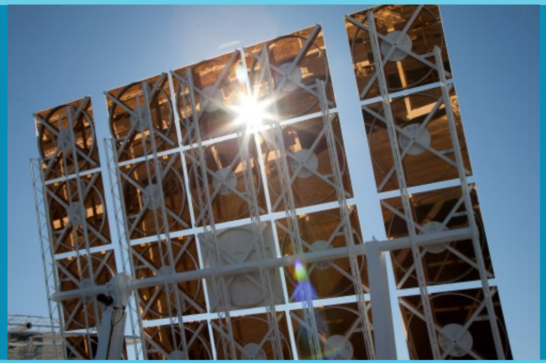
Thermal Energy Storage Technologies



PRESENTED BY

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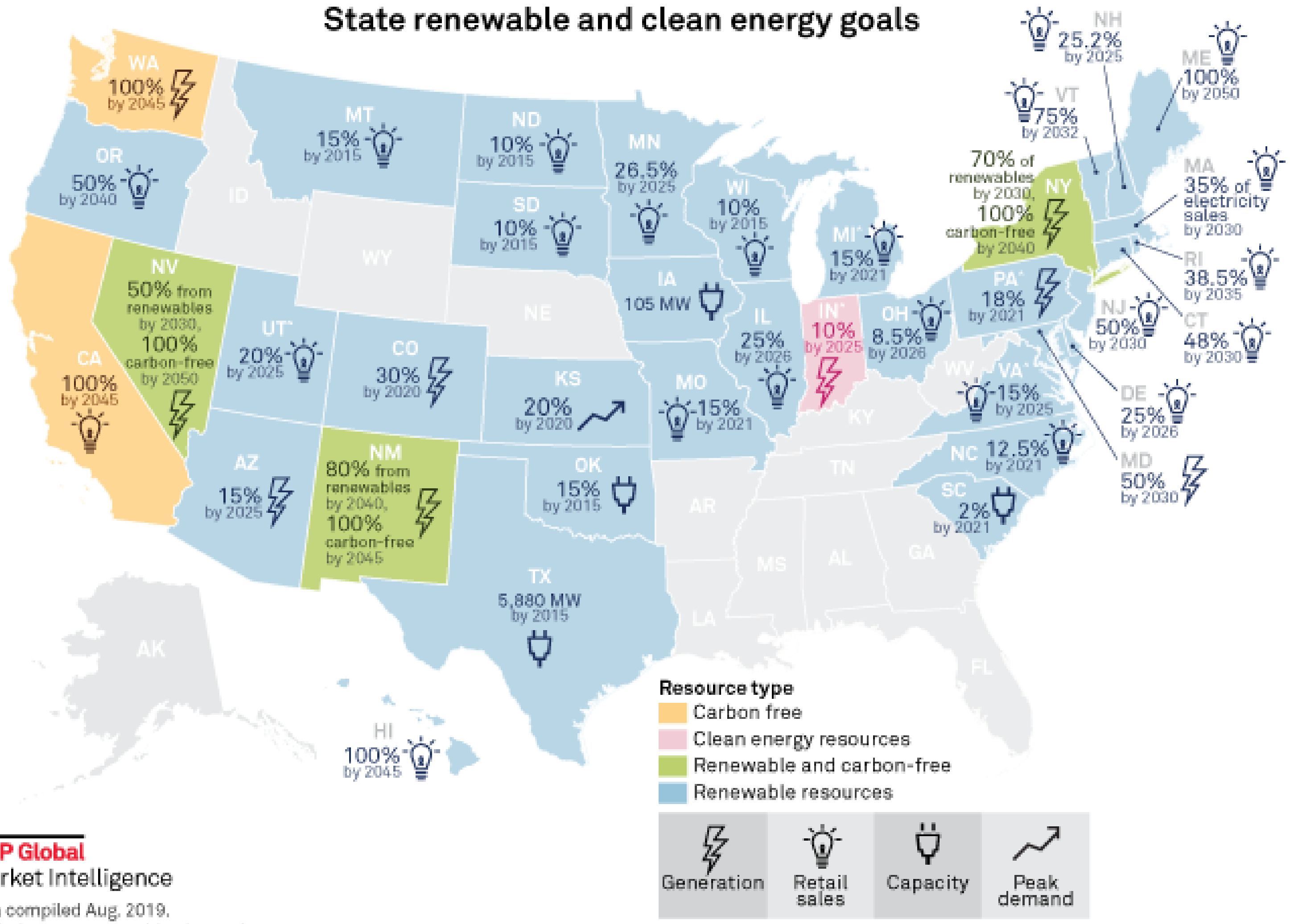
Problem Statement

Large-capacity, long-duration energy storage solutions are needed to ensure grid stability with increasing intermittent renewables

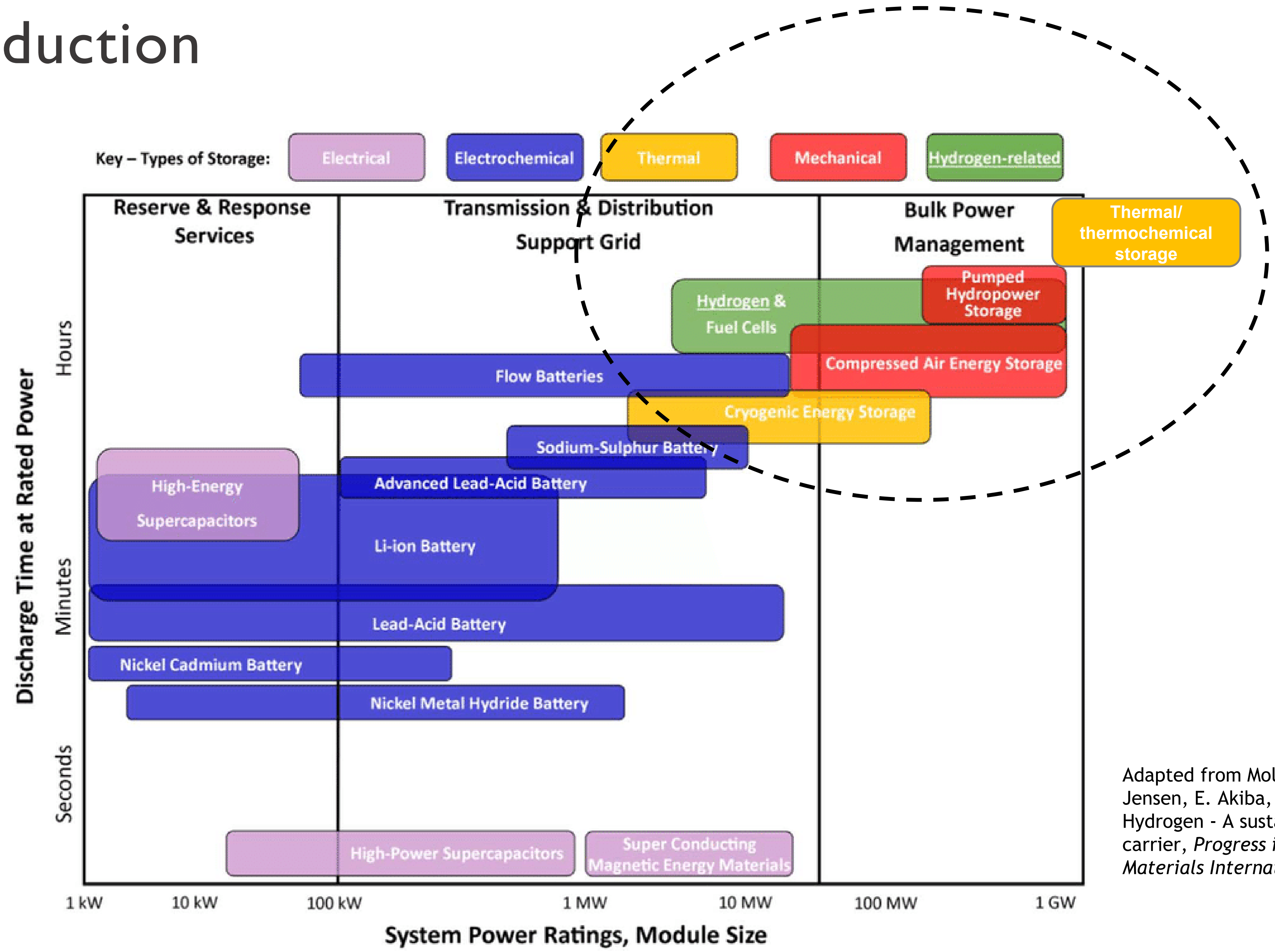


S&P Global
Market Intelligence

Data compiled Aug. 2019.
* Includes non-renewable alternative resources.
Indiana, Kansas, North Dakota, Oklahoma, South Carolina, South Dakota, Utah and Virginia have renewable portfolio goals instead of standards.
Virginia's RPS goal is based on the volume of electricity sold in 2007.
Map credit: Ciaralou Agpalo Palicpic
Sources: S&P Global Market Intelligence; Sierra Club; Union of Concerned Scientists; Database of State Incentives for Renewables & Efficiency; and state public utility commission websites

https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-states-face-uneven-paths-in-movement-for-100-clean-energy-53419260

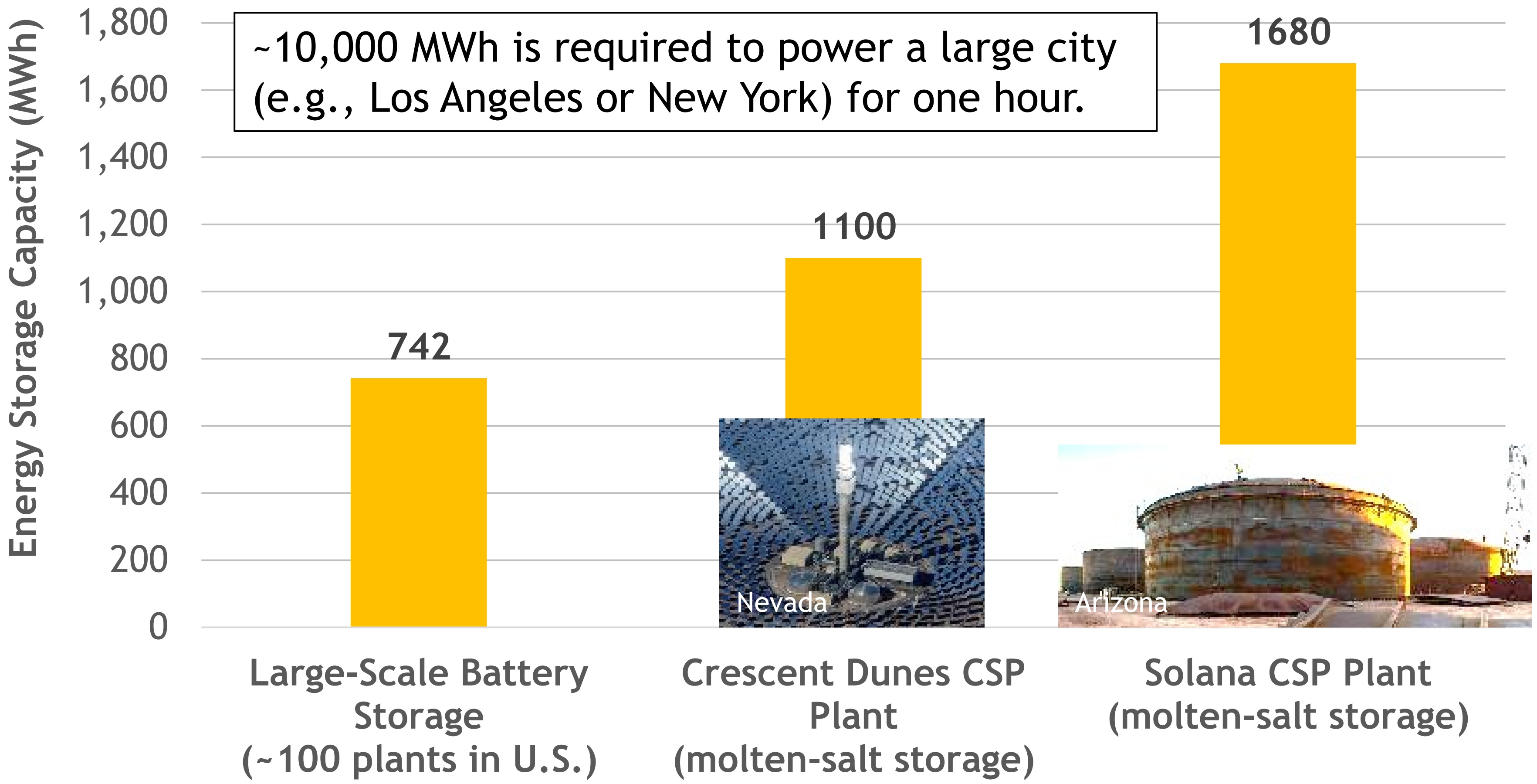
Introduction



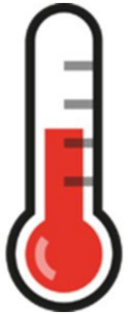
Adapted from Moller, K.T., T.R. Jensen, E. Akiba, and H.W. Li, 2017, Hydrogen - A sustainable energy carrier, *Progress in Natural Science-Materials International*, **27**(1), p. 34-40

Growing Need for Large-Scale Energy Storage

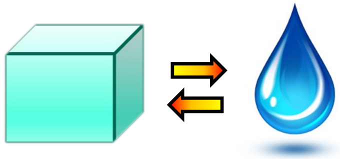
Battery data from U.S. Energy Information Administration (June 5, 2018)
CSP data from https://solarpaces.nrel.gov/projects



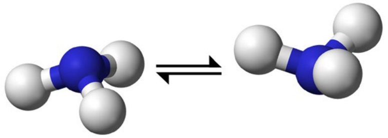
Thermal Energy Storage - Overview



- 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 thermal energy into chemical bonds (e.g., decomposition/synthesis, redox reactions)

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

Sensible Heat Storage

Molten Salt Storage

- Nearly 30 GWh_e of global capacity using concentrating solar power

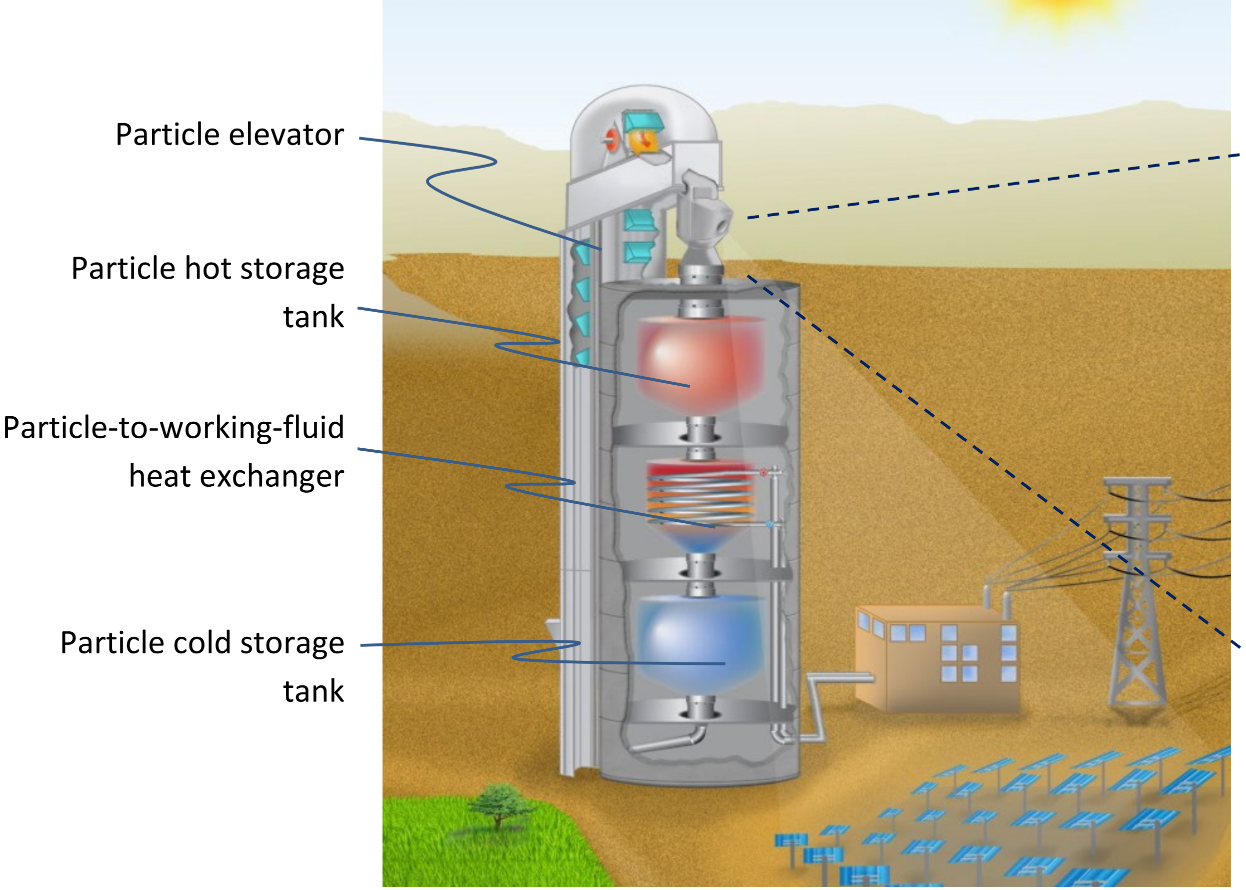
futurenergyweb.es

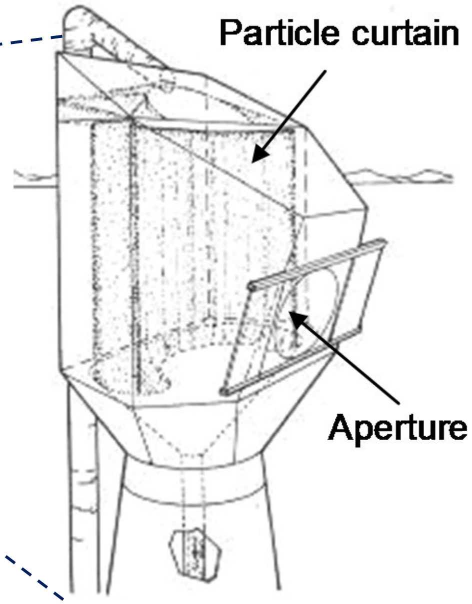
Solana Parabolic Trough Plant, AZ
(280 MW_e with 6 hrs storage (1.5 GWh_e)

Crescent Dunes Solar Tower, NV
110 MW_e with 10 hrs storage (1.1 GWh_e)

Solid Particle Storage – Moving Particles

High-Temperature Particle-Based CSP

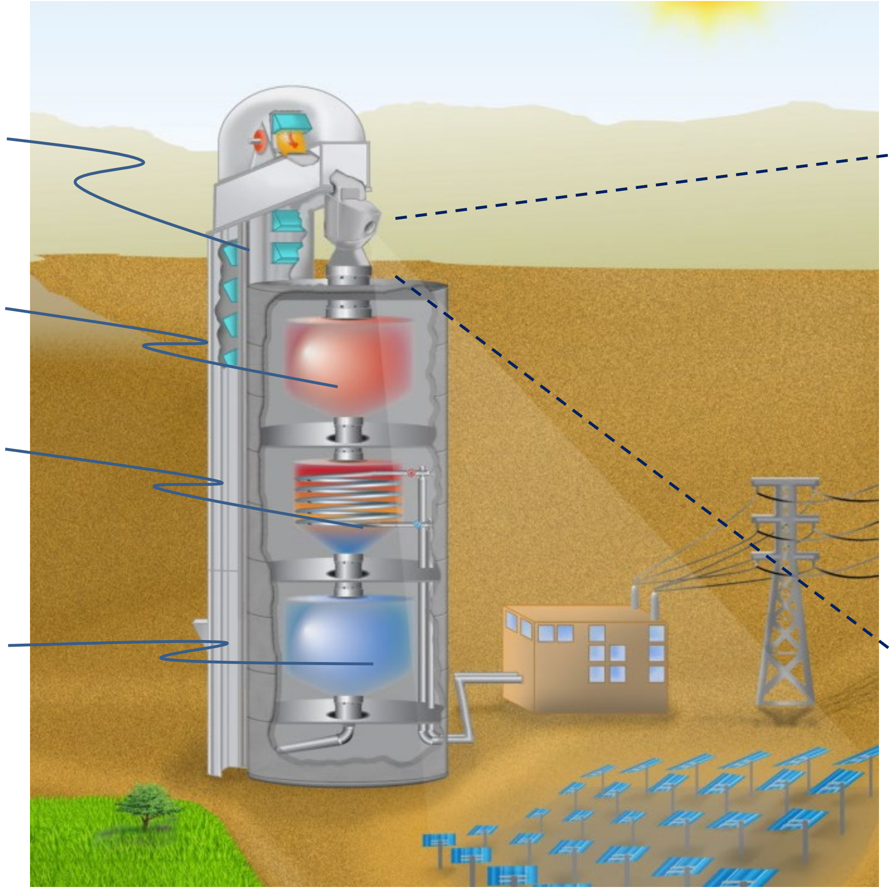


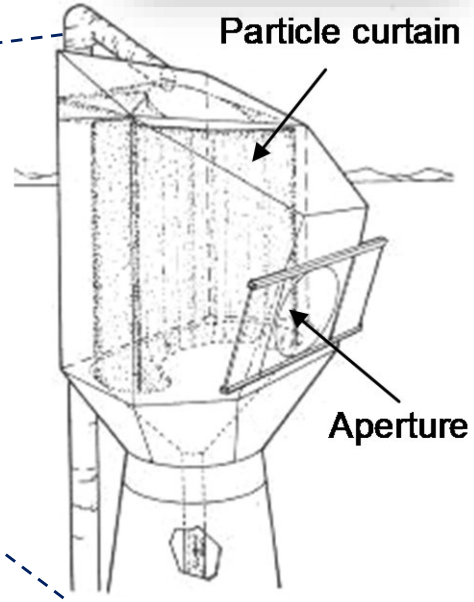


Falling particle receiver

Solid Particle Storage – Moving Particles

High-Temperature Particle-Based CSP





Falling particle receiver

National Solar Thermal Test Facility
Sandia National Laboratories

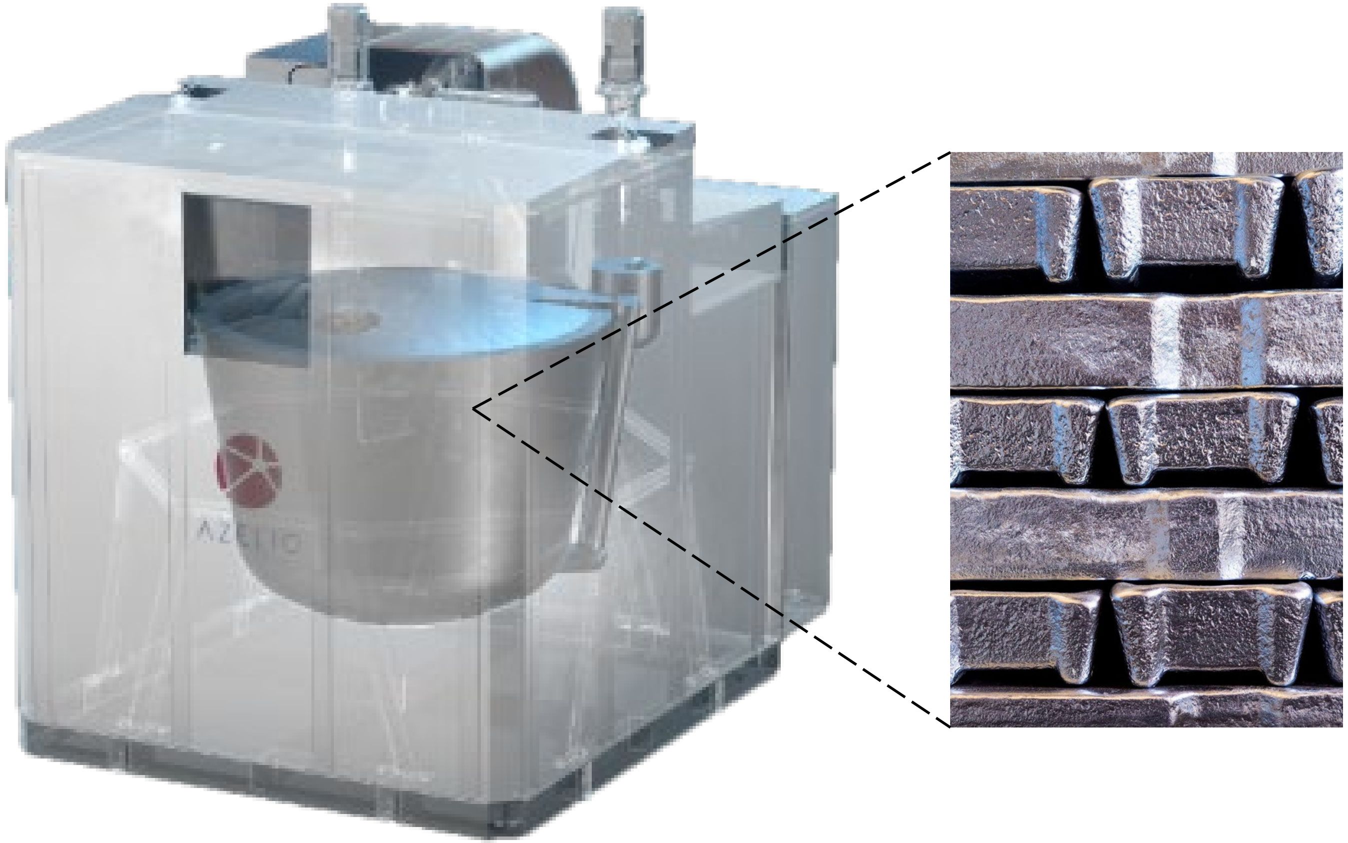
Solid Particle Storage – Fixed Bed

Siemens Gamesa Electric Thermal Energy Storage pilot demonstration with thermal storage capacity of 130 MWh at temperatures of 750 °C (image from website).

Latent Heat Storage

Molten Aluminum Alloy Phase Change - Azelio

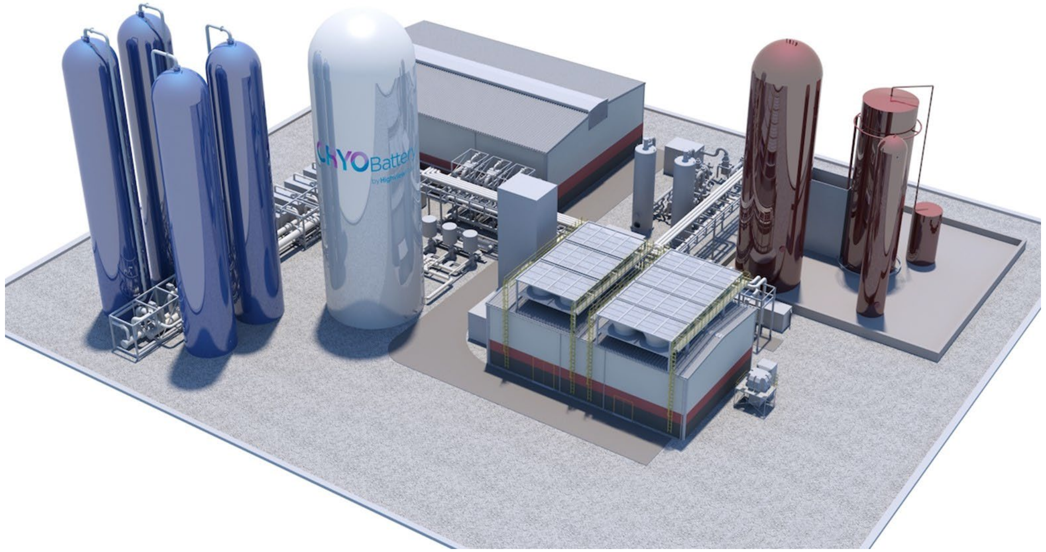
- Electricity melts recycled aluminum at 600 C
- Stored heat is used to generate electricity using Stirling engine



https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/LDES/Torbj%C3%B6rn_Lindquist.pdf

Liquefied Air Phase Change – Highview Power

- Electricity is used to compress air (Claude cycle) that is then stored as cryogenic liquid
- When needed, liquid is allowed to vaporize, expanding through turbines to generate electricity



Images: Highview Power

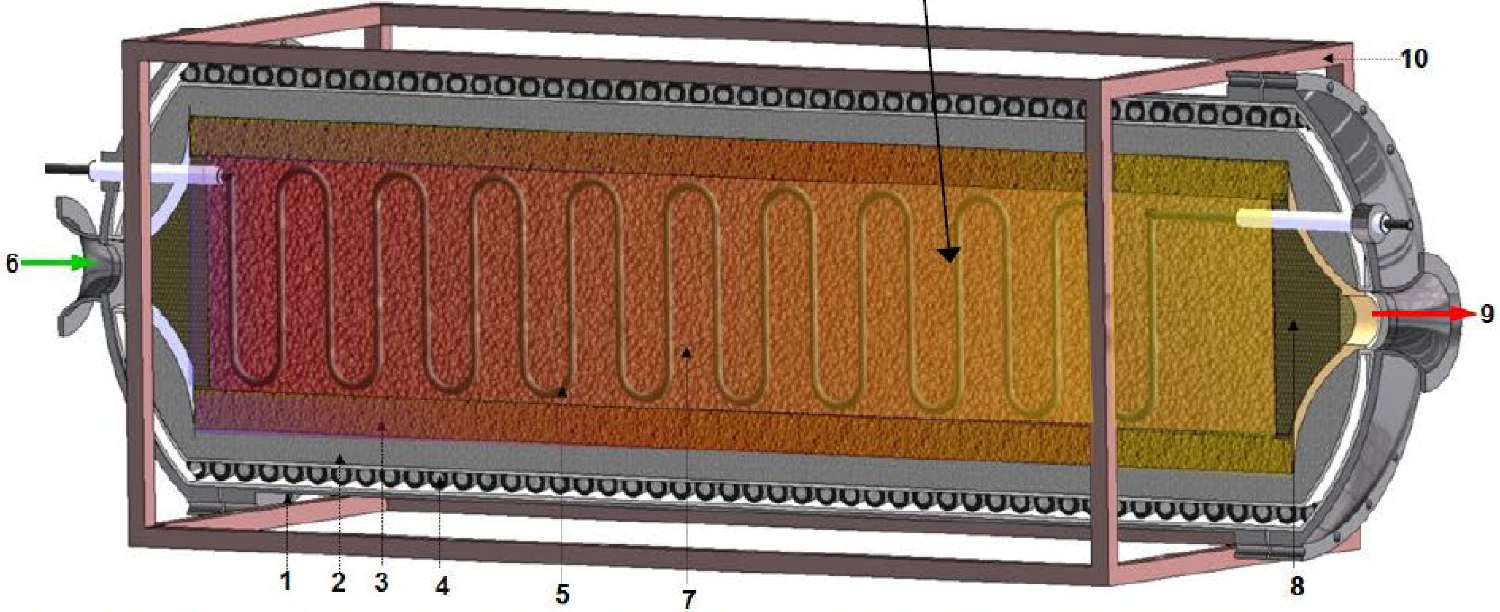
Highview Power Liquid Air Energy Storage
50 MW/400 MWh

Thermochemical Storage

Thermochemical Storage – Example

Scalable Thermochemical Option for Renewable Energy Storage (STORES)
Petrasch et al., Michigan State U., ARPA-E

- $MgO + 2MnO + \frac{1}{2}O_2 \leftrightarrow MgMn_2O_4$
- Charged by electrical heating,
- 1000-1500 °C,
- 2000 $MJ/m^3_{th\text{-}ch}$
- 40 ft-container module:
  26 $MWh_{th\text{-}ch}$: 11-16 MWh_e



1. Carbon steel enclosure, 2. Microporous insulation, 3. Refractory bricks, 4. Cooling air circulation tubes, 5. Molybdenum disilicide heating elements, 6. Compressed air inlet (from compressor), 7. Magnesium manganese oxide reactive material, 8. Ceramic grit support, 9. Heated air outlet (to turbine), 10. Supporting frame (standard shipping container dimensions)

Summary

Thermal Energy Storage Summary

	Sensible Heat Storage	Latent Heat Storage	Thermochemical Storage
Storage mechanism	Energy stored as temperature difference in solid (e.g., concrete, rock, sand) or liquid media (molten salt)	Energy stored using phase change materials (e.g., salts, metals, organics)	Energy stored in chemical bonds
Energy Density	~200 – 500 kJ/kg (for ~200 – 400 °C temperature differential)	~100 – 200 kJ/kg for nitrate salts; ~200 – 500 kJ/kg for metals; ~1000 kJ/kg for fluoride salts	~300 – 6,000 kJ/kg
Advantages	• Demonstrated large energy capacity (~GWh) • Inexpensive media • Solid media does not freeze and can achieve >1000°C	• Good for isothermal applications • Can provide large energy density with combined sensible and latent heat storage	• Large energy densities • Small heat losses • Potential for long-term storage • Compact storage system
Challenges	• Heat loss at high temperatures • Lower energy density requires larger volumes • Molten salts freeze at ~200 °C.	• Potential for corrosion • For larger ΔT, may need cascaded systems (adds costs and complexity) • Low maturity	• Higher complexity • Low maturity • Higher capital costs
Maturity	**High**	**Low**	**Low**
Cost	• ~$1/kg for molten salts and ceramic particles • ~$0.1/kg for rock and sands • ~$1/MJ – $10/MJ (system capital cost)	• ~$4/kg – $300/kg • ~$10/MJ – $100/MJ (system capital cost)	• ~$10/MJ – $100/MJ (system capital cost)

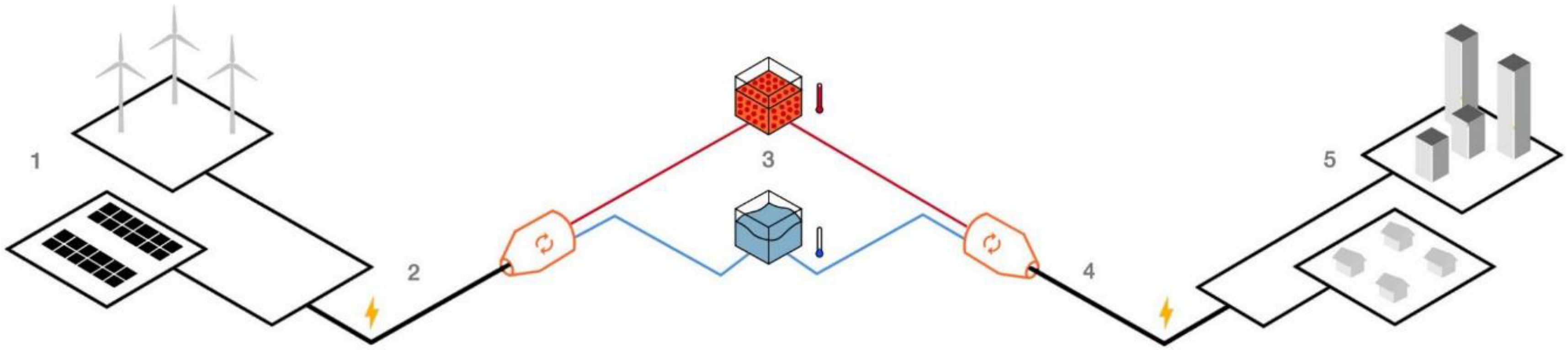
Questions?

Cliff Ho, (505) 844-2384, ckho@sandia.gov

Backup Slides

Two-Tank Heat Pump Storage

“Malta”



1. Collects
Energy is gathered from wind, solar, or fossil generators on the grid as electrical energy and sent to Malta’s energy storage system.

2. Converts
The electricity drives a heat pump, which converts electrical energy into thermal energy by creating a temperature difference.

3. Stores
The heat is then stored in molten salt, while the cold is stored in a chilled liquid.

4. Reconverts
The temperature difference is converted back to electrical energy with a heat engine.

5. Distributes
Electricity is sent back to the grid when it is needed.

Google X

https://x.company/projects/malta/