Facility Attributes
- Designated Technology User Facility with $36 million F&I Budget
- 8 Petaflop HPC, data center, and visualization room
- Hydrogen system & chemistry labs
  - production, compression, storage, dispensing
- Integrated Labs
  - REDB, Thermal, Modeling/RTS, Outdoor Test Areas, Fixed Equipment, Future ESR/AMP/NWTC 2.0

Key Research Enablers
- Hardware and controls experimentation
- Power Hardware in the Loop (PHIL) and Controller Hardware in the Loop (CHIL)
- Fundamental science for energy materials
- Modeling and simulation
- Data analytics and visualization
- Education and training
Trends Driving Change in Energy

- Increasing Interdependencies
- Energy Diversification
- Vehicle Electrification
- Grid-Connected Smart Buildings
- Big Data, Artificial Intelligence, and Machine Learning
- Cybersecurity
- Resilience
- Millions of Devices at the Grid Edge
Moving Toward the Future Energy System

- DOE has been successful in driving down the costs of technologies, but LCOE will not result in the success of the past.
- The future energy system will be more complex, distributed, and interdependent, integrating all types of energy systems.
- If done correctly, the future energy system can be more efficient, resilient, and affordable.
- 10-20MW is a critical size—typical distribution system size.
The Future Energy System Will Have More Power Electronics-based Resources (Generation, Storage, Loads, and Mobility)

**Generation**
- PV, wind, fuel cells, microturbines use power electronic interfaces to the grid
- Over 50% of generation by 2050

**Storage**
- Batteries use power electronic interfaces to connect to the grid
- Pumped hydro can add power electronics to increase controllability and provide grid services

**Building Loads**
- Over 60% of major home appliances, PE based by 2021
- Lighting switching to LEDs
- Variable speed drives for motors

**Mobility**
- EVs – 7 million by 2025
- MD/HD – Electrifying
ARIES Research Platform – At-Scale

IESS at Flatirons Campus

Virtual Emulation Environment

20MW

Generation & Storage

Transmission/
Distribution & Storage

<2MW

Lodes & Storage

Utility-Scale Solar

Wind Farm

Hydrogen Plant

Battery Storage

Fossil & Nuclear Generation

PV Inverter

Thermostat

Electric Vehicle

Smart Meter

Water Heater

Battery
A partnership with the Vehicles, Buildings, and Solar Offices

- Focus on specific end user outcomes.
- Minimize cost of energy to user.
- Buildings are the largest electrical users.
- EVs will be charged at buildings.
- Demand charges need to be eliminated.
- Grid impacts minimized.
- Integration of PV is/will be common.
- Both electrons and heat need to be stored.
- New batteries are needed.
- New thermal storage are needed.

Behind-The-Meter Storage (BTMS) Low TRL Work Guided by System Level Thinking.
Why thermal storage?

Big-box grocery retail building load profile

- Air conditioning electric power
- Refrigeration electric power
- All other electric

Time of day (hr)

Electrical power (kW)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Denver, CO
July

Clearly much of the load in a BBS is associated with cooling. Time shifting this load may be more efficient (cost effective) using thermal storage.
Adding EV fast charging

However electrical energy storage will be likely be needed to deal with EV fast charging loads.
...adding PV to the mix

Behind the meter PV installations and a changing utility rate structure will impact storage needs moving forward.
BTMS: Basic Premises

• Technologically agnostic in the approach to storage systems (both electrochemical and thermal storage).

• EV Charging will occur at buildings.

• All low TRL research will be guided by the system requirements.

• Non-critical materials will be a foundation.

• Current targets for vehicles will not lead to batteries that meet long-term storage requirements.

• Thermal storage and management will enable optimizing energy efficiency and minimizing cost in buildings applications.

• System safety is critical in a building environment.

• Testing of new materials in full systems will be the metric for success (safety, lifetime, energy density, and cost).

• This project takes advantage of the major investment the Vehicles Battery program has made in infrastructure, capabilities, and materials development coupled with the Buildings investments in thermal management and storage.

• Ongoing and integrated cost analysis will be essential to success.
Behind the meter storage (BTMS) a full systems approach

Multi-scale characterization

Metrics and target determination

Integration experiments

Materials Discovery

Integrated-system modeling and design

Full System Design

All aspects of the system from materials to design and controls are part of the solution.
BTMS: Metrics and target determination
DEFINE THE PROBLEM

What are the *optimal* system designs and *energy flows* for *thermal* and *electrochemical* behind-the-meter-storage with on-site PV generation enabling *fast EV charging* if we vary climate, building type, and utility rate structure?
Integrated research capabilities advancing diverse technologies for buildings, vehicles, and fast charging
BTMS Materials Development

BTMS battery chemistry

- Non-critical materials will be a foundation.
- **System safety is critical in a building environment.**
- Current targets for vehicles will not lead to batteries that meet long-term storage requirements.

✓ **Initial target chemistries:** Graphite/LFP, LTO/LMO & LTO/LMNO
✓ **Key differences vs. conventional LIBs:** Working voltage window and operating temp.

![Graphite (Cu) vs LCoO2 (Al)](image)

- Conventional LIBs
- BTMS LIBs

\[ \mu_A \quad \mu_C \quad \mu_C \quad \mu_C \]

- LUMO
- HOMO

- Li\textsubscript{4}Ti\textsubscript{5}O\textsubscript{12} (Al)
- LiMn\textsubscript{2}O\textsubscript{4} (Al)
- LiNi\textsubscript{0.5}Mn\textsubscript{1.5}O\textsubscript{4} (Al)
Physics-based Machine Learning – Understanding fade and life prediction

Using existing data from Nissan Leaf to define performance and mechanisms related to fade

Correlated and aligned analysis

Mechanism validation

Electrochemical Characterization

Physics-based Machine Learning

Life modeling and prediction

Life validation

Clustering similar fade for different cells undergoing variable aging profiles, identifying outlier data

Predicting performance using first 96 cycles to less than 1.5% mean error

Using existing data from Nissan Leaf to define performance and mechanisms related to fade

Predicting battery life and performance over 20 years with fidelity, given major variations in use case, requires significant science.

T. Tanim et al., J. Power Sources 2018, 381, 56
The Science of Safety

The potential safety risks of large-scale energy storage within buildings must be addressed by the BTMS design.

Need to address:
• No cell to cell propagation in potential thermal runaway.
• Requirement for reducing the combustible load at the storage level.
• Design for repair/maintenance and end of life.

These must be balanced against cost metrics.

BTMS will have a much higher emphasis on total design for safety moving forward.
Conclusions

Continual feedback from EnStore to/from the experimental team is critical for progress.

The best outcome will rely on a technologically agnostic solution to stationary storage that is guided by a system level assessment.

Non-critical materials must be a foundational issue if costs are to be controlled.

Safety of the energy storage solution will be a key outcome.

Thermal storage and management will enable optimizing energy efficiency and minimizing cost in buildings applications.

Advanced lifetime models will be necessary for long lifetime outcomes.
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Thank you

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