U.S. DEPARTMENT OF
ENERGY
Office of Electricity

2022 Office of Electricity Energy Storage Program Peer Review

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Overview of Event

- **Held Oct 11-13th, 2022 in Albuquerque, NM**
- **230 attendees including 8 delegates from NM State Legislature, NM PRC, representatives from Tribal Governments (208 paid registrations)**
- **Peer Reviewers: 8 academic, 8 industry, 2 national lab**

Peer Review Sessions

Session 1: Innovative Deployment Projects

Session 2: Equity, Resilience & Policy

Session 3: Safety and Reliability

Session 4: Sodium Batteries

Session 5: Medium and Long Duration Storage

Session 6: Flow Batteries

Session 7: Zinc and Lead Batteries

Session 8: Power Electronics

Session 9: Analysis and Tools

Session 1: Innovative Deployments

- *Demonstrating energy storage in innovative projects and use-cases further informs DOE analysis tools and models.*

Cordova Electric

OPALCO

- Cordova Electric Coop has been able to reduce diesel consumption and improve system reliability. Learnings from project commissioning and standards compliance issues with are widely adaptable for future projects.
- ORCAS Power and Light (OPALCO) demonstrating island resiliency and capacity deferrals for submarine cable upgrades
- APS Atrisco project demonstrating success in making a high school a resilient community resource.
- Development and approval of IEEE1547.9 standard for interconnecting energy storage to the utility grid
- Project work with Villalba, PR, to improve critical infrastructure resilience using energy storage

Session 2: Equity, Resilience & Policy

Direct engagement with utilities, PUC's and communities to help foster greater understanding that energy storage can play a key role in supporting their resilience, decarbonization and equity goals

The Energy Storage for Social Equity (ES4SE) Project

- Connected 14 communities in 11 states with potential energy solutions that support equitable outcomes while demonstrating the role of energy storage in energy equity
- ES4DE addresses affordability, poor reliability, energy and freshwater availability, and other challenges faced by communities in need. OE/PNNL is providing technical assistance in developing microgrids, off-grid systems, photovoltaics plus battery storage for commercial and residential buildings, and resilience hubs

Reducing institution and regulatory hurdles

- OE Program continued its extensive outreach program, providing policy analysis and outreach to regulatory commissions around the U.S. across a broad spectrum of topics. E.g. Illinois. Washington, DC
- Market and regulatory hurdles tied to several topics addressed in ongoing research, including energy storage and decarbonization modeling, the value of long-duration energy storage, rate design for behind-the-meter energy storage, modeling of energy storage in integrated resource plans, addressing energy storage in local zoning ordinances, and barriers to adoption of vehicle-to-grid technologies for fleets.

Previous OE Equity Projects

Navajo Nation , AZ

Partnering with DOE-OE, Sandia, NTUA, UEP

Commissioned May 2022

3 kW / 13 day Rechargeable Zn Mn O_2 Battery Developed by UEP.

There are 18,000 Residents off-Grid on the Reservation

Atrisco Heritage Academy, Albuquerque, NM

Energy Storage for Social Equity

85% Hispanic,

Reduce peak demand during occupied hours

Battery: 721 kW/4hr = 2884 kWH
plus **roof-mounted PV = 850 kW**

Total cost with PV: **$3.1 M**

Contract awarded – May 2021
BESS ground work – 1/22 – 3/22
Commissioned – October 13, 2022

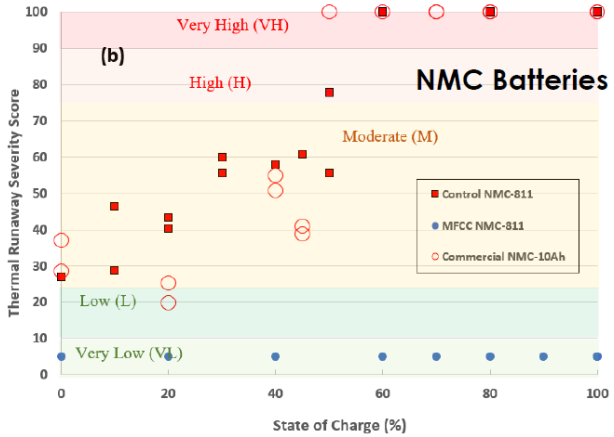
SBIR Project 2022 Resilient PE for Tribal Applicatios

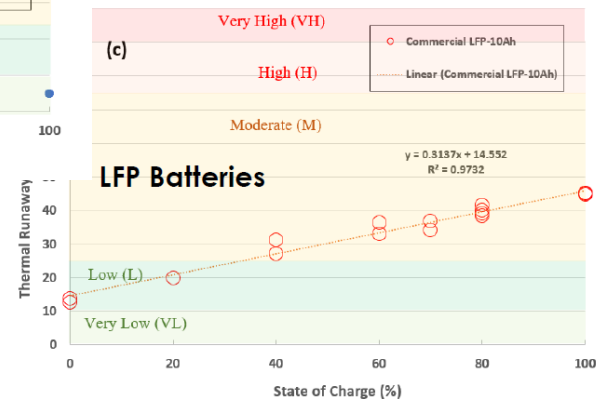
Studies on a 6 town Microgrid in Villalba, Puerto Rico

Rural Storage Applications. Joint U/S/ India Project

Session 3: Safety and Reliability

Ensuring the safe and reliable operation of energy storage requires a holistic systems approach: from improved chemistries, modeling, codes and standards, and stakeholder engagement.





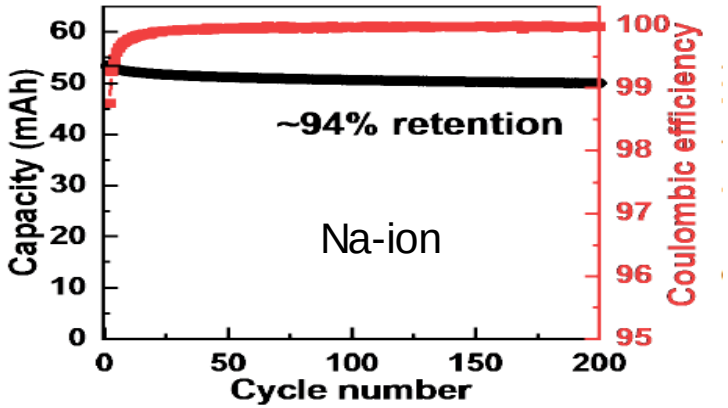
- OE program receiving increasing requests for project and educational support from utilities, manufacturers, fire service, and other labs (NREL, Moss Landing). Increased emphasis on characterization/safety of second-life Li-ion systems for grid applications.
- Safety characterization of solid-state batteries (SSB) helping to identify risk profiles for various electrolytes.
- Research on quantifying Cl production in mixed acid VRB's highlights potential hazards.

Session 4: Sodium Batteries

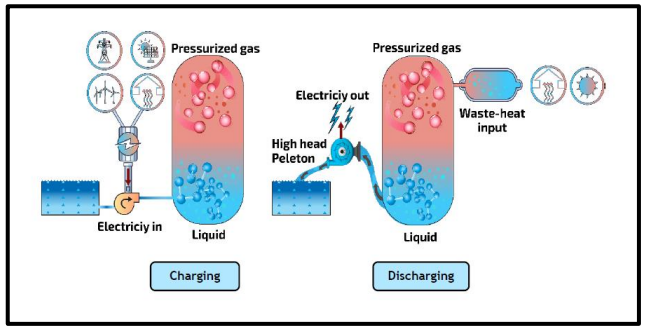
Developing sodium batteries that offer the potential for safer, reliable, cost-effective grid-storage that is not limited by many of the supply-chain and safety-related challenges of current commercial battery systems.

- The session represented research across a wide range of technology readiness levels, including creative, early-stage work on highly conductive solid state sodium electrolytes and basic electrode materials development for sodium ion batteries
- More mature low-to-intermediate temperature molten sodium/molten salt battery research was highlighted, with researchers identifying low-cost, high voltage chemistries capable of commercially attractive energy and current densities. New sodium-aluminum battery concept targeted for long-duration storage applications.
- The planar ZEBRA batteries were further highlighted by guest presenters from Republic of Korea (Keeyoung Jung, RIST; Jinhyuk Choi; KEPCO), who showed automated prototype manufacture of ~6Ah planar intermediate temperature ZEBRA batteries.

RIST (ROK) Collaboration



Session 5: Medium and Long Duration Storage



GLIDES

CSP

Grid modeling of LDES

- The Low-Carbon Electricity Analysis Framework (A-LEAF) an integrated national-scale power system simulation framework. Applied to a variety of issues affecting LDES deployment (policy/market design, future climate conditions, transmission expansion) to determine the future system optimal generation portfolio, operation, and cost. Energy storage system performance and degradation modeling for systems engaged in grid operations

Numerous LDES technologies were designed and evaluated

- Seawater batteries
- Freeze-thaw battery technologies
- Long-duration solar thermal energy storage
- Pumped storage hydro systems

Current CEC Long Duration Projects

MW/MWh	Technology	Vendor	Expected Completion
400kW / 10hr X2	Vanadium Redox Flow Battery	Invinity Energy Systems	2023, 2024
400kW / 10hr X2	Zinc Hybrid Cathode Battery	EOS	2023, 2024
400kW / 10hr	Flywheel	Kinetic ES Corporation	2024

MW/MWh	Technology	Vendor	Expected Completion
10kW / 100hr X2	Iron Air	Form Energy	2023
10kW / 100hr X2	Zinc Air	E-Zinc	2023
10kW / 100hr	Thermal Storage	Antora Energy	2024

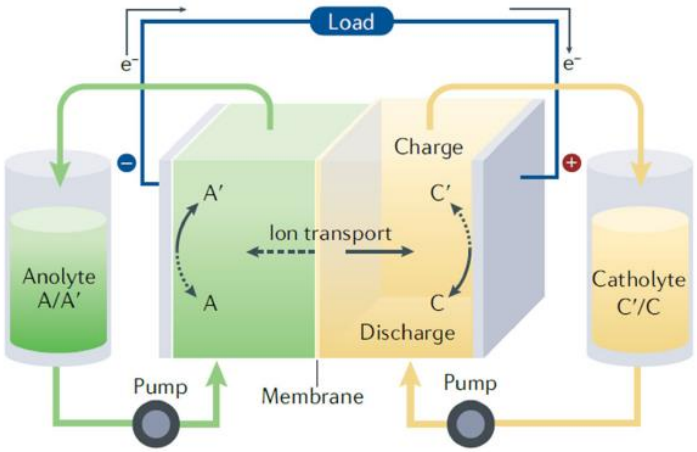
200kW / 10hr 50kW / 10hr	Aquifer Pumped Hydro	N/A	2024 2023
50kW / 10hr X2	Vanadium Redox Flow Battery	Invinity Energy Systems	2023
50kW / 10hr	Flywheel	Kinetic Energy Storage Corp.	2024

DOE /Sandia Support for CEC Projects through joint MOU

- Technical review of proposals
- Analysis of operational data
- Expertise on Fire / Safety issues
- Support of system commissioning

Session 6: Flow Batteries

Flow batteries utilizing earth abundant materials can enable cost-effective discharge durations > 10+ hours



flow battery configuration

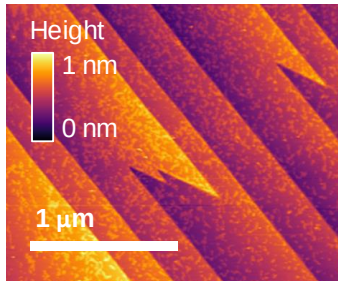
- Newly designed polymer gel interface significantly reduces the active materials crossover and stabilize the cycling capacity. Its long-term stability is currently being tested.
- New homogenous catalyst identified to accelerate the kinetics of the organic active materials. The new aqueous organic flow battery can be operated at a much higher current density.
- Optimization of the organic synthesis has been carried out at pilot scale for low-cost large-scale synthesis of the organic active materials.

Session 7: Zinc and Lead Batteries

The mature US manufacturing, domestic supply chains, and established recycling make Zn-MnO_2 and Pb acid technologies attractive for grid scale storage but require significant performance improvements.

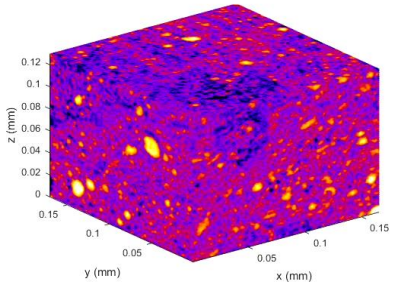
Atomic level (~nm, nAh)

Example: monolayer growth of $PbSO_4$ on barite 001.



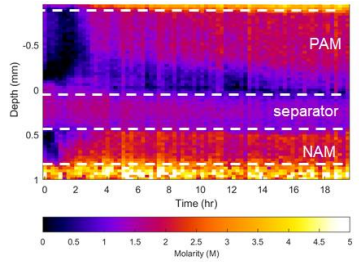
Particle level (~µm, µAh)

Example: Reconstructed volume from CT scan of a paste electrode (color = density)



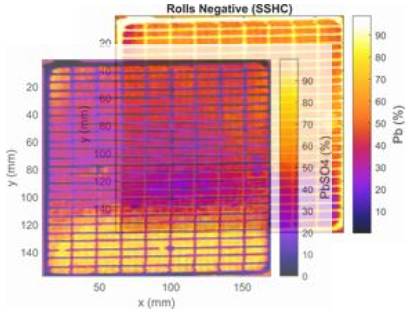
Cell level (~mm, mAh-Ah)

Example: Electrolyte mapping during formation



Battery level (~100 Ah)

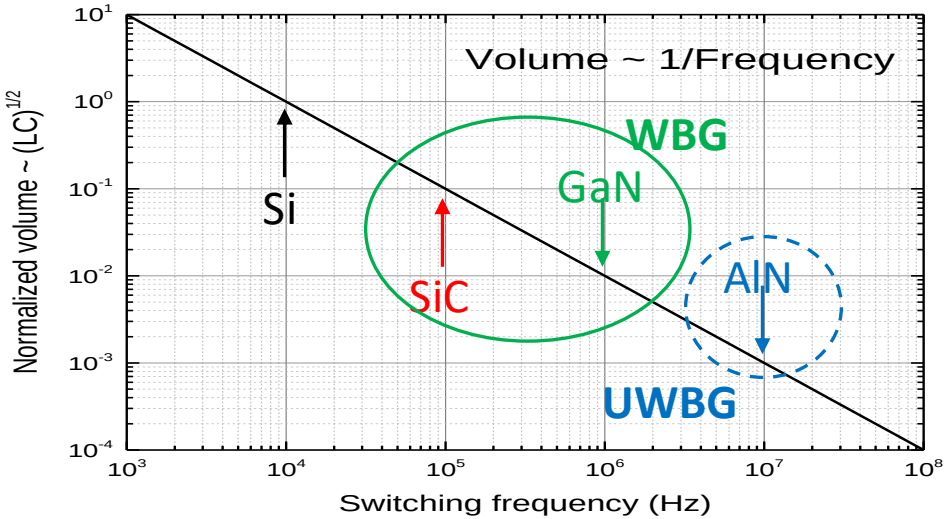
Example: cycling at PNNL and XRD from EOF battery plates



- UEP Gen 1 battery manufactured and deployed – energy retention > 80% after 7 years.
- Alkaline Zn-MnO2 improvements include 3D printed anodes, CuO based cathodes, polymer electrolytes.
- New mild acid anode improve dendrite free cycling 3X over traditional Zn foil electrode.
- Utilizing National Laboratory capabilities to understand deep cycle Pb-acid degradation.

Session 8: Power Electronics

Power conversion systems (PCS) are critical to enable both the physical connection between the energy storage resources and the utility interface and for controlling the exchange of electrical energy. PCS technology determines how energy storage resources are integrated into the grid and which end-use applications, services, and revenue streams they may participate in



- Power electronics R&D spans from basic materials research in semiconductor switches, capacitors, and transformers to developing and validating new materials in systems level architectures. E.g recent R&D 100 Iron nitride (Fe4N) transformer core – so called soft magnetics.
- Optimizing PR interface for enhanced control and safety of the energy storage system. PE based controls for newly built systems and 2nd life EV batteries is critical area of research.

DOE OE POWER ELECTRONICS DEVELOPMENT

2003 — World's first Fiber Optic Electrical Transducer to Pass Military Vibration and Shock Certification
Exceeds 30Mhz
Capable of Operating up to 34.5kV without additional Insulation, Isolation, or Cooling

2004 — World's First High Temperature SiC Single-Phase Inverter
3 kW (1200 V/150 A peak)
250 °C Junction Temperature
Integrated Gate Driver

2005 — World's First Voltage Controlled 4500V/400A Turn-Off Thyristor
4500V and 400A rated
Integrated Si MOSFET and GTO
Embedded Current Sensing Capability

2006 — World's First Highly Accelerated Lifetime Testing (HALT) of High Voltage SiC Modules
Dramatically Accelerates Design Cycle
-100 °C to 250 °C (1.7 °C/s Ramp)
48 in × 48 in Table Size
6 axis 75 gRMS Vibration

2007 — World's First High Temperature SiC Power Module
50 kW (1200 V/150 A peak)
250 °C Junction Temperature
Integrated HTSOI Gate Driver

2008 — World's First Monolithically Integrated Single Chip Transistor
Integrated SJT/Diode Chip at 1200V

2009 — World's First Commercially Available Ultra-High-Voltage SiC Thyristor
Rating exceed 6.5kV, 200kHz, 80A
> 200°C
junction temperature

2010 — World's First High Voltage, High Temperature, Reworkable SiC Half-Bridge Power Module
> 15 kV / 100 A, > 200 °C
Reworkable
Wire Bond Free, Low Parasitic Design
Device Neutral
HV Isolated Gate Driver

2011 — World's First High frequency, high temperature, SiC half-bridge power module
15 kV/100 A, 20 kHz, 200C
Reworkable
Low Parasitic Design
Device Neutral
HV Isolated Gate Driver

2012 — World's First Avalanche Rugged Multi-kV Power Mosfet
1 Joule at 5000V

2013 — World's highest voltage normally off SiC JFET
6.5 kV, 20kHz, 60A
200°C Junction Temperature

2014 — World's First Commercial Monolithic Switch
1.2 kV SiC Device

2014 — Green Tech Gold

2015 — World's first 3D printed iron nitride and nylon composite transformer core
Operating temp up to 150C, 10X lower loss than bulk iron nitride, up to 1Mhz

2016 — World's First high power modular GaN-based inverter
20 kW per Module
Integrated GaN Gate Driver
Stackable to 100 kW

Session 9: Analysis and Tools

Investment in analytics and tools is advancing our ability to model, optimize, value, and control energy storage systems (ESSs) to improve performance and enhance market penetration

Analysis and Tools Panel at the 2022 DOE OE Energy Storage Program Annual Meeting & Peer Review

- **New analytical methods and frameworks developed, including:**
  - Various model-based and learning-based approaches for energy storage control and dispatch
  - Enhanced techno-economic assessment frameworks for non-battery energy storage and hybrid storage systems
  - End-of-life analysis for stationary storage systems to minimize environmental impacts and costs, while feeding information back into the design process
  - Degradation models and aging analysis of battery energy storage with feedback for integrated forecasting and dispatch of energy storage
    - Enhanced methods and tools for assessing and predicting the future cost and performance of ESSs
    - Models designed to site and size storage systems in the distribution network
- **Enhanced and new energy storage tools and package:**
  - QuESt
  - Energy Storage Evaluation Tool
  - New Pumped Storage Hydro Valuation Tool
  - Open-source tool for evaluating and predicting battery aging
  - EverBatt battery recycling process and supply chain model
  - Model Selection Platform
  - Global Energy Storage Database