G3P3 Panel:

Technoeconomic and Scaling Considerations for Gen3 Particle Technology

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U.S. Department of Energy Gen3 Summit, G3P3 Panel

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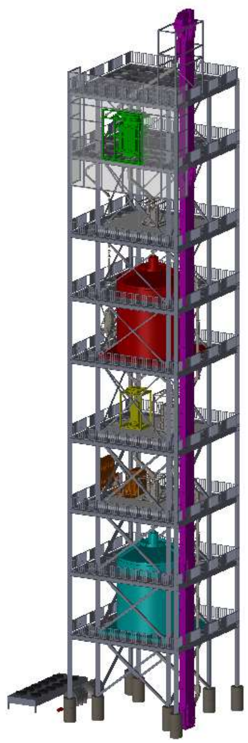
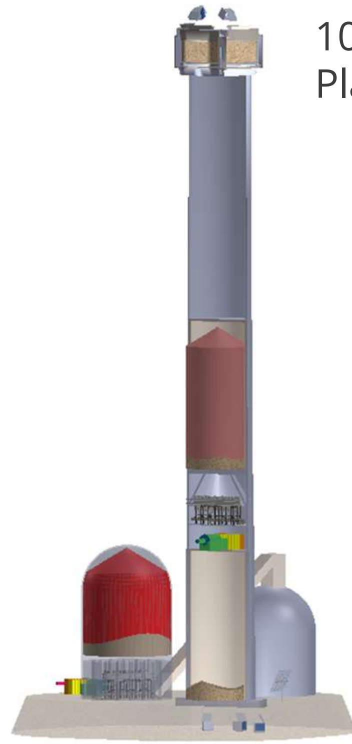
Comparison of 1 MW and 100 MW_e concepts

1 MW_t Particle Pilot Plant Design



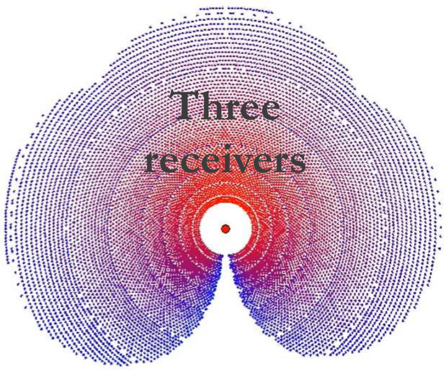
100 MWe Particle CSP Plant Concept

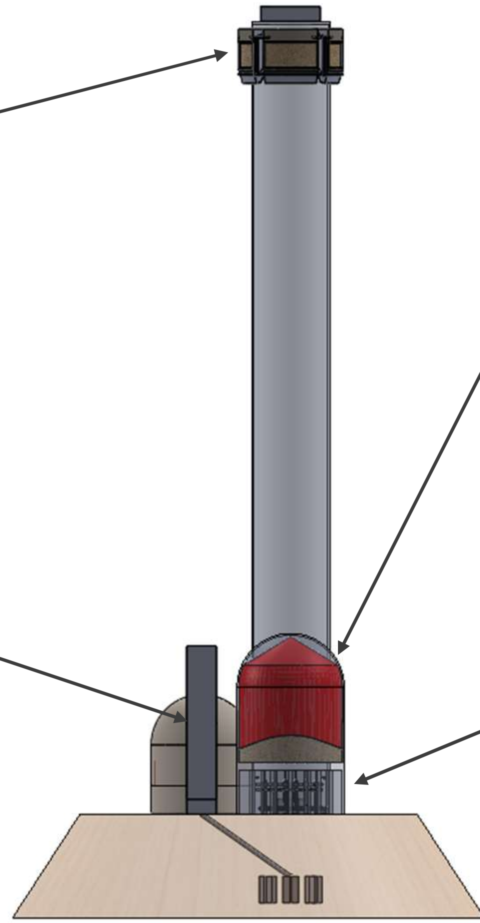


Design decisions as system increases size from pilot to commercial scale:

- What is the preferred tower construction method and height to meet optical power requirements?
- Should storage be vertically integrated in to the tower or ground-based?
- What is the preferred method of particle conveyance and flow control?
- Should thermal equipment (receiver, storage bin, heat exchanger, lift) scale in number or size?
- Should particle cost or properties be prioritized (naturally occurring or engineered)?

Component Scaling Considerations





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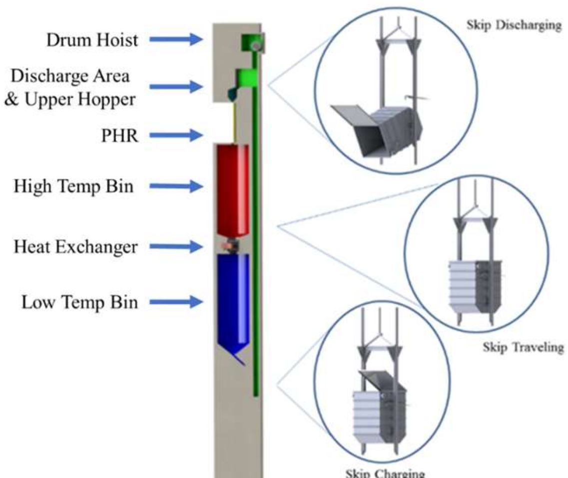
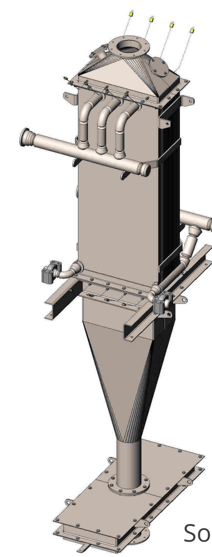


Repole and Jeter (2016)



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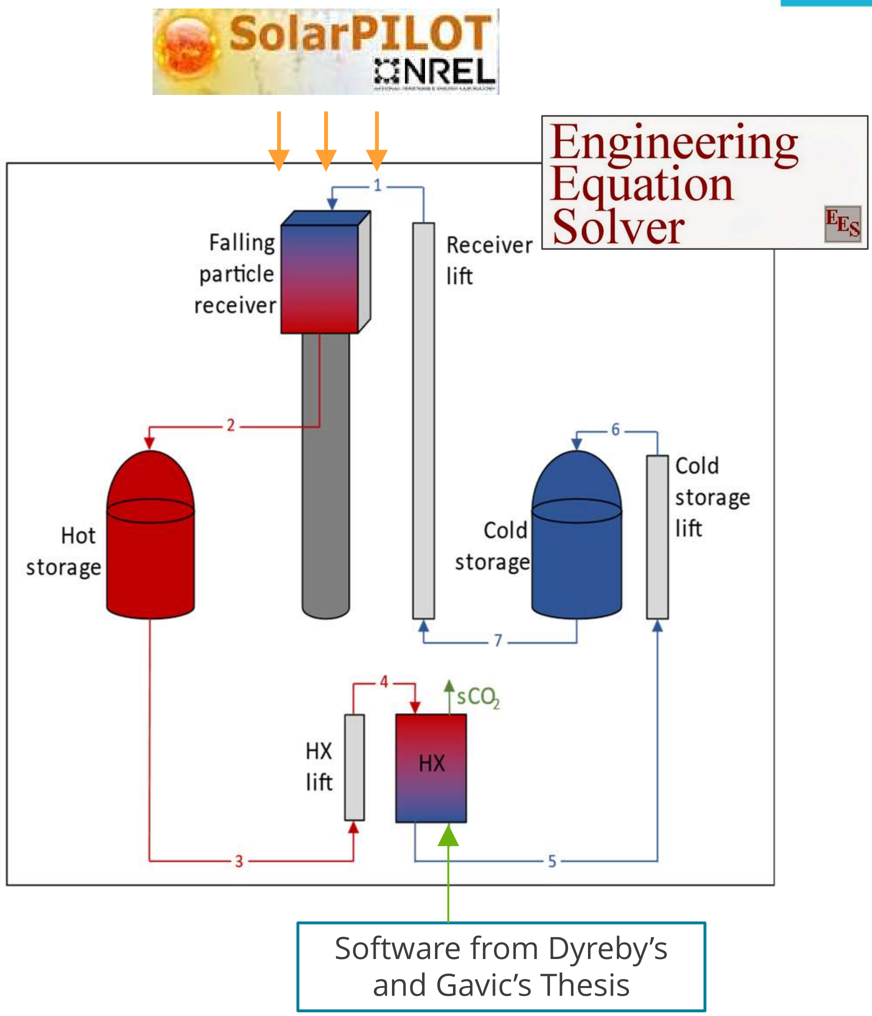
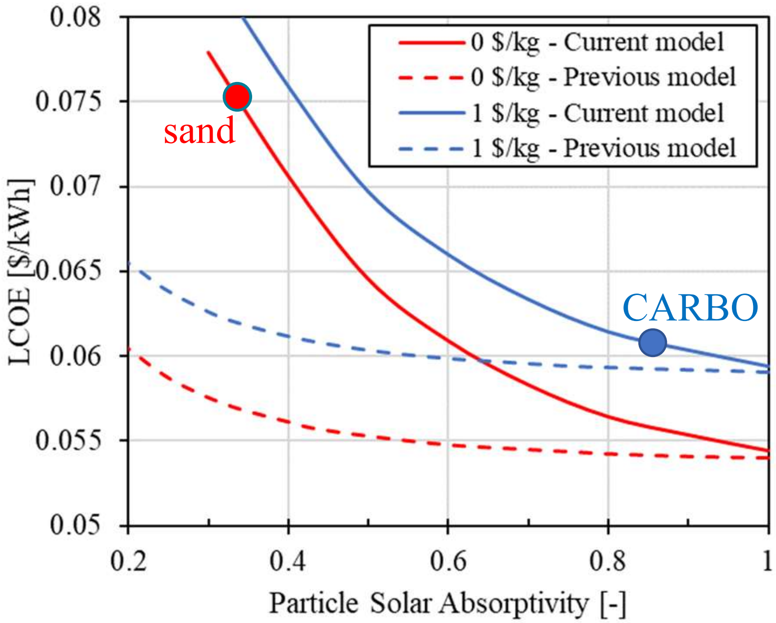
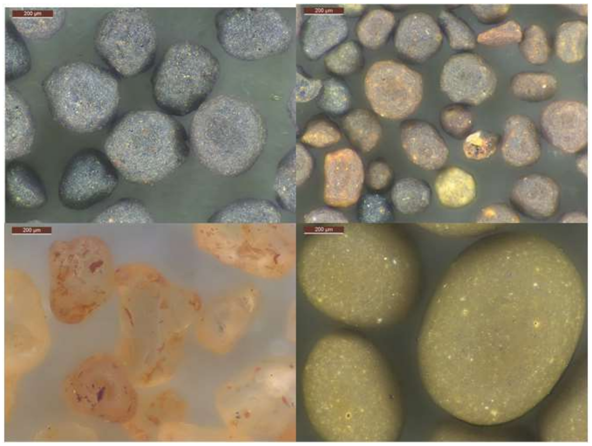
Technoeconomic System Analysis

- Techno-economic model for a commercial particle plant developed for LCOE analysis
- Cost and performance models developed from vendor quotes and prototype designs
- Model
  - Solar field modeled with SolarPILOT
  - Power cycle modeled with Software from Dyreby's and Gavic's Thesis
  - Particle-based components developed in EES
    - Receiver
    - Storage
    - Lifts
    - Primary heat exchanger



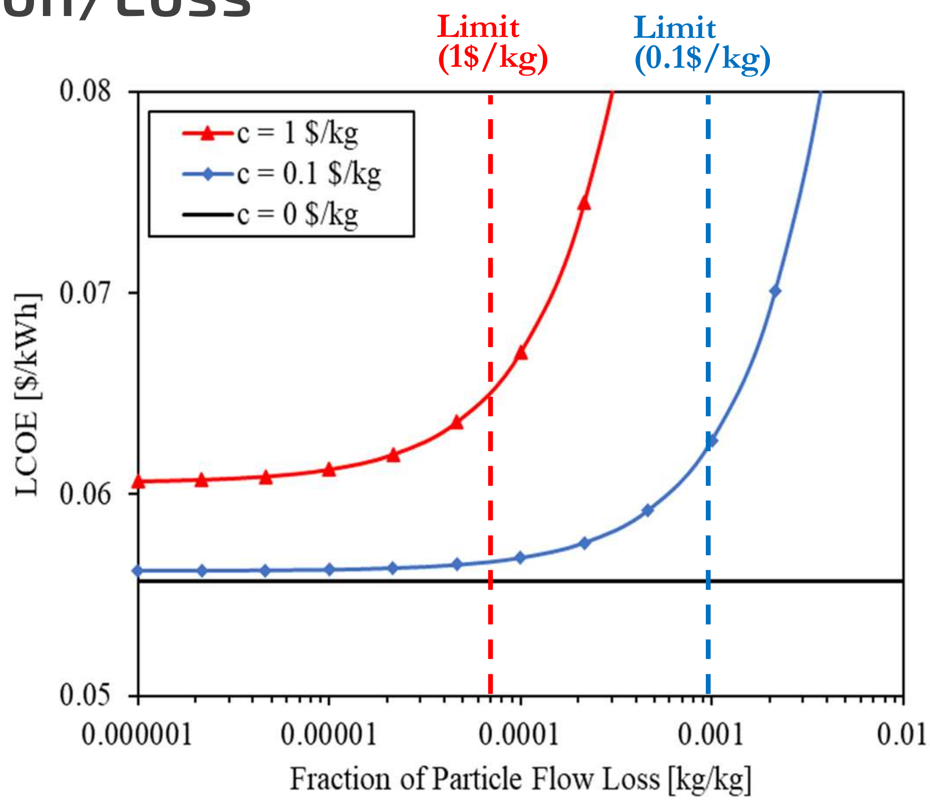
Particle Receiver – Optical Properties





- Analytical model developed to calculate the apparent optical properties in a curtain from intrinsic particle surface
- Free particles must have an absorptivity above 60% to improve LCOE compared to CARBO
- Particle durability and flow properties must also be considered when evaluating tradeoffs

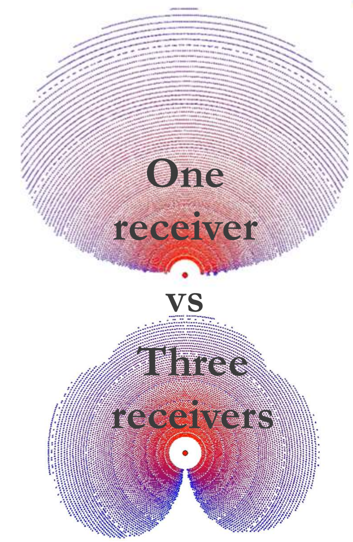
Particle Attrition/Loss



- Non-hermetically sealed particle system with directly irradiated receiver can be susceptible to particle loss
- Particle loss can significantly impact LCOE if rate exceeds 0.001% of system throughput
- LCOE is less sensitive to lower cost particles, but loss rate should never exceed 0.1% of system throughput

Probabilistic Analysis

- A probabilistic analysis was performed to quantify LCOE uncertainty and identify key parameters that impact the LCOE
- Four independent particle-based CSP configurations were studied:
  - One receiver and ground storage
  - One receiver and tower-integrated storage
  - Three receivers and ground storage
  - Three receivers and tower-integrated storage
- Uncertainty distributions were assigned to component costs and performance parameters that are unknown

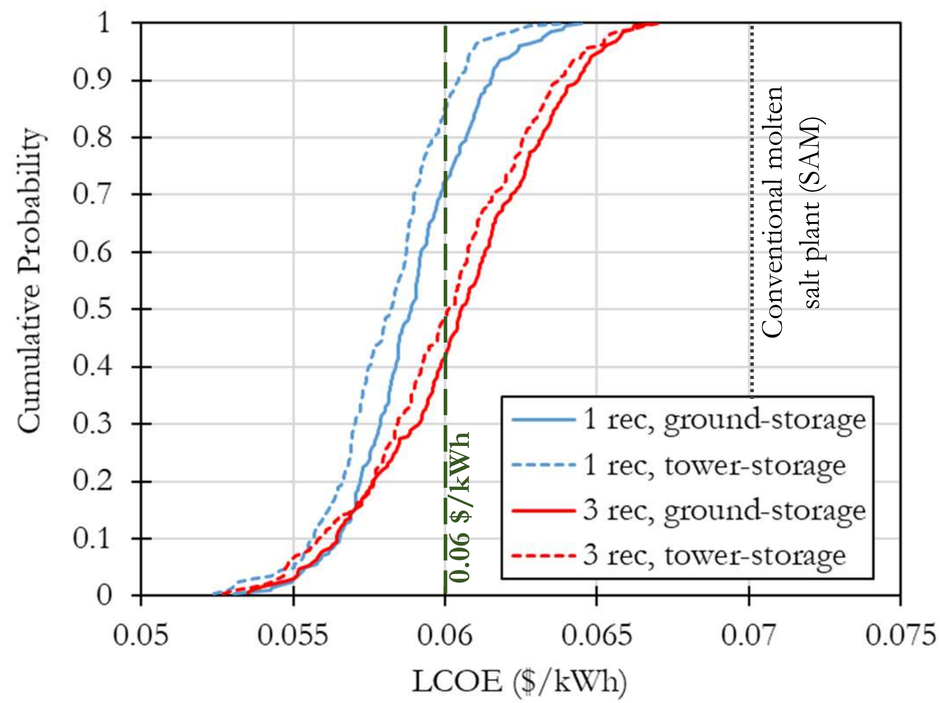


Parameter Uncertainties

		Variable	Units	Desgin Value	Min Value	Max value
ALL MODELS	Cycle	Compressor efficiency	-	0.8	0.8	0.89
		Turbine efficiency	-	0.87	0.87	0.93
	Rec	Particle cost	$/kg	1	0.75	1.25
	BOP	BOP cost	$/kWe	167	125.25	208.75
	PHX	PHX cost	$/m^2	6594.5	4158	9031
		Flow disribution/piping cost	$-s/kg	4753	3564.75	5941.25
1-REC MODEL	Rec	Cavity cost	$/m2	37400	28050	46750
	lift	Lift cost	$-s/m-kg	58.37	43.7775	72.9625
3-REC MODEL	Rec	Cavity cost	$/m2	48620	36465	60775
	lift	Lift cost	$-s/m-kg	116.74	58.37	175.11
GROUND-BASED TES	Tower	Tower cost fixed	$	1194300	725696	1648700
	TES	Bins cost	$/m^0.675	133.11	72.566	196.43
	PHX	Horizontal conveyor + Flow control + hoppers	$-s/kg	9153	6864.75	11441.25
TOWER INTEG TES	Tower + TES	Tower cost variable	-	0.5	0	1
	PHX	Flow control + hoppers	$-s/kg	1946	1459.5	2432.5

Probabilistic Analysis – Results

- **1-receiver designs**
  - Achieves lowest LCOE if receiver advective loss does not scale with size
- **3-receivers designs**
  - Results in smallest receiver aperture dimensions and tower height
  - Opportunity to incorporate redundancy in receiver and particle conveyance system
- **Tower-storage designs**
  - Achieve lower LCOE than designs with ground-based storage in non-seismic areas
- **All Configurations**
  - Similar LCOE probability for < 0.06 $/kWh



Conclusions/Future Work

- Most likely configuration for commercial scale particle-based CSP system will incorporate three falling particle receivers, ground-based storage, skip hoist conveyance, and moving packed-bed heat exchangers
- Future technoeconomic studies should look to incorporate:
  - Transients for starting and stopping components
  - Active heliostat control and aiming strategy
  - Identify break point for ground-based vs. vertically-integrated storage
- Component analysis at commercial scale should focus on:
  - Allowable heat exchanger ramp rate and lifetime for shell and plate moving-packed bed design
  - Storage bin design and thermal performance for ground or tower based systems
  - Improved receiver predictions for advective heat loss in open cavity receivers
  - Demonstrations of commercial skip hoist charging and discharging with measured heat loss

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