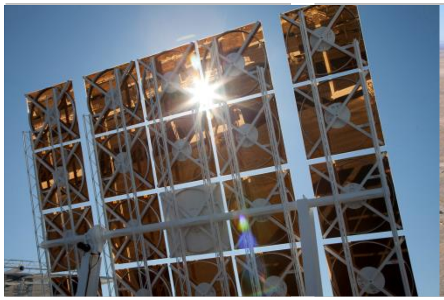
1697-1503

Gen 3 Particle Pilot Plant (G3P3):

Integrated High-Temperature Particle System for CSP

Exceptional service in the national interest

Sandia National Laboratories



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SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Introduction to the Team

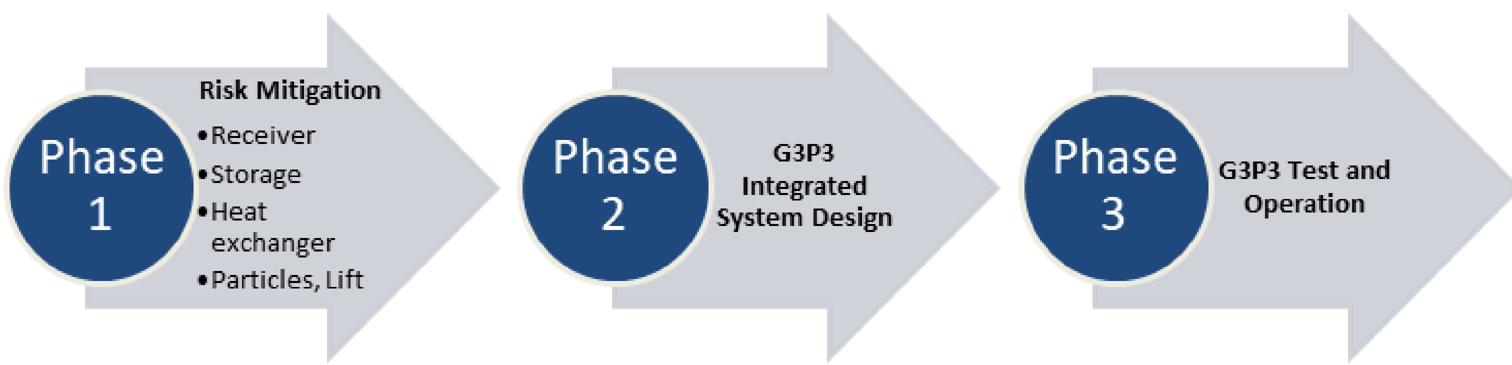
Role	Proposed Team Members	
PI / Management	• Sandia National Labs (PI, PMP, financial, facilities)	
R&D / Engineering	• Sandia National Laboratories • National Renewable Energy Laboratory • Georgia Institute of Technology • King Saud University • German Aerospace Center	• CSIRO • U. Adelaide • Australian National University • CNRS-PROMES
Integrators / EPC	• EPRI • Bridgers & Paxton / Bohannan Huston • INITEC Energia	
CSP Developers	• SolarDynamics • SolarReserve	
Component Developers / Industry	• Carbo Ceramics • Solex Thermal Science • Vacuum Process Engineering • FLSmidth	• Materials Handling Equipment • Allied Mineral Products • Matrix PDM
Utility	• Saudi Electric Company	

Overview

- Objectives and Value Proposition
- G3P3 System Overview
- Gaps and Risks
- Conclusions

G3P3 Objectives

- **De-risk**, **design**, **construct**, and **operate** a multi-MW_t particle receiver system
  - Heat working fluid (e.g., sCO_2 or air) to ≥ 700 °C
  - 6 hours of energy storage
  - > 2,000 hours of on-sun operation
  - Meet SunShot cost and performance goals
- **Leverage** international expertise and CSP activity
- Accelerate **commercialization** of G3P3 technology



Value Proposition

- Proposed particle receiver system has significant advantages over current state-of-the-art CSP systems
  - Sub-zero to over ~1000 °C operating temperatures
  - No freezing and need for expensive trace heating
  - Use of inert, non-corrosive, inexpensive materials
  - Direct storage (no need for additional heat exchanger)
  - Direct heating of particles (no flux limitations on tubes)

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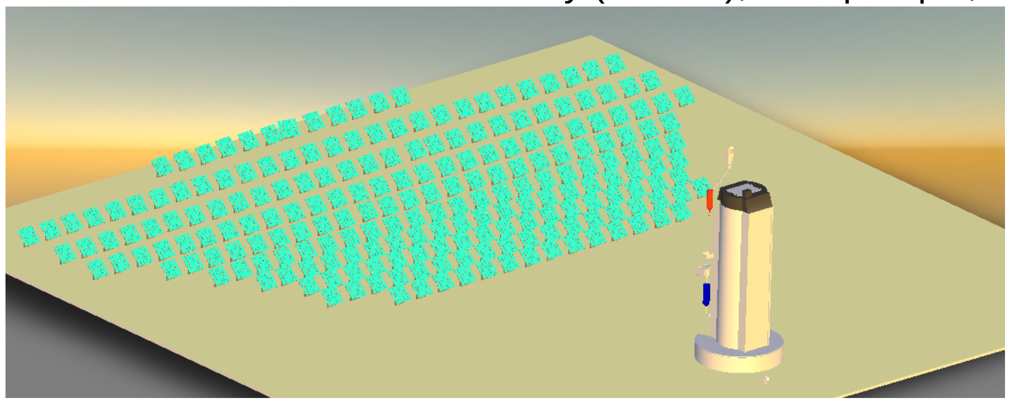
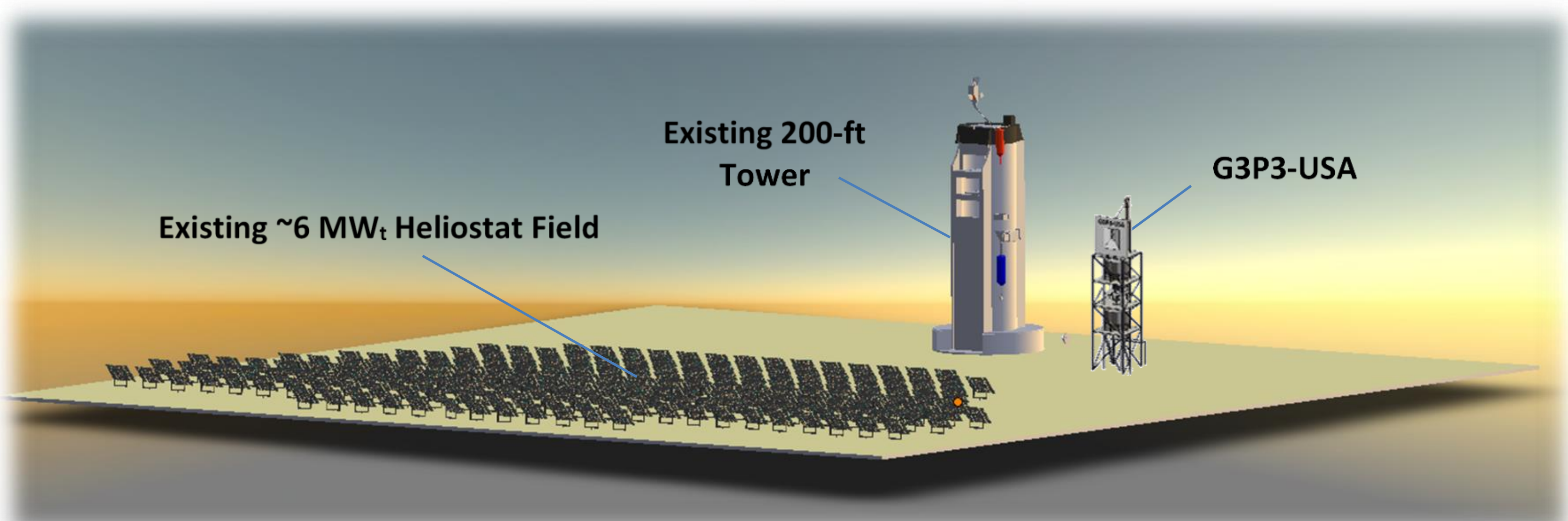
Gen 3 Particle Pilot Plant (G3P3)

Integrated System

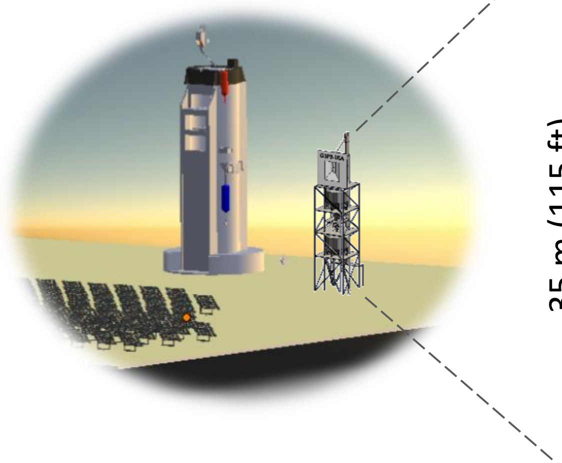
National Solar Thermal Test Facility (NSTTF), Albuquerque, NM



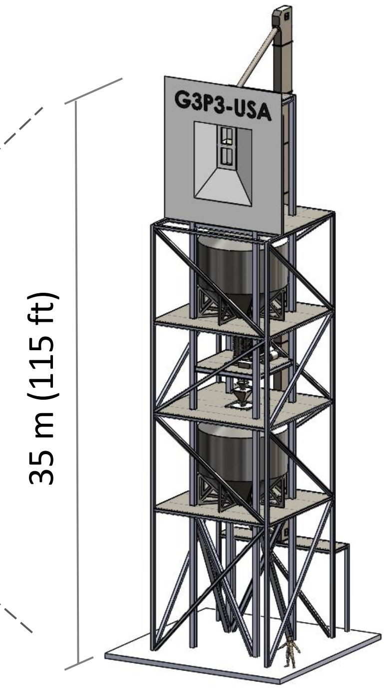


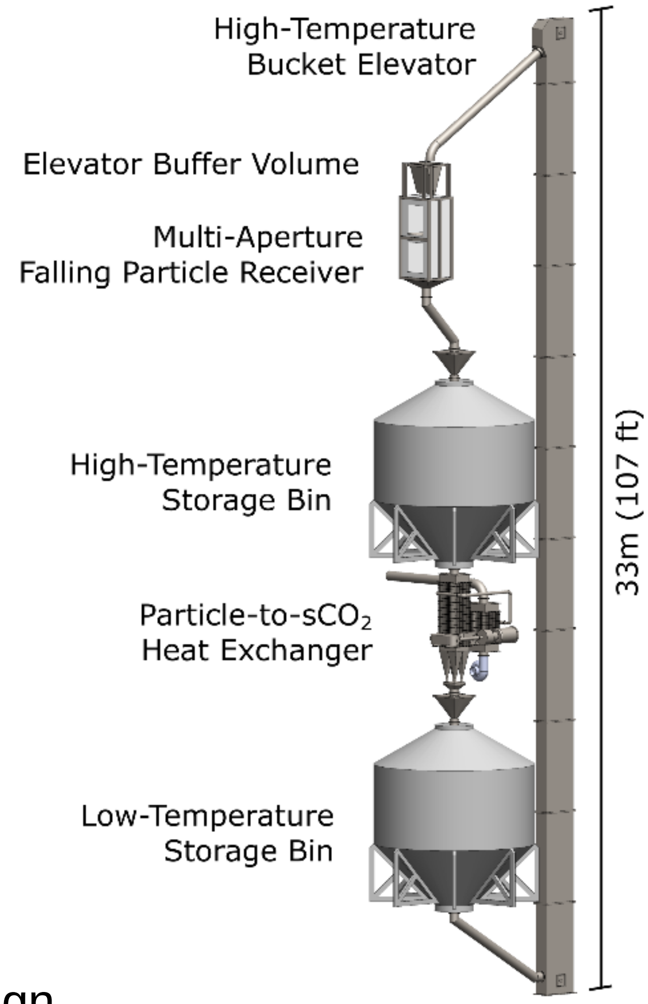
Gen 3 Particle Pilot Plant (G3P3)

Integrated System



G3P3-USA system next to the existing 200-ft tower at the NSTTF





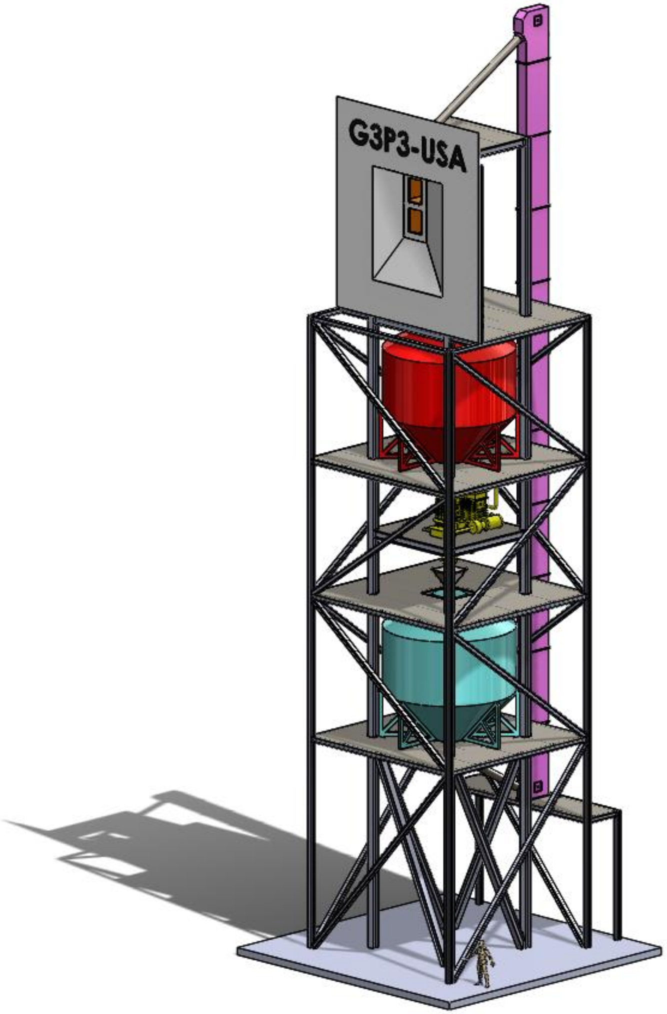
Baseline Design

Overview

- Objectives and Value Proposition
- G3P3 System Overview
- Gaps and Risks
- Conclusions

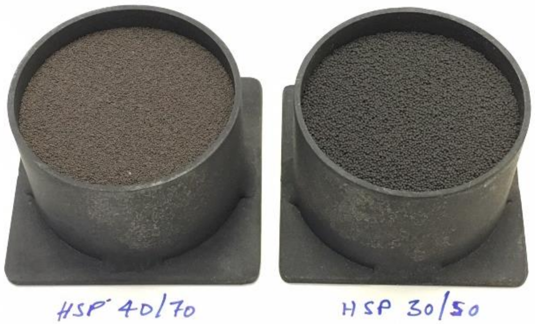
Gaps and Risks

- Particles
- Receiver and Feed Bin
- Particle Storage
- Particle Heat Exchanger
- Particle Lift and Conveyance
- Balance of System



Particles

- Cost
  - ≤ $1/kg
- Durability
  - Low wear/attrition
- Optical properties
  - High solar absorptance
- Flowability, low erosion
- Inhalation hazards (e.g., silica, PM2.5)



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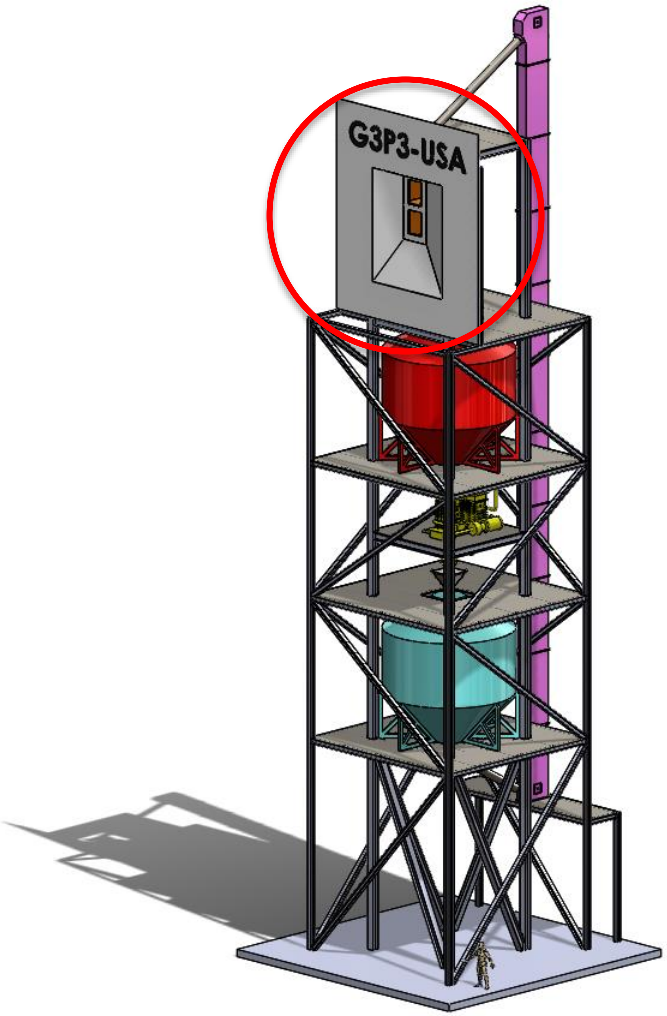
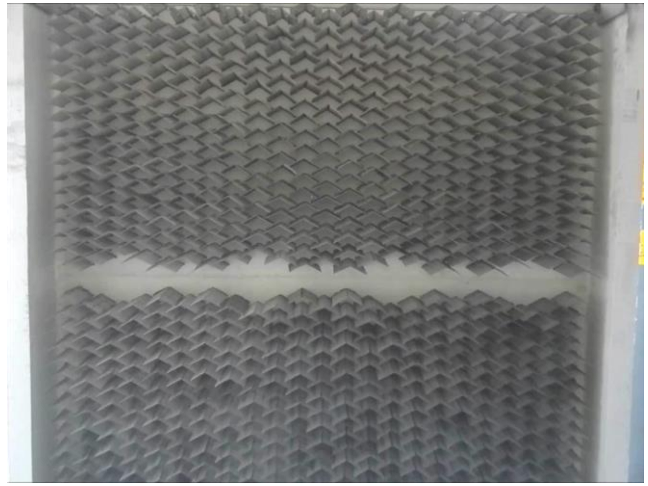
Receiver

- Thermal efficiency
  - Minimize convective/radiative heat loss
- Particle mass flow control
  - Maintain particle outlet temperature
- Damage/overheating of refractory receiver walls
- Particle emissions / inhalation hazards

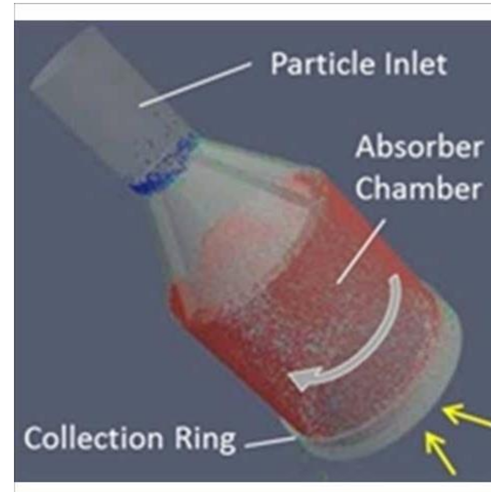


Particle Receiver Designs

Free-Falling (SNL)



Obstructed Flow (KSU, GT)



Centrifugal (DLR)

Mitigate risks associated with thermal efficiency, cost, and capacity

Fluidized Bed (CNRS/PROMES)

Receiver Innovations

Multistage Release

- Increases particle curtain opacity
  - Mitigates dispersion with longer drop distances
- Reduces particle loss and impact of wind
- Scalable to commercial systems 10 – 100 MW_e

Free Falling

Staged Falling

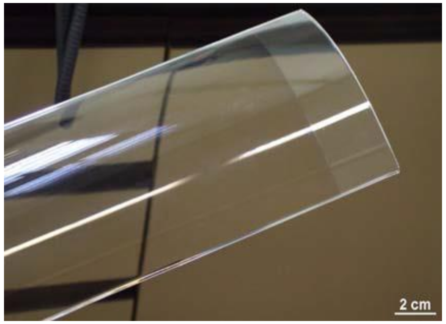
From Jin-Soo Kim (CSIRO)

Patent Pending

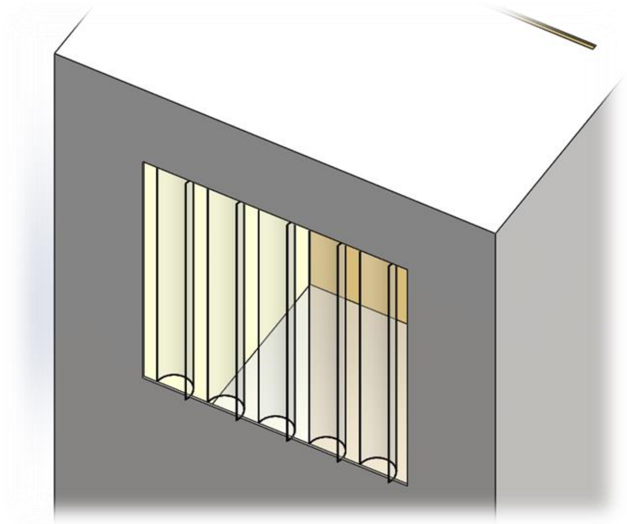
Receiver Innovations

Aperture Covers / Wind Diverters

- Quartz glass transmits solar radiation but creates a barrier to thermal radiation loss, wind, and convection loss
- Soiling of glass windows and reflective losses are challenges
  - Use quartz half-shells with spacing
  - Integrate with air curtain to reduce soiling



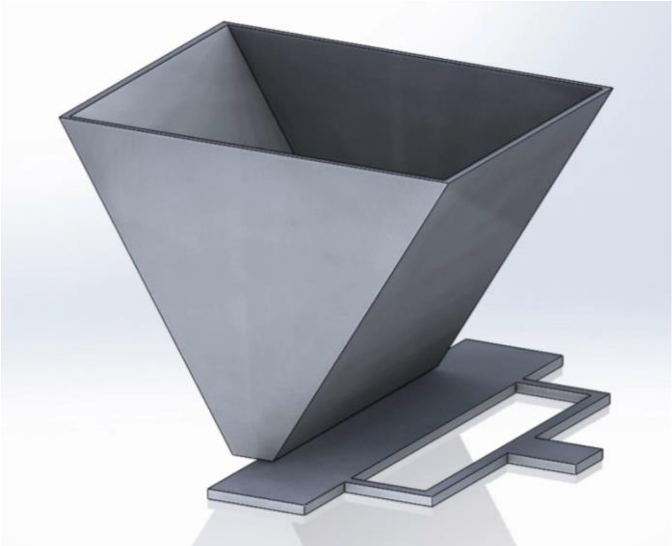
Mitigate risks of radiative/convective heat losses and particle losses while reducing reflective losses and soiling

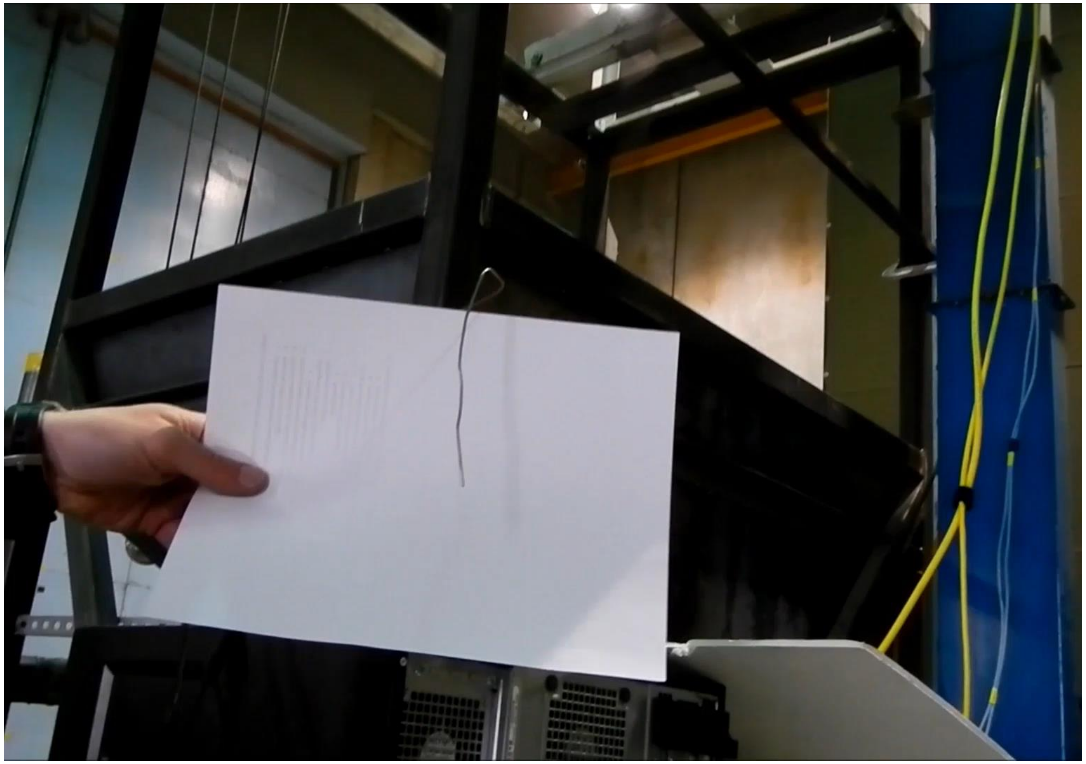


Patent Pending

Receiver Innovations

Automated Particle Mass Flow and Temperature Control





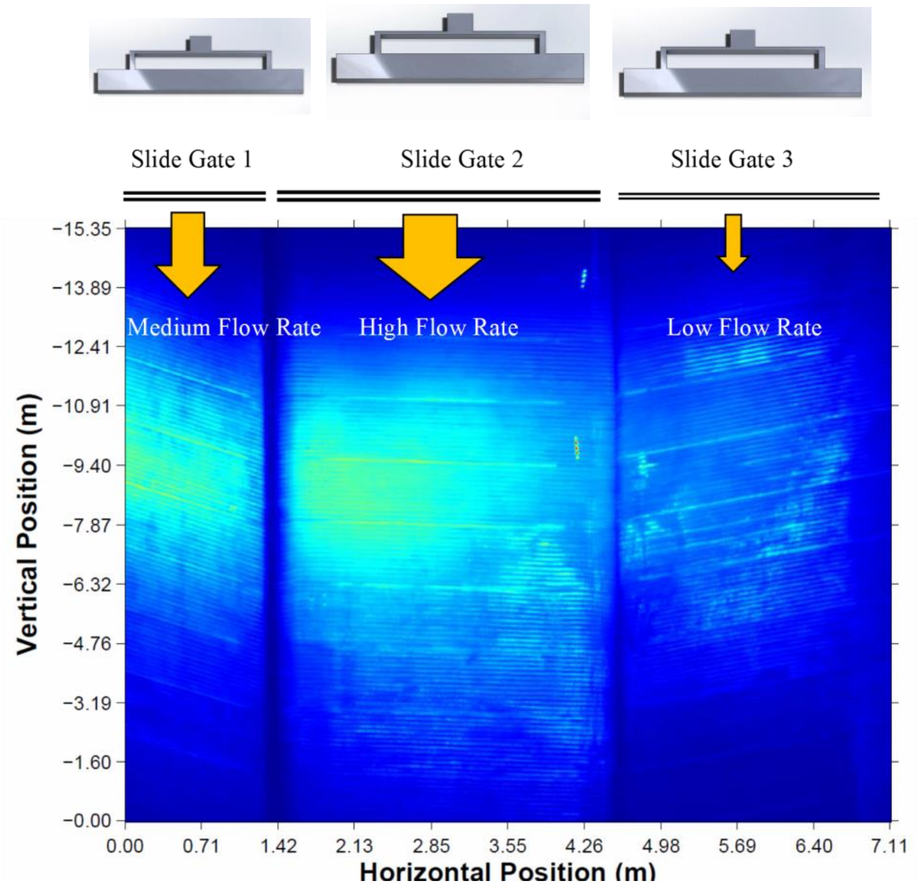
Mitigate risk of variable DNI on particle outlet temperature

Automated Particle Flow and Temperature Control

Patent Pending

Receiver Innovations

Automated Particle Mass Flow and Temperature Control



Multiple Slide Gates

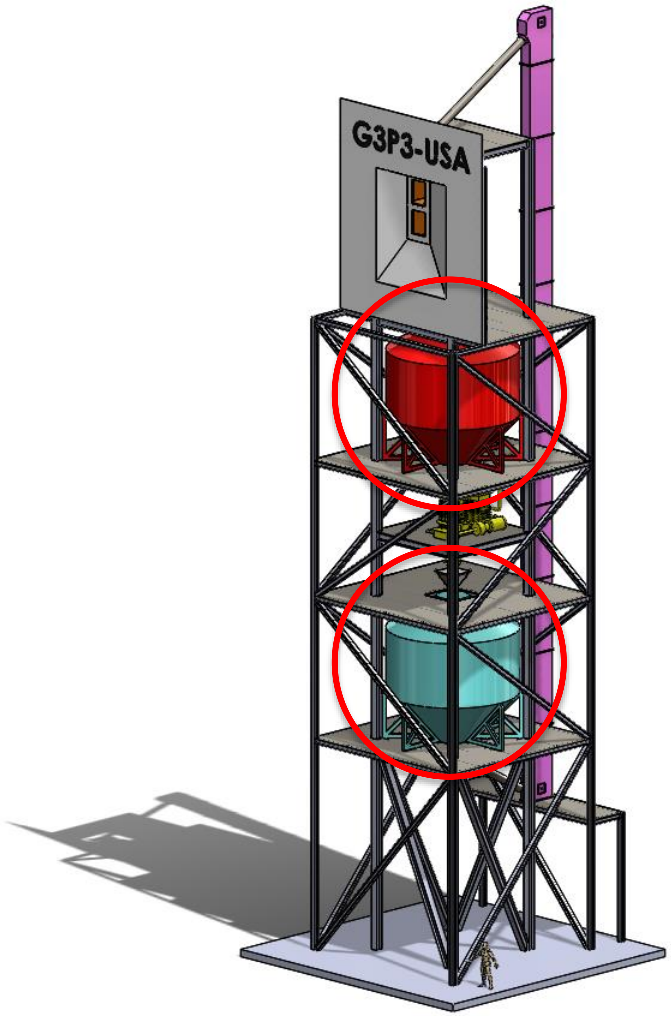
Slide gates can be "numbered up" to scale to larger systems

Mitigate risk of non-uniform and transient irradiance on heating of particles

Patent Pending

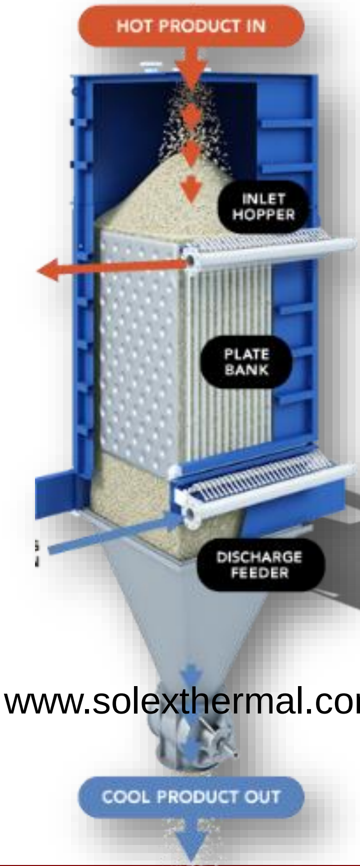
Storage System

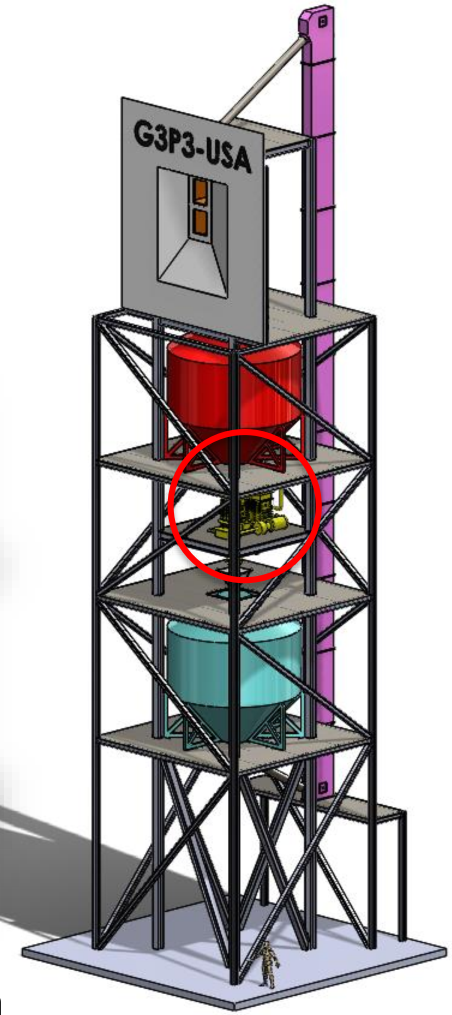
- Demonstrate charging and while minimizing heat loss
  - Robust, cost-effective insulation
  - Thermomechanical stresses
- Evaluate abrasion on interior of storage bin at temperature
  - Abrasion-resistant materials
  - Low-cost materials
- Particle-level sensing
- Scaling issues



Particle-to-sCO_2 Heat Exchanger

- Risks
  - Heat transfer to high-pressure working fluid
    - Bulk thermal conductivity very important for moving packed beds
    - Fluidization?
  - Thermomechanical stresses / fatigue
  - Erosion
  - Cost
- Sandia, Solex and VPE have developed a moving packed-bed heat exchanger design for particle-to-sCO_2 heat transfer





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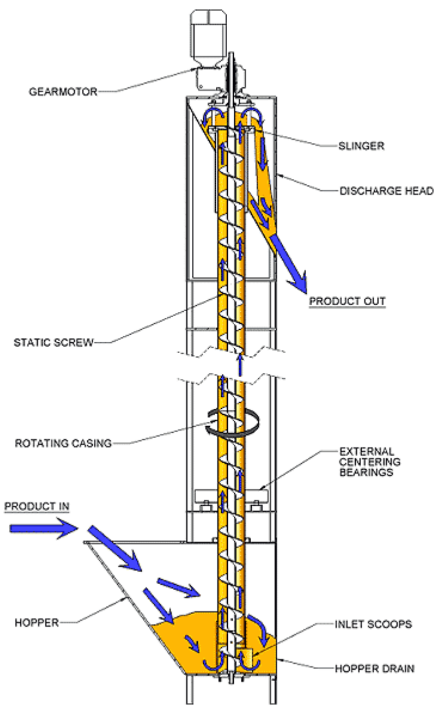
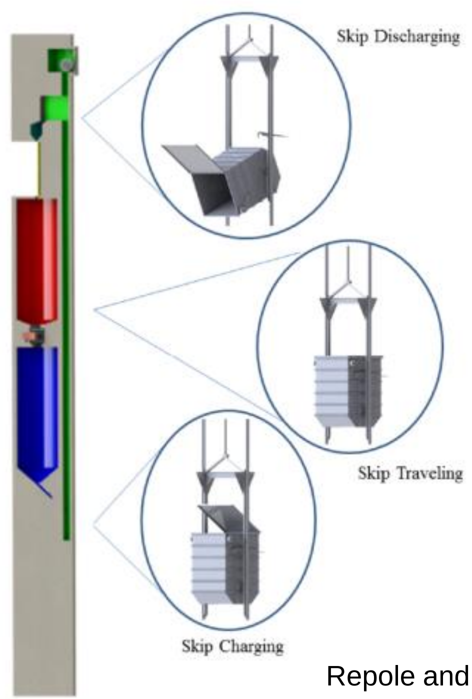
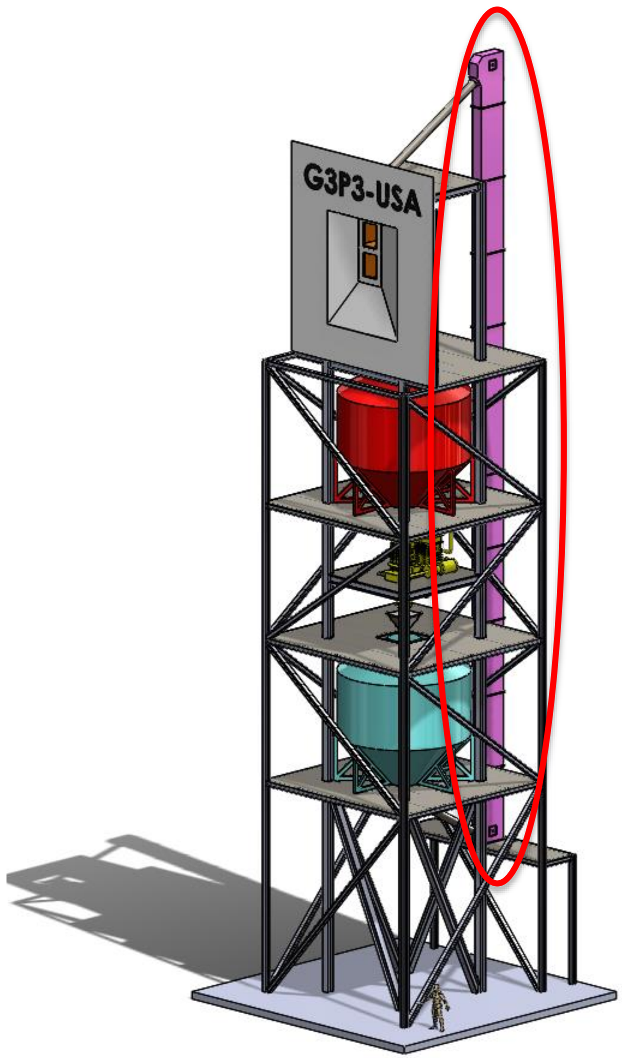
Particle Lift

- Low particle abrasion and attrition
- High efficiency
- Insulation
- Sufficient flow capacity and control



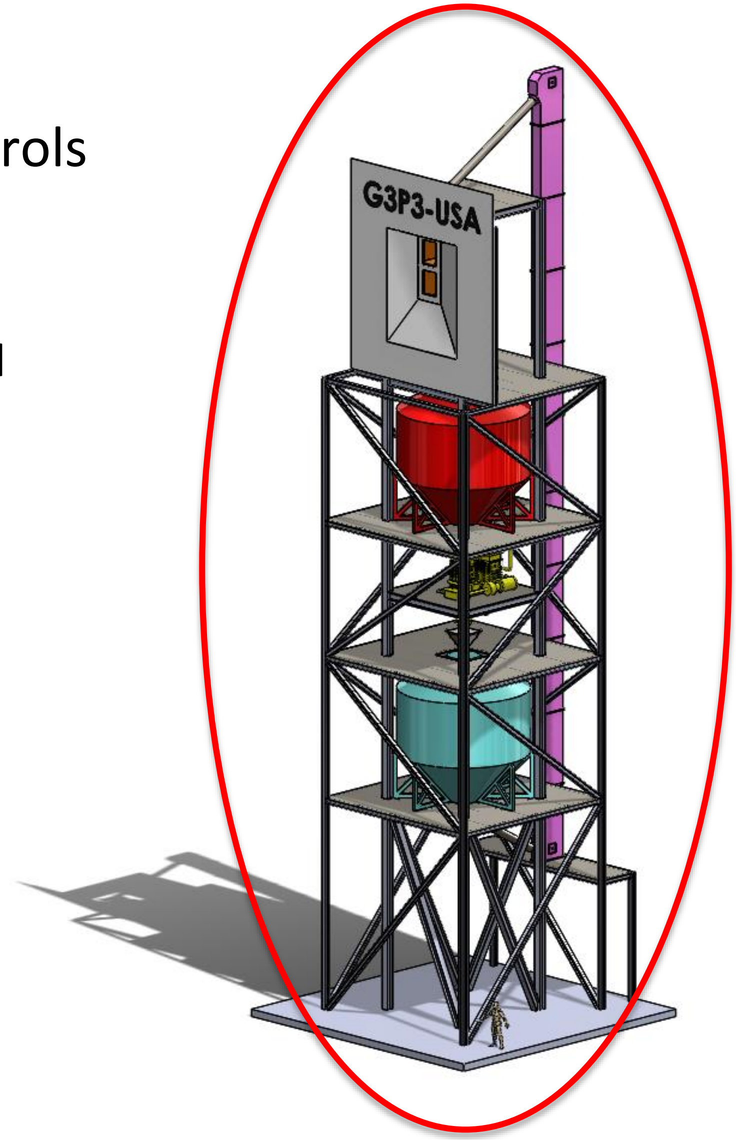




Repole and Jeter (2016)

Balance of System

- System instrumentation and controls
  - Diagnostics
  - Bypass valves for startup/shutdown
  - Isolation valves for maintenance and emergency shutdown
  - Particle mass flow monitoring
  - Particle level sensing
- Duct work
  - Differential thermal expansion
  - No need for hermetic seals



Overview

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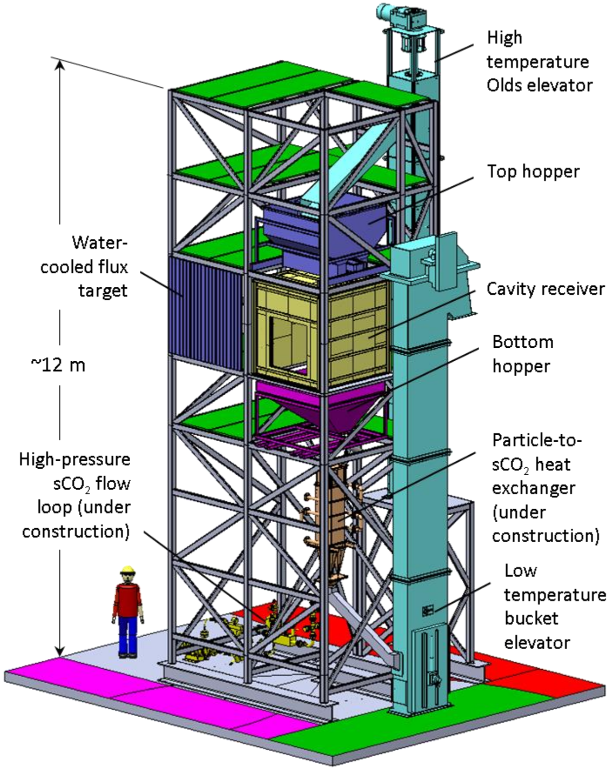
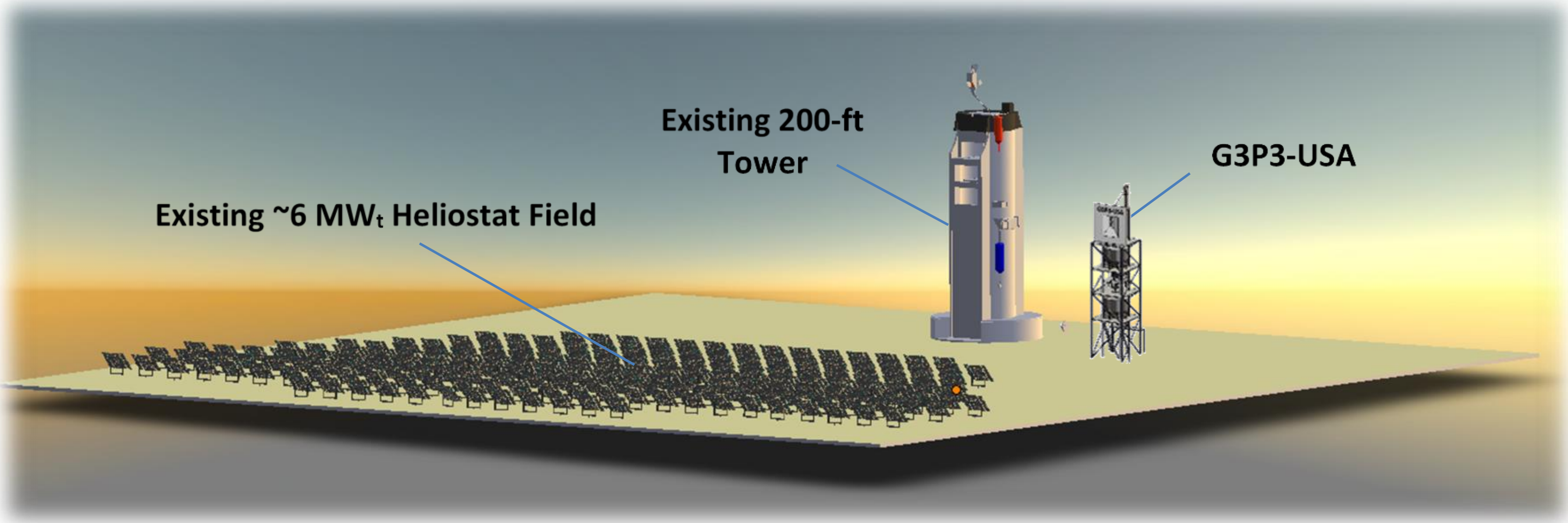
Gen 3 Particle Pilot Plant (G3P3)

- Significant advantages
  - Direct heating of particles
    - Wide temperature range (sub-zero to >1000 °C)
    - Inexpensive, durable, non-corrosive, inert
  - Demonstrated ability to achieve >700 °C on-sun with hundreds of hours of operation
- Gaps and risks
  - Particle attrition and wear; dust formation
  - Heat loss (receiver, storage, heat exchanger, lift)
  - Particle-to-working-fluid heat transfer
  - Thermomechanical stresses in heat exchanger and storage tanks
  - Materials erosion



On-sun testing of the falling particle receiver at Sandia National Laboratories

Questions?



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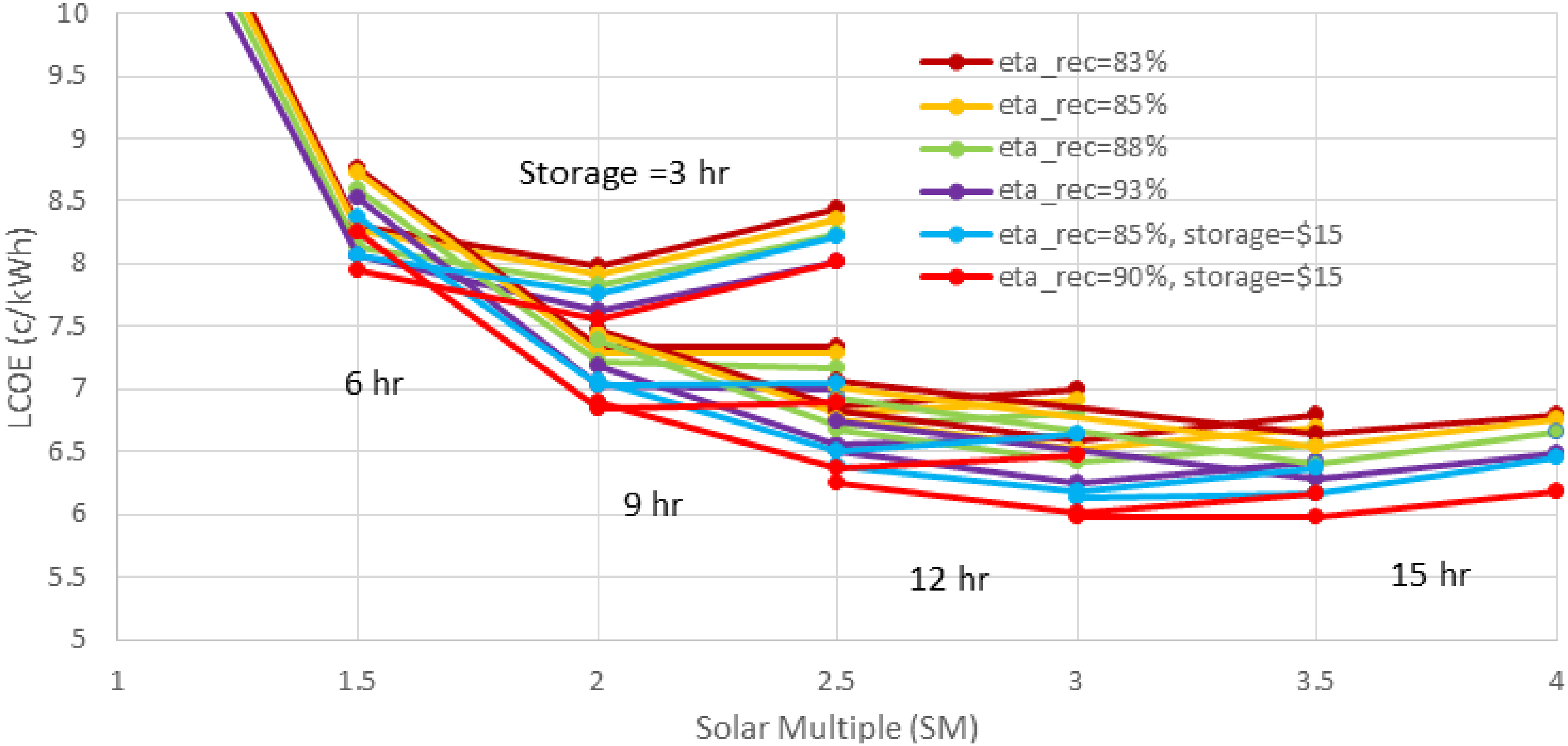
BACKUP SLIDES

Economics of Commercial Scale System

Sandia National Laboratories

SAM Modeling of LCOE for 100 MW_e Particle Power Tower

Particle receiver and storage costs from [15] were used except where noted. All other costs assume SunShot targets.



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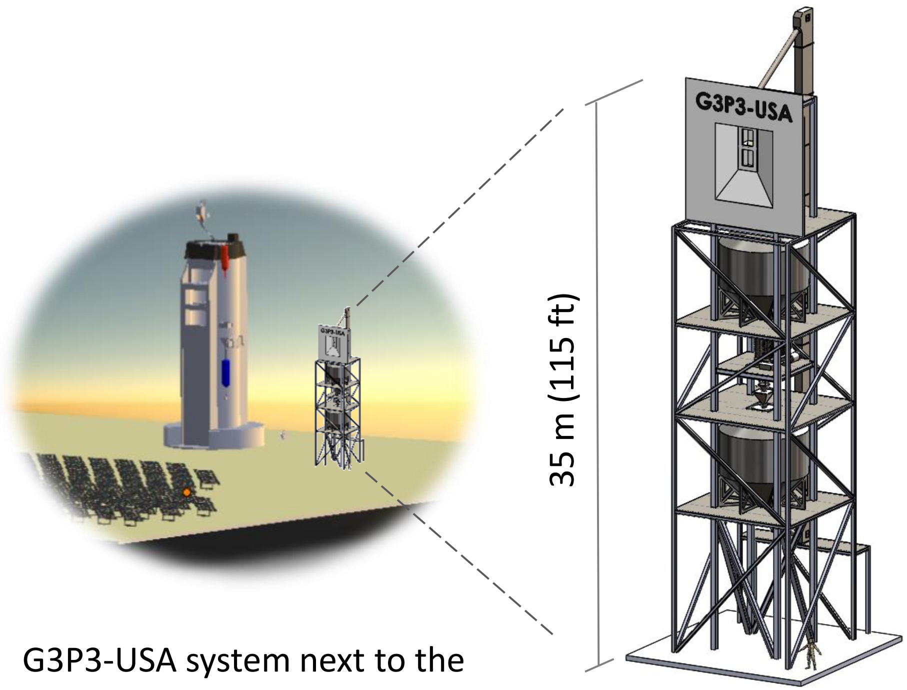
G3P3-USA



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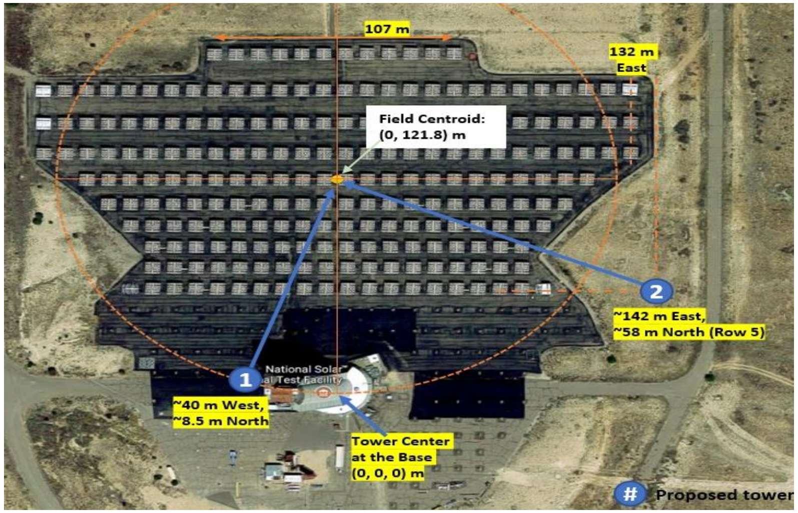

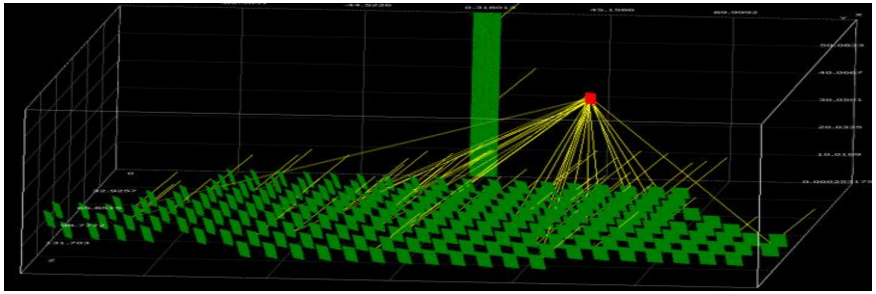

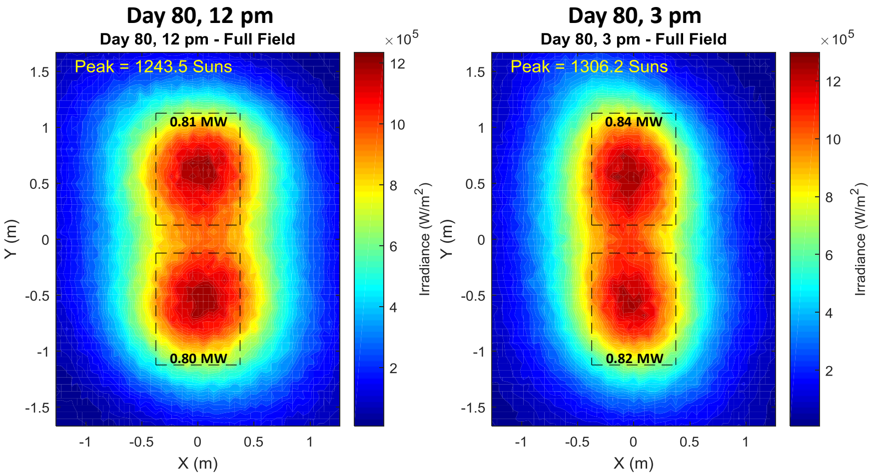

Properties of Alternative Particles

Material	Composition	Properties: Density (kg/m^3)	Properties: Specific Heat (J/kg-K)	Advantage	Dis-advantage
Silica sand	SiO_2	2,610	1,000	Stable, abundant, low cost	Low solar absorptivity and conductivity; inhalation risk
Alumina	Al_2O_3	3,960	1,200	Stable	Low absorptivity
Coal ash	SiO_2, Al_2O_3, + minerals	2,100	720 at ambient temperature	Stable, abundant, No/low cost	Identify suitable ash, attrition
Calcined Flint Clay	SiO_2, Al_2O_3, TiO_2,Fe_2O_3	2,600	1,050	Mined abundant	Low absorptivity, attrition
Ceramic particles	75% Al_2O_3, 11%SiO_2, 9%Fe_2O_3,3%TiO_2	3,300	1,200 (at 700°C)	High solar absorptivity, stable	Relatively higher cost

Mitigate risks of attrition, high cost, and low heat absorption