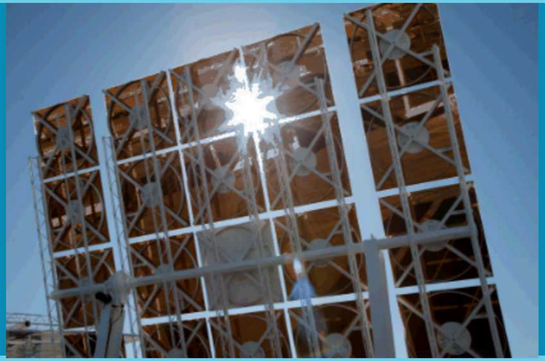
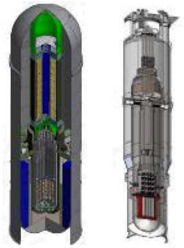
SAND2019-14235PE

Zero-Carbon Emission Power Generation Technologies





PRESENTED BY

Clifford K. Ho and Danielle Redhouse

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Introduction

National Nuclear Security Administration labs

Science labs

Nuclear energy lab

Environmental management lab

Fossil energy lab

Energy efficiency and renewable energy lab

Sandia is one of 17 U.S. National Laboratories

Sandia's National Security Mission

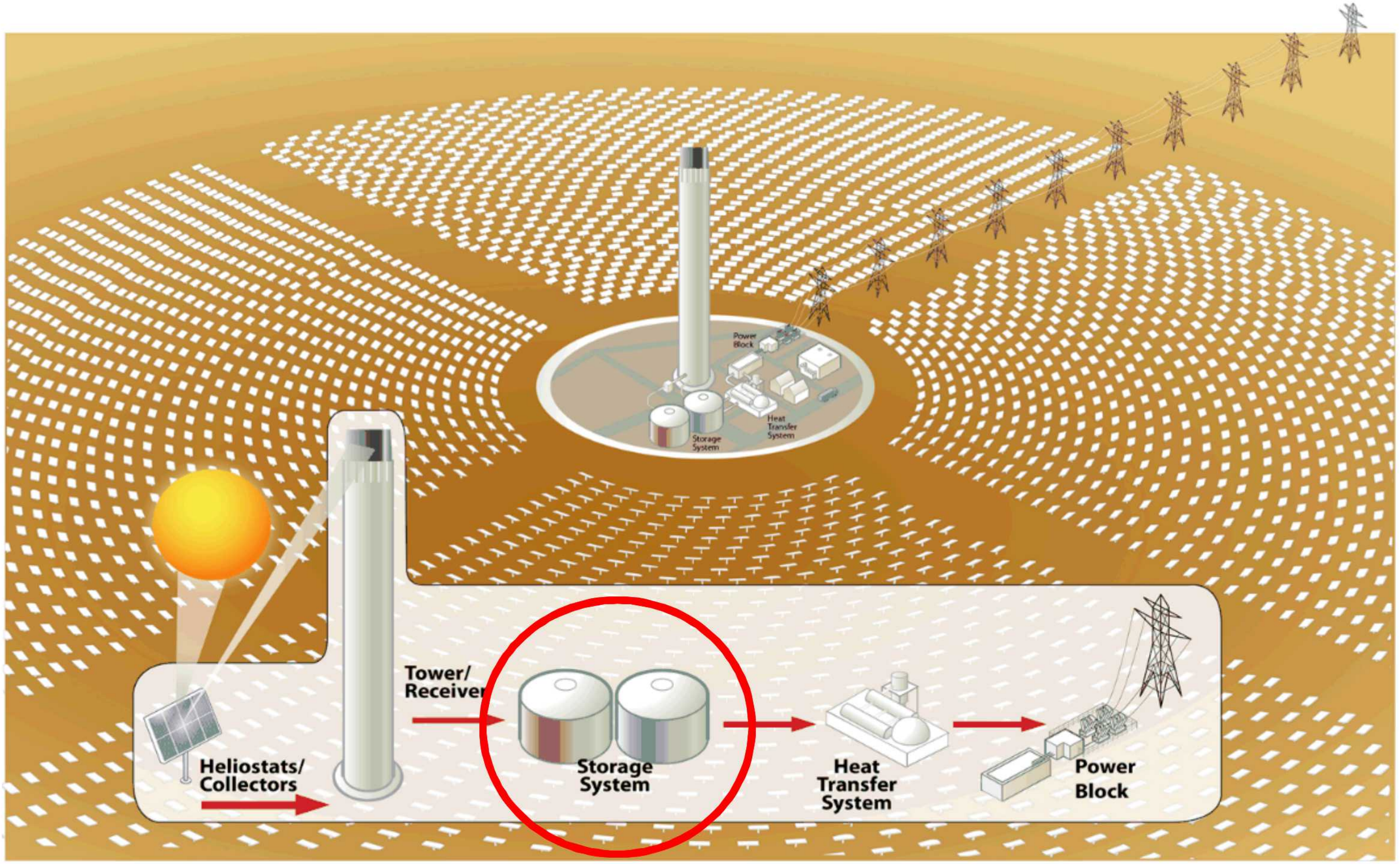
- Nuclear Deterrence
- Nuclear Nonproliferation
- National Security Programs
- Energy & Homeland Security
- Advanced Science & Technology

Energy Research at Sandia

- Renewable Energy
  - Solar photovoltaics
  - Concentrating solar thermal power
  - Wind energy
  - Marine and hydrokinetic energy
  - Geothermal energy
- Energy Storage
  - Thermal, thermochemical
  - Batteries
  - Hydrogen
- Nuclear Energy
  - Small modular reactors

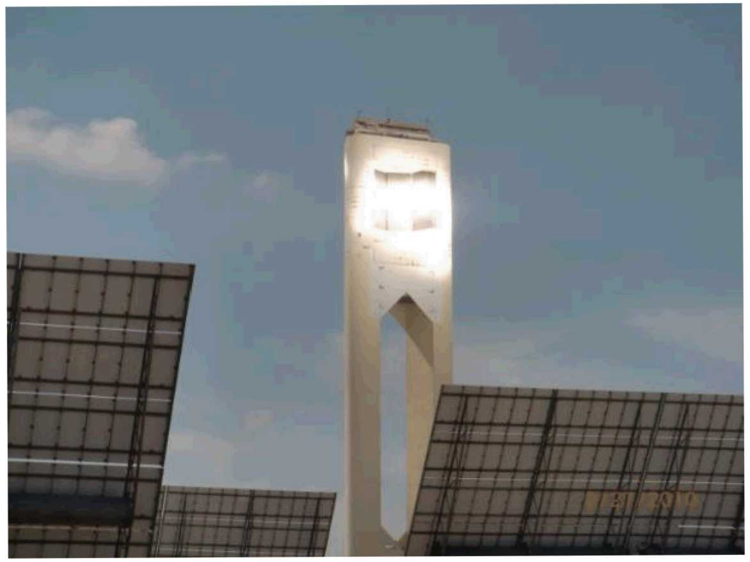
CSP and Thermal Energy Storage

- Concentrating solar power uses mirrors to concentrate the sun's energy onto a receiver to provide heat to spin a turbine/generator to produce electricity
- **Hot fluid can be stored as thermal energy efficiently and inexpensively** for on-demand electricity production when the sun is not shining



PS10 and PS20 (Seville, Spain)

- First commercial power tower plants in the world (2007, 2009)
- 11 MW and 20 MW
- Saturated steam
  - 250 C, 45 bar steam, wet cooling



Ivanpah Solar Power Tower
California (near Las Vegas, NV)

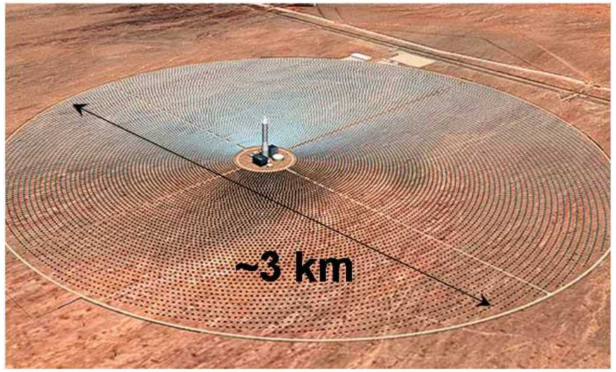
http://news.nationalgeographic.com

Three towers, 392 MWe, superheated-steam at 540 C, 160 bar, air-cooled (2014)

Gemasolar
(near Seville, Spain)

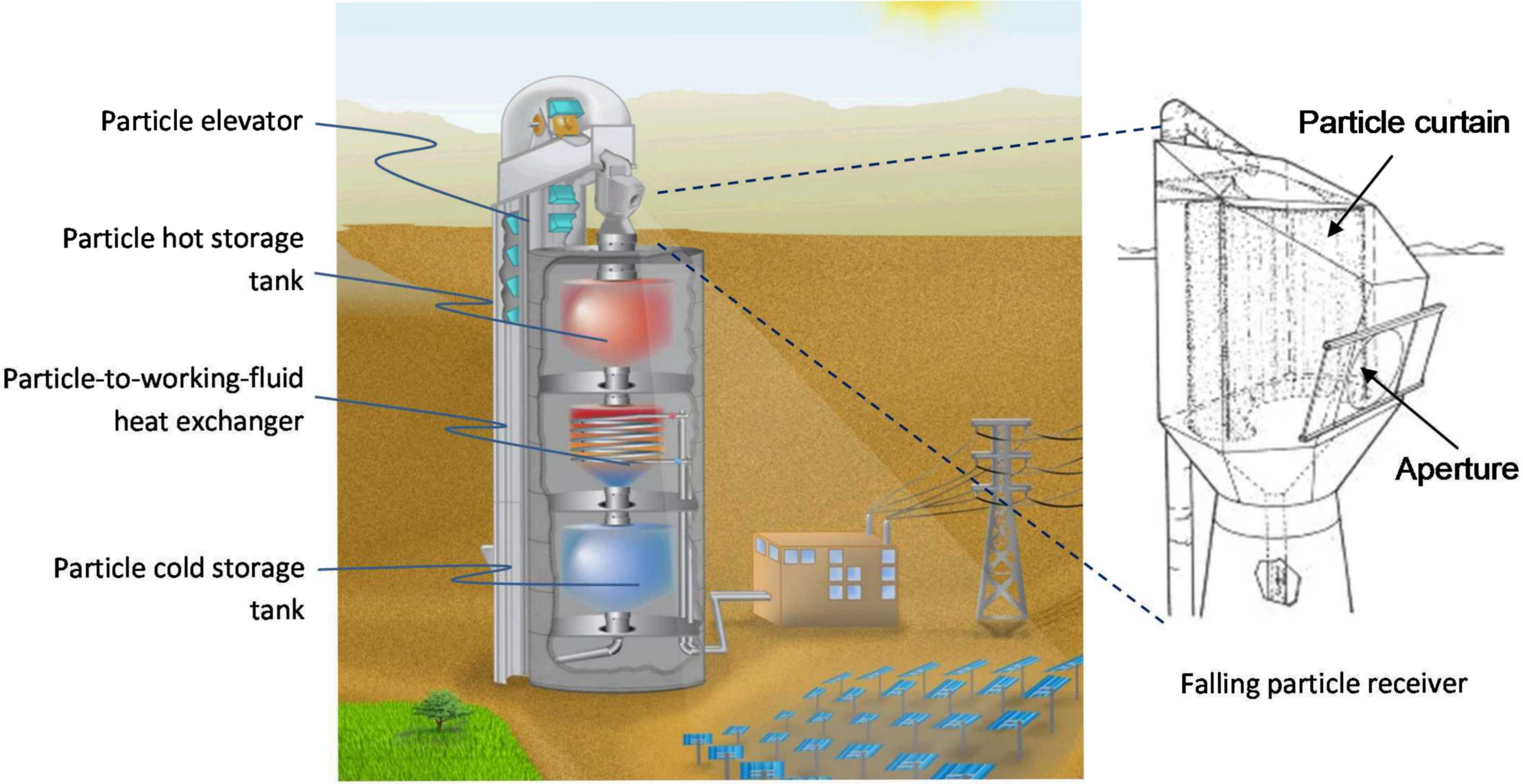
- 1st commercial power tower (19 MW) in the world with "24/7 dispatchable energy production" (15 hours of thermal storage using molten salt), wet cooling. Commissioned in May 2011.

Crescent Dunes
Tonopah, Nevada



110 MWe, 570 C molten-salt, 10 hours of storage, hybrid air-cooled condenser (2015)

High Temperature Falling Particle Receiver



Falling particle receiver

National Solar Thermal Test Facility
Sandia National Laboratories

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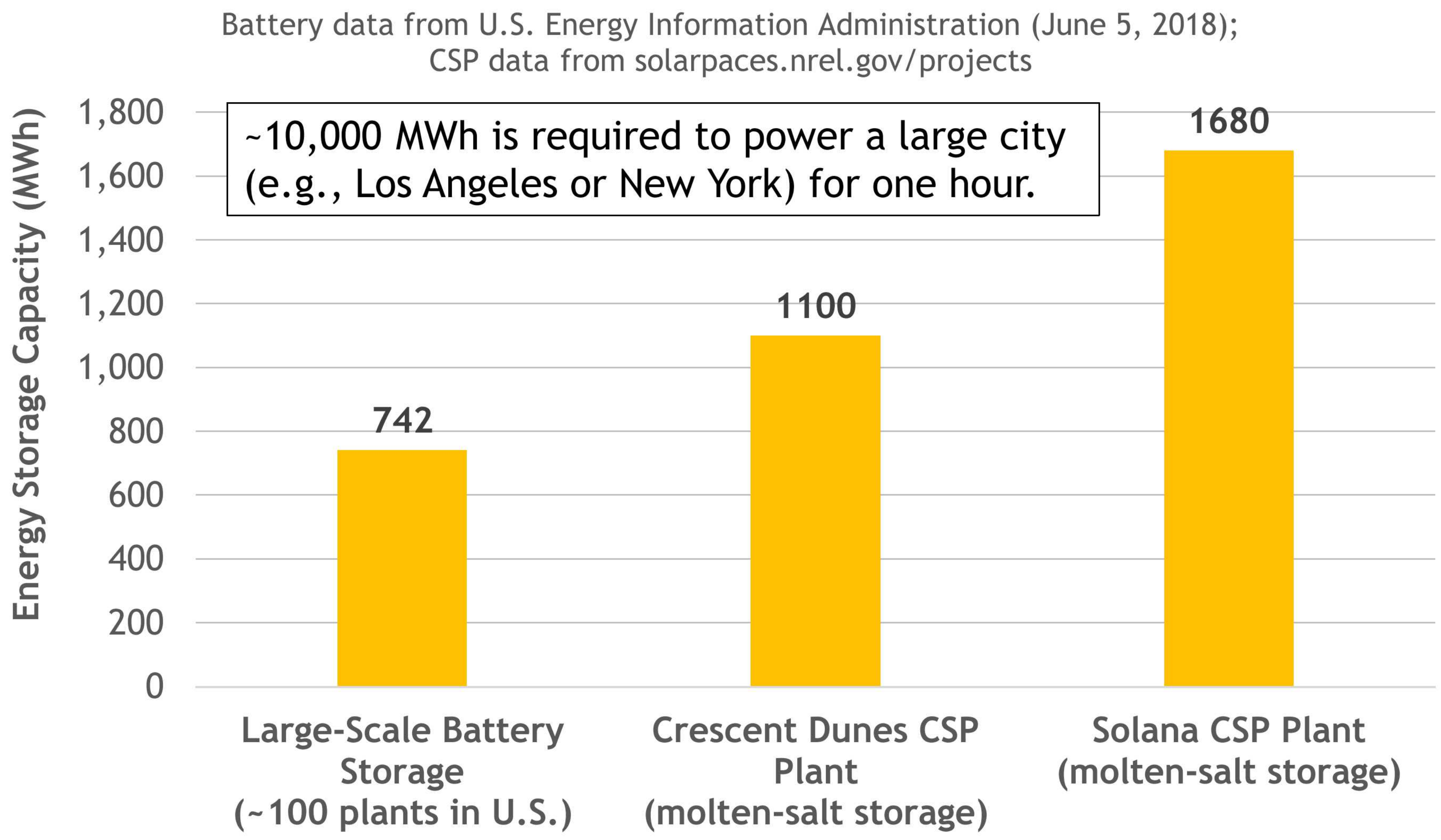
Comparison of Large-Scale Battery and Thermal Energy Storage Capacity in the U.S.



Solana Generating Station

280 MW parabolic trough plant
Phoenix, AZ (Gila Bend)
Started 2013

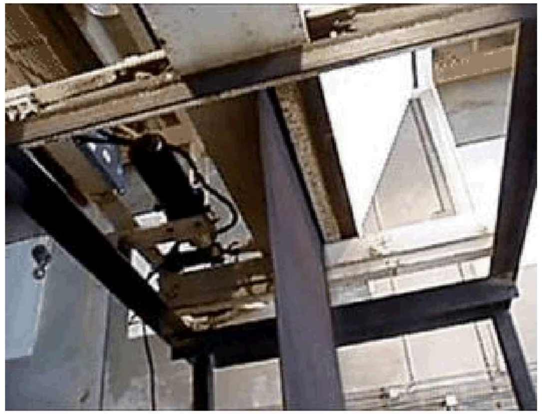
futurenergyweb.es

6 hours of molten-salt storage heated from ~300 – 400 C (1.7 GWh)

Types of Thermal Energy Storage

- Sensible (single-phase) storage
  - Use temperature difference to store heat
  - Molten salts (nitrates <600 C; carbonates, chlorides 700 – 900 C)
  - Solids storage (graphite, concrete, ceramic particles), >1000 C
- Phase-change materials
  - Use latent heat to store energy (e.g., molten salts, metallic alloys)
- Thermochemical storage
  - Converting solar energy into chemical bonds to store energy (e.g., decomposition/synthesis, redox reactions)

Molten-salt storage tanks at Solana CSP plant in Arizona. Credit: Abengoa



Falling particles for direct solar heating

Energy Storage R&D at Sandia

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

Sandia Hydrogen R&D

Sandia provides deep, quantitative understanding and a scientific basis for…

Materials – for hydrogen <u>production</u>, <u>storage</u> and <u>utilization</u>

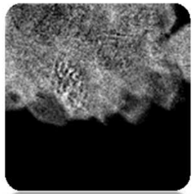
Safety – risk analysis and the creation of risk-informed standards

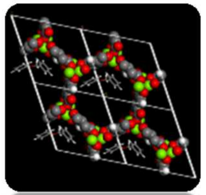
Hydrogen Production from Renewables

Advanced water-splitting materials and technologies for large-scale H_2 production

Hydrogen Storage Materials and Solutions

Discovering the behavior and performance of solid storage materials

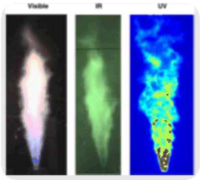




Hydrogen-Materials Compatibility

Low-cost, hydrogen-compatible materials and the science basis for their qualification

Hydrogen Fueling Infrastructure



H_2 release behavior and risk assessment to define the safety envelope for storage & delivery

Technologies for Non-Vehicle Applications

Marine and rail applications

Fuel Cells

Membrane systems for enhanced electrochemical performance

Comparison of Energy Storage Options

	Energy Storage Technology					
	Solid Particles	Molten Nitrate Salt	Batteries	Pumped Hydro	Compressed Air	Flywheels
Levelized Cost[1] ($/MWh$_e$)	10 – 13	11 – 17	100 – 1,000	150 - 220	120 – 210	350 - 400
Round-trip efficiency[2]	>98% thermal storage ~40% thermal-to-electric	>98% thermal storage ~40% thermal-to-electric	60 – 90%	65 – 80%	40 – 70%	80 – 90%
Cycle life[3]	>10,000	>10,000	1000 – 5000	>10,000	>10,000	>10,000
Toxicity/ environmental impacts	N/A	Reactive with piping materials	Heavy metals pose environmental and health concerns	Water evaporation/ consumption	N/A	N/A
Restrictions/ limitations	Particle/fluid heat transfer can be challenging	< 600 °C (decomposes above ~600 °C)	Very expensive for utility-scale storage	Large amounts of water required	Unique geography required	Only provides seconds to minutes of storage

[1]Ho, C.K., A Review of High-Temperature Particle Receivers for Concentrating Solar Power, *Applied Thermal Energy*, 2016; Kolb, G.J., Ho, C.K., Mancini, T.R., Gary, J.A., 2011, Power Tower Technology Roadmap and Cost Reduction Plan, SAND2011-2419, Sandia National Laboratories, Albuquerque, NM; Akhil et al., 2015, DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, SAND2015-1002, Sandia National Laboratories, Albuquerque, NM. For solid particles and molten salt, we assume a 30 – 50% thermal-to-electric conversion efficiency and 10,000 lifetime cycles for the thermal-to-electric storage and conversion systems; the cost includes the storage media (bulk ceramic particles and sodium/potassium nitrate salts ~$1/kg with ▫T = 400 °C and 9 hours of storage), tanks, pumps/piping/valves, other parts and contingency, and the power block at $1000/kW$_e$ with 19 operating hours per daily cycle (including 9 hrs of storage) and 90% availability. For batteries, cost is based on sodium-sulfur, vanadium-redox, zinc-bromine,lead-acid, and lithium-ion batteries capable of providing large-scale electricity.
[2]Roundtrip efficiency defined as ratio of energy in to energy retrieved from storage; Djajadiwinata, E. et al., 2014, Modeling of Transient Energy Loss from a Cylindrical-Shaped Solid Particle Thermal Energy Storage Tank for Central Receiver Applications, Proceedings of the Asme 8th International Conference on Energy Sustainability, 2014, Vol 1.; Siegel, N.P., 2012, Thermal energy storage for solar power production, Wiley Interdisciplinary Reviews-Energy and Environment, 1(2), p. 119-131.; http://energystorage.org/energy-storage/energy-storage-technologies; http://energymag.net/round-trip-efficiency/
[3]Siegel, N.P., 2012, Thermal energy storage for solar power production, Wiley Interdisciplinary Reviews-Energy and Environment, 1(2), p. 119-131.

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Danielle will add slides