Westinghouse Modular Heat Storage: A Flexible Approach to Next Generation Grid Needs

Cory Stansbury

Principal Engineer

Heat Storage for Gen IV Reactors for Variable Electricity from Base-Load Reactors, Idaho State University, July 23-24, 2019

WAAP-11446

Westinghouse

OUR VISION & VALUES

Westinghouse will remain the first choice for safe, clean and efficient energy solutions.

We enhance our delivery of that vision by living our values:

- Safety & Quality First
- Valuing Ethics, Integrity & Diversity
- Passion for Serving Our Customers Globally
- Dedication to Each Other Through Servant Leadership
- Creating Value for Shareholders, Customers & Employees
- Consistently Delivering Our Commitments

Brief History of Westinghouse Energy Storage Activities

- Energy storage investigations started at an “Innovation Kickoff” meeting held in early 2015; FENOC representatives were on hand and were supportive of energy storage as one topic area à Group voted to pursue this project
- Project focused initially on assisting legacy plants and pure arbitrage
- Inability to cleanly tie into existing plant balance of plant (components did not have enough margin) and lack of customer interest shifted focus
- Project continued, focusing on integration into new-build (especially next generation plants) and in standalone form
- Part of winning submission to ARPA-E “DAYS” project in 2018

Westinghouse

Brief History of Westinghouse Energy Storage Activities

Large scale storage market

Technologies Considered

- Compressed air energy storage
- Cryogenic energy storage
- Thermal energy storage
- Batteries
- Hydrogen
- Pumped hydroelectric
- Desalination
- District heating
- Synthetic Fuel

Decision Criteria

1. Competitive landscape / technology gaps
2. Overall economics
3. Upfront capital cost scalability
4. Plant Integration (legacy or new build)

Evaluated Characteristics

1. **Geographic independence**
2. Demand responsiveness
3. Footprint
4. Operation and maintenance (O&M) feasibility
5. Environmental impact

Westinghouse

High-Level Goals

Given a goal of competing in the large/very large storage arena (GWh+) and coupling to nuclear plants, product should:

- Utilize common materials which are widely/locally sourceable
- Operate at low pressures and have intrinsic safety characteristics
- Minimize additional piping/heat exchange area contacted by primary working fluid
- Be modular in nature and fast to construct with varying workforce skill levels
- Achieve long life (>20,000 cycles)
- Require minimal maintenance, inspection, and renewal costs
- Meet cost and performance goals relative to a wide selection of markets and stacked services

Westinghouse

Embrace Simple / Low Cost Solutions in Creative Ways

Why Concrete?

A wide variety of thermal storage solutions were investigated:

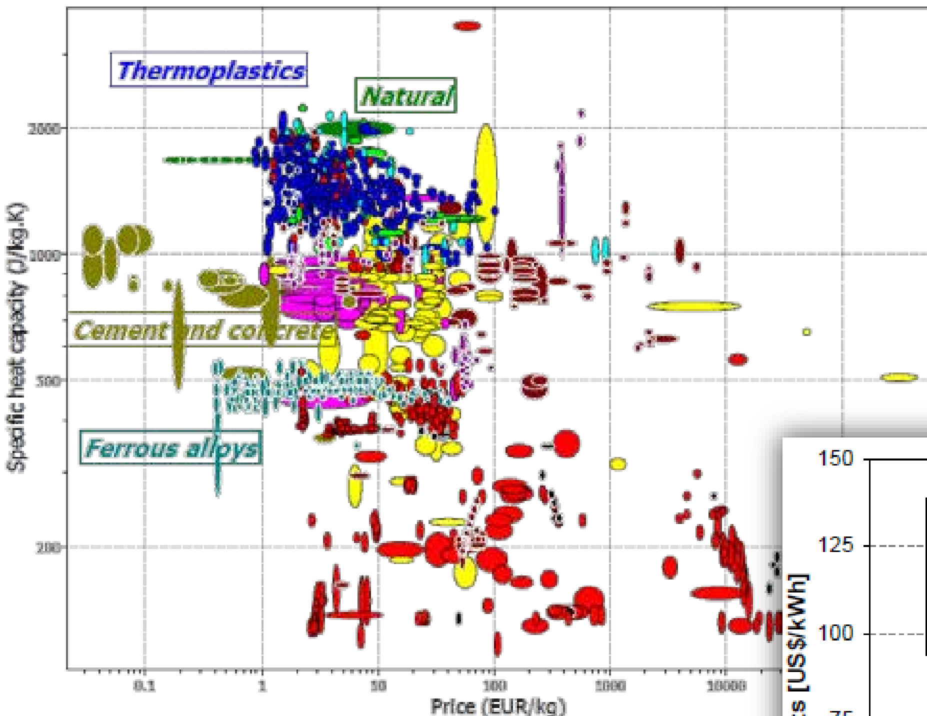
- Salts
- Reversible chemical reactions
- Phase change materials
- Packed beds
- Hot oils
- Supercritical fluids
- Hybrid combinations

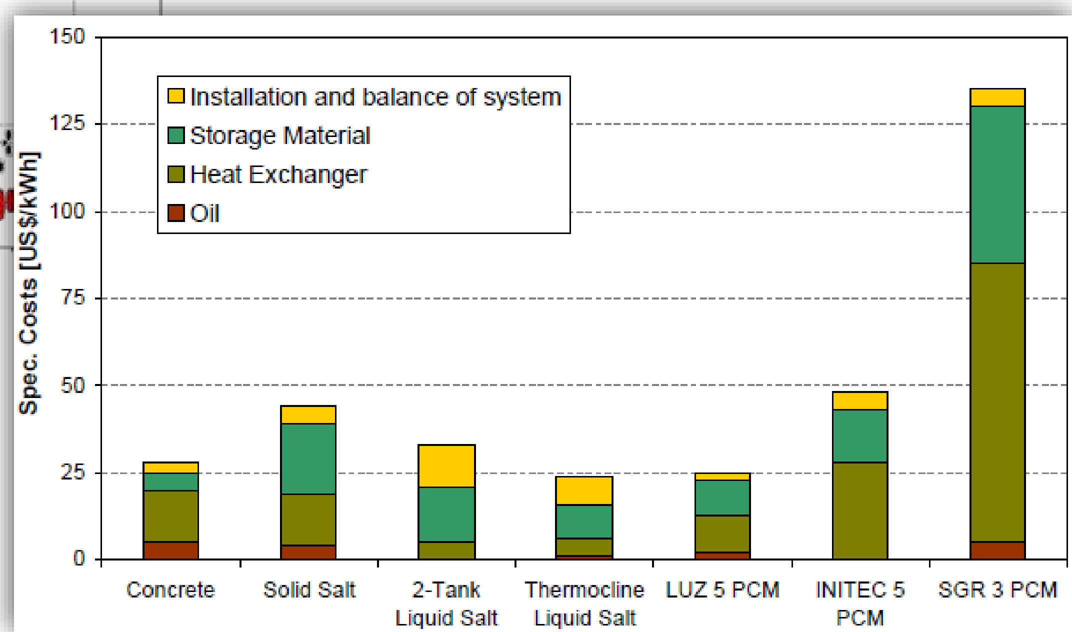
Concrete + Oil Offered a Variety of Desirable Properties

- Locally-available
- Significant understanding of performance at temperature
- “Engineered” and prequalified with material selections
- Extremely low-cost (possibility for Low marginal cost/kWh)
- Low risk of uncontrolled energy release
- Enormous experience in construction at large scale

Concrete was judged to give a good combination of consistency / “designability” and low cost

Why Concrete?





References

1. A. Inés Fernández et. al, “SELECTION OF MATERIALS WITH POTENTIAL IN THERMAL ENERGY STORAGE,” Universitat de Barcelona.
2. U. Herrmann; M. Geyer, “Overview on Thermal Storage Systems,” Flabeg Solar International GmbH, Workshop on Thermal Storage for Trough Power Systems, February 2002.

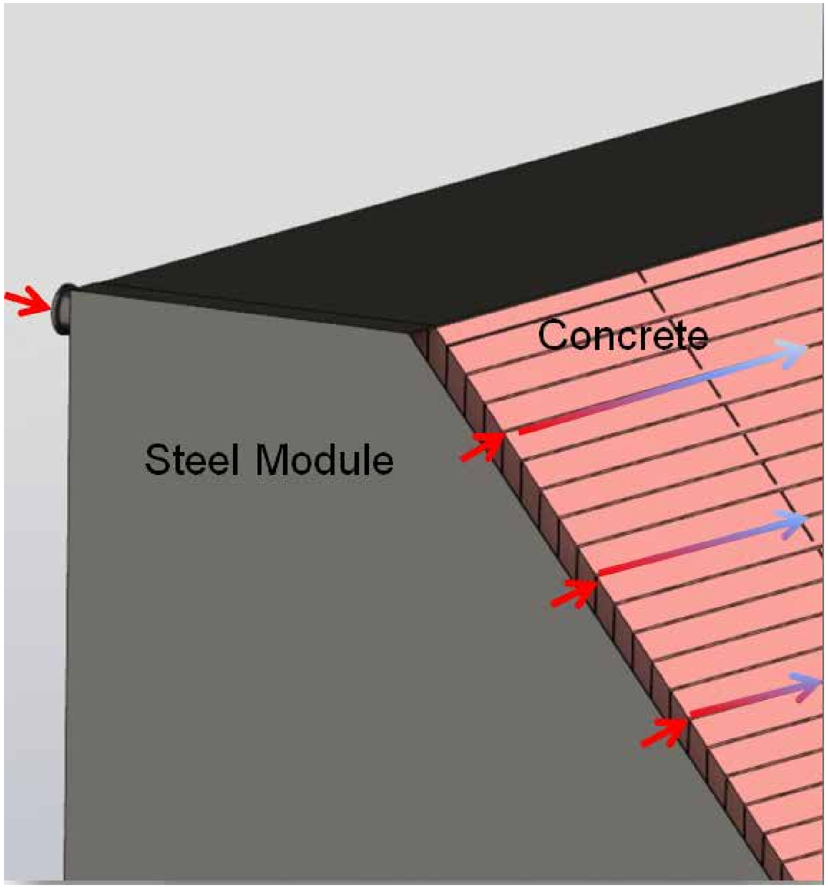
Challenges with Sensible Heat Storage

- Materials with great specific heat tend to have poor thermal conductivity
- At low temperatures and pressures, costs associated with tubes in concrete become more challenging
  - Tube pitch must be tight to evenly heat concrete, increasing volume of oil, tube amount, and fabrication difficulties
  - Tube, header, and oil cost quickly dwarf concrete costs
  - Concrete/tube interface is predisposed to cracking with cycling, making heat transfer more difficult
- Westinghouse wondered if oil and concrete could be made to play nicely together…?

Westinghouse

The Westinghouse Solution

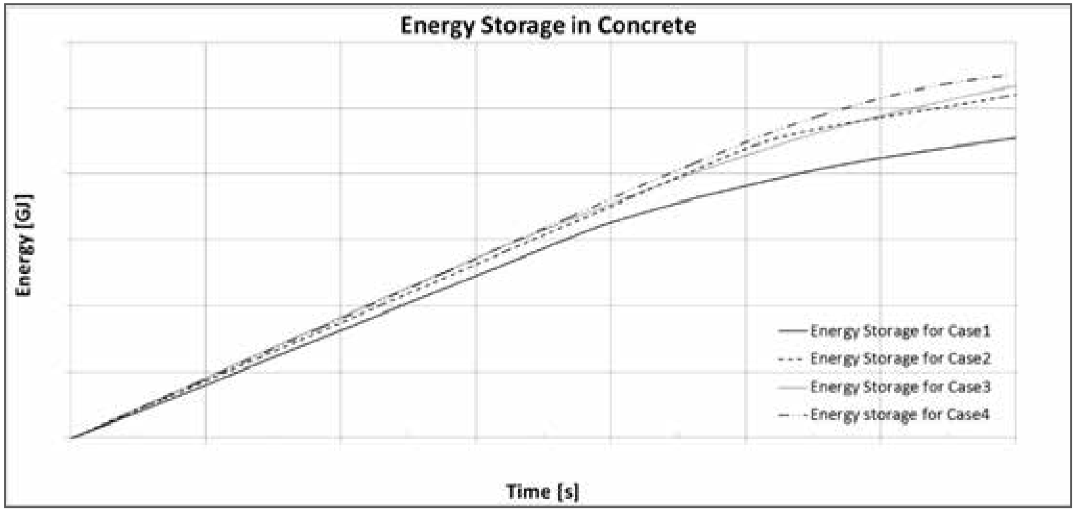
- Westinghouse is looking to flip the traditional method inside-out
- If we can develop a concrete and oil which are compatible, we can eliminate tubing
- Using thin plates with narrow gaps creates huge surface area relative to volume and minimizes oil fraction

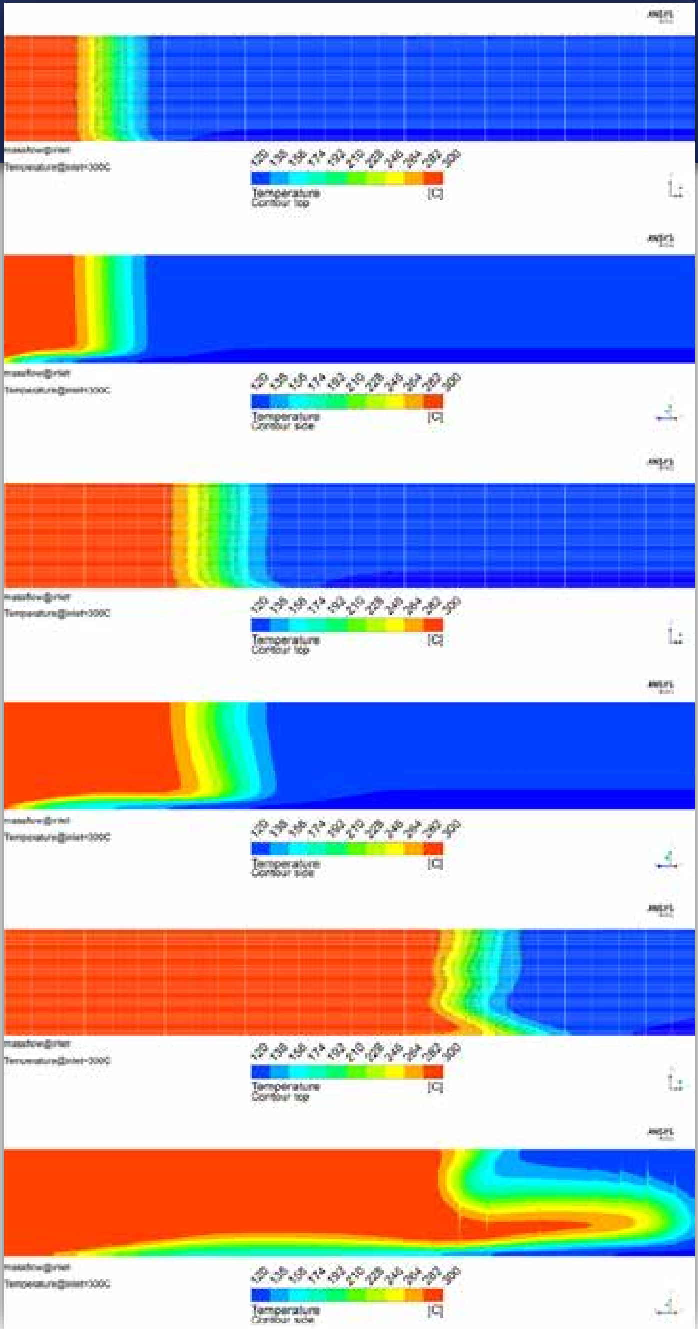


Westinghouse

The Westinghouse Solution

- The large amount of surface area, relative to heat storage, along with the high dT of charge (low velocity), means that a slow, thermal wave is established in the concrete





Concrete Development and Characteristics

Precast panel considerations and goals:

- Fabrication/erection tolerances
- Cast-in features
- Thermal properties
- Expansion/contraction/cracking caused by
  - Thermal
  - Hydration
  - Creep/shrinkage
- Cost
  - Materials
  - Fabrication
- High density / low porosity
- Eliminate traditional reinforcement (i.e. rebar)
- Concrete mix must not degrade at high temperatures or have adverse interaction with the heat transfer fluid

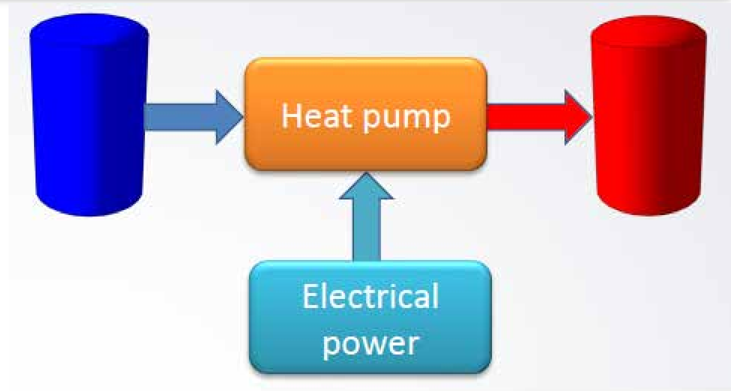
Three Applications: One Heat Storage Block

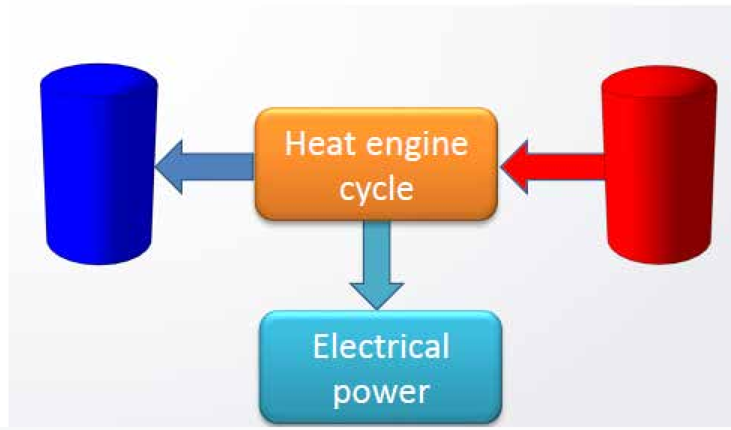
- Stand-alone storage: Pumped heat supercritical CO_2 (sCO_2) concept (ARPA-E)
- Coupled storage with new-build PWR: Provides additional operational flexibility and economic certainty in future markets
- Coupled storage with advanced reactors: lead fast reactor (LFR) + heat storage = unmatched flexibility and economics in generation

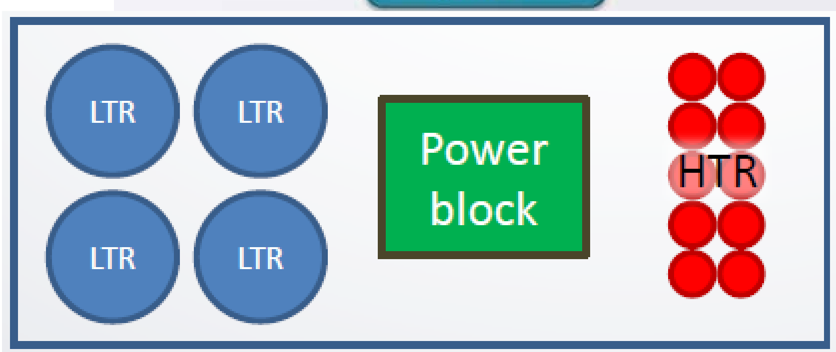
Thermal Storage Technology is Flexible

Applications - Standalone Storage

- Under development as part of ARPA-E “DAYS” project
- Pumped Heat Energy Storage (PHES) uses a heat pump and electricity to create a hot and cold reservoir (HTR & LTR)
- This cycle is reversed and the differential is used in a power cycle to generate electricity
- Not a new idea, but sCO_2 allows performance at 300°C / 0°C which would have required much greater temperature extremes prior; thus permitting low cost solutions, like concrete and ice



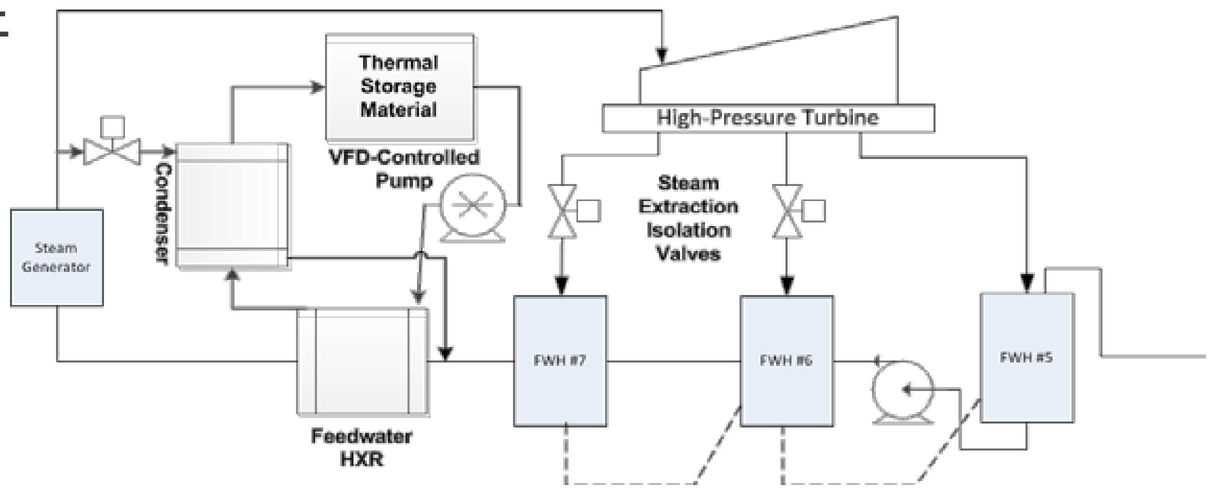




Westinghouse

Applications - New Build PWR

- When the BoP is designed from the onset to interface with thermal storage, these systems can be integrated
  - Use main steam to heat oil/concrete, thus reducing output
  - Provide additional output by using stored heat to eliminate extraction steam flow needed for feedwater heating, thus keeping it in the turbine (more steam in turbine = more MW)
- Modeling suggests 20-25% additional output is possible w/ ~60% RTE



“Future-Proof” New Nuclear

Modeling of Financial Performance

Westinghouse is working to develop our own evaluation tools and understanding

- Financial/technical model of 11 storage technologies + multiple implementations of thermal storage (including sensitivity)
  - Captures capital cost and levelized cost of storage (LCOS)
  - Models across multiple mission sets to capture nuance of how performance metrics impact different energy storage applications
  - Integrated with broader, characteristic-based evaluation tool to help rank technologies on an overall scale
- Hour-by-hour model of coupled “hybrid” plant performance, capital costs, levelized costs, and financial viability against state-of-the-art combined cycle plants in grids with high percentages of non-dispatchable generation
- Initial results are extremely promising to offer a step-change in achievable financial performance

Westinghouse

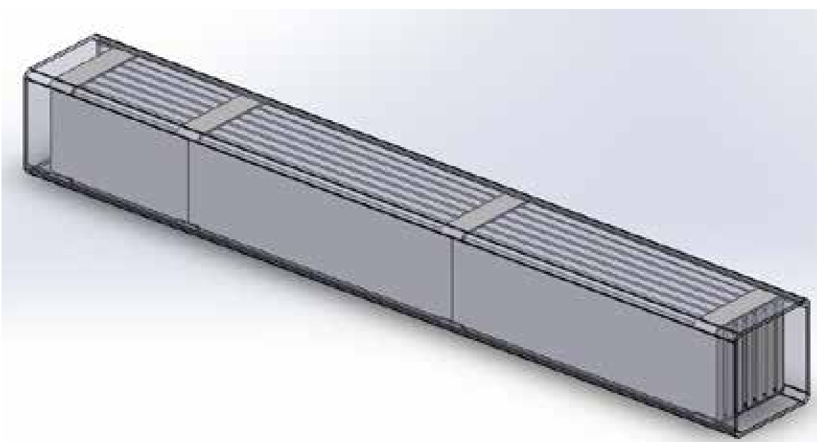
External Engagement and Modeling

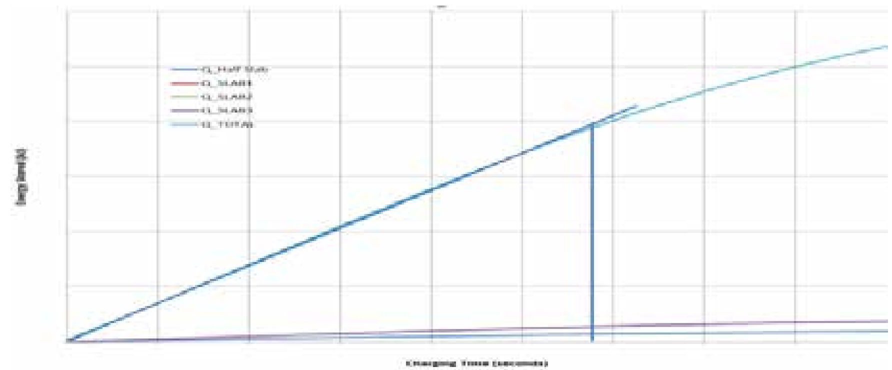
- Engagement of Experts:
  - Steve Brick: Clean Air Task Force
  - Jesse Jenkins: MIT and Harvard
  - Customized Energy Solutions
- What is a reasonable penetration level for non-dispatchable sources?
- How is storage valued in different markets? How is this impacted by penetration?
- What is the impact of technical characteristics?
  - Charge Rate - $/kWh
  - Round Trip - $/kW
- What is an ideal combination of renewables, nuclear, nuclear hybrid, standalone, and nuclear-coupled storage?

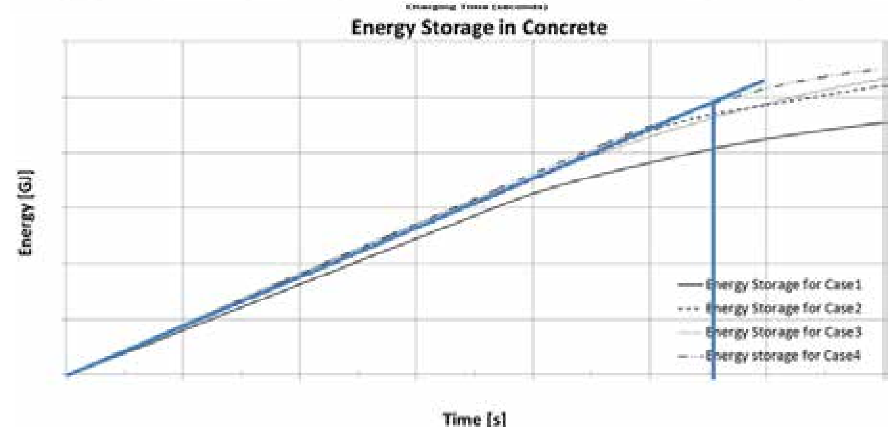
Westinghouse

Proof of Principle Testing

- Small scale test designed to prove concept
- Test is instrumented to show "thermal wave" and characterize performance
- Results will be compared against CFD to validate computational methods
- Test uses marble plates in a square "tube"
- Similar scaling to full scale, 40-foot "module" (achieves ~81% of the linear charge duration of full scale)

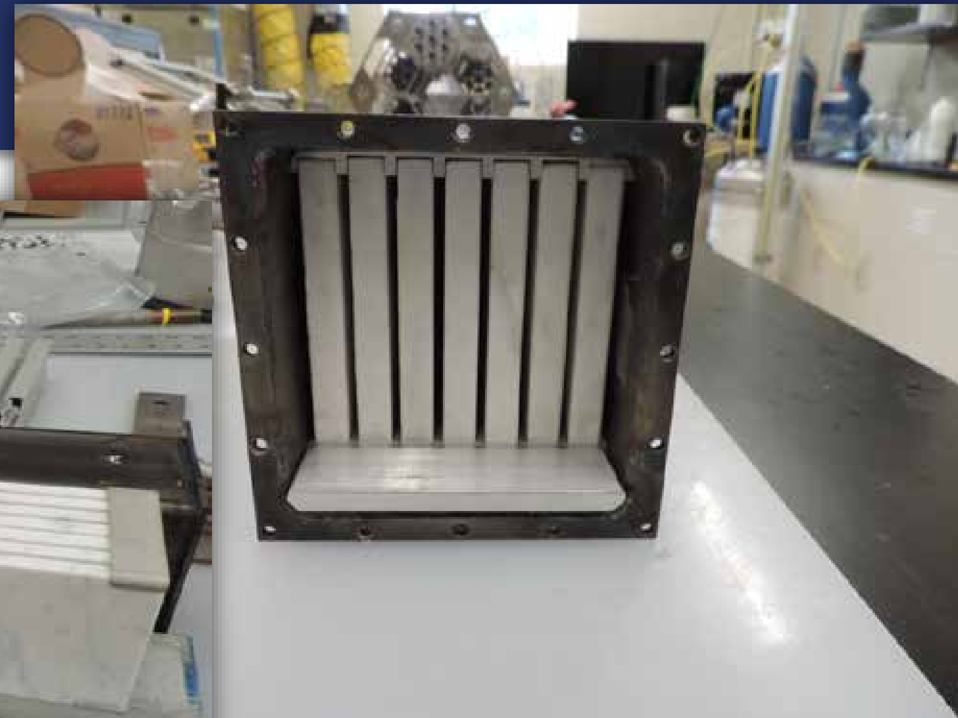






Westinghouse

Proof of Principle Testing



Questions?