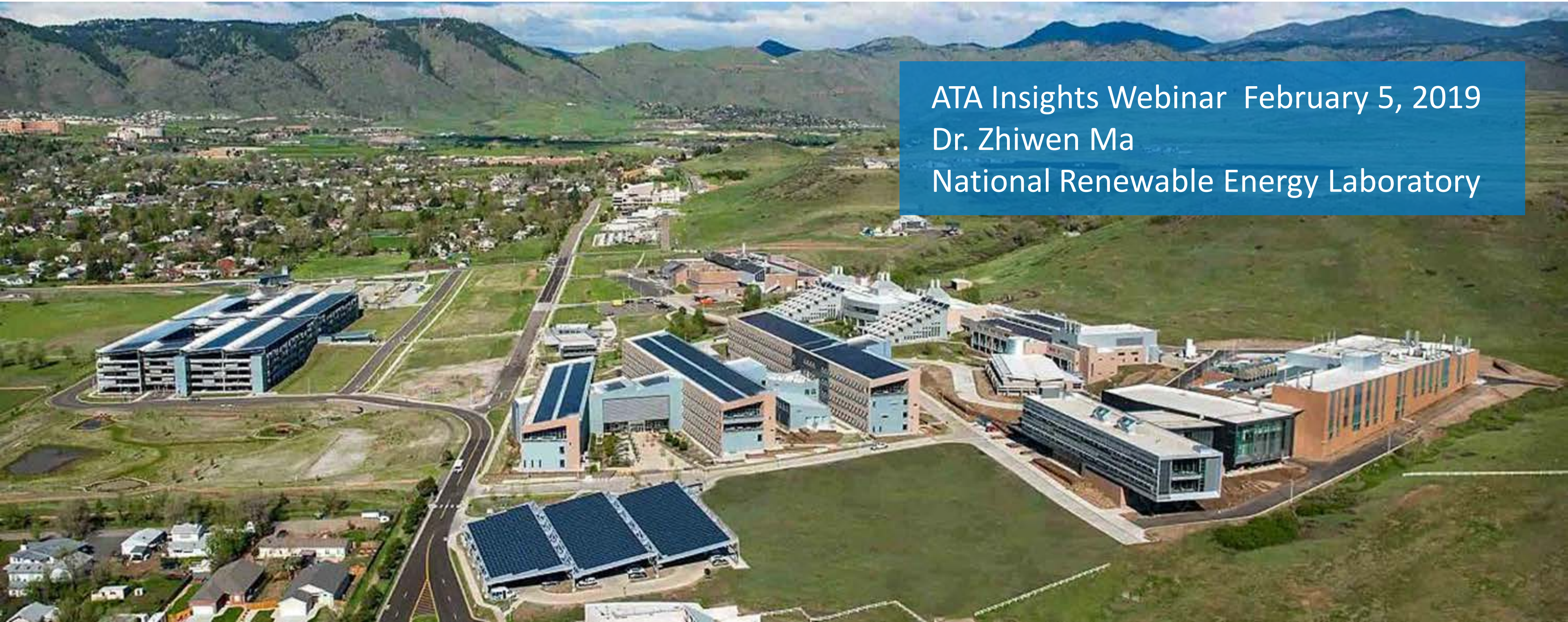
Cost-Effective Thermal Energy Storage Development to Support Variable Renewable Power Generation



ATA Insights Webinar February 5, 2019
Dr. Zhiwen Ma
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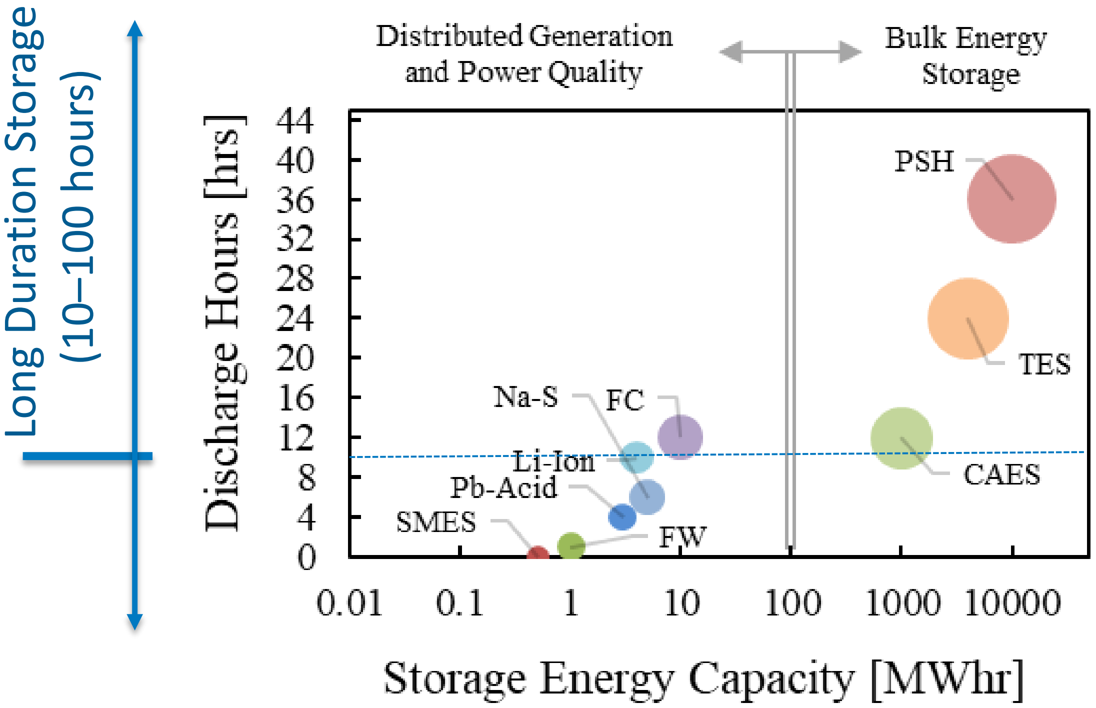
Outline

- Energy storage background
- NREL ENDURING Project for Long Duration Energy Storage (LDES)
- NREL Concentrating Solar Power (CSP) development with energy storage

Thermal Energy Storage Position in Energy Storage

Acronyms	Storage Technologies
PSH	Pumped storage hydropower
CAES	Compressed Air Energy Storage
TES	Thermal Energy Storage
Li-Ion	Lithium-Ion Batteries
Na-S	Sodium-Sulfur Batteries
Pb-Acid	Lead-Acid Batteries
FC	Hydrogen Fuel Cell
FW	Flywheels
SMES	Superconducting Magnetic Energy Storage



TES can provide grid-scale LDES storage without the geographical restrictions of PSH and CAES, but is under represented.

TES Types for Power Generation

- Sensible Heat Energy Storage
  - Molten liquid salt
  - Solid media
- Latent Heat Energy Storage
  - Phase change materials
- Thermochemical Energy Storage
  - Metal oxide
  - Ammonia
  - Sulfur cycle
  - Hydrogen or fuels

Solid storage media can be obtained from nature with little processing, and the resources are abundant, low cost, and environmentally compatible.

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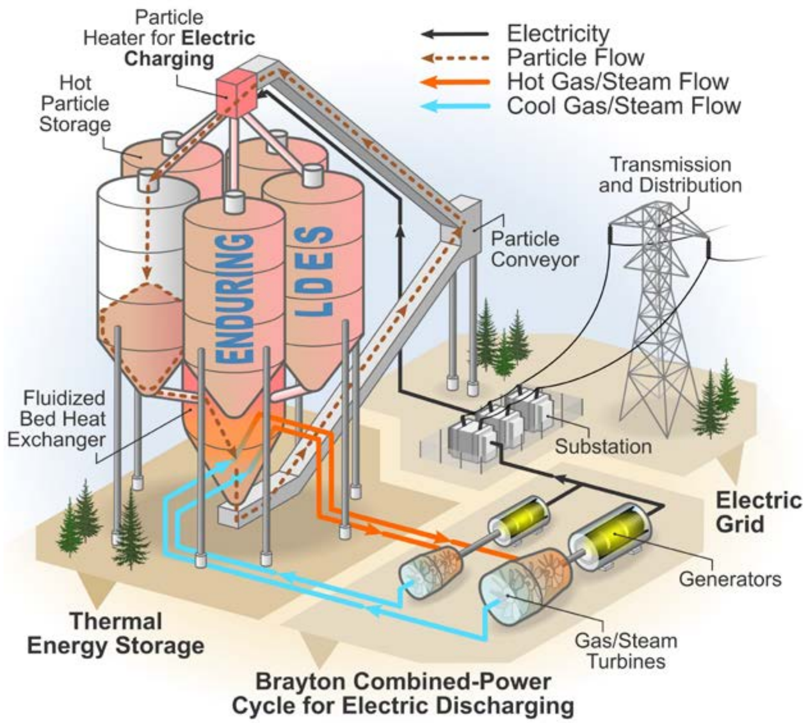
Economic Long-Duration Electricity Storage by Using Low-Cost Thermal Energy Storage and High-Efficiency Power Cycle (ENDURING)

The ENDURING LDES as a standalone TES for grid-scale electricity storage



Project Overview:

- Phase 1 three-year $2.8 million funding from the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) Duration Addition to Electricity Storage (DAYS) Program, and $430K cost share.
- The project will develop components for cost and performance targets and for demonstrating the technology to market.
- The ENDURING LDES system aims at providing electricity for several days with low-cost grid storage, to enable the integration of large-scale variable wind and solar power.

ENDURING Project Team

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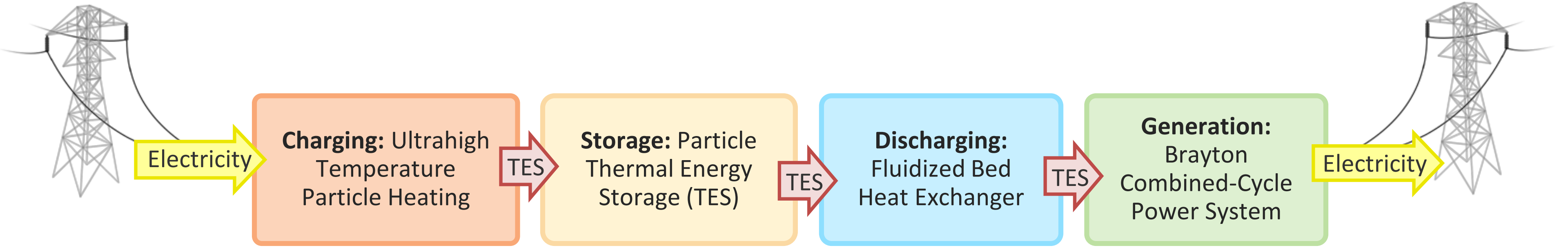
ENDURING System Features

ENDURING LDES operates as a thermal battery, in a large scale.



- Aim at 10-100 hours of storage, 60 - 300 MWe (scalable).
- Increase cycle efficiency with ultrahigh temperature (>1,100°C) particle TES.
- Develop novel fluidized bed heat exchanger with gas/particle direct contact.
- Adapt GE’s high-efficiency turbine system for efficient Brayton combined cycle.
- Leverage the potential assets from retired thermal power plants.
- Site throughout the United States without geographic restrictions.

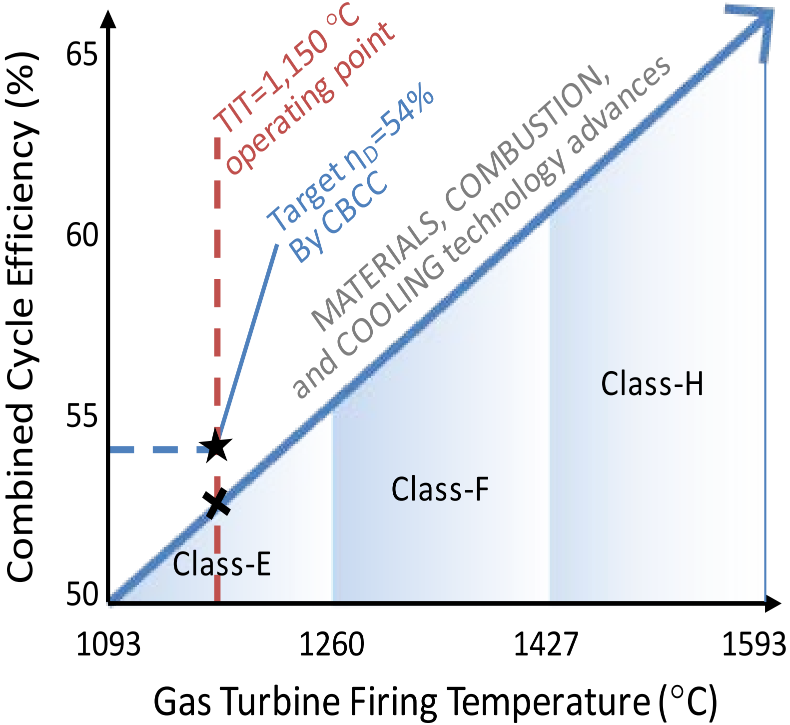
Storage Media: Stable, Inexpensive Particles

Metric		Sand	Sintered Bauxite
Media	Weight (kiloTon)	189	165
	Cost ($MM)	4.72	53.68
	Cost ($/kWht)	0.09	0.98
Containment	Volume (m^3)	71,000	42,000
	Total cost ($MM)	63.32	37.14
	Cost ($/kWht)	1.16	0.68
	Capital cost ($/L)	0.89	0.89
TES Cost Sum ($/kWht)		**1.25**	**1.67**

Preliminary estimates of the TES cost for a 300-MWe, 100-hour LDES system (As a comparison, a salt TES at ~25$/kWht)

Roundtrip Efficiency — a Key Parameter for Energy Storage

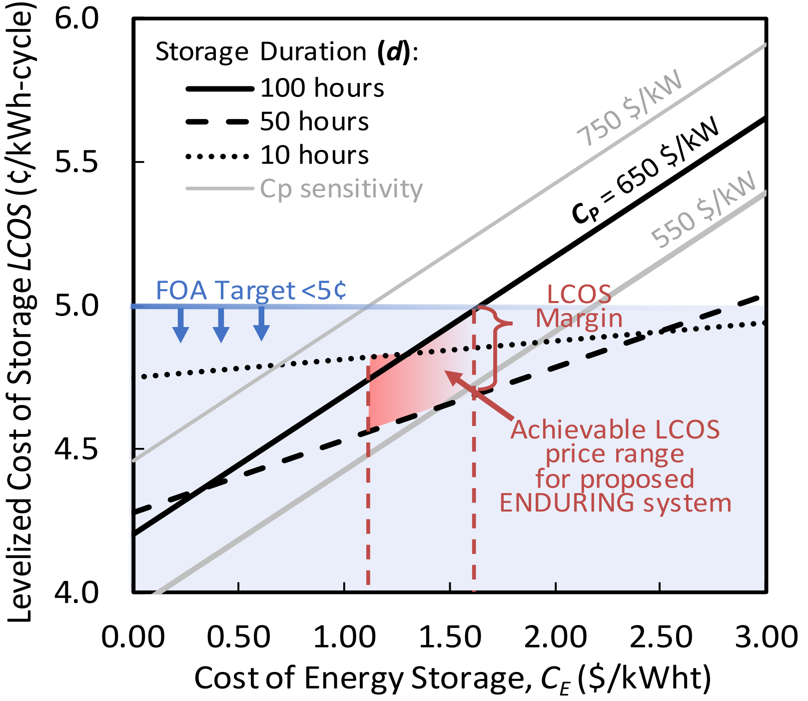
Storage Technology	Stored Media	Roundtrip Efficiency Range
Batteries and Flow Battery	Electron/ion charge	70-90%
Reversible Fuel Cell	Hydrogen	30-49%
Compressed Air Energy Storage	High pressure air in a cavern	40-60% (high with gas input)
Pumped storage hydropower	Water potential energy	70-80%
Thermal Energy Storage	Internal Energy	40-70%*



In hours to days energy storage, TES can get a competitive roundtrip efficiency for electricity storage. (* based on PTES overview, Benato, 2018)

Performance and Cost Targets

Metric	Target	Notes
Levelized cost of storage (LCOS, ¢/kWh-cycle)	4.7–5.0	2.5¢/kWh electric charging
Power cycle efficiency	> 54%	GE power system
Round-trip efficiency	> 50%	60–300 MW
Power system cost ($/kW)	600 – 700	Leverage retired power plants
Capital cost of particle TES storage ($/kWh)	< 2	10–100 h duration
DAYS assumed service life	20 years	Actual 30–40



Targeted LCOS <5¢/kWh-cycle at 2.5¢/kWh charging electric price with the decoupled power and duration

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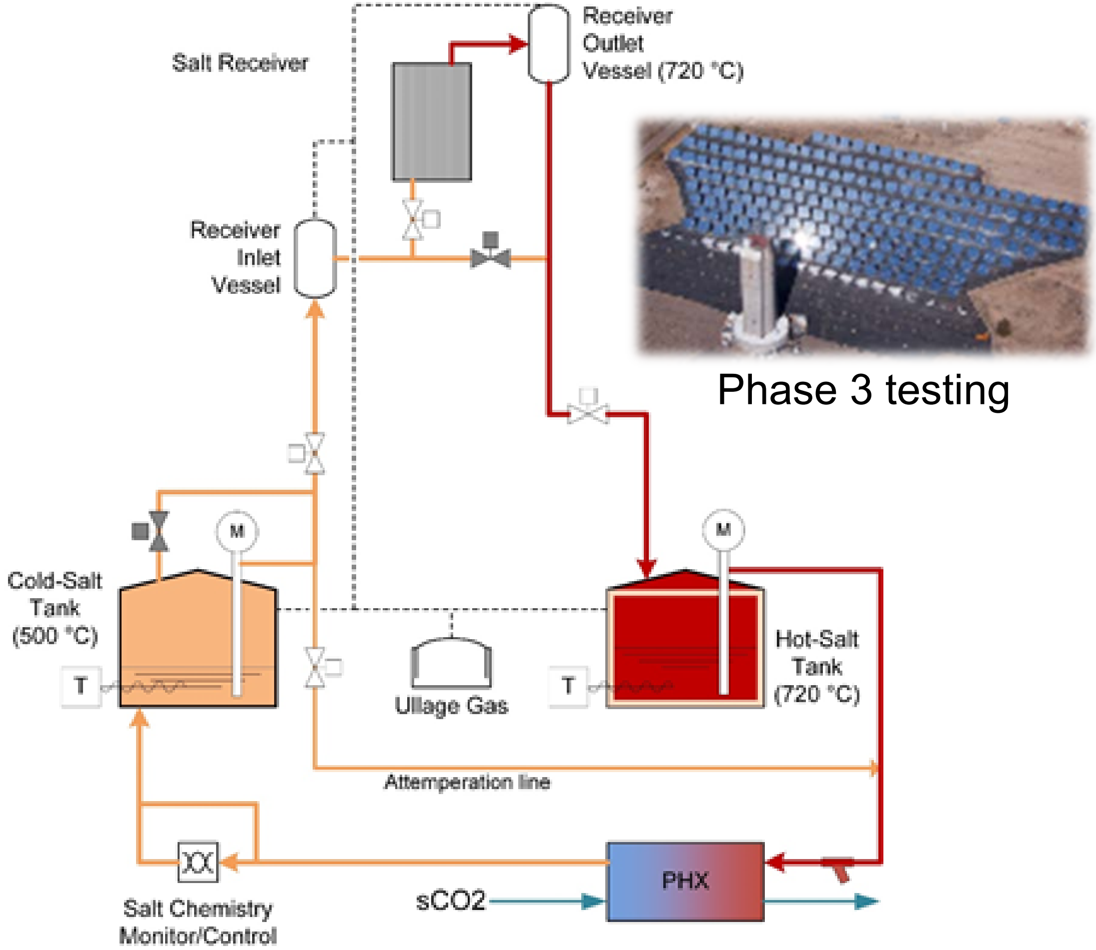
- NREL Concentrating Solar Power (CSP) development with energy storage:
  - Molten-salt pathway
  - Gas-phase pathway
  - Pumped thermal energy storage technology

CSP Gen3: Liquid-Phase Pathway to SunShot

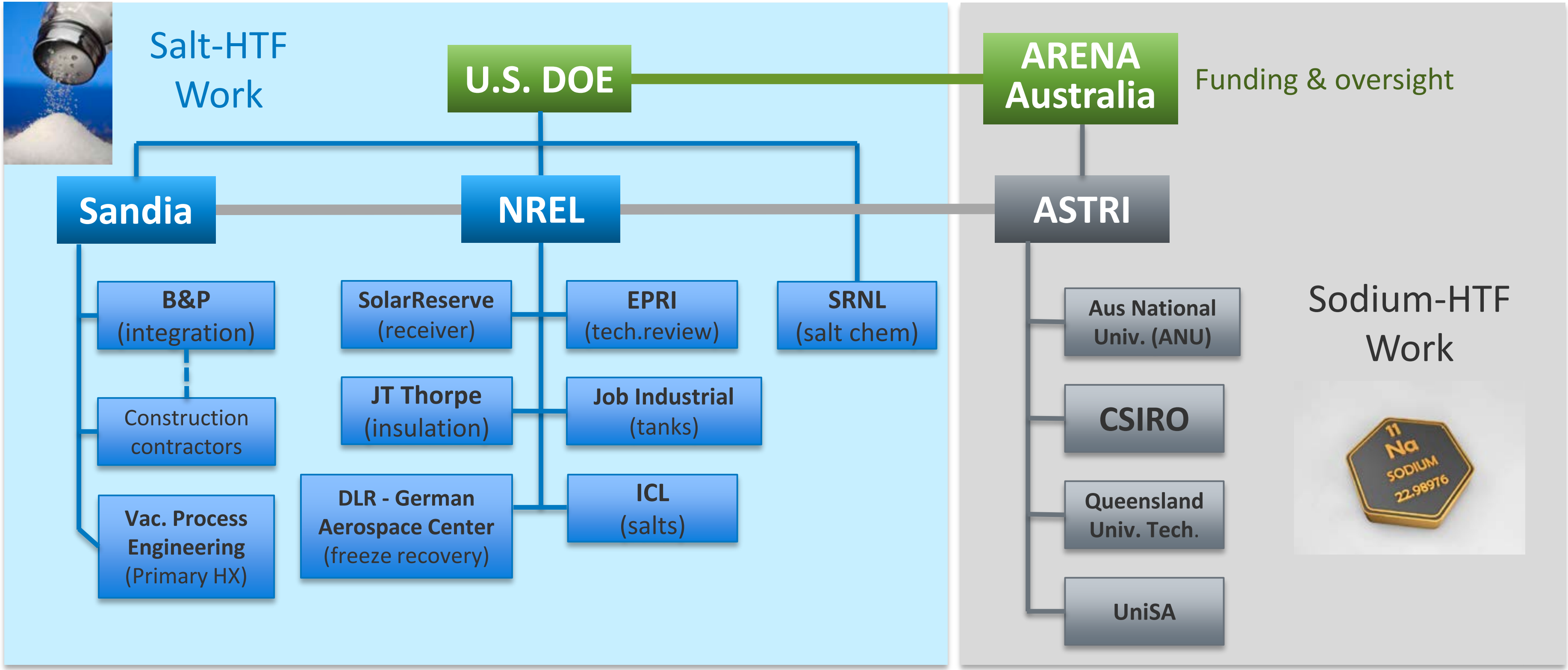


Phase 3 testing

Project Objectives:

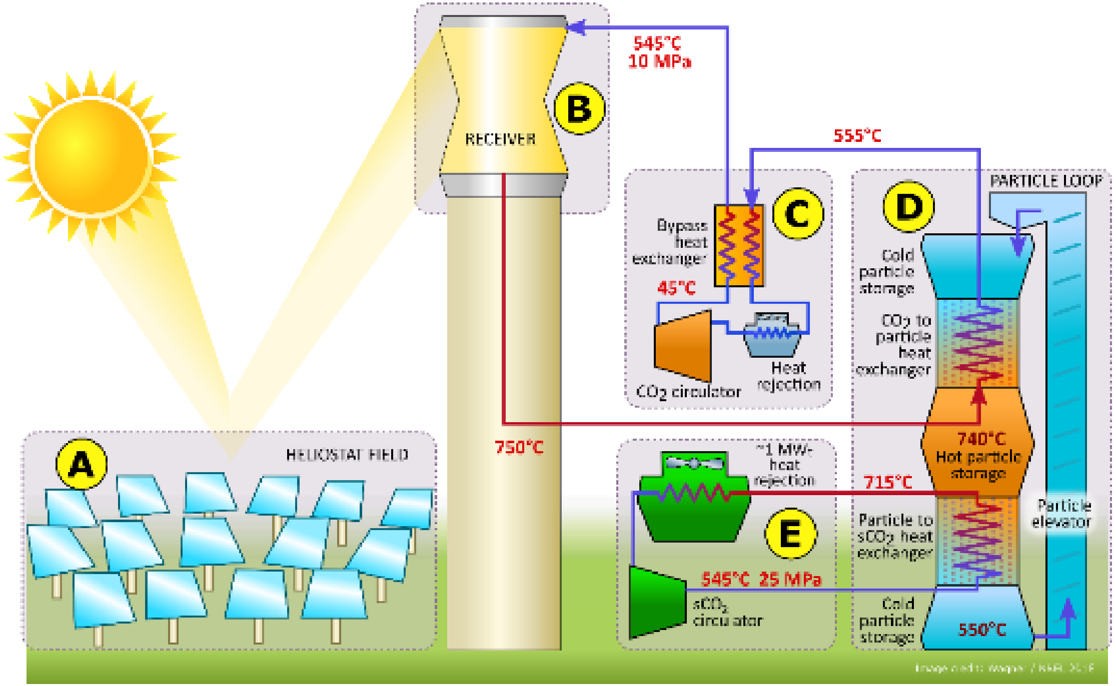
- NREL leads a multi-national team to test the next generation CSP technology by advancing molten-salt power tower technology to higher temperatures and efficiencies.
- The goal of the work is to design, develop, test, and validate at 2-MWt, an integrated system that uses a liquid salt.
- Map path to full-scale commercialization through system simulation and industry collaboration

Gen3 CSP: Liquid-Phase Team



Gen3 CSP Gas-Phase System Development

- Gen3 Integration FOA Topic 1 award
- 2-year, $9.4M DOE funding ($1.9M cost share)
- Project lead: Brayton Energy



Project Objectives

Develop the first integrated high-pressure gas phase power tower system with particle storage.

- Reduce risk associated with integrated system operation, thermal storage technology performance, and receiver lifetime and efficiency demonstration.
- Leverage existing components and develop new technology on gas circulator, gas-to-particle heat exchangers, and solid media insulation and storage.

Gen3 CSP: Gas-Phase Project Team

Brayton Energy

- Shaun Sullivan
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- Megan Watkins
- Jack Hinze
- Jake Boxleitner
- Jim Kesseli
- Jim Nash
- Bill Caruso

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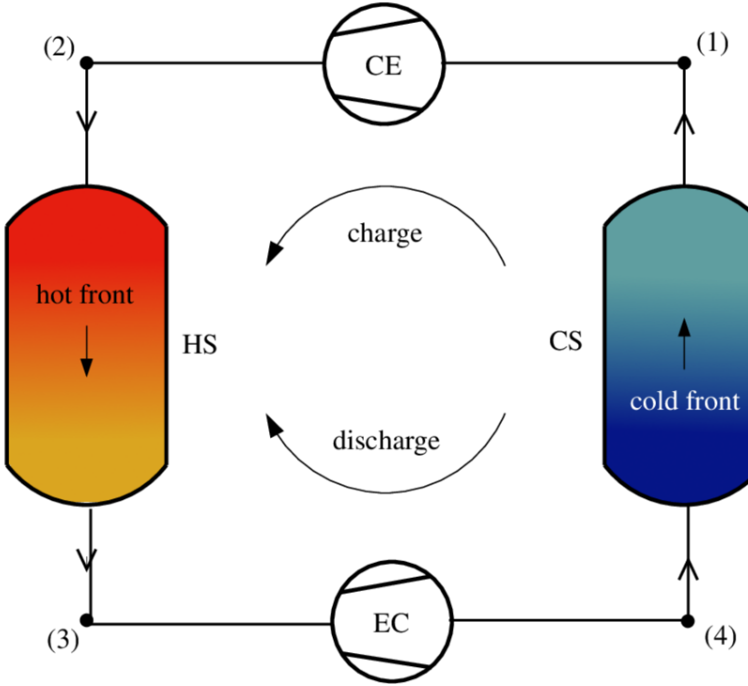
Integrated Pumped Thermal Storage and Power Cycle



Uniqueness & Potentials

- Solar availability is inherently variable. The novel storage system combines CSP power cycles – "Pumped Thermal Energy Storage", with packed bed/liquid salt as storage media.
- The cycle employs 'sub-ambient heat rejection' to reduce effect of high ambient temperatures.
- The project develops transient thermodynamic and economic models, and assess 'value' with grid analysis tools.

Increase efficiency, dispatchability, and flexibility of CSP through integration with a novel PTES storage system.

CSP-PTES Project Team

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Thank you

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Questions?

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