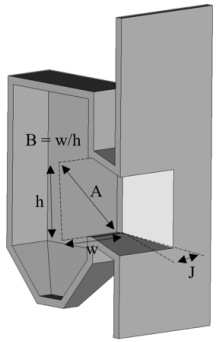
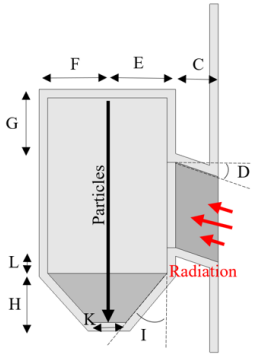
SNOUT and Cavity Design/Optimization

- A SNOUT (i.e. converging tunnel) lessened the impact of wind in G3P3



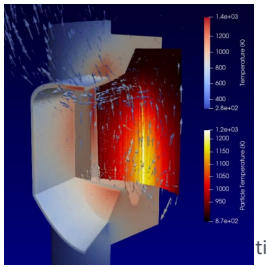
- For G3P3, a design optimization study was performed to minimize losses

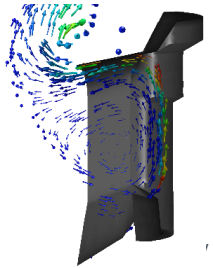




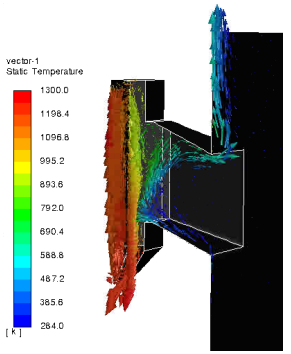
Item	Description
A	Aperture Area
B	Aperture Aspect Ratio
C	Tunnel Length
D	Tunnel Angle
E	Curtain Depth
F	Behind Curtain
G	Header
H	Hopper Depth
I	Hopper Angle
J	Width Multiplier
K	Hopper Exit Size
L	Below Aperture

- Effects are also observed at larger scales





- Helped find a robust cavity geometry that minimizes advective losses and wind impacts



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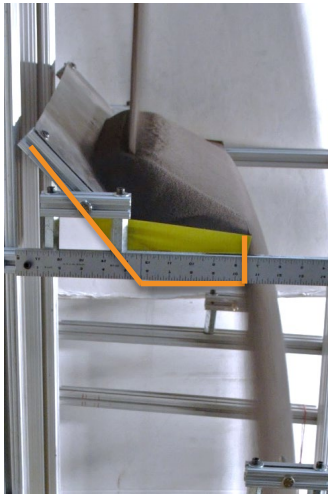
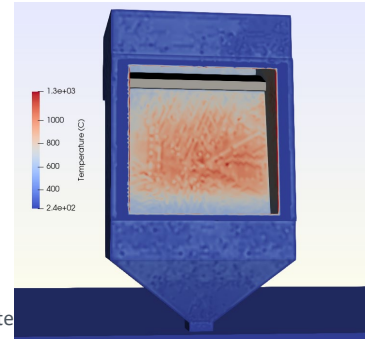
Multistage Receivers (stAIR)

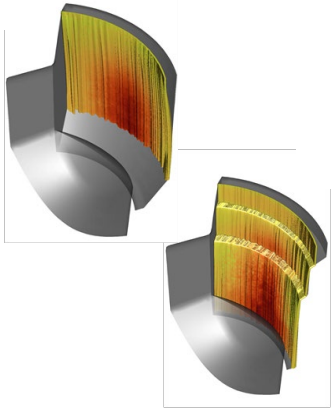
- Multistage receivers (troughs) provide better particle handling and resilience
  - Increase particle residence time
  - Increase curtain opacity
  - Improves curtain uniformity
- Trough shape can impact particle flow
- Technology is well suited for scaling and minimizing risks from large particle drops



G3P3 Trough Shape

Decreases Cavity Temperatures





Scaling FPR Technology

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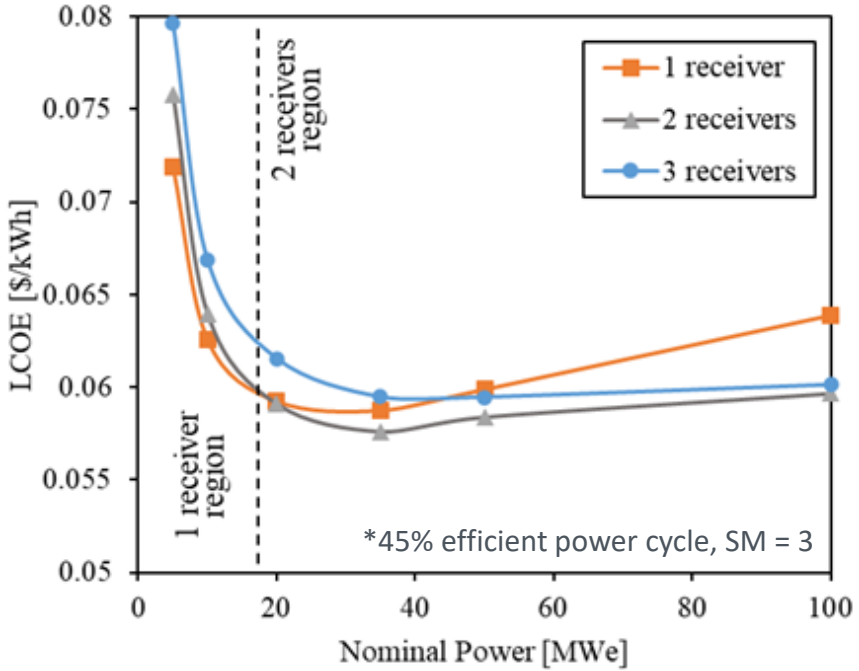
What Sizes Should Be Considered?

- Minimum LCOE was achieved with 2 receivers at ~100 MW_{th}
- Thermal losses scale with receiver size
- Increased receiver above 150 MW_{th} increased levelized cost of energy



*Brantley Mills et al "Technoeconomics of Particle-based CSP Featuring Falling Particle Receivers..."

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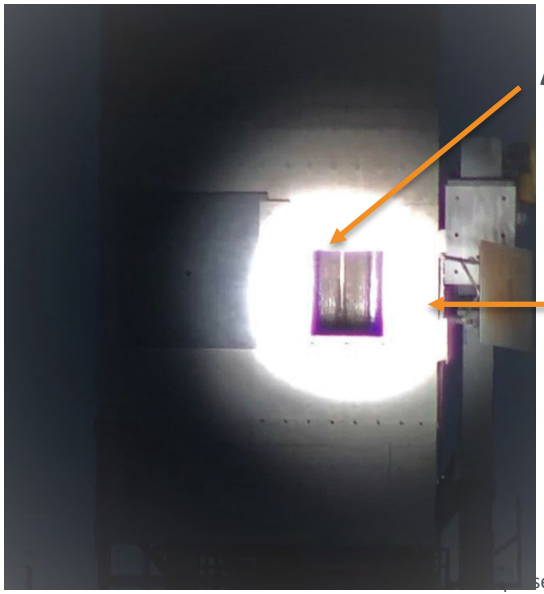
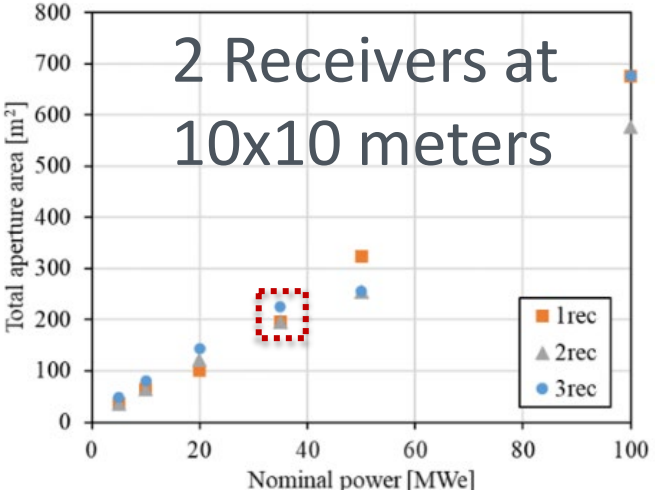
Receiver Aperture Area and Width

- A 1:1 aspect ratio is considered due to beam shape





- Aperture size to spillage?
  - Larger aperture greater losses, smaller aperture more reflected flux

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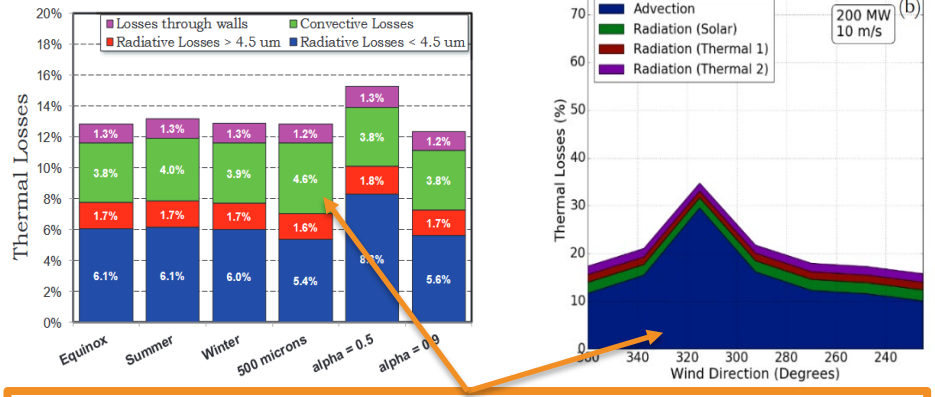
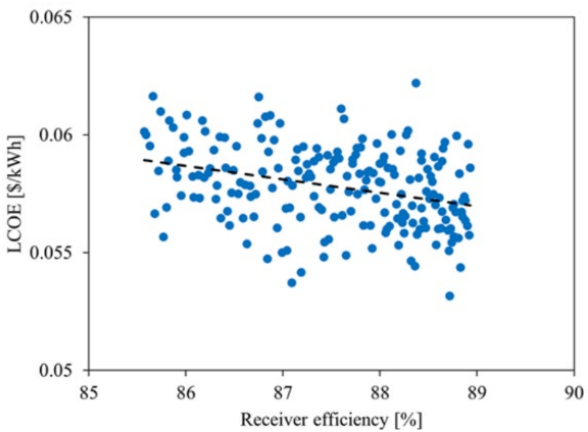
Larger Aperture – Greater Losses



Advective losses make up a large portion of receiver thermal losses

- Mitigation strategies can be used to recapture or prevent advective losses
- Efficiencies up to 92% could be possible



Hot air exiting the aperture dramatically decreases receiver efficiency

Portillo et al. "Sensitivity Analysis of the Levelized Cost of Electricity..."

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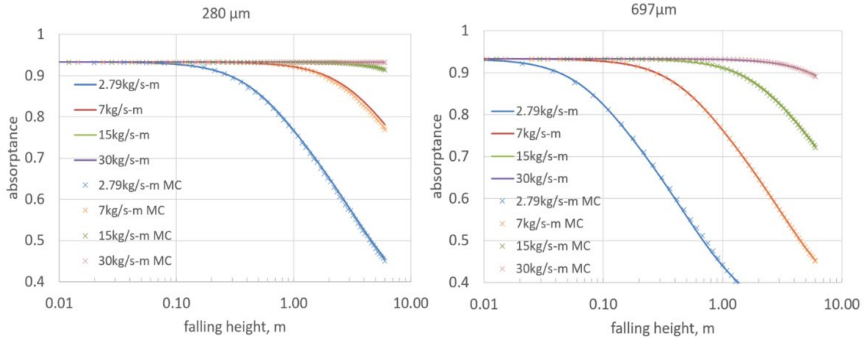
Maintaining an Opaque Curtain

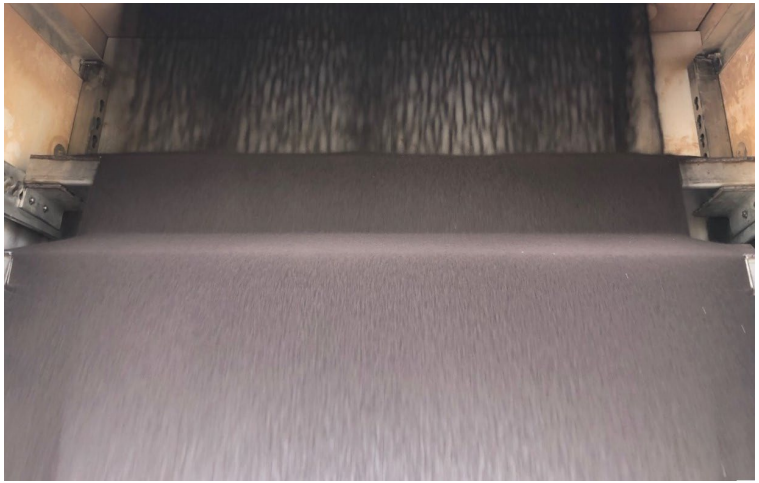
- Particle curtain transmissivity increases with drop height
- Impediments act to “reset” particle curtain velocity

*JS Kim et al “Numerical and Experimental Investigation of a Novel Multi-Stage Falling Particle Receiver”



Increasing velocity

Increasing transparency



1 MW falling particle receiver

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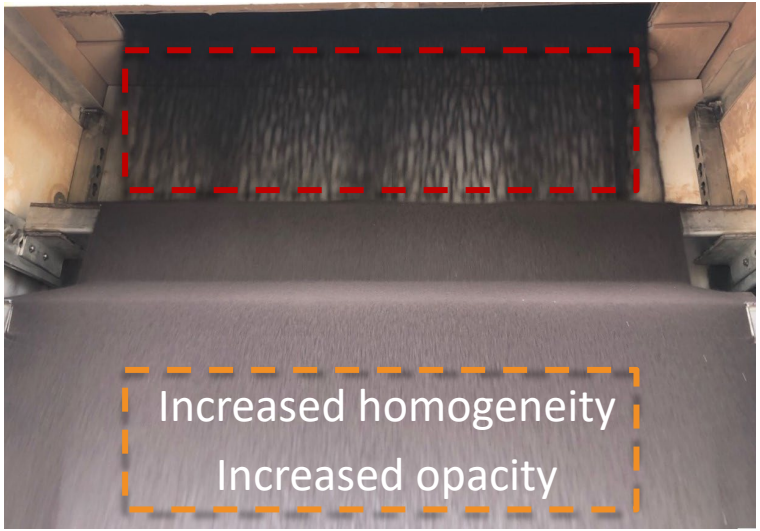
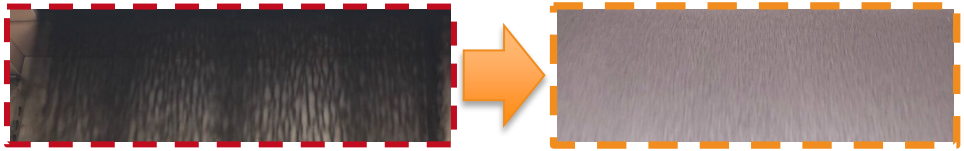
Maintaining an Opaque Curtain

- Imperfection in the particle curtain are reduced
- Transmissivity decreased over free falling curtain



Increasing velocity

Increasing transparency



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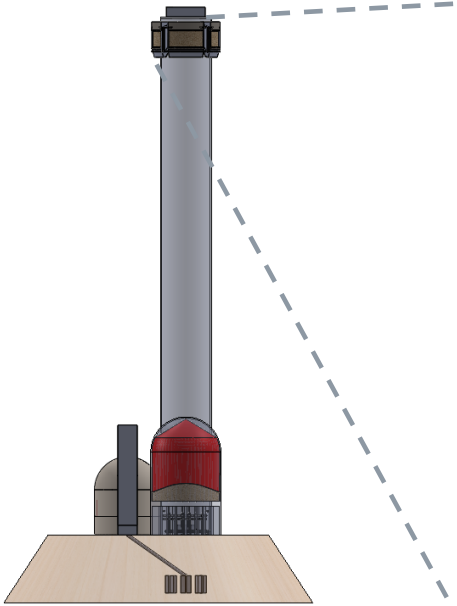
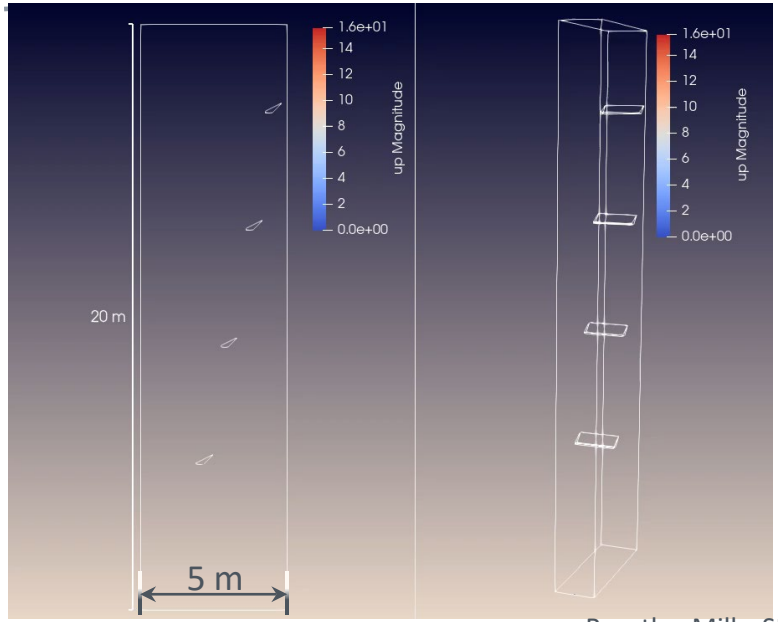
Particle Curtain Behavior

100 MW
Tower Design



Jeremy Sment SNL

Commercial Scale Falling
Particle Receiver Simulation



Brantley Mills, SNL

- Particle curtain behavior over large drops unclear
- Recently funded project will investigate

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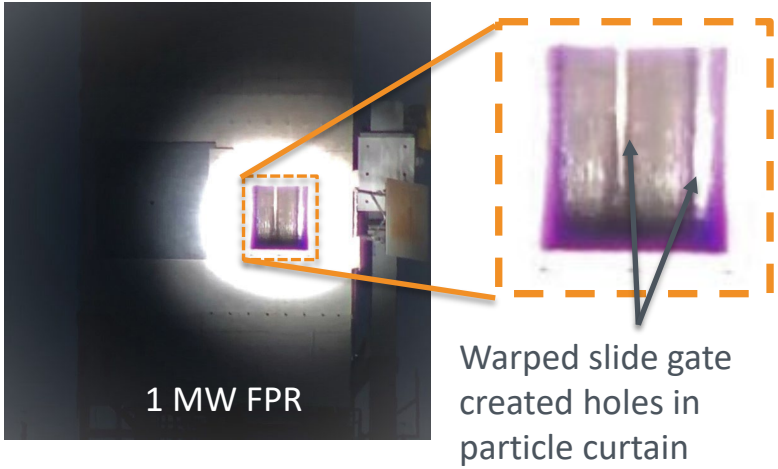
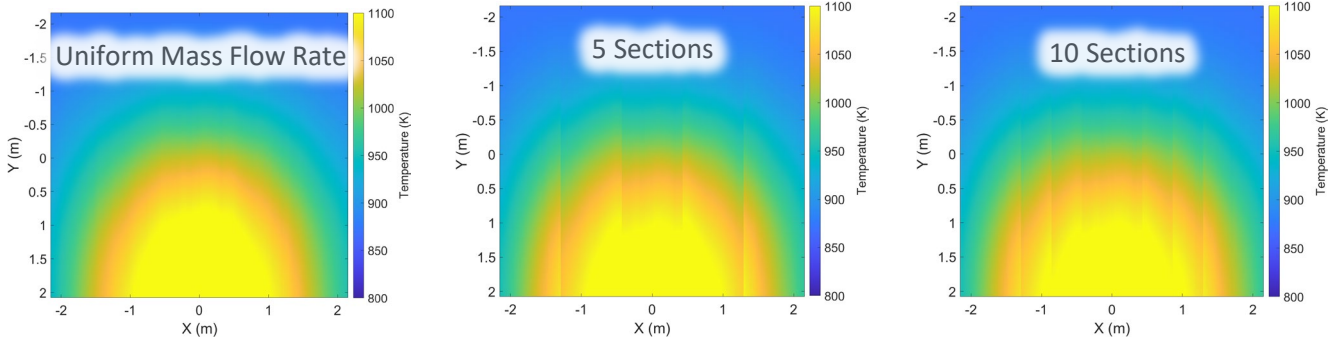
Generating a Particle Curtain

- Slide gates at 1 MW scale (~1 m long) warped and failed at ~700 °C
- Modular slide gates are being developed
  - ~0.5 meter gates



Warped slide gate created holes in particle curtain



- Creates redundancy
- Increases performance

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Unanswered Questions

- What is the optimal receiver size to beam size?
  - Reflective SNOUT surfaces?
- How do particle curtains behave at drop distances of 10 meters?
- What advective loss mitigation strategies will work at commercial scale?
  - Aero windows, wind fences, receiver recirculation, etc.