



SolarPACES

Concentrating Solar Power, Thermal,
and Chemical Energy Systems

September 23-26, 2025
Almería, Spain

31st SolarPACES Conference

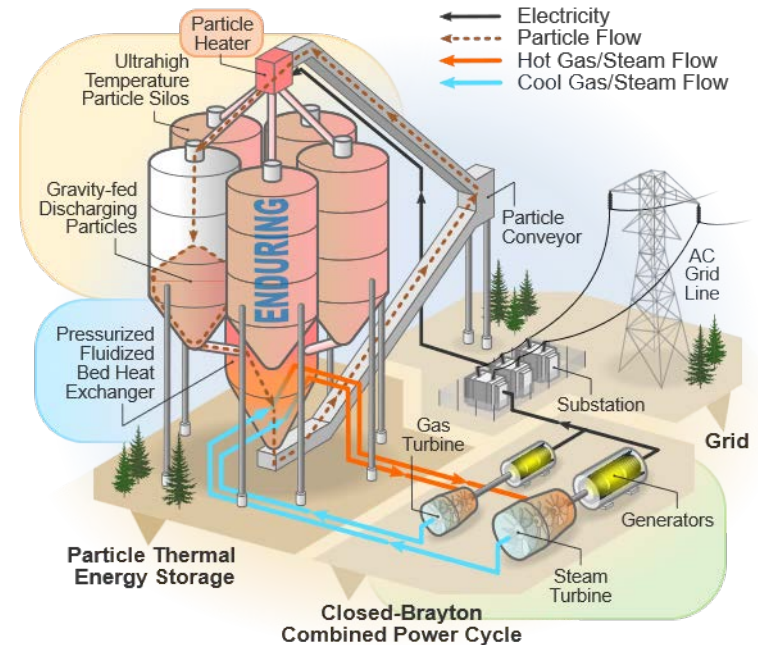
Pilot Development Progress to Demonstrate Electric Thermal Energy Storage (ETES) Using Low-Cost Particles

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SolarPACES Conference, Almeria, Spain
September 25, 2025

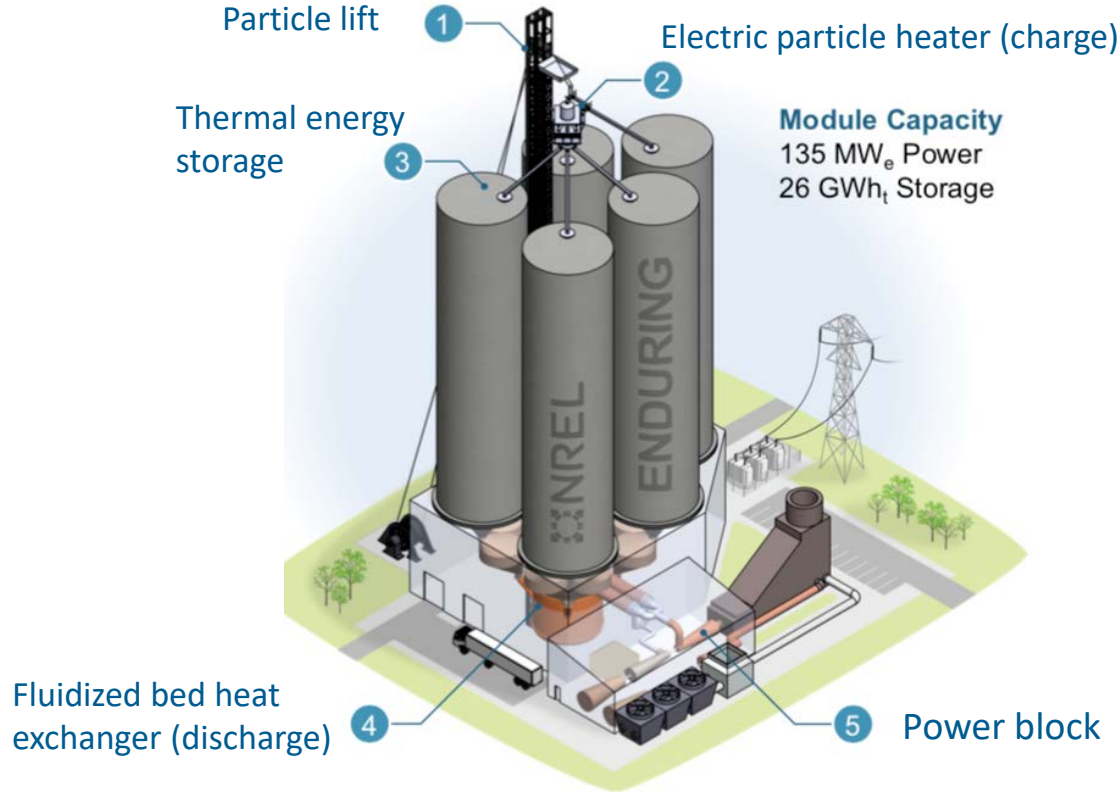
This presentation was produced when the laboratory operated as the National Renewable Energy Laboratory (NREL). The laboratory is now the National Laboratory of the Rockies (NLR).

Outline

- Introduction of Electro-Thermal Energy Storage (ETES)
- Component Developments
- System Integration
- Outlook for ETES Scale-Up
- Summary



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



ENDURING System:

- Particle thermal energy storage for low-cost, large capacity long-duration energy storage.
- **Scalable for 0.01-20 GWh storage, 10-400 MW_e generation**

Decoupling energy storage and power generation ensures independent variation of power capacity and storage duration, serving scalable storage needs

Why Long Duration Energy Storage (LDES)?

Enhance grid resiliency

- Shift to variable renewable energy generation will create supply/demand imbalances
- Energy **storage** needed to provide **balancing** on different timescales:

Daily – peak hours

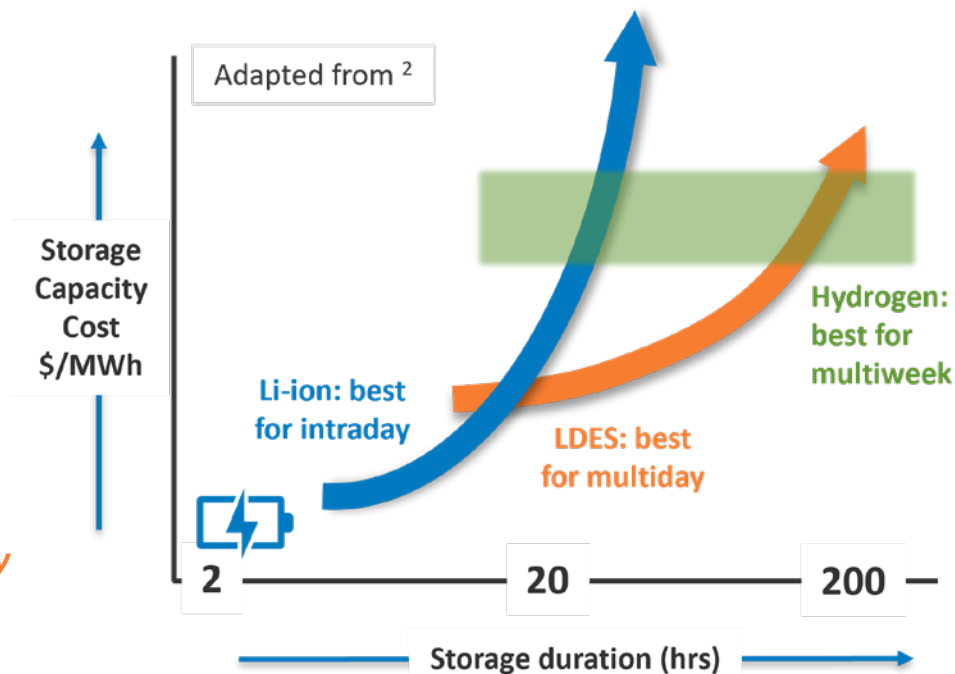
Primary technology: **Li-ion batteries**

Multiday – weather anomalies

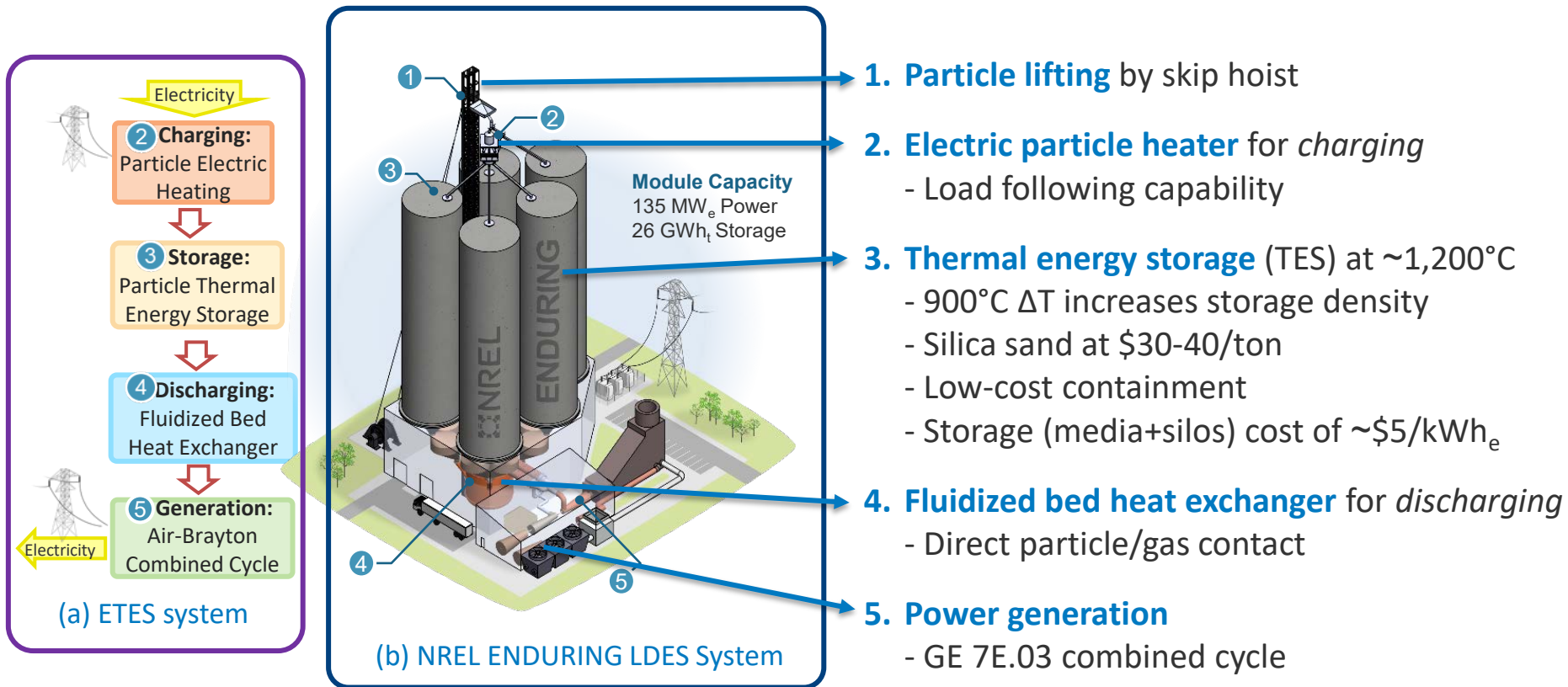
Primary technology: **Long Duration Energy Storage**

Multiweek – seasonal mismatches

Primary technology: **Hydrogen**



Electric-Thermal Energy Storage (ETES) for LDES



Demonstration project: validate and demonstrate scalable thermal energy storage

Development History and Technology Gap

Project Impact:

- Validate system integration & controls
- Verify innovative charge heater and discharge fluidized bed heat exchanger designs at commercially relevant scale
- Advance technology to TRL 6

Demonstration and Integration
Addressing Customer Questions

2023-



2021-2024

SETO Projects on Particle CSP

- Pumped Thermal Energy Storage
- Enclosed Particle Solar Receiver
- Industry Process Heat



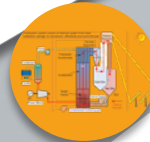
2019-2022



2012-2019

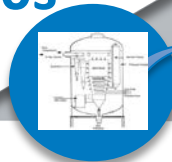
SETO SunShot and Gen3 CSP develop Particle-Based CSP

- Developed particle-based storage
- Supercritical CO₂ power cycle



1980s-1990s

B&W demos 70 MW
Pressurized Fluidized Bed
(PFB) System



Technology impacted
by downturn of coal.

ARPA-E DAYS ENDURING Project

- ETES system design with laboratory prototypes.

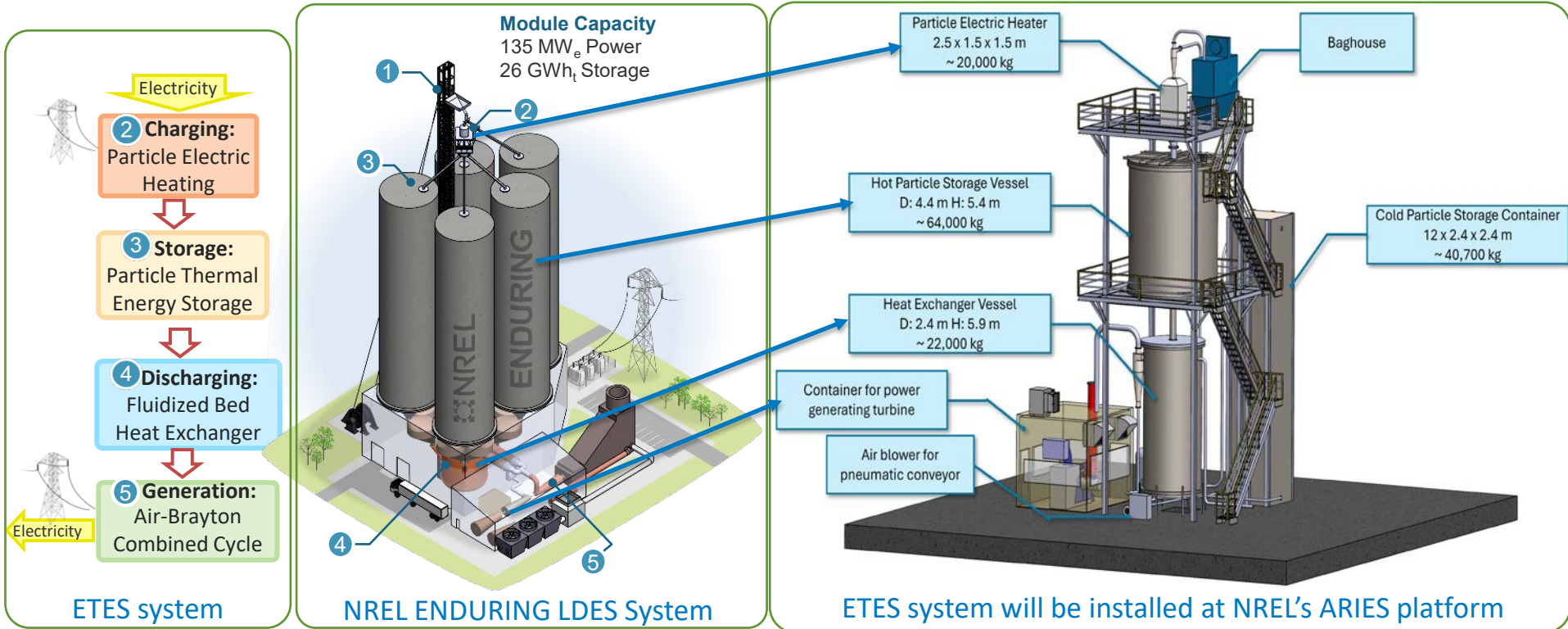
Comparison of LDES Technologies

	Particle ETES	Compressed Air Energy Storage	Pumped Hydro	Li-Ion Battery	Flow Battery
Size (MW _e)	10–400	150–500	>100	0.1–50	1–20
Duration (hours)	>10 to 100	>6 to 10	>6 to 10	1–4	4–8
Round-trip efficiency	40%–70%	40% -60%	70%–85%	85%	70%
Response time	Minutes (warm start)	Minutes	Minutes	Seconds-minutes	Seconds-minutes
Life cycle	++	++	++	+	–
Power system cost*	\$700–\$1,500/kW	\$1,000–1,500/kW	\$600–\$2,500/kW	\$300+/kWh _e	\$500/kWh _e
Energy storage cost	\$4–\$10/kWh_e	\$150–\$300/kWh _e	>\$60/kWh _e		
Siting flexibility	++	–	–	++	++

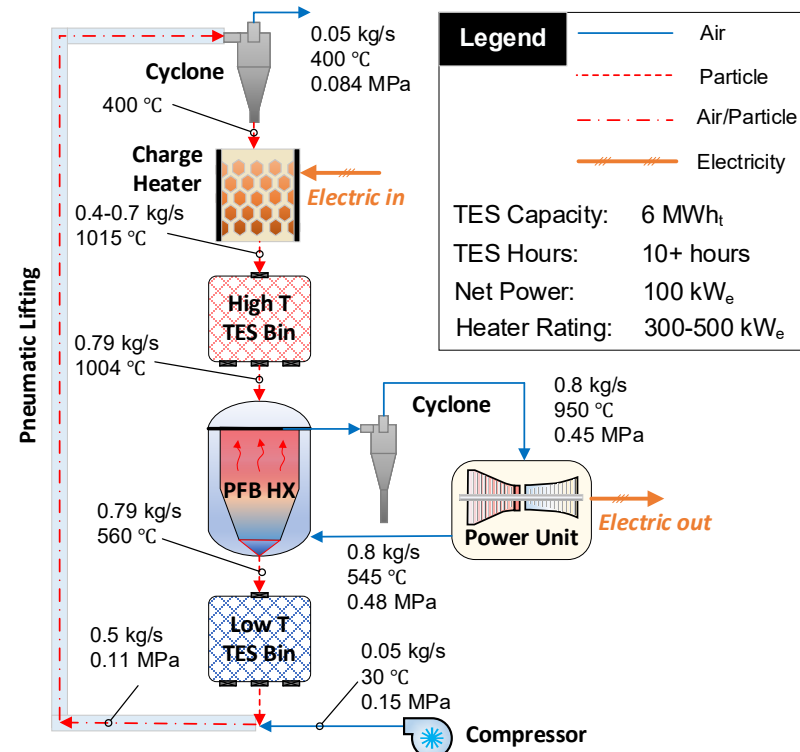
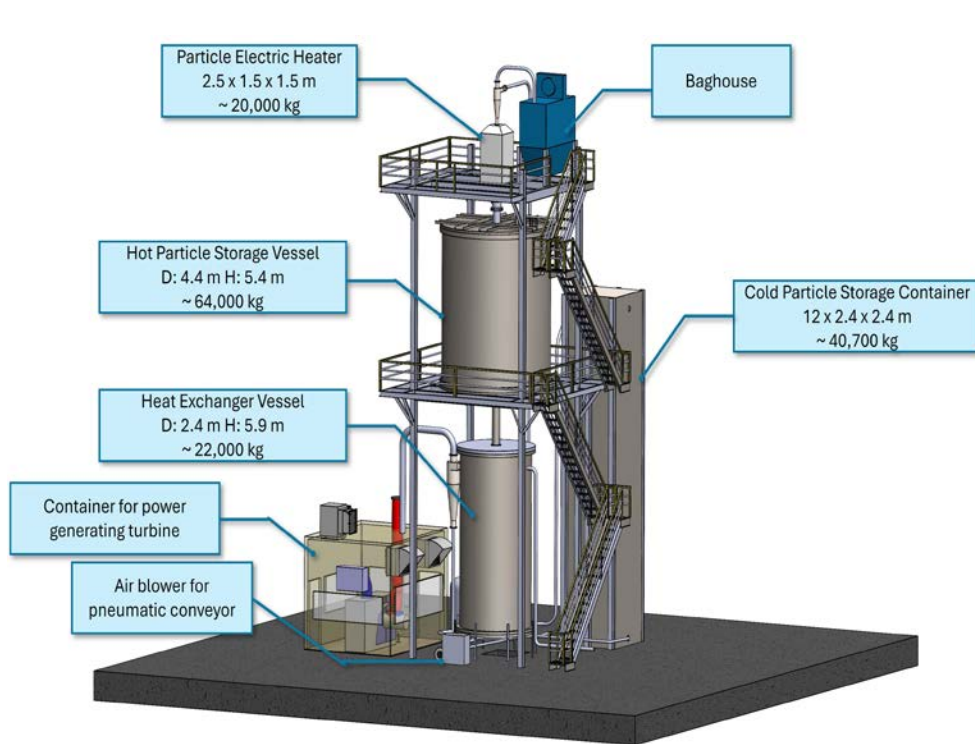
ETES Benefits: Large capacity, low storage cost, flexible siting:

- Separating power system and storage favors LDES to expand storage capacity economically.
- With spinning reserve at hot start, ETES can respond rapidly to synchronize grid demand.

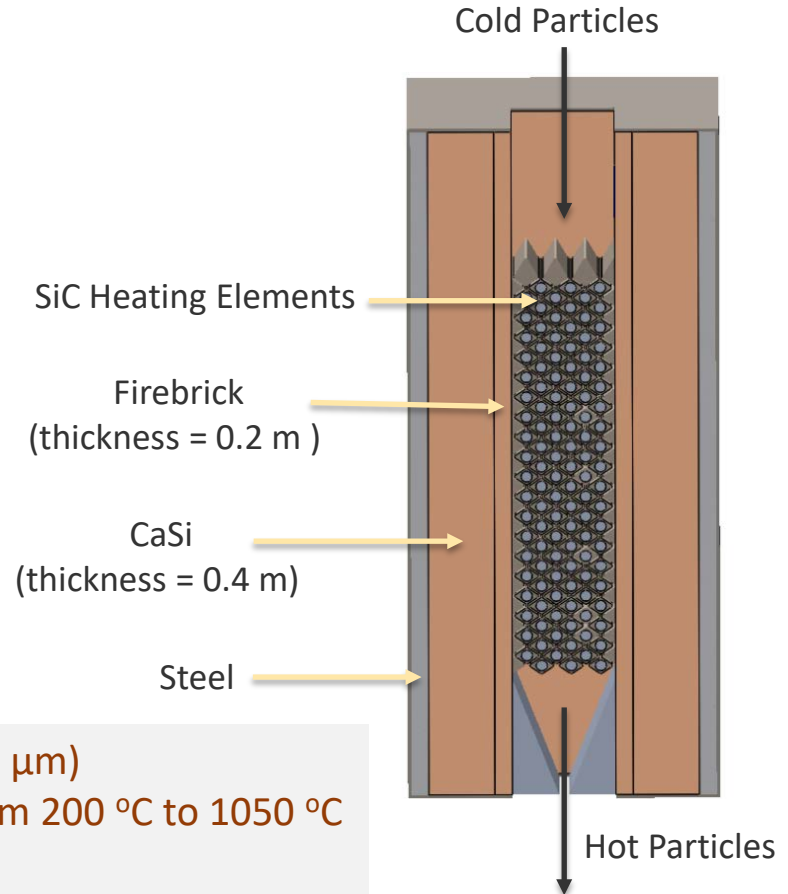
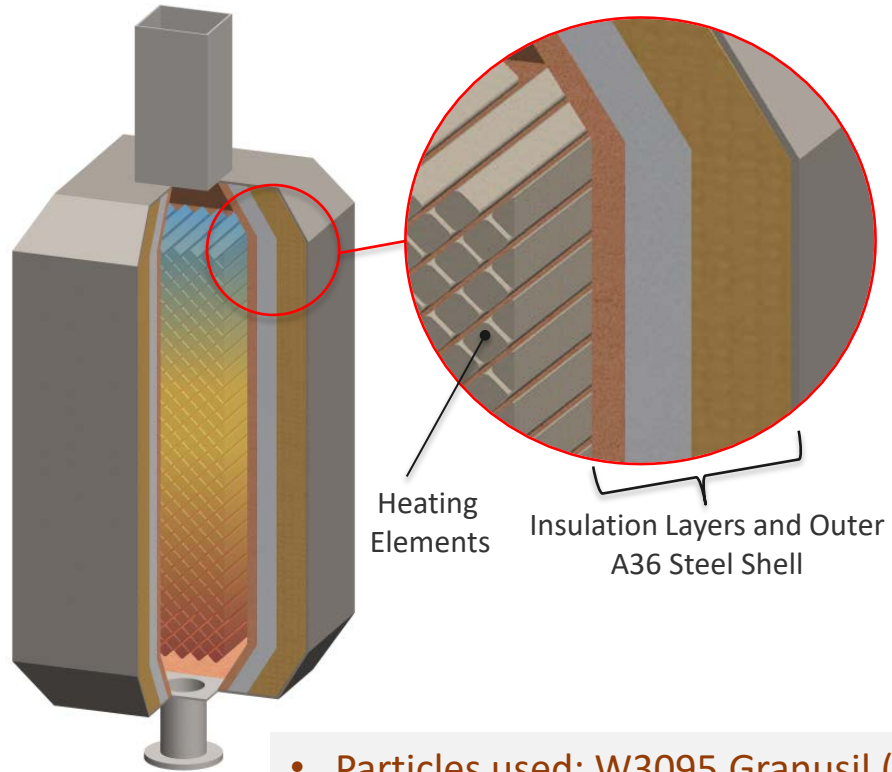
Electric-Thermal Energy Storage for LDES @ ARIES



100-kW_e Demonstration System

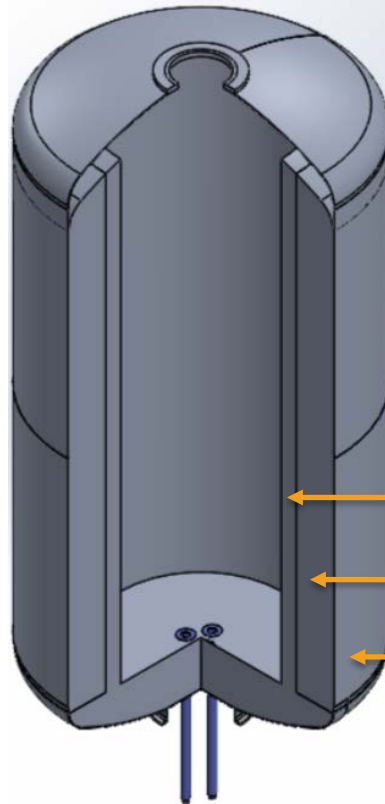
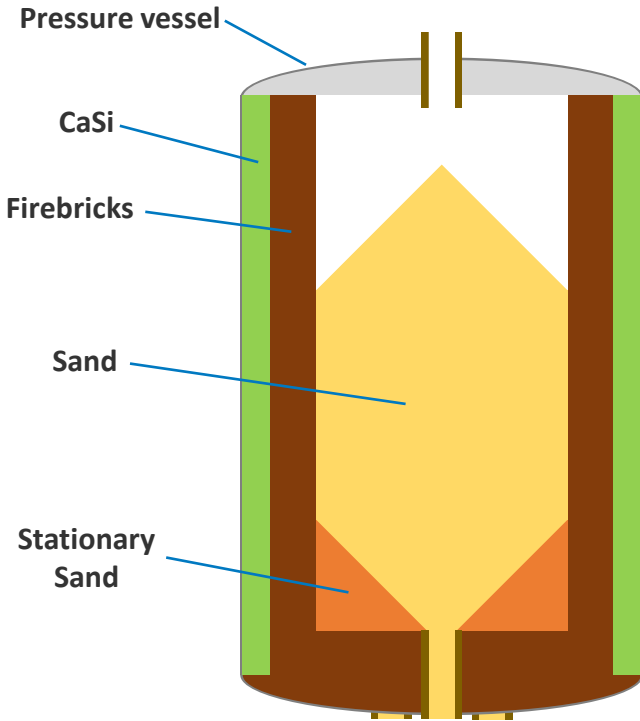


Major Components: Electric Particle Heater



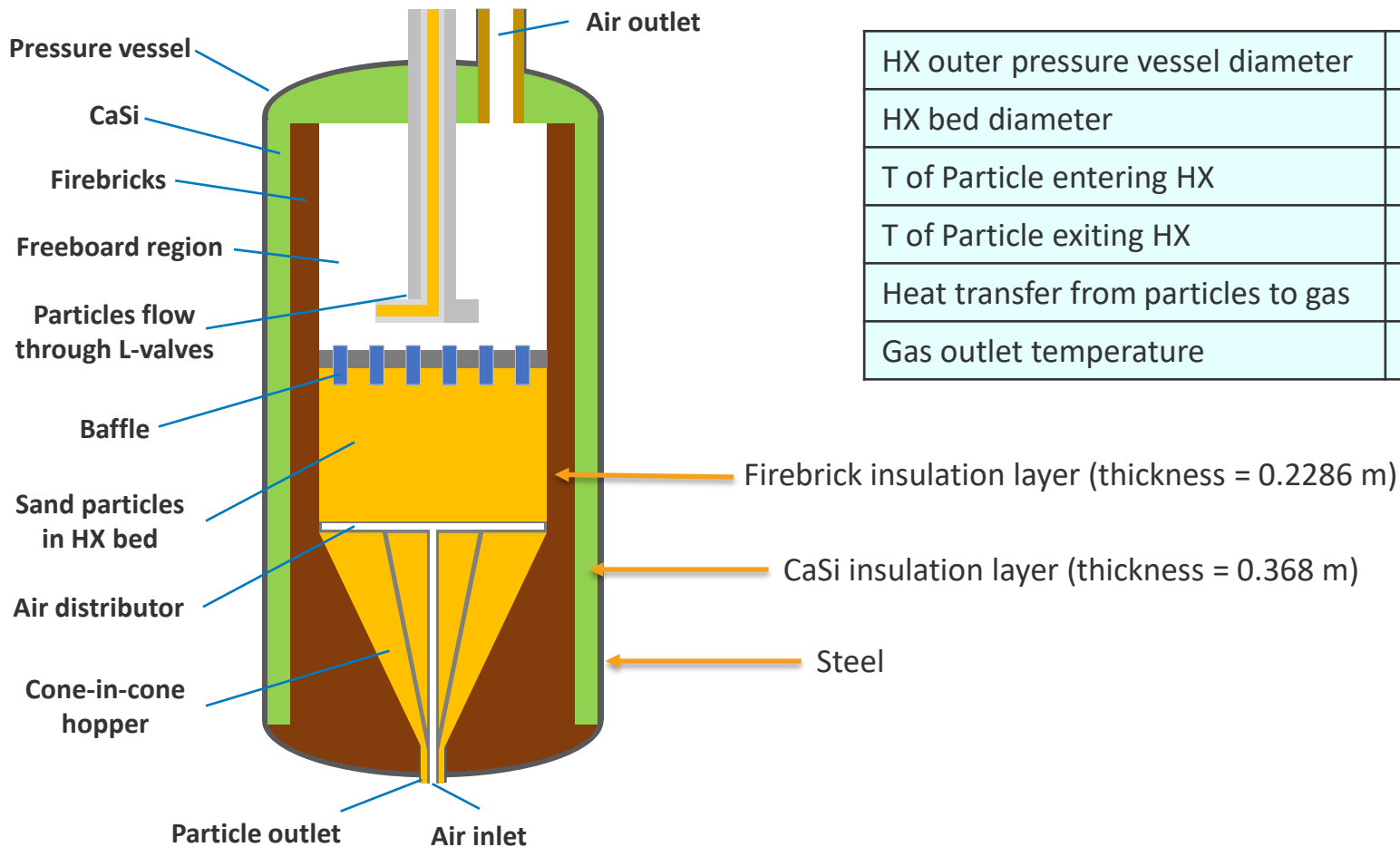
- Particles used: W3095 Granusil (825 μm)
- Target particle temperature rise: from 200 $^{\circ}\text{C}$ to 1050 $^{\circ}\text{C}$
- Heating elements material: SiC
- Insulation material: Firebrick, CaSi

Major Components: Hot Storage Bin



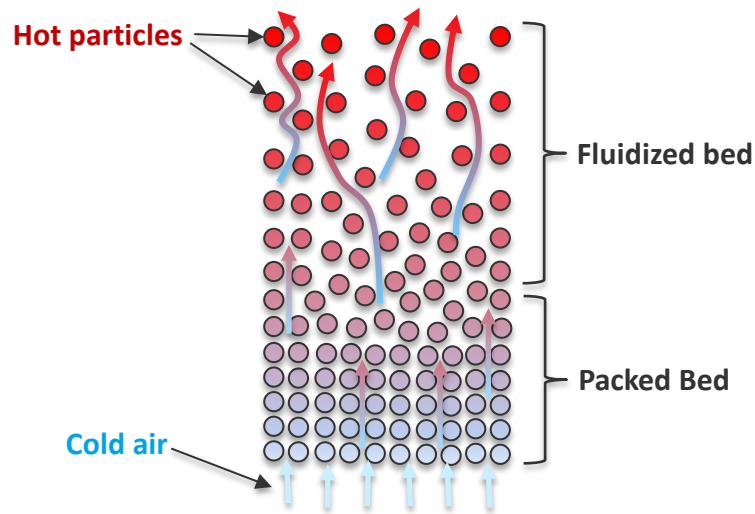
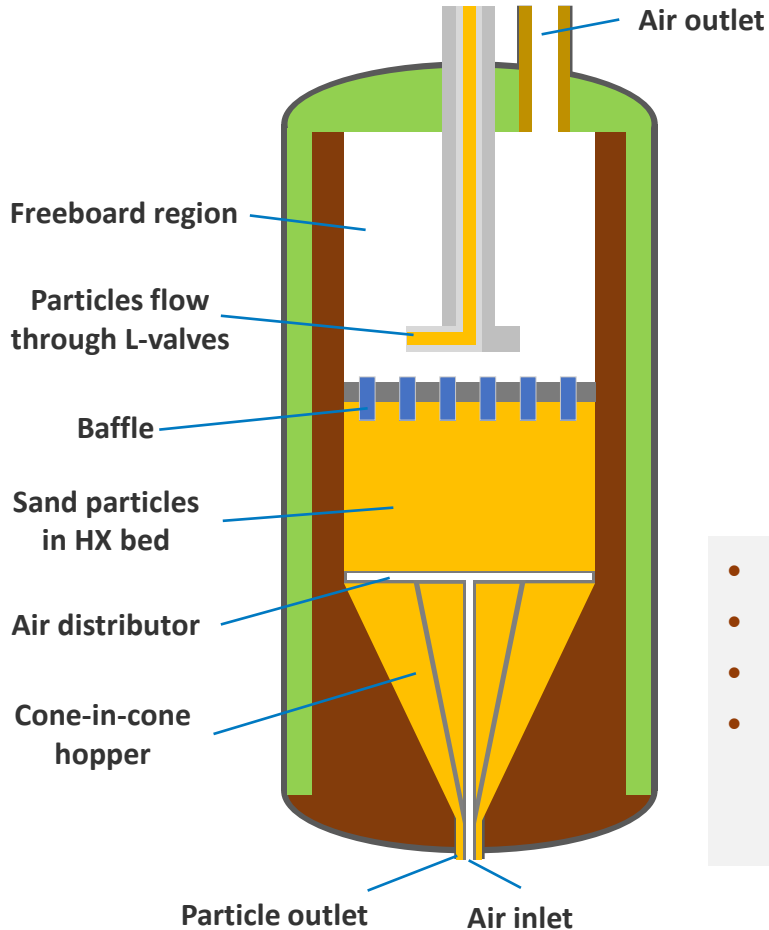
- Storage capacity: $\sim 32,000$ kg
- Hot sand temperature: 1015 °C
- Total energy stored: 33.36 GJ
- Storage duration: 25 hrs
- Heat loss (over 24 hours): 3%
- Pressure: 0.48 Mpa
- Inner height: 5.4 m
- Inner diameter: 2.16 m

Major Components: Fluidized Bed Heat Exchanger



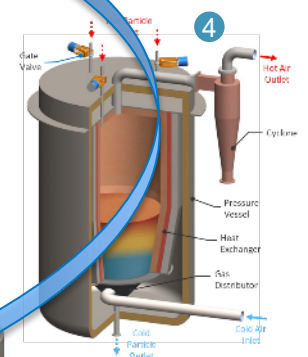
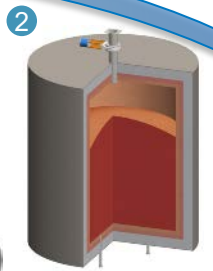
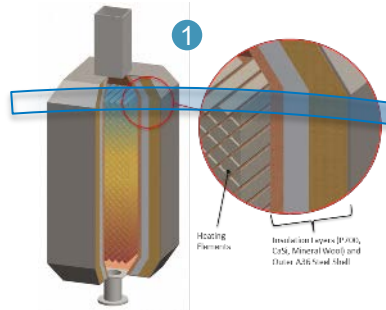
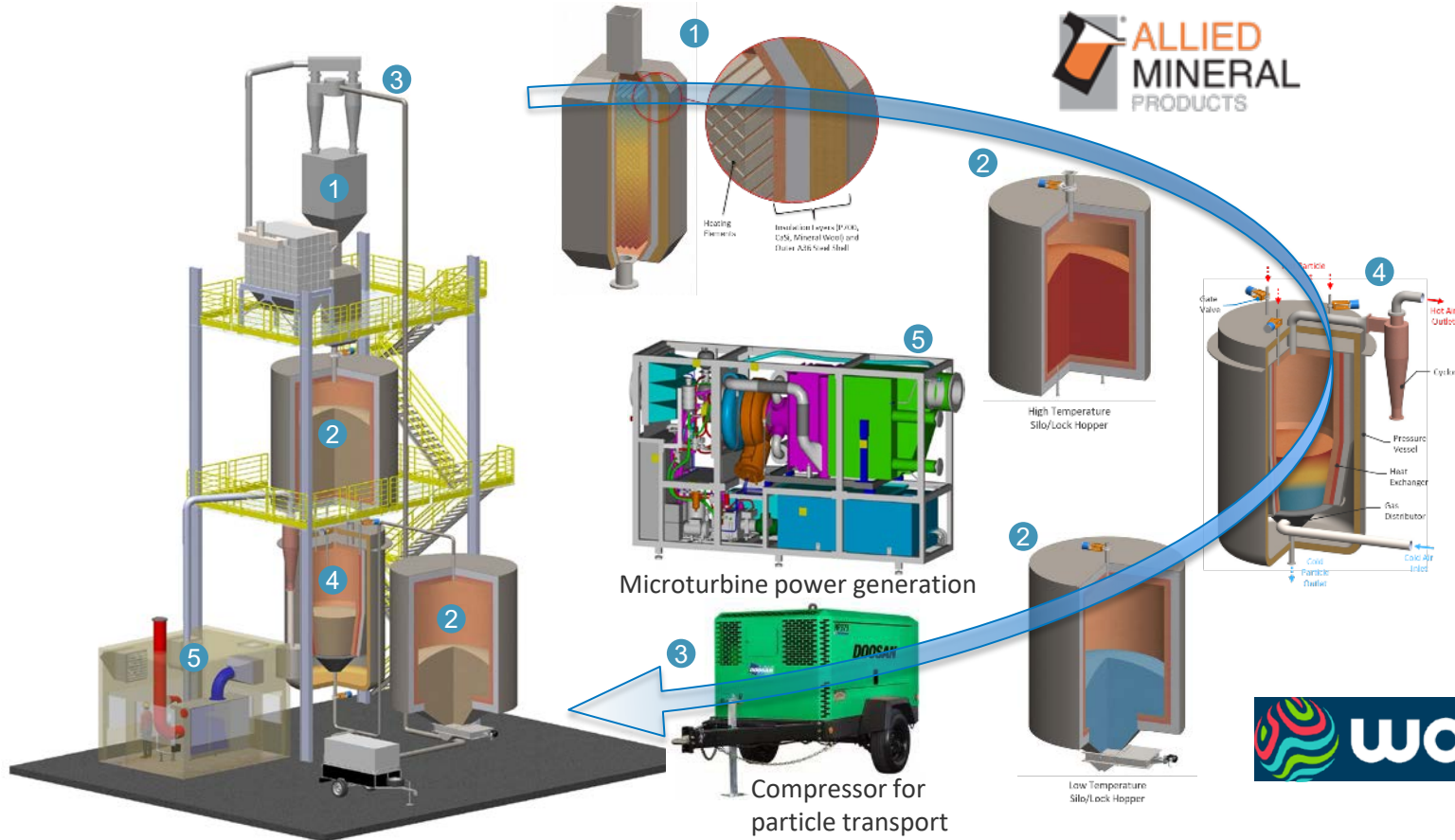
HX outer pressure vessel diameter	3.22 m
HX bed diameter	2 m
T of Particle entering HX	1018.13 °C
T of Particle exiting HX	268.17 °C
Heat transfer from particles to gas	670.4 kW
Gas outlet temperature	1003.13 °C

Major Components: Fluidized Bed Heat Exchanger



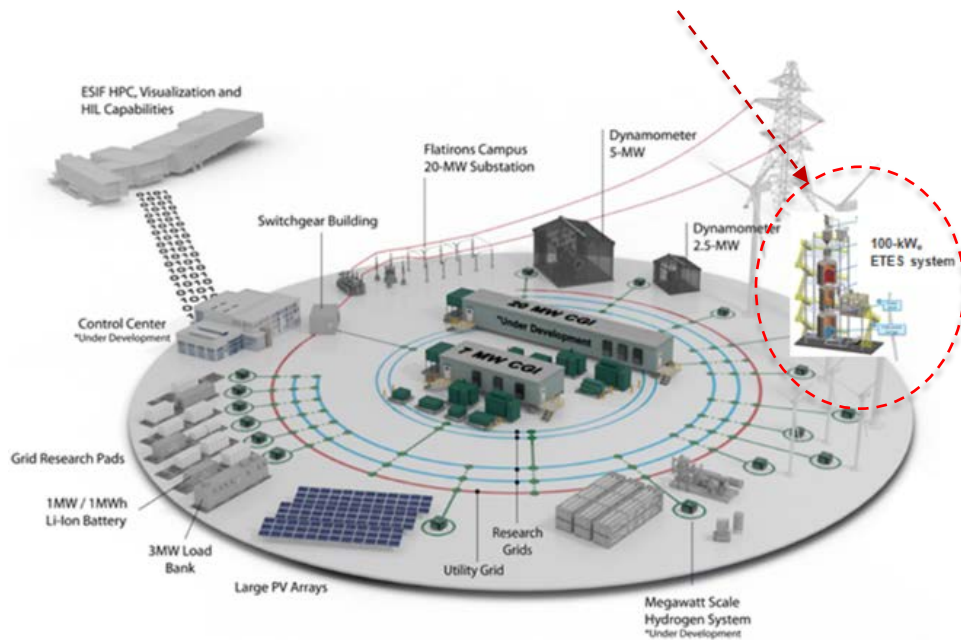
- Direct contact fluid-solid fluidized bed heat exchanger
- Mixed bed operation
- Thermal stratification along the bed height
- Using larger particles to increase fluidizing flow rate without significantly changing the fluidization regime and achieving higher heat transfer.

Component Scale-Up and System Integration



NREL's ARIES Platform for Energy Storage Research

ARIES configuration and ETES addition



Demonstration of grid integration, hybrid integration, and mitigation of grid congestion and disruptions.

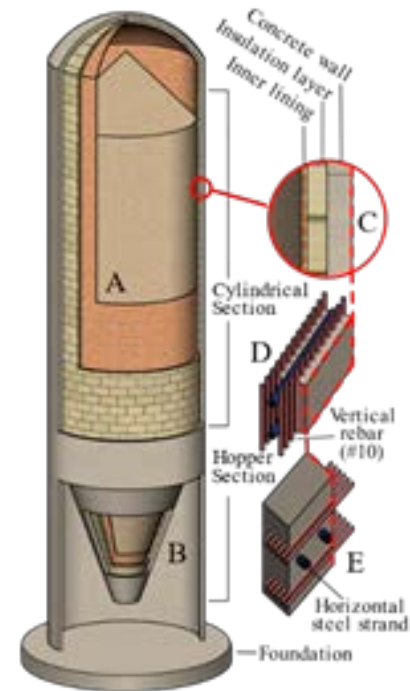


NREL ARIES (Advanced Research on Integrated Energy Systems) Facility

- Wind and solar generation (2 MW)
- Electrochemical batteries (1 MW)
- Specialized grid computational simulators
- Controllable grid interface at 7 MW and (soon) 20 MW
- Secure controls and communications with a cybersecurity emulation network
- Community-scale energy system controls and power electronics integration

Summaries

- Developed system components and projected that the component designs meet the cost and performance targets for demonstration and technology to market.
- The ENDURING LDES system provides power for several days by low-cost, high-performance storage cycles, addressing grid storage needs by enabling large-scale grid integration of variable duration alternative energy sources, thereby increasing their grid value.
- Five awarded patents, 8 published journal papers, and a book chapter to support the particle-based ETES development.



Questions?

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