Pacific Northwest
NATIONAL LABORATORY

Presentation ID: 702

Sodium-Ion Battery Development

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DOE OE Energy Storage Peer Review & Annual Meeting, 2026

U.S. DEPARTMENT of ENERGY

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Project overview

- **Project Goal:** Demonstrate a **safe**, **low-cost, long-life** sodium-ion pouch cell **with ~150 Wh kg^{-1}** cell-level energy
- **Current Practice:**
  Low energy density, cycle life, and electrolyte stability restrict broader adoption.
- **Why PNNL:**
  Unique pouch/prismatic cell capabilities backed by leading battery experts.
- **Innovation:**
  Developing a safe, long-life, and cost-effective Na-ion battery for grid energy storage applications.
- **Impact:**
  Low-cost and adaptable energy storage systems to support the modernization of the nation's power grid.
- **Vertical/Investment Area**: Materials and Systems Innovation
- **Alignment:**
  Accelerating the development and testing of advanced energy storage technology that is more cost-effective, safe, and durable, which is crucial to meeting the Administration's goal of providing reliable, secure, and resilient energy.

Project objectives

- Develop cost competitive, high-performance Na-ion batteries through deep understanding of battery fundamentals.
  - Develop Co-free layered cathode materials with low or zero amount of Ni.
  - Develop high-performance hard carbon anodes
  - Develop safe, long cycle life and high voltage
  - Understand the mechanisms of battery fading in bulk structures and at interphases across time scales.
  - Scale-up of materials and pouch cell demonstration

Project milestones in FY26

- **Milestone 1.**

  Achieve > 80% capacity retention over 300 cycles for the pouch cell with ~130 Wh/kg specific energy density at ~1 Ah capacity. (12/31/2025, **Achieved**)

- **Milestone 2**

  Improve PNNL's baseline material and electrode engineering to demonstrate pouch cells with > 1Ah capacity capable of achieving > 140 Wh/kg specific energy density. (03/31/2026, **Achieved**)

- **Milestone 3.**

  Establish baseline materials cost for PNNL sodium ion battery technology and project costs for MW scale systems at various durations. (06/30/2026, **ongoing**)

- **Milestone 4.**

  Demonstrate pouch cells with >1 Ah capacity capable of achieving > 140 Wh/kg specific energy density, and < 90 $/kWh materials cost at a capacity retention >80% over 300 cycles. (09/30/2026, **Achieved**)

Achievements summary in FY26

Research highlights

- Demonstrated **a ~142 Wh kg^{-1} sodium-ion pouch cells with stable cycling**
- New electrolyte formulations enabling **long cycle life, stable high-voltage operation, and improved cell safety.**

Publications

- Evaluation and Perspective from Component Materials to Cells, Modules, and Packs, Adv. Energy Mater.
- Accelerating Electrochemical Energy Storage for a Reliable, Affordable, Resilient and Secure Electric Grid. Battery & Supercaps. 2026, published online.
- Development of Materials for All Solid-State Sodium-Sulfur Batteries: Review and Prospects, Adv. Energy Mater.
- Electrolyte Design with Non-fluorinated Solvents for High-Voltage Anode-free Sodium Metal Batteries, *Nature Sustainability*, 2026, 9, 306
- Physics-Informed Machine Learning Exploration of Na Storage Mechanisms in Disordered Carbon, Energy Storage Mater. 2026, 86, 104967.

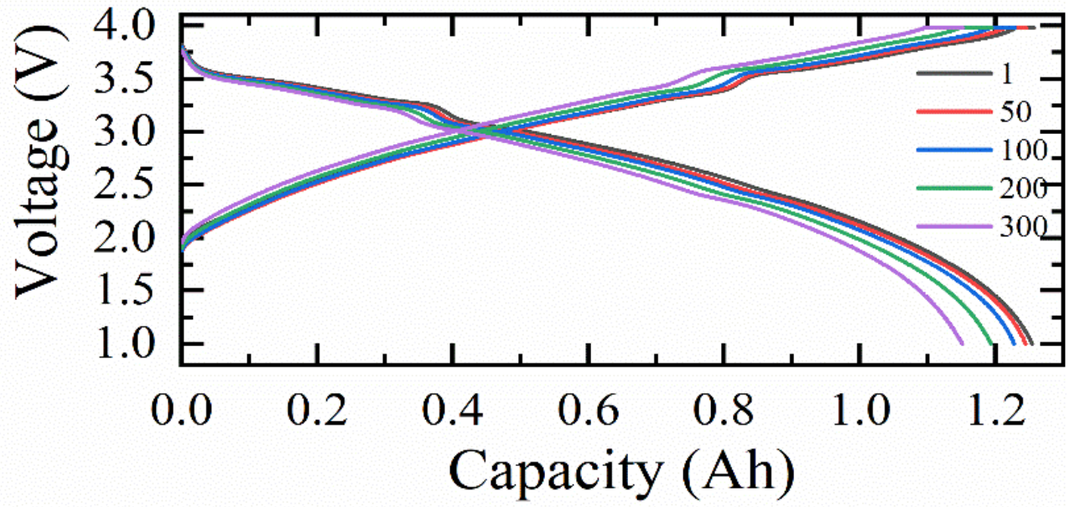
Patent : High Performance Cathodes for Sodium-ion Batteries and Batteries Using Such Cathodes

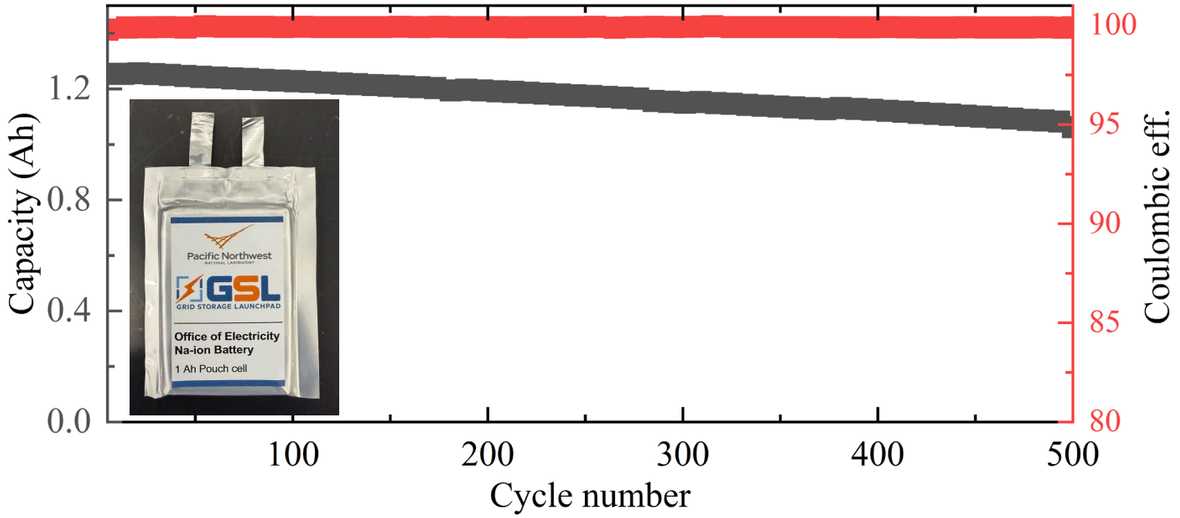
Presentations

- Towards High-Performance Na-ion Batteries, 248th ECS meeting, October 2025
- Progress of Sodium ion Alliance for Grid Energy Storage, NAATBatt Sodium-Zinc Battery Workshop, November 2025
- Sodium-ion Alliance for Grid Energy Storage, Gordon Research Conference, February 2026
- Alliance for Sodium-ion Battery Development, TechConnect World 2026, March 2026
- Fading Mechanisms of Na-ion Batteries: Particle Cracking vs. Interfacial Reactivity, MRS Spring meeting, April 2026
- SAGES Initiative: Unlocking the Potential of Sodium-Ion Batteries for Grid Energy Storage, 2026 BCI Convention + Power Mart Expo, May 2026
- Advanced Carbon Materials and Composites for Battery Applications, Carbon Conference, July 2026

Project achievements in FY26 (1)

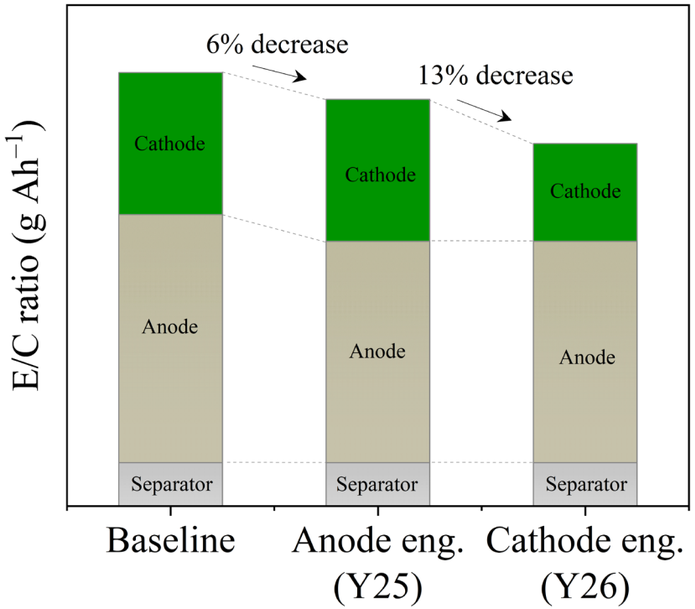
1.2 Ah pouch cell with stable cycling demonstrated

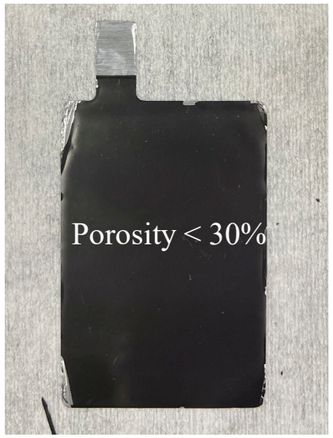


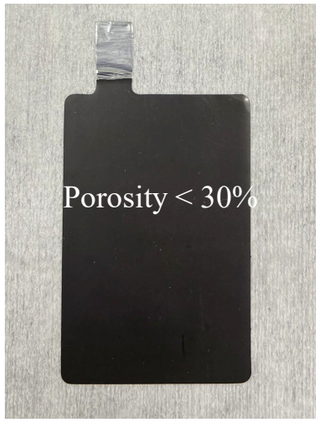


- $Na_xMn_{0.5}Ni_{0.4}Fe_{0.1}O_2$ (MNF-541)||HC pouch cells with area loading of > 3 mAh/cm^2 demonstrated excellent cycling stability: **>87%** capacity retention over **500 cycles**
  - Pouch cell energy density **~136 Wh/kg** (cell capacity of ~1.2 Ah).

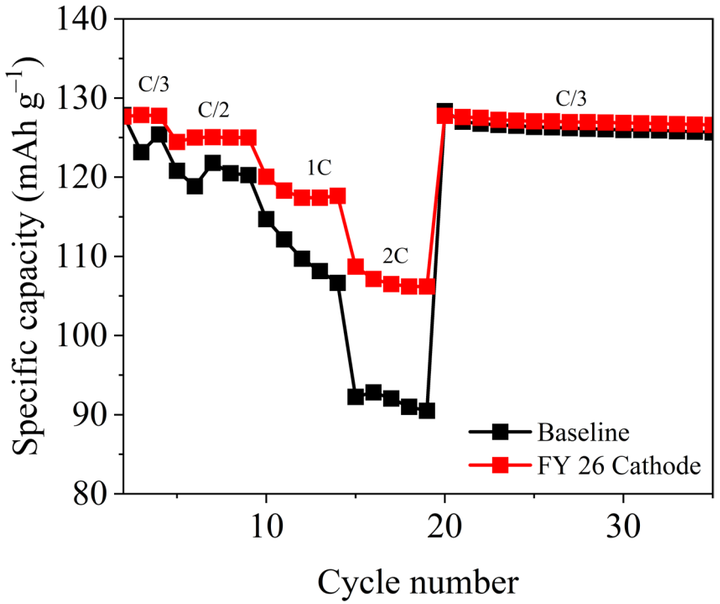
Technical Approaches







Materials engineering

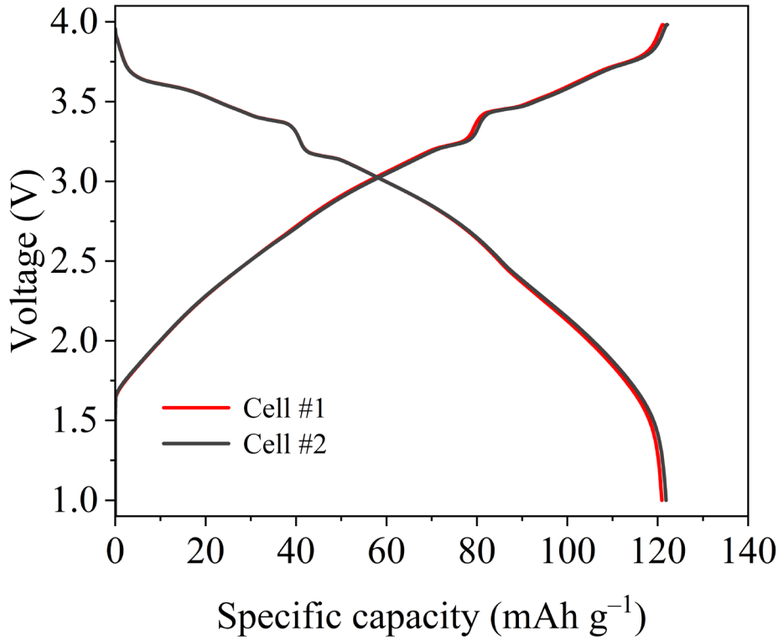


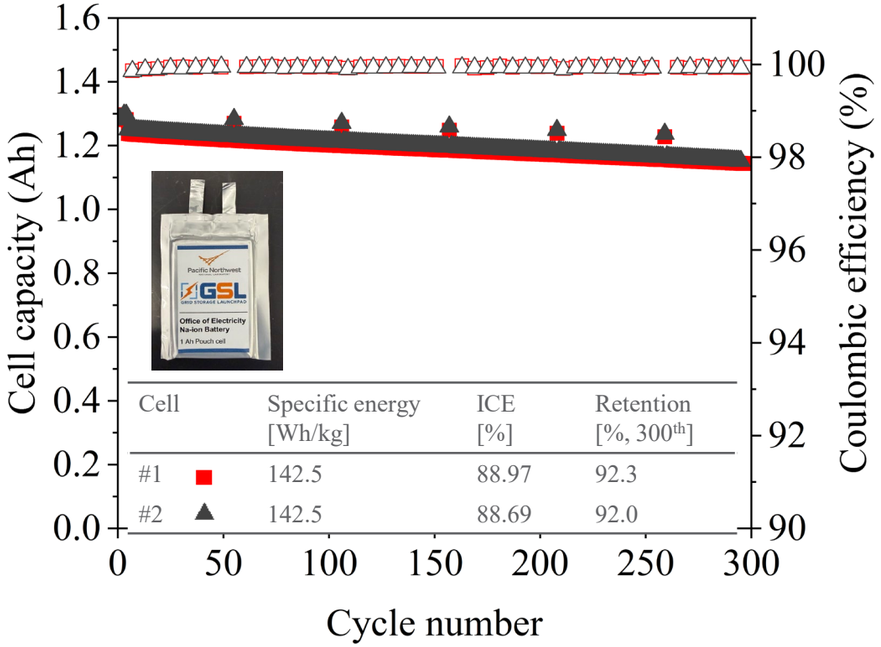
- Reducing inactive components, Reducing electrode porosity, cell performance
  - Cathodes with <30% porosity exhibits increased brittleness:
    - They show good rate performance

✓ **Materials-to-electrode engineering to Improve cell level energy density**

Project achievements in FY26 (3)

MNF-541//HC pouch cells met performance milestone



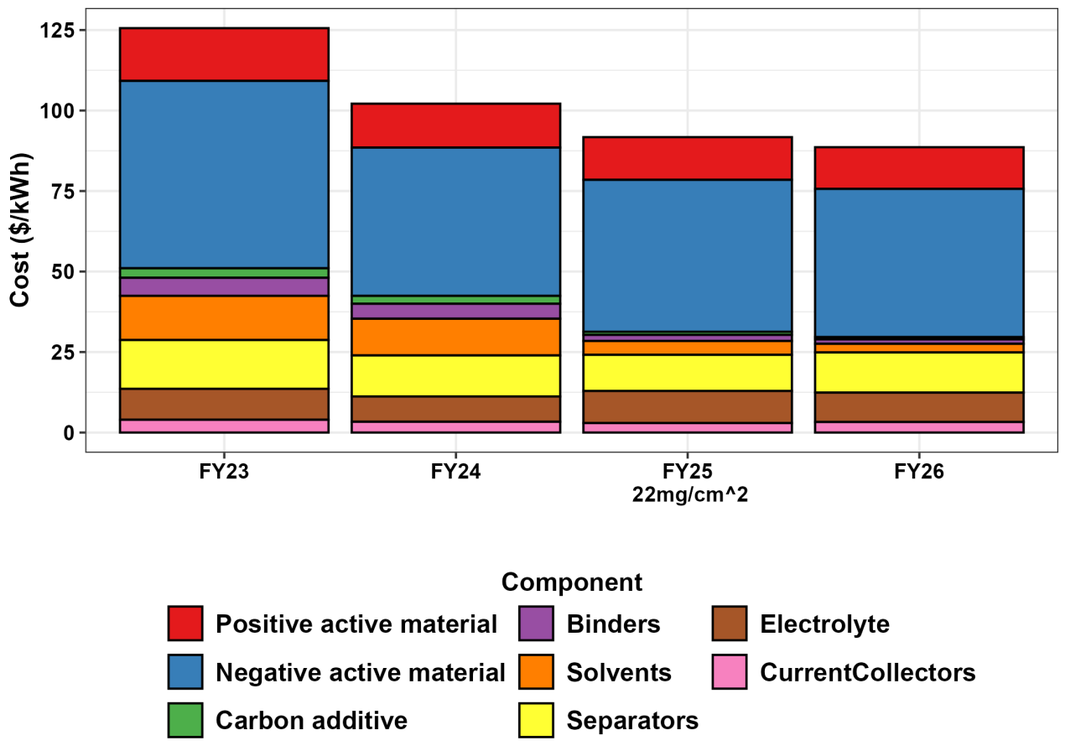


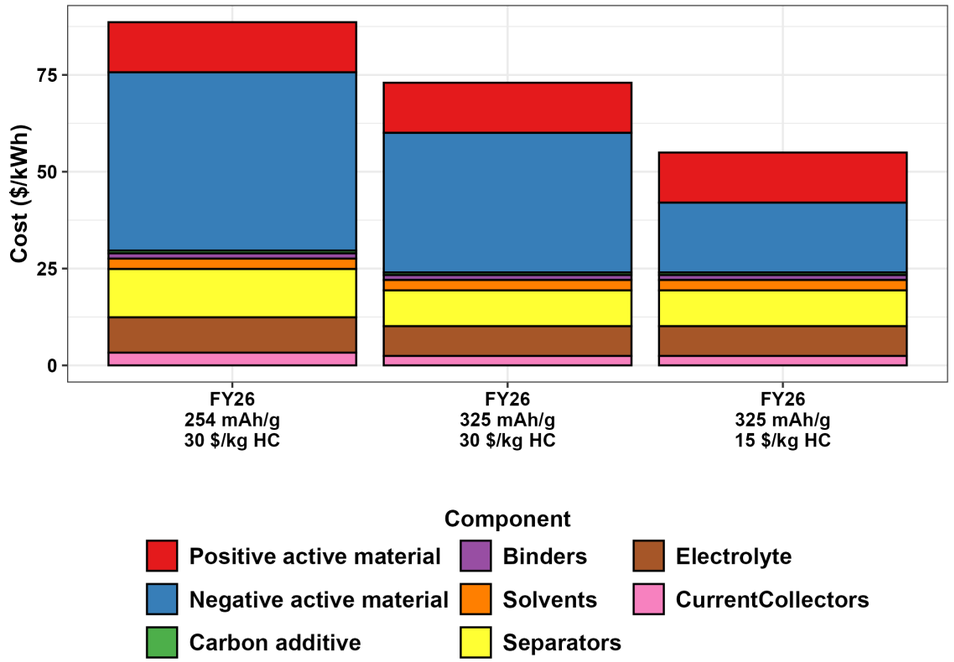
Cell	Specific energy [Wh/kg]	ICE [%]	Retention [%, 300th]
#1 ■	142.5	88.97	92.3
#2 ▲	142.5	88.69	92.0

- The $Na_xMn_{0.5}Ni_{0.4}Fe_{0.1}O_2$ (MNF-541)//HC pouch cells Achieved the milestone:
  - Stable cycling performance, 92% after 300 cycles
    - The cycling CE is > 99.9%.

✓ **The cell delivered ~142 Wh/kg Cell-level energy density.**

Project achievements in FY26 (4)

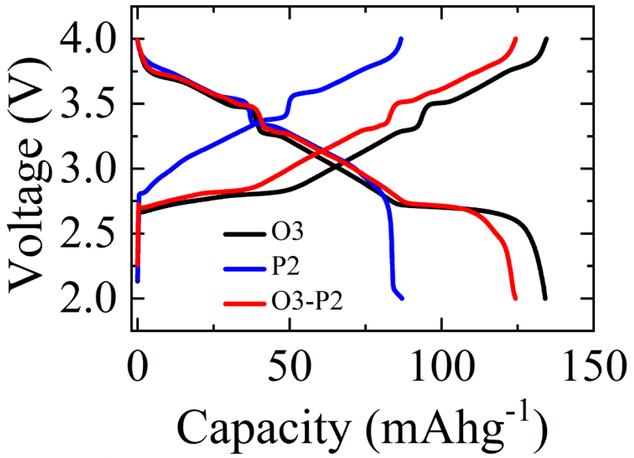


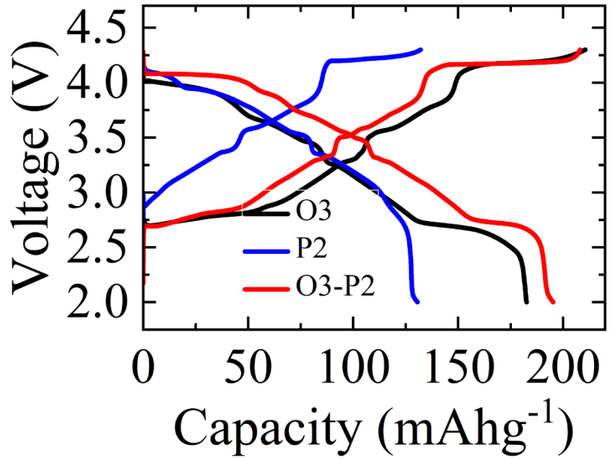


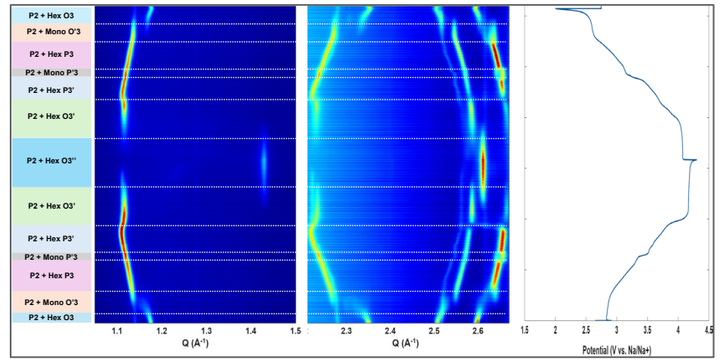
- The HC is priced 30 or 15 $/kg; contributing to a major percentage of the cell's cost.
- The nickel component significantly drives the cathode cost, making up 86% of the NaxMNF-541 cost.

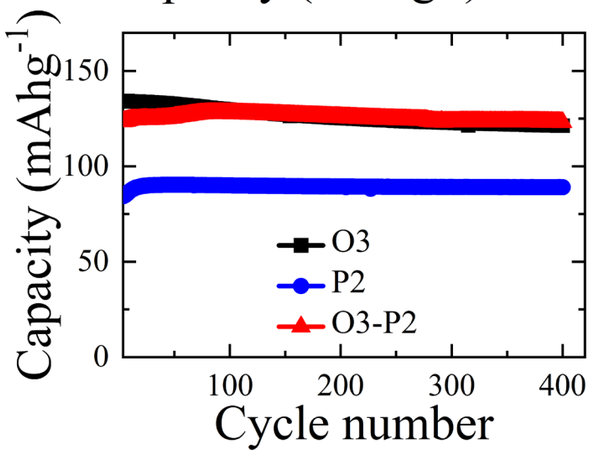
✓ **The material cost of the $Na_xMn_{0.5}Ni_{0.4}Fe_{0.1}O_2$-hard carbon sodium-ion battery by the BatPaC model is ~$55/kWh (15 $/kg HC and 325 mAh/g HC).**

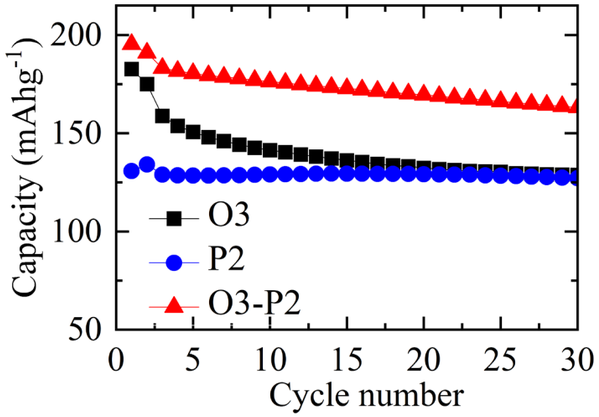
Understanding the Reaction mechanism of MNF-541

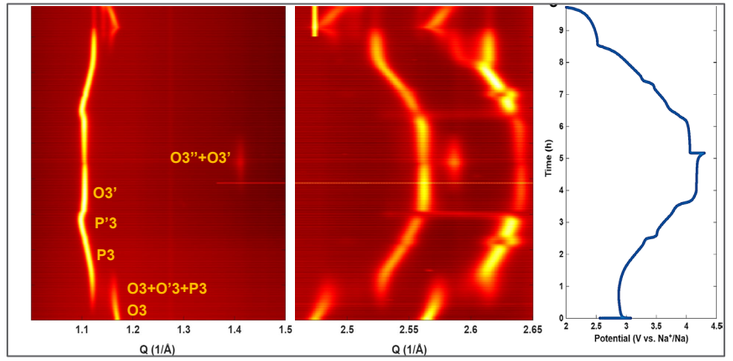






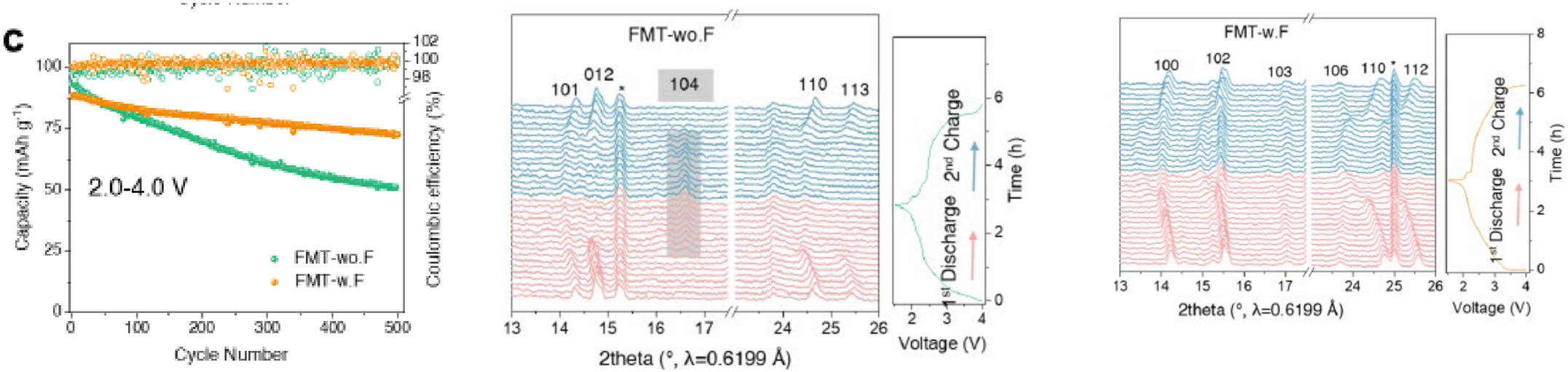






- Biphasic O3/P2 MNF-541($Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$) outperforms pure O3 and P2
  - ✓ Phase synergy design for improved performance.
    - Phase transition is more reversible in O3-P2 compared to O3
      - ✓ Minor P2 phase in O3-P2 acts as a structural scaffold

Cost-effective cathodes: Co- and Ni-free



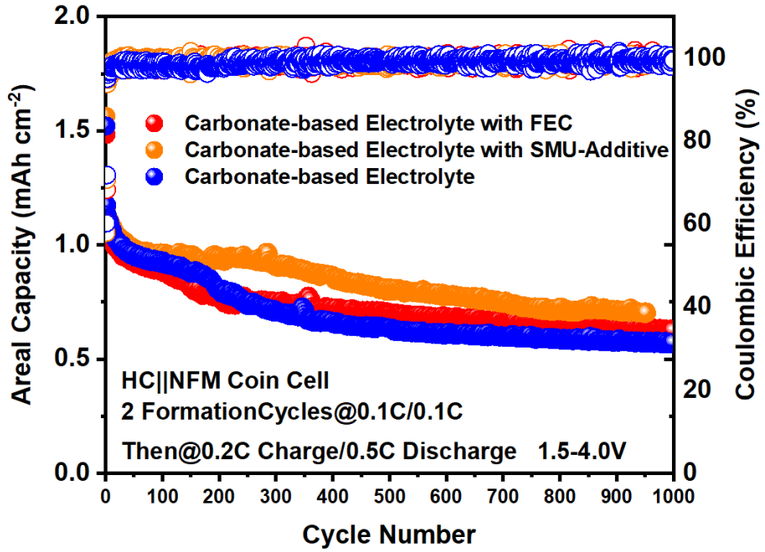
- Fluorine incorporation: Alters phase evolution and transition metal redox behavior, Improves ambient stability, and Suppresses irreversible structural transformations during cycling, and improved cycling stability.

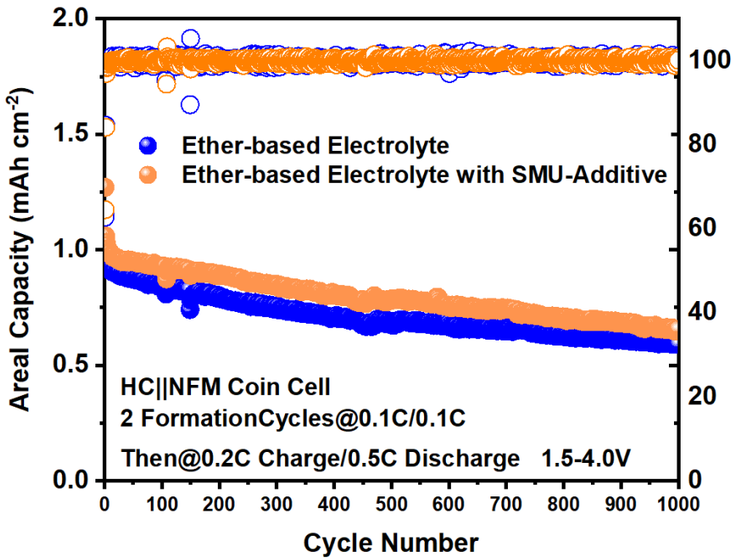
✓ **Fluorine incorporation in Fe-Mn-Ti P2 layered cathodes improves structural and performance stability**

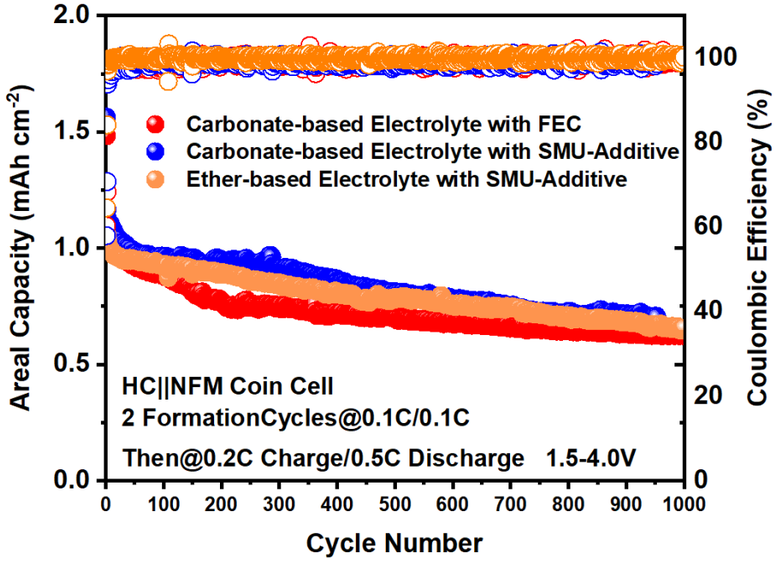
VIRGINIA TECH

BROWN

Development of electrolyte with enhanced cycling stability

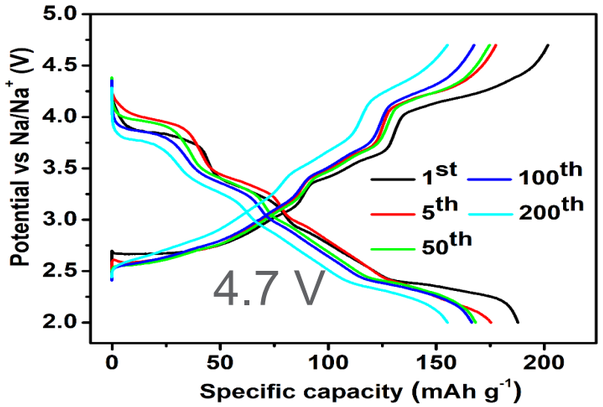


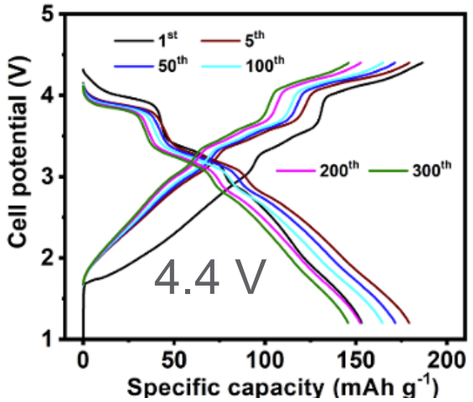


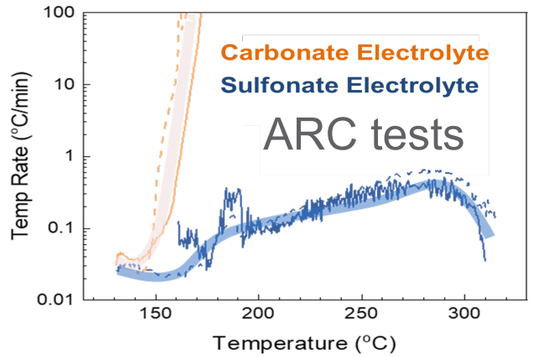


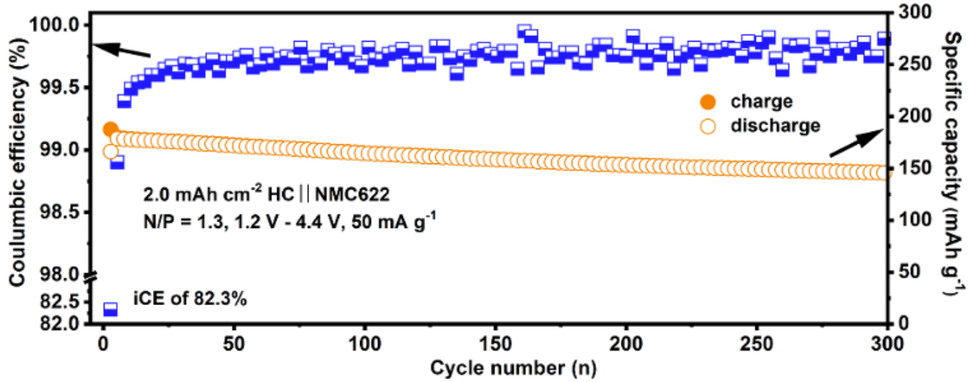
- New carbonate-based electrolyte that enhances interfacial stability, suppresses side reactions, and delivers improved electrochemical performance for SIBs.
  - ✓ **Engineering carbonate-based electrolytes with a functional interphase-forming additive to improve cycling stability**.

High-voltage Electrolyte Design for Na-ion Batteries







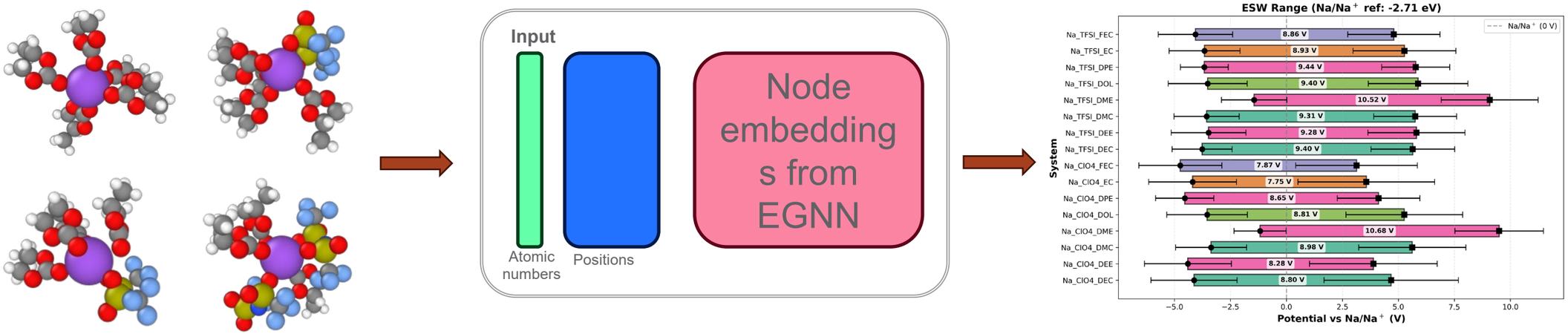


- 87% retention for NaIINMC622 cells at 4.7 V after 200 cycles, and 84% retention for HC||NMC622 cells at 4.4 V after 300 cycles. NMF achieve 700 cycles at 4.2 V without thermal runaway in ARC tests.

✓ **New safe and high voltage enabled and pre-salt sulfonamide electrolytes**

A Physics-Aware ML-MD Framework for Electrolyte Screening

Electrochemical properties depend on both molecular structure and local chemistry



Input: 3D solvation structures

ML Model

Prediction

- Electrochemical properties depend on both molecular structure and local chemistry, i.e. solvation environment, which is sensitive to concentration, electric double layer structure and cycling condition.

Encode the entire solvation environment into the framework!

Summary and Impact

- Demonstrated **~142 Wh/kg** MNF-541/HC pouch cell with good cycling performance.
- Using our optimized pouch cell data, we demonstrated the material cost of the MNF541-hard carbon sodium-ion battery can achieve **~$55/kWh when HC priced at $15/kg**
- Characterization revealed that the synergistic coexistence of P2 and O3 phases improves structural stability and electrochemical reversibility.
- New low-cost cathode chemistry **without Co or Ni**, with sustained performance.
- New electrolyte formulations enabled **long cycle life, stable high-voltage operation, and improved cell safety.**

Acknowledgements and contributors

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- **PNNL contributors**
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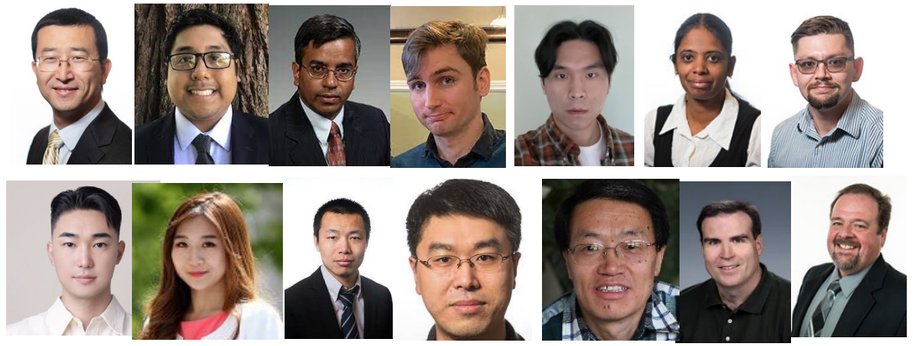
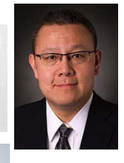


- **External collaborators**

- Dr. Jagjit Nanda

- Dr. Jonathan Lee & Sabrina Wan

- Prof. Donghai Wang



- Prof. Chunsheng Wang

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