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

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Project Vision

50 – 400 MWe Power, 0.5 – 80 GWht (10-100 hours)
grid storage using low-cost particle thermal energy storage

Total project cost:	$3.2M
Current Q / Total Project Qs	Q8 / Q12

DAYS
Annual Meeting
March 1 & 2, 2021

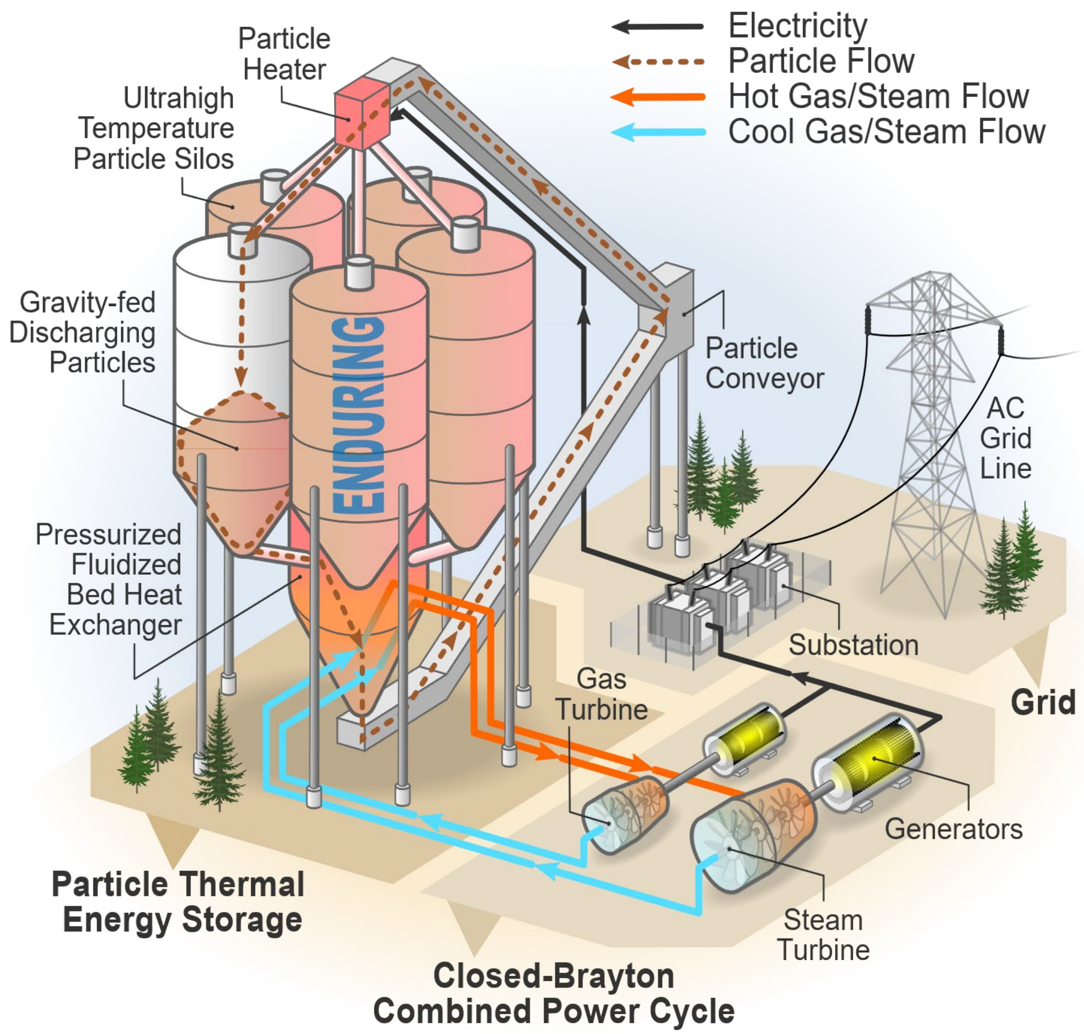
The Concept

Objective

- Innovative electric charging, fluidized-bed heat exchanger design, integration with existing combine-cycle power system.
- Provide grid-scale energy storage for high renewable integration and site flexibility.

Significance

- The ENDURING system operates as a large-scale, low-cost thermal battery capable of **50–400 MWe, 10–100 hours**.
- Able to leverage retiring thermal power plant infrastructure for low capital cost.



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ENDURING Project Team


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Jeff **Gifford**


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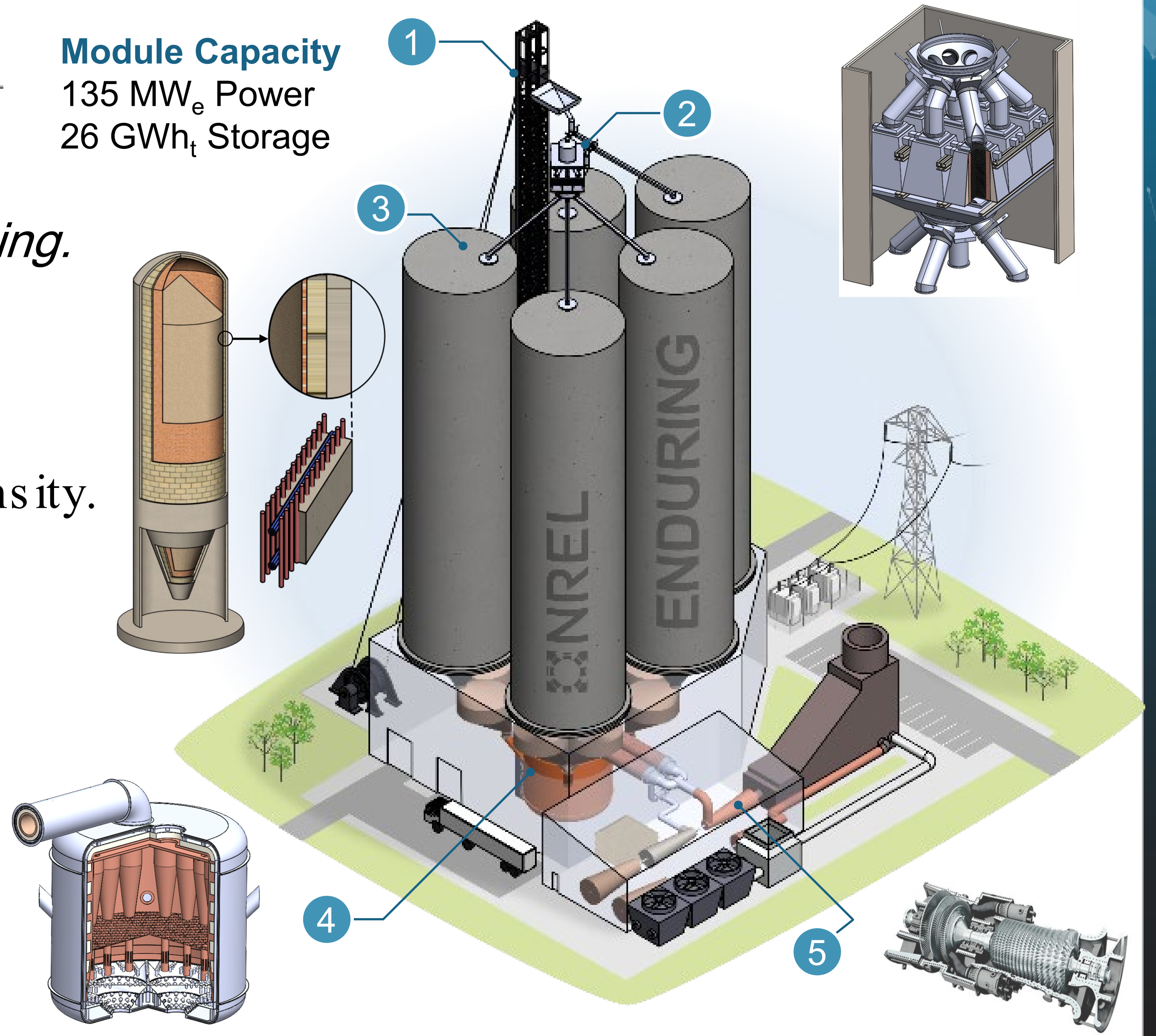
Jason **Schirck**

System Integration

1. **Particle lifting** by skip hoist.
2. **Electric particle heater** for *charging.*
   - Load following capability.
3. **Thermal energy storage** (TES) at 1,200°C.
   - 900°C ΔT increases storage density.
   - Silica sand at $30-40/ton.
   - Low-cost containment.
   - Storage cost of ~$2/kWht.
4. *Discharging* **Fluidized bed heat exchanger**.
   - Direct particle/gas contact.
5. **Power generation**
   - GE 7E.03 combined cycle

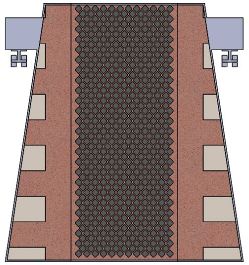


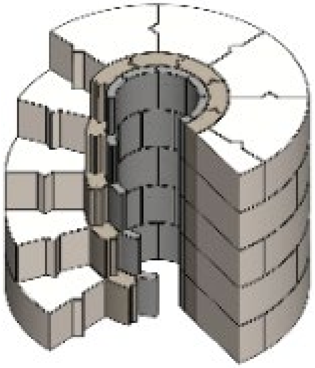
Scalable for 0.5- 80 GWh_t storage, 50-400 MW_e generation

Project Objectives and Timeline

BP2: Prototype Development

Materials subjected to thermal tests at 1200C





Building prototypes: Electric heater, TES bin, cold and hot fluidized beds

BP1: Material and Designs

BP2 Development: Concept verification via laboratory prototypes

- >10 kW benchtop particle heater
- >5 kW fluidized bed gas/particle test prototype
- >100 kWh TES material and design verification

BP1 Research: Fundamental designs and materials

- Select particles, charging heater, storage insulation, containment
- Fluidized bed, lock hopper, particle feeding and dispensing
- Power system configuration, efficiency, cycle optimization

April 2019 — BP1 — 2020 | 2021 — BP2 — April 2022

BP1 major milestones were accomplished except hot prototype delayed by COVID.

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Material Selection and Testing

Materials Screening and Testing
- Storage Media
- Insulation Material

Electric Charging Particle Heater
- Heating Elements
- Heater Module

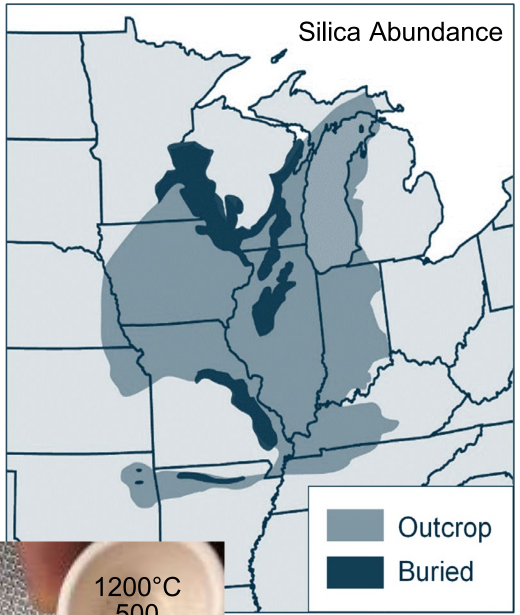
Particle Storage
- Particle Lifting
- Containment

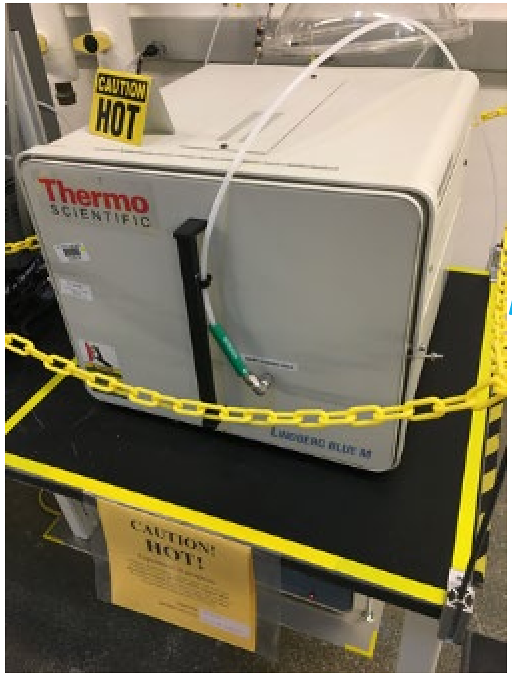
Discharging Heat Exchanger
- Laboratory Test
- Product Design

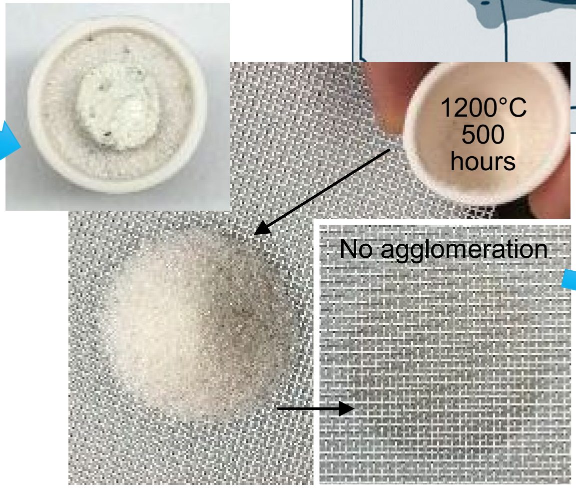
Power Island
- Combined Cycle
- Modular System

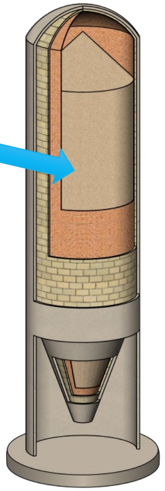
1,200°C duration and cycle tests:

- >99% pure silica sand ($30-40/ton)
- Furnace tests in air, N_2, and humidified air.







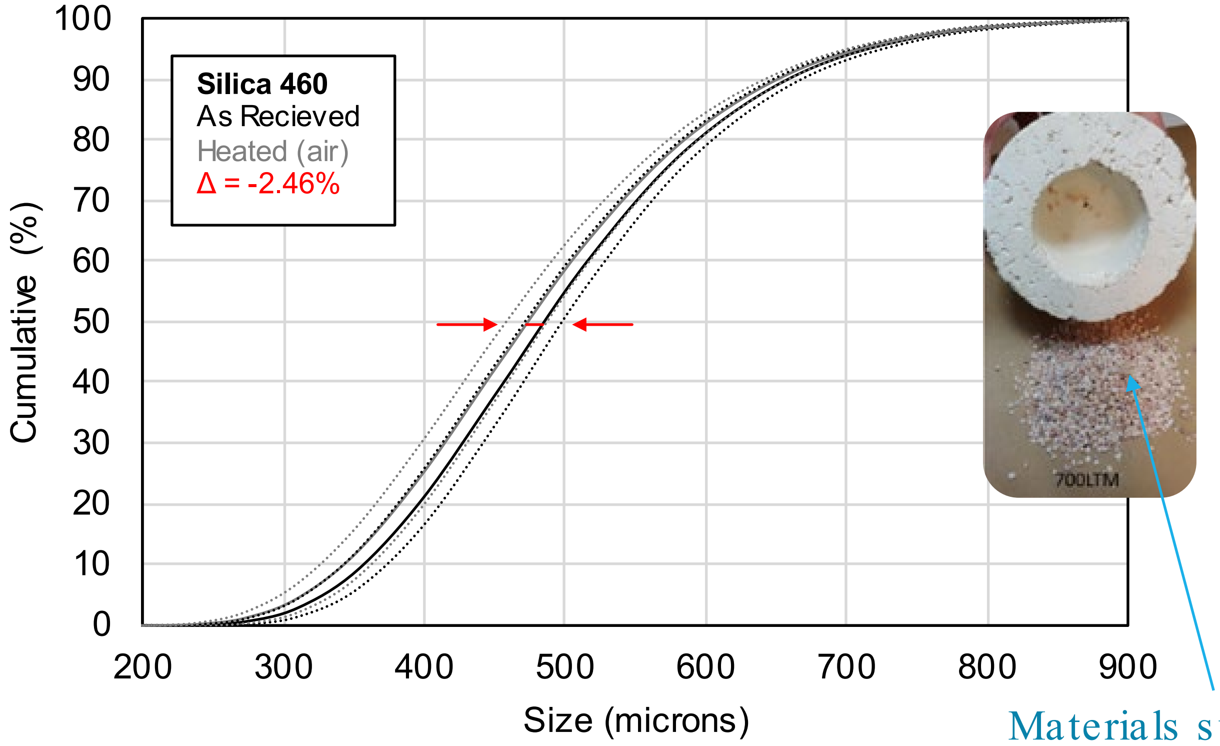


Challenges: Material stability at applicable thermal energy storage conditions (TES)

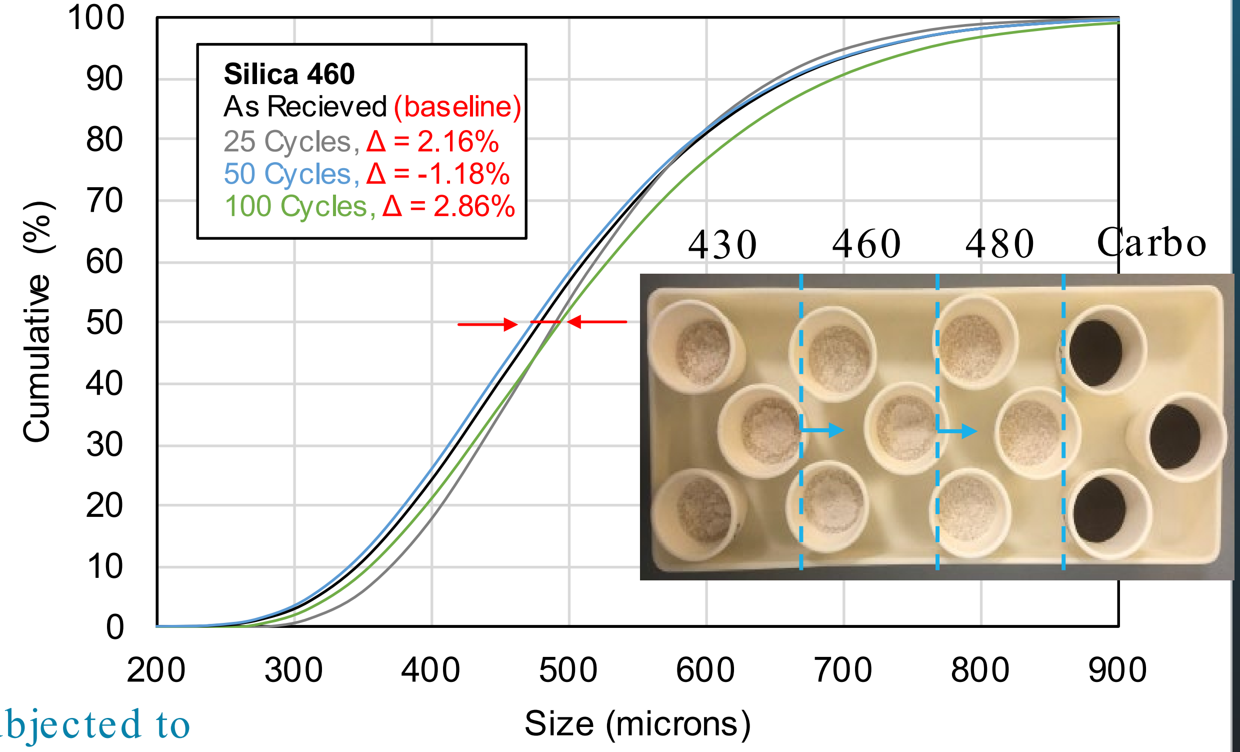
Storage Media Thermal Stability and Compatibility

Changes of particle size distribution are small via thermal tests.

500-hour heating test at 1,200°C



Performed 100 cycles at 300°C – 1,200°C



Materials subjected to thermal compatibility tests

- Stable, low-cost silica sand allows thermal storage from <-100°C to >1000°C.
- Abundant reserve in Midwest and reusable without environmental impact.

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Electric Charging Particle Heater Development

Materials Screening and Testing
- Storage Media
- Insulation Material

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Electric Charging Particle Heater
- Heating Elements
- Heater Module

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Particle Storage
- Particle Lifting
- Containment

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Discharging Heat Exchanger
- Laboratory Test
- Product Design

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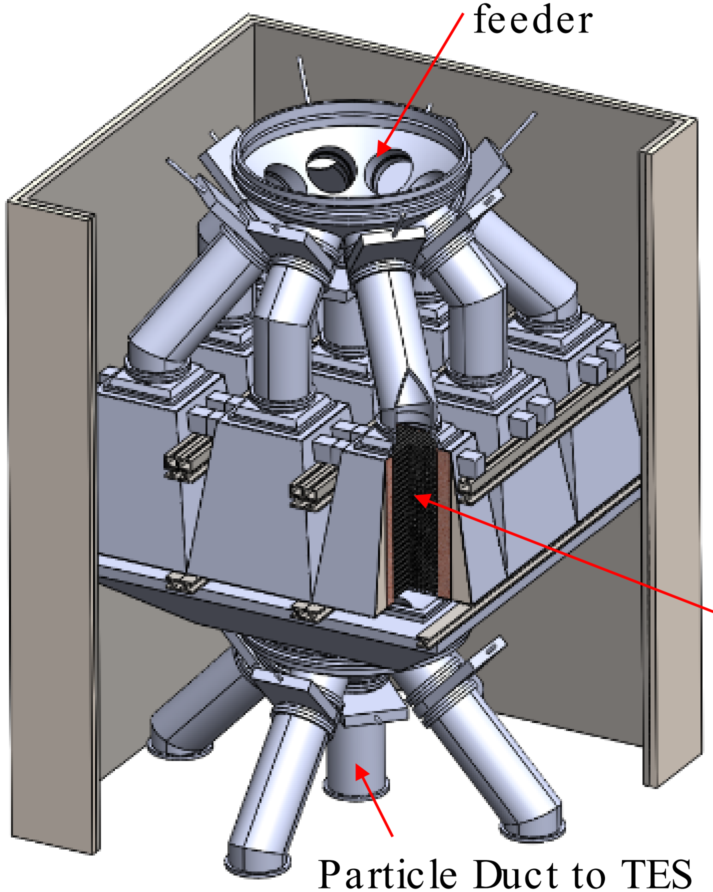
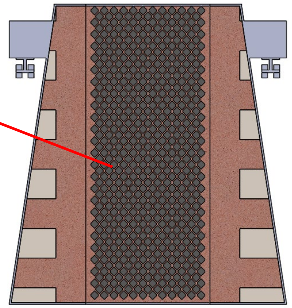
Power Island
- Combined Cycle
- Modular System



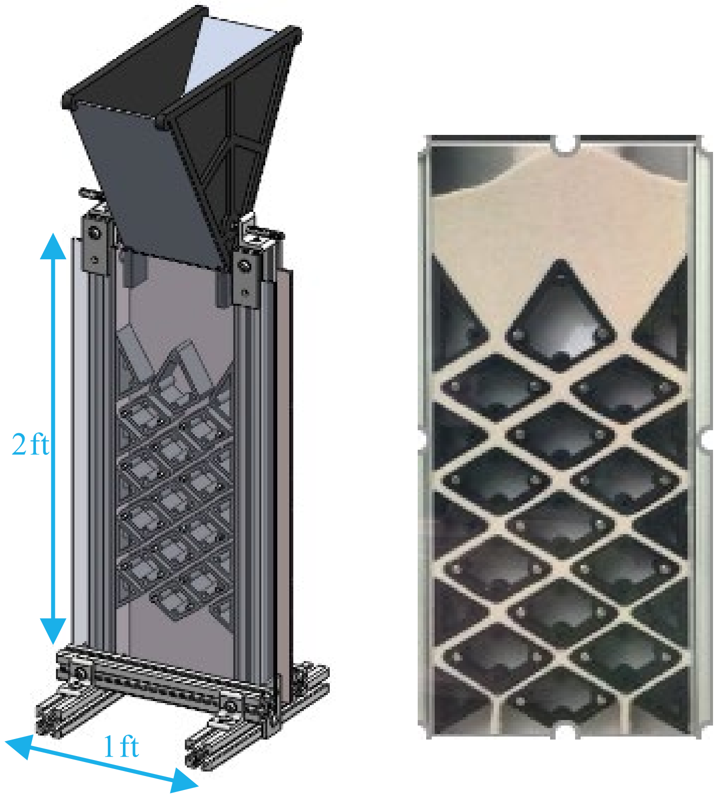
1. Modular design for load following
2. Estimated 7.3$/kW for heater bare minimum cost (not including electric supply/control)
3. Heating particles from 300 °C to 1,200°C

Heater Module Design

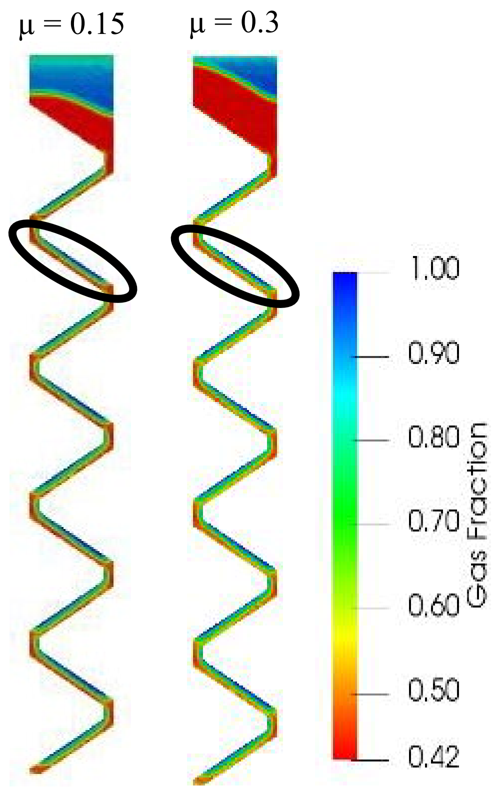


Challenges: Achieve high energy density for small volume and low cost; verify fabrication, performance, and reliability.

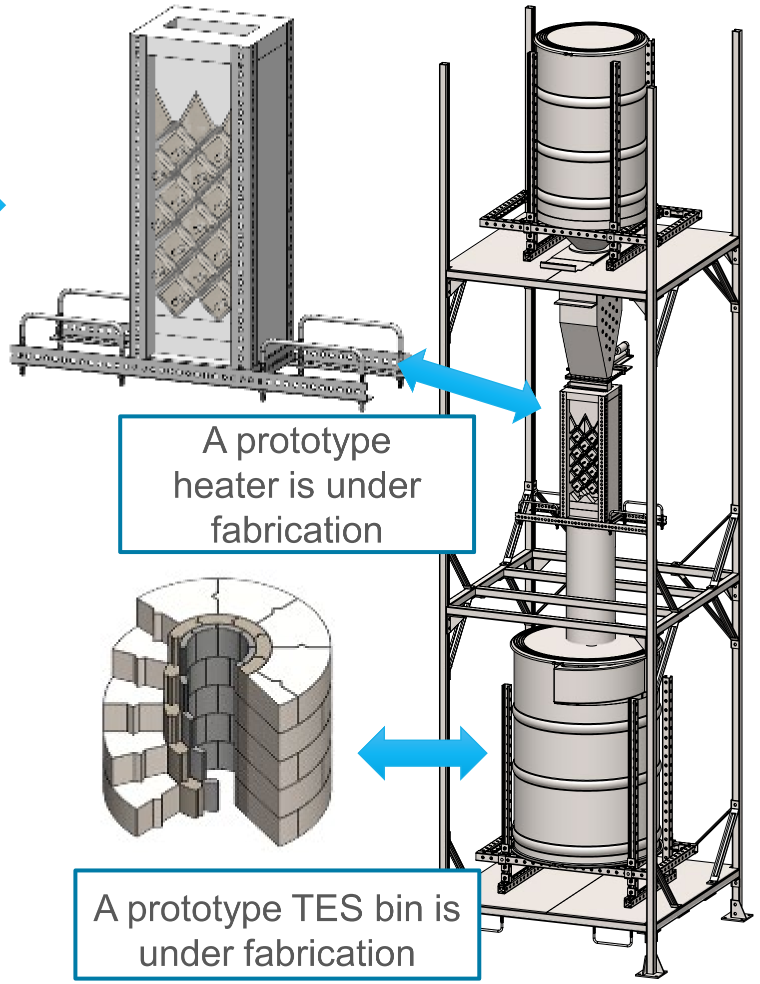
Prototype Development and Testing Progress



Cold flow testing of heater design



Modeling particle flow and heat transfer inside heater



Hot testing of prototype heater and TES bin

A Prototype heater was designed and modeled, to be fabricated, and tested.

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Particle Thermal Energy Storage Development

Materials Screening and Testing
- Storage Media
- Insulation Material

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Electric Charging Particle Heater
- Heating Elements
- Heater Module

↓

Particle Thermal Energy Storage
- Particle Lifting
- Containment

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Discharging Heat Exchanger
- Laboratory Test
- Product Design

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Power Island
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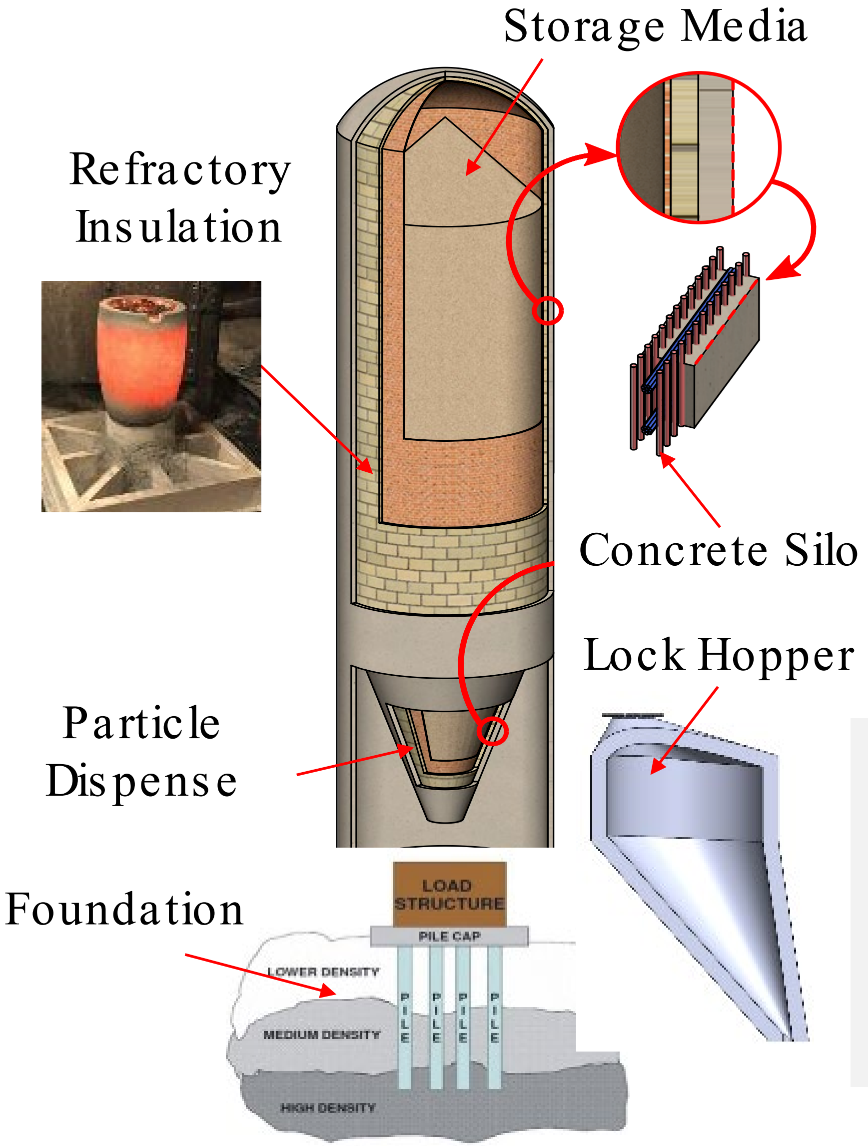

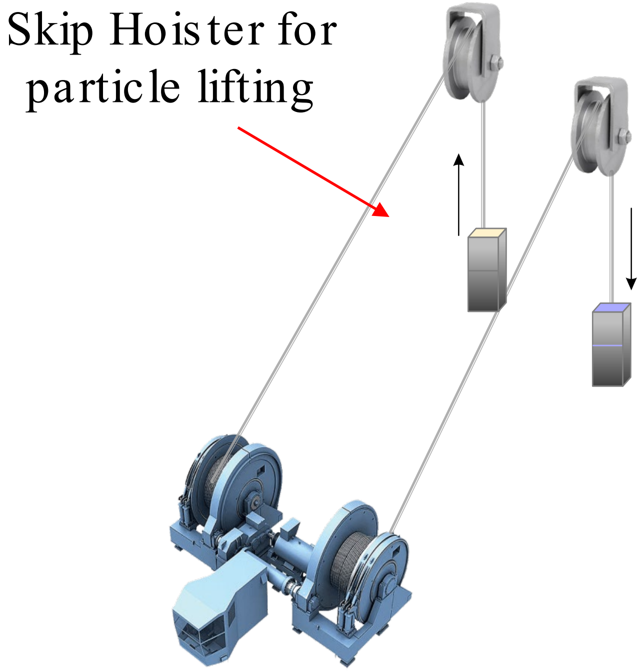

1,200°C TES
- High storage density(900°C ΔT)
- Low-cost media and containment in thermocline configuration → ~$2/kWht storage cost

Pressurized Fluidized Bed Heat Exchanger

Materials Screening and Testing
- Storage Media
- Insulation Material

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Electric Charging Particle Heater
- Heating Elements
- Heater Module

↓

Particle Thermal Energy Storage
- Particle Lifting
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Discharging Heat Exchanger
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Power Island
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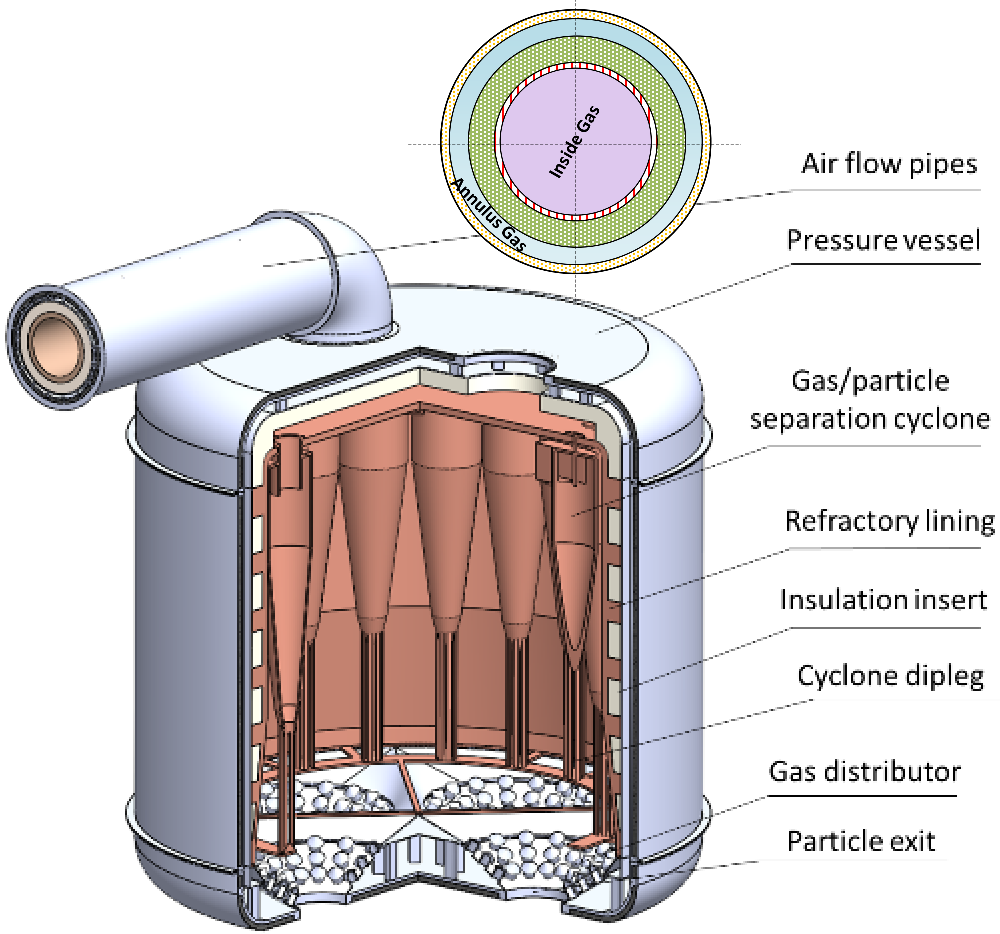


Challenges: Realize gas/particle counter-flow configuration

Innovative fluidized bed heat exchanger for energy discharge:

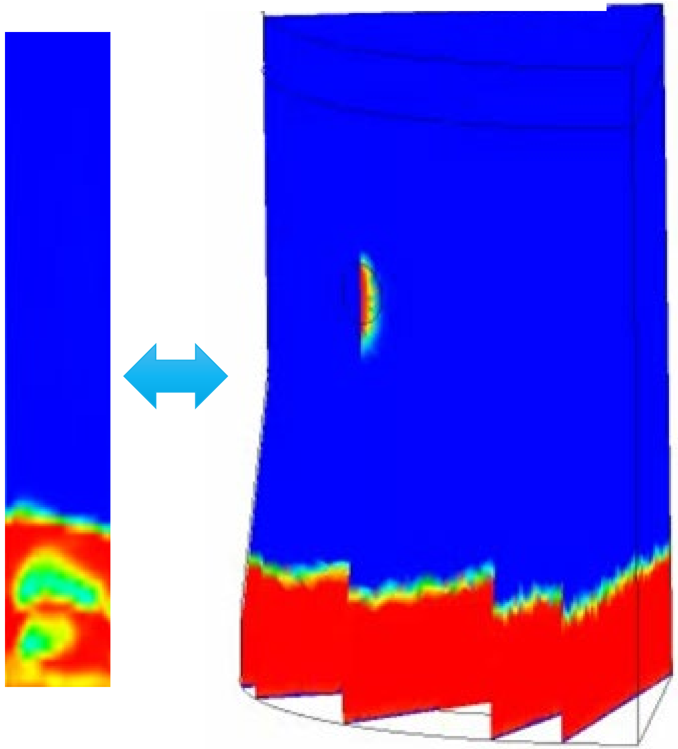
- Key component leverages commercial experience.
- Direct gas/particle contact to reduce exergy loss and cost.
- Cost below $100/kWe
- It can be built on Allied Mineral’s refractory materials and B&W manufacturing.

Prototype Development and Design Modeling

Cold prototype under testing

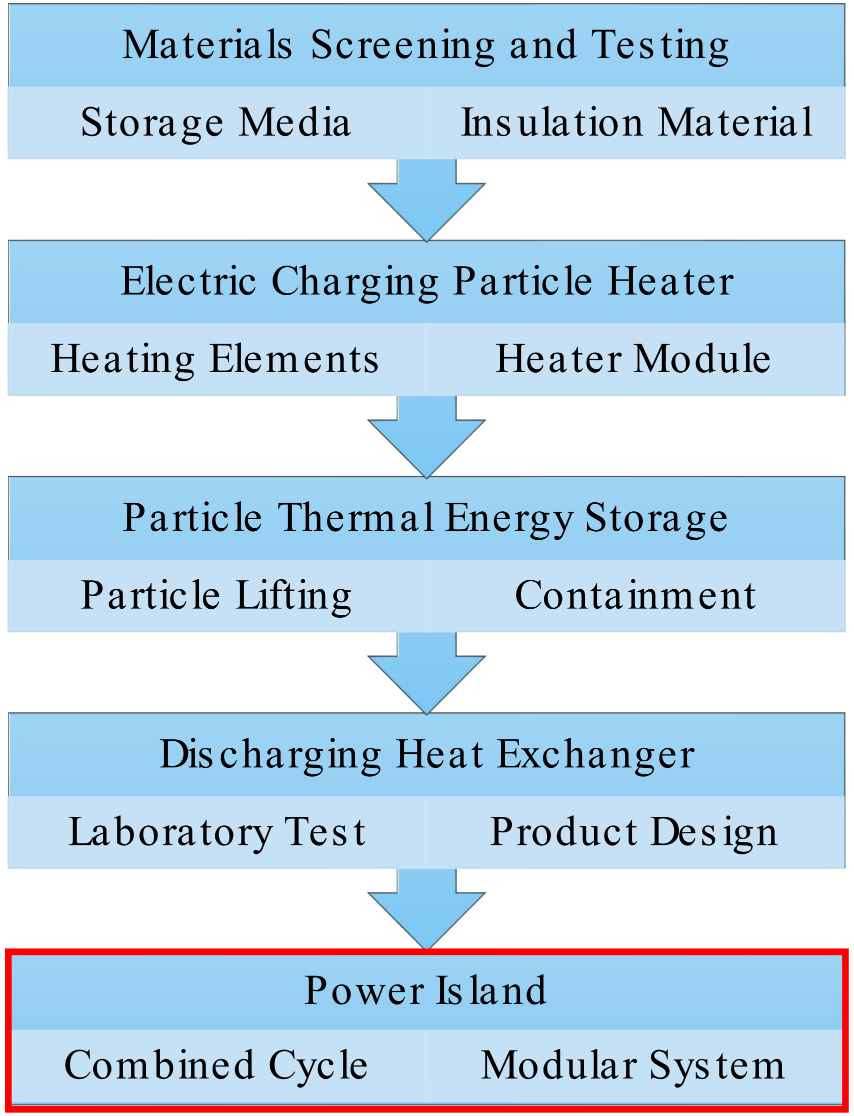
Hot prototype under development

Prototype and product fluidized bed modeling



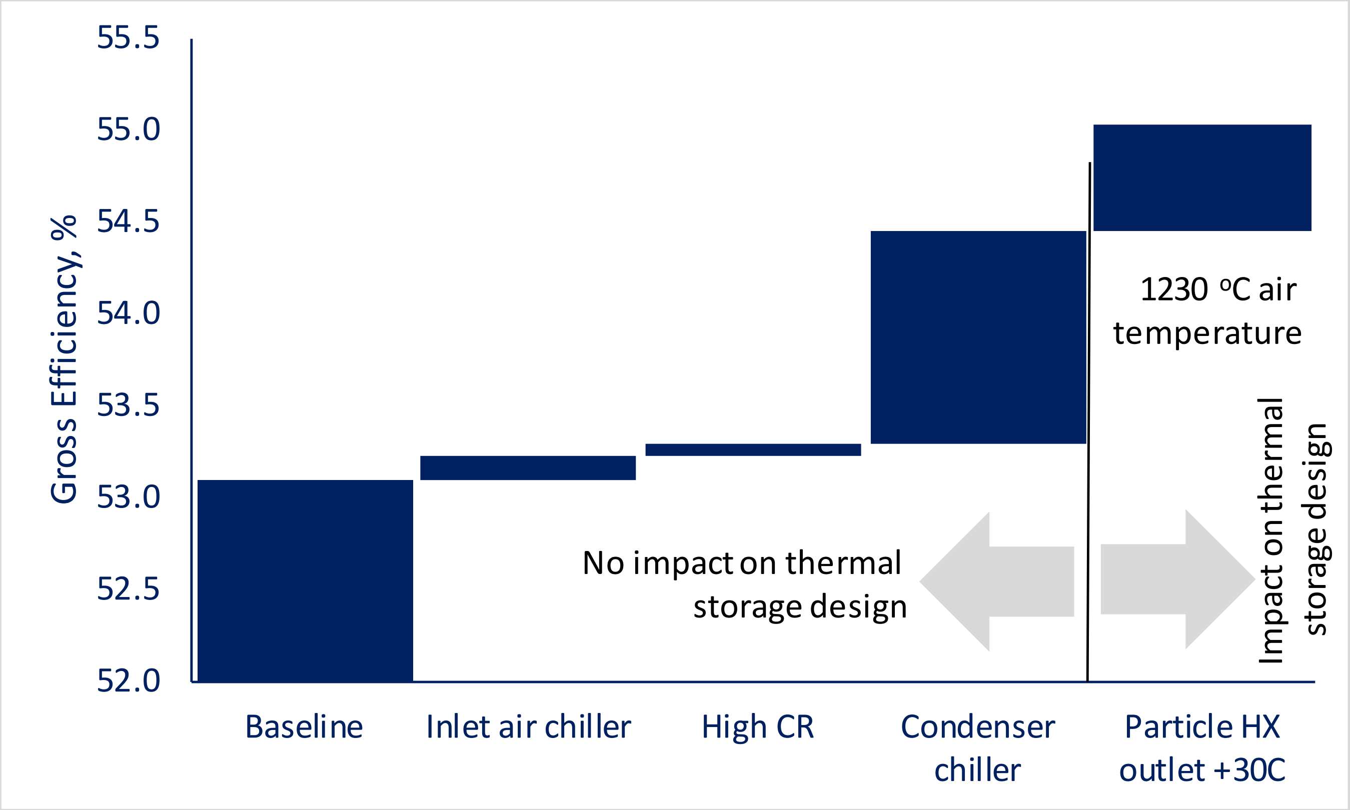
Focused research by modeling and cold/hot prototype testing

Combined Cycle Power Generation

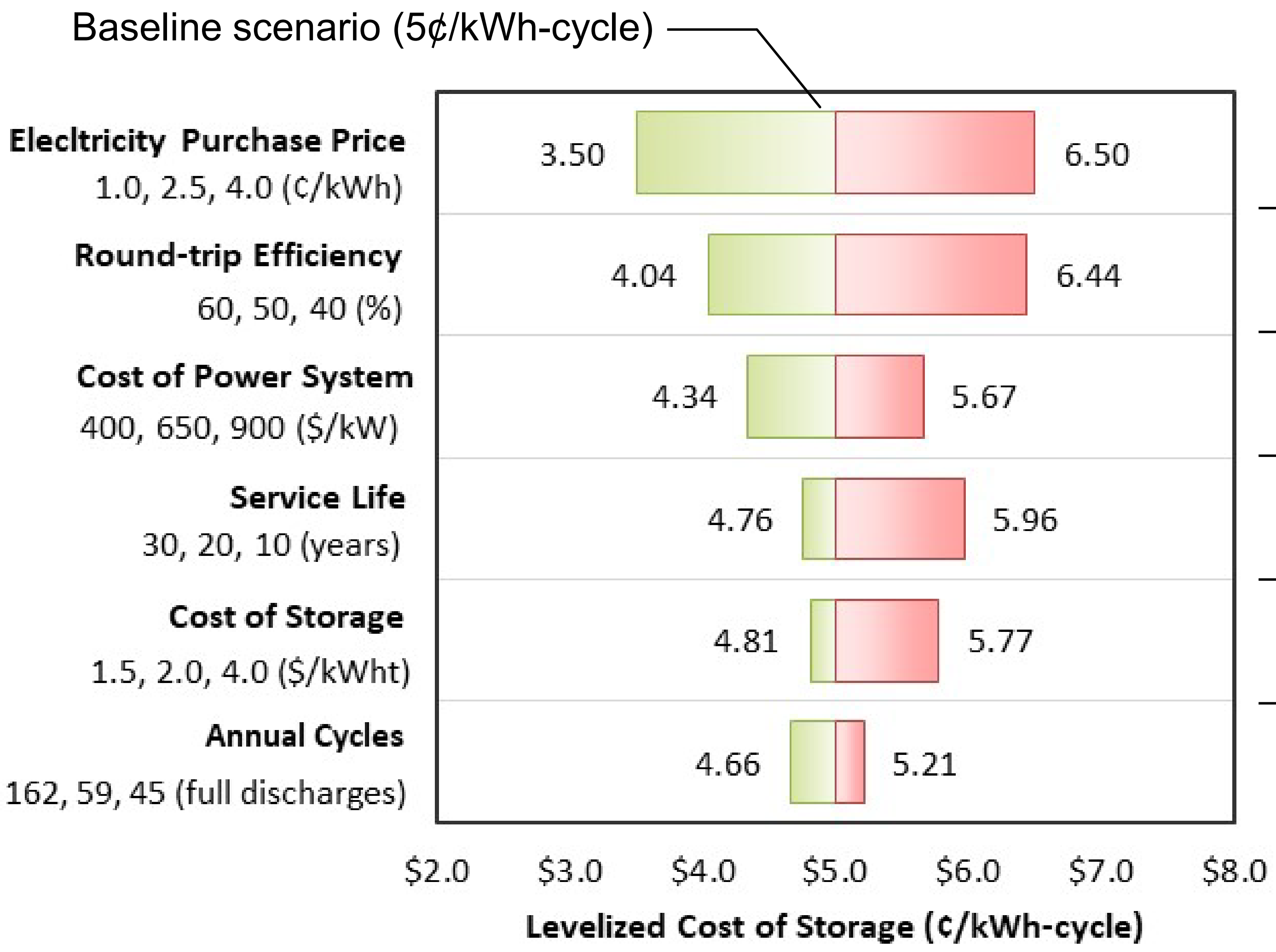


GE Global Research analyzed combined cycle performance:

- **GE 7E.03** Combined Cycle efficiency >54% achievable
- Using a chiller for additional energy storage during off peak hours to improve overall storage efficiency



ENDURING System Economic Analysis



- Curtailment leads to low EPP at 1c/kWh
- EPP without discounts at 4 c/kWh

- Implementation of Carnot battery at 60%
- Leveraging coal- or gas-plants at 40%

- Leveraging power generation infrastructure
- Basic new equipment of a power system

- Typical life of a thermal power plant
- Reference life of chemical storage

- Improved construction of TES containment
- Initial small capacity TES unit

- Mix of daily & DAYS storage (*25-hr duration*)
- Long duration DAYS storage (*100-hr*)

Most sensitive to electricity purchase price and round-trip efficiency.

Several paths can support the economical goal of LCOS<5¢/kWh.
Challenges: Need product and plant design for installed cost.

Challenges, Risks, and Potential Partnerships

- Verify product-scale design, fabrication, performance, reliability, and operability.
  - Lack of field application hinders particle TES deployment.
- Pilot demonstration at 1–5 MW scale mitigates component and system risks.
  - Develop product-relevant prototype design, fabrication, and operation for charging heater, fluidized-bed heat exchanger, particle handling, and TES containment.
  - A 60-meter-tall particle lift structure near NREL can be a test site for pilot prototype testing.
- Potential partner on pumped thermal energy storage.
  - ENDURING TES can support thermal power cycles and industry heat supply.

Seek support for a pilot demonstration.

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Summary Slide

- Low cost, grid-scale ENDURING storage supports renewable integration:
  - Adapting a GE turbine provides an expedited commercialization path to market.
  - The system can achieve large power and storage capacity.
- Achieved major milestones in Budget Period (BP) 1 and work on BP 2 goals:
  - Developed design tools, designed components and system preliminarily.
  - Modeling system and component performance.
  - Conducted technoeconomic analysis.
  - Validated storage materials.
  - Develop multiple prototypes under fabrication or testing.
- Risk mitigation, technology to market, and partnership:
  - ENDURING storage can be added to a thermal-power plant.
  - Four patents applied, five papers published, six presentations given in BP1.
  - Seek partners for pilot demonstration to prove the technology.

Thank you!
Q&A

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