Pacific Northwest
NATIONAL LABORATORY

Sodium-Ion Battery Development

Fred Omenya

Presentation 602

DOE-OE Peer Review
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U.S. DEPARTMENT OF ENERGY BATTELLE

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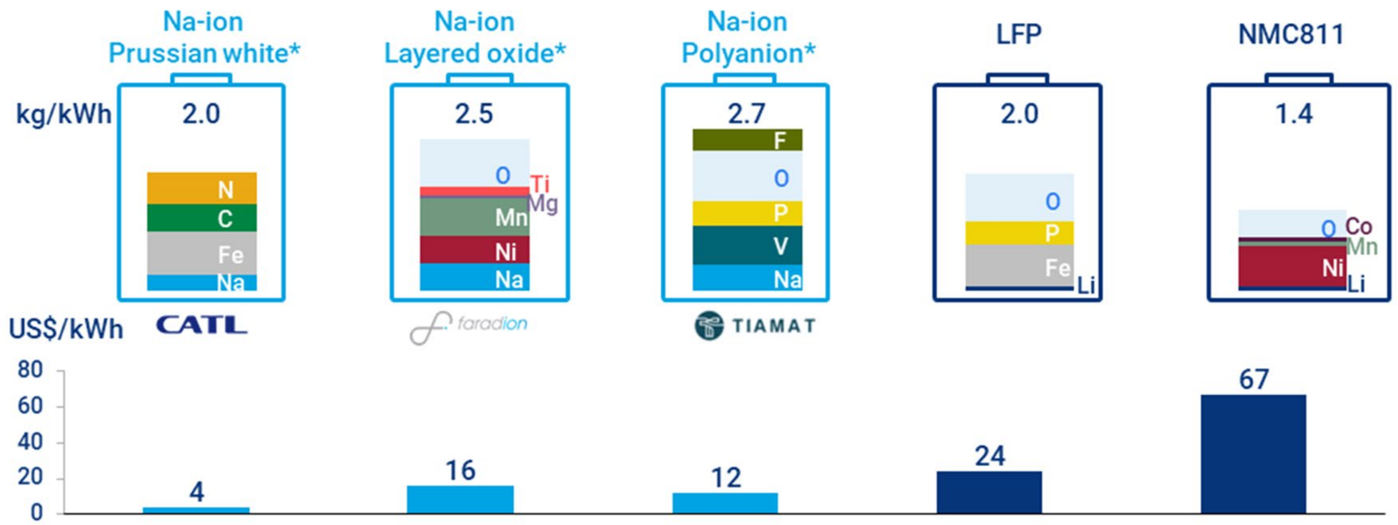
Project overview

“Sodium-ion batteries: disrupt and conquer?”

Sodium-ion (Na-ion) battery chemistries contain lower-value materials than lithium-ion (Li-ion) ones

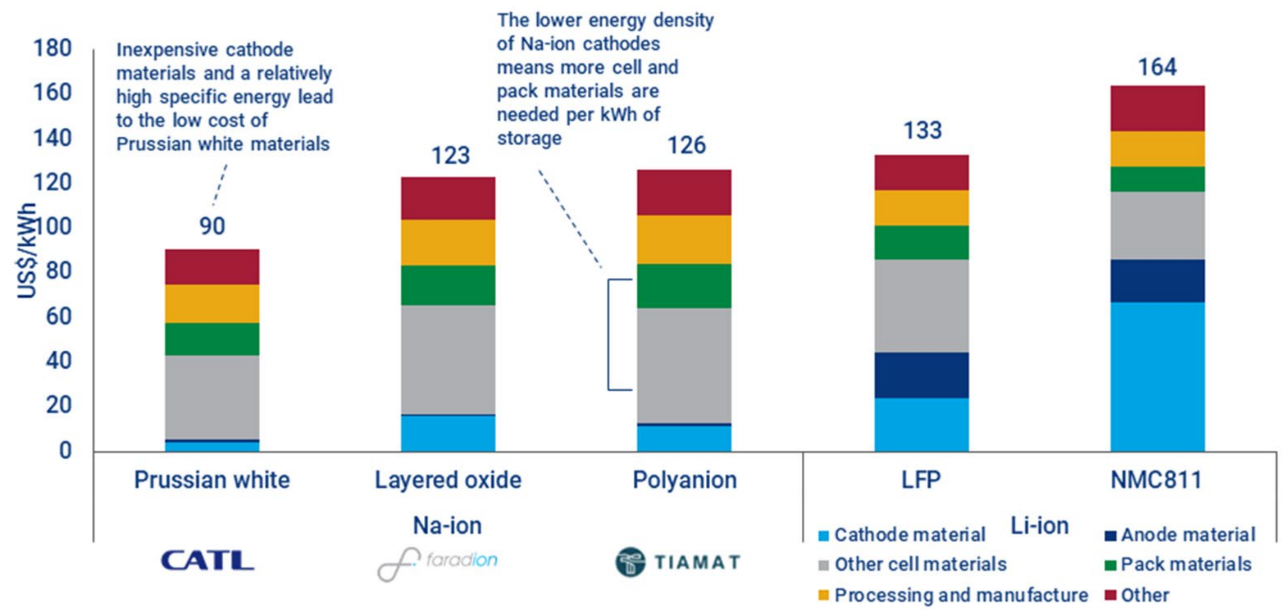
Metal intensity and 2022 cost of Na-ion and Li-ion cathodes



*Prussian white = $Na_2Fe[Fe(CN)_6]$, Layered oxide = $Na_{0.833}Ni_{0.317}Mn_{0.467}Mg_{0.1}Ti_{0.117}O_2$, Polyanion = $Na_3V_2(PO_4)_2F_3$

Sodium-ion (Na-ion) batteries present a lower cost option than lithium-based counterparts

2022 battery pack costs by chemistry



The Na-ion market outlook (Wood Mackenzie 02-21-2023)

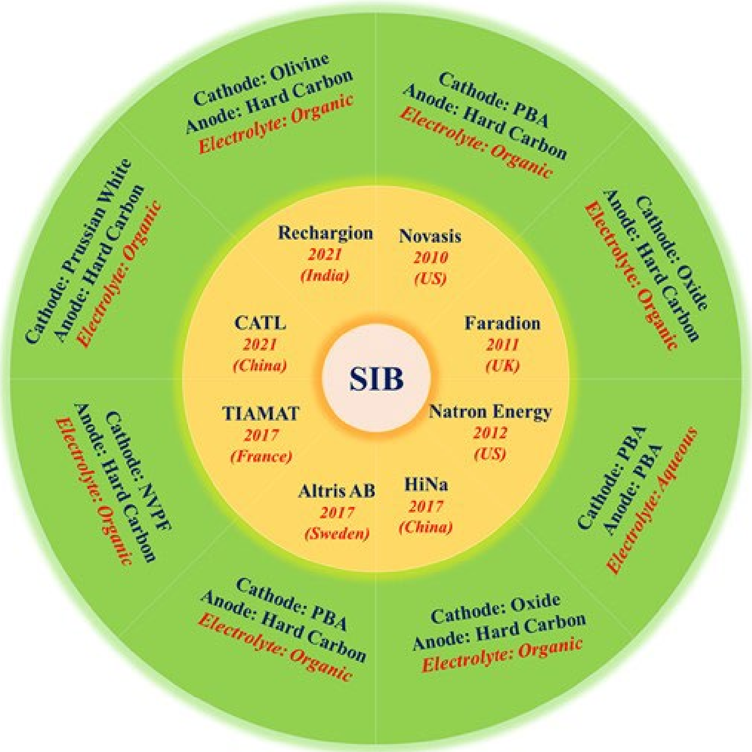
“We forecast just under 40 GWh of base case Na-ion cell production capacity by 2030. A further 100 GWh of production capacity is possible if Na-ion cells see success by 2025.”

https://www.woodmac.com/news/opinion/sodium-ion-batteries-disrupt/

Project overview

Global prominent operators and challenges to "US"

Important Sodium Ion Companies 2024



World's largest sodium-ion battery goes into operation

The first phase of Datang Group's 100 MW/200 MWh sodium-ion energy storage project in Qianjiang, Hubei Province, was connected to the grid.

JULY 2, 2024 MARIJA MAISCH

https://futurebatterylab.com/the-big-beginners-guide-to-sodium-ion-batteries/
https://doi.org/10.1093/oxfmat/itac019
https://www.pv-magazine.com/2024/07/02/worlds-largest-sodium-ion-battery-goes-into-operation/

Project objectives

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

Project milestones in FY24

- **Milestone 1.**

  Demonstrate 50 mAhr capacity in single layer pouch cell with energy retention of > 80% over 300 cycles. (12/31/2023, completed)
- **Milestone 2**

  Optimize electrode composition and density to achieve > 80% energy retention over 400 cycles.. (03/31/2024, , completed)
- **Milestone 3.**

  Establish baseline materials cost for sodium ion battery technology and project costs for selected 1, 10, and 100 MW scale systems at 2-10 hour durations (06/30/2024, completed)
- **Milestone 4.**

  Evaluate sodium ion pouch cell prototype with optimized electrode composition capable of achieving > 80% energy retention over 400 cycles with a projected MW scale materials cost of $95/kWh (09/30/2024, completed)

Achievements summary in FY24

- **Research highlights**

- The baseline pouch cell with $Na_xMn_{0.5}Ni_{0.4}Fe_{0.1}O_2$ and new generation Na_xMNF-5311 cathode demonstrated ~88% retention over 900 cycles at a capacity of ~50 mAh/cm^2.
- Using our pouch cell performance parameters in the BatPaC model, the material cost of the Na_xMNF541-HC sodium-ion battery is $95/kWh when the cathode and HC are priced at $4.32/kg and $30/kg respectively.
- Next generation cathode material with 20% Ni content can deliver a specific capacity of ~120 mAh/g and high-capacity retention.

- **Publications**

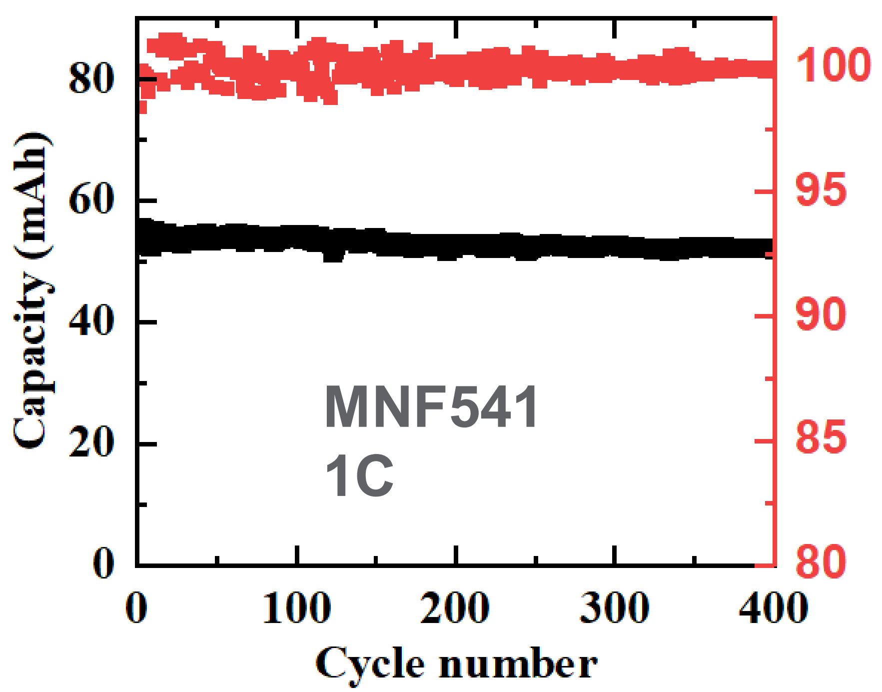
- B. Xiao, et al. *Protonation Stimulates the Layered to Rock Salt Phase Transition of Ni-rich Sodium Cathodes*. ***Advanced Materials.*** 2024, 36, 2308380.
- L. Phung et al. Synergetic Dual-Additive Electrolyte Enables Highly Stable Performance in Sodium Metal Batteries. ***Small.*** 2024, 1, 2402256.

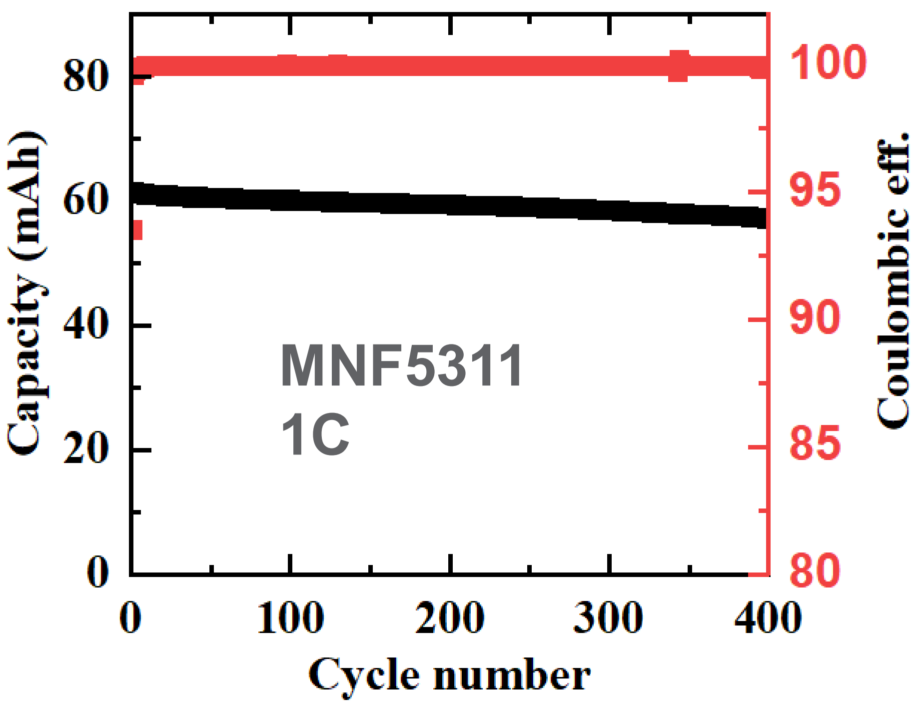
- **Professional activities**

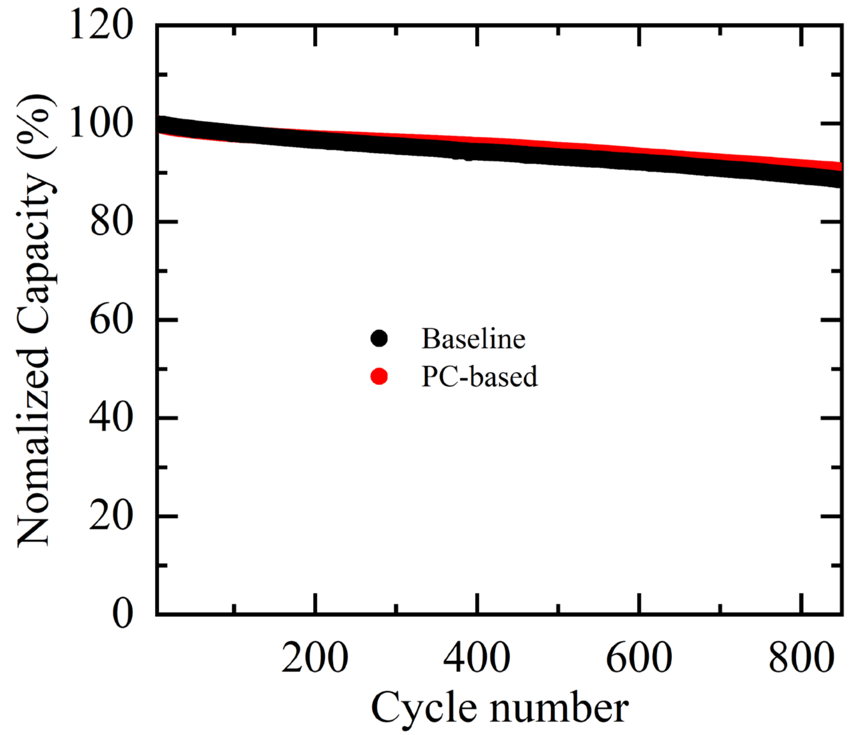
- Invited talk at The 14th symposium on Energy Storage Beyond Li-Ion
- Invited panelist at Battery Council International 2024 Convention
- *Invited talk at 2023 NAATBatt sodium-zinc battery workshop*
- *Chair of the Sodium-ion safety panel at The 8th Energy Storage Safety & Reliability Forum*

Project achievements in FY24

$Na_xNMF541$-HC and $Na_xNMF5311$-HC pouch cells



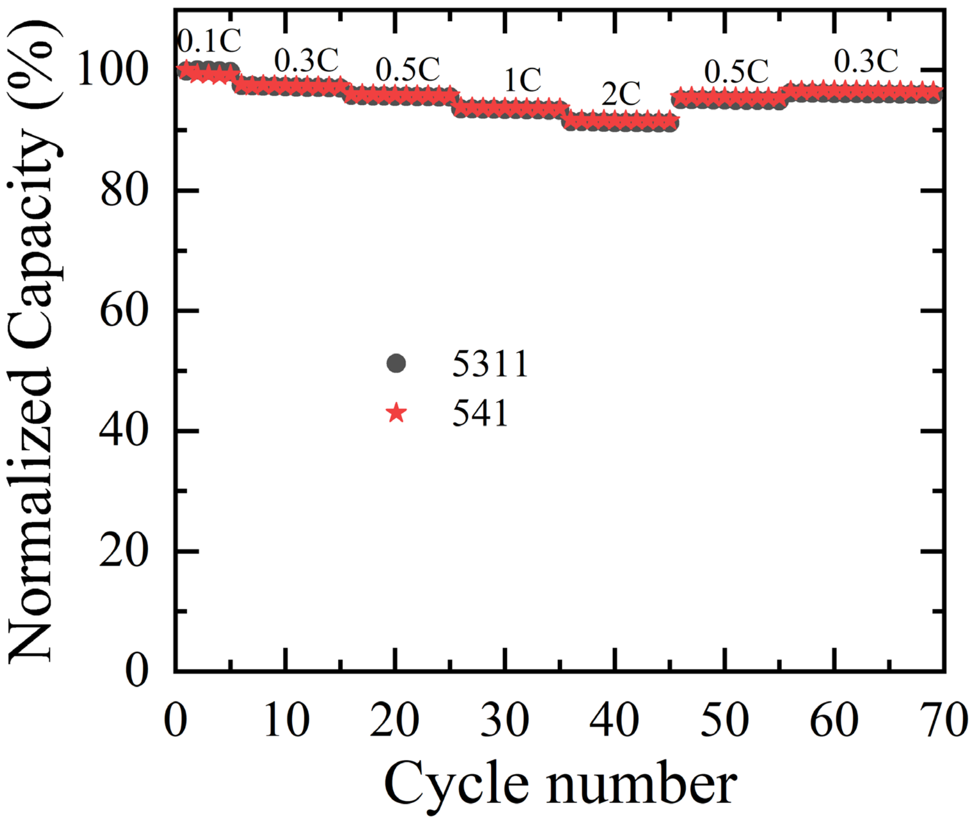


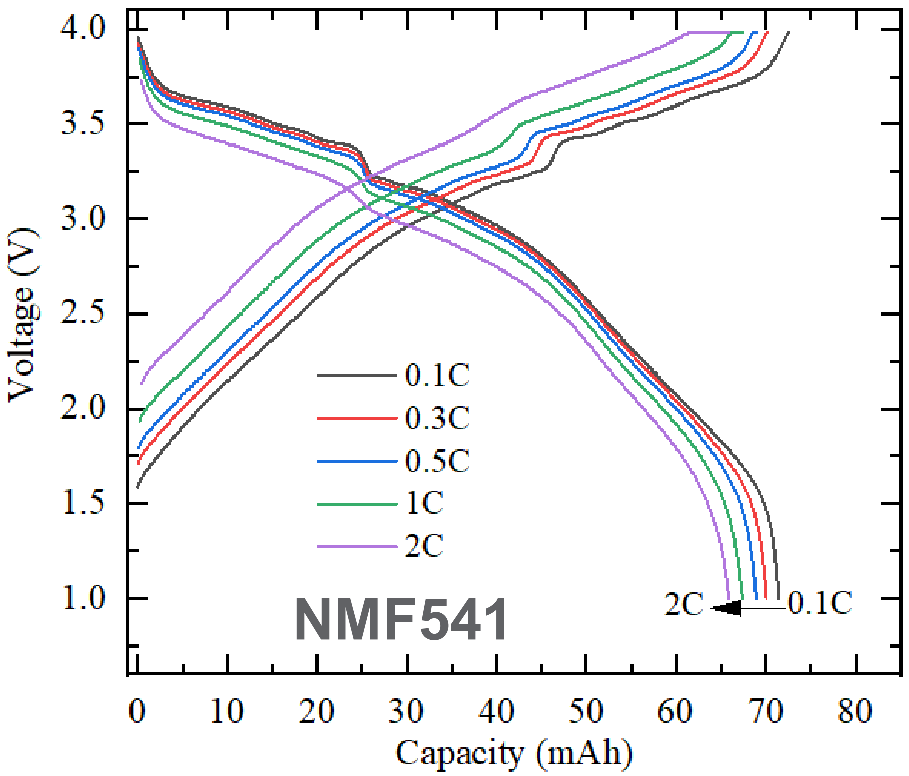


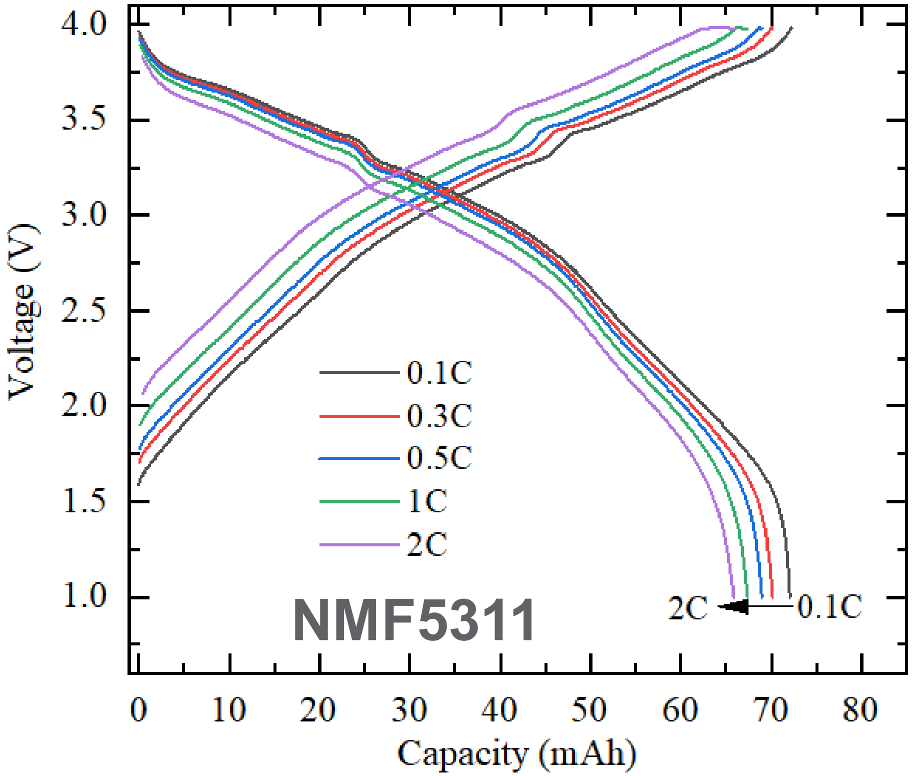
- Both the Baseline $Na_{0.85}Ni_{0.4}Mn_{0.5}Fe_{0.1}O_2$ (Na_xNMF-541)-HC and the new generation Na_xMNF-5311- HC pouch cells Achieved the milestone:
  - Capacity of >50 mAh, ~93% capacity retention over 400 cycles
- The baseline demonstrated extended pouch cell cycling performance with over 1200 cycles
  - Delivering 88% capacity retention after 900 cycles.

Pouch cell evaluation

High-Rate capability



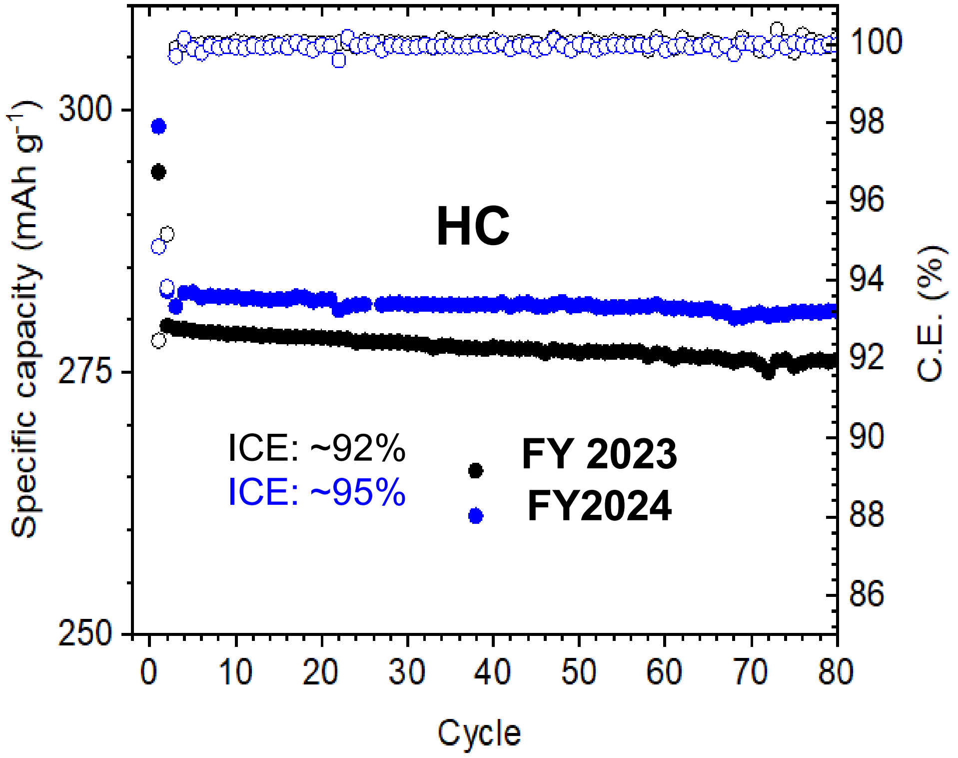


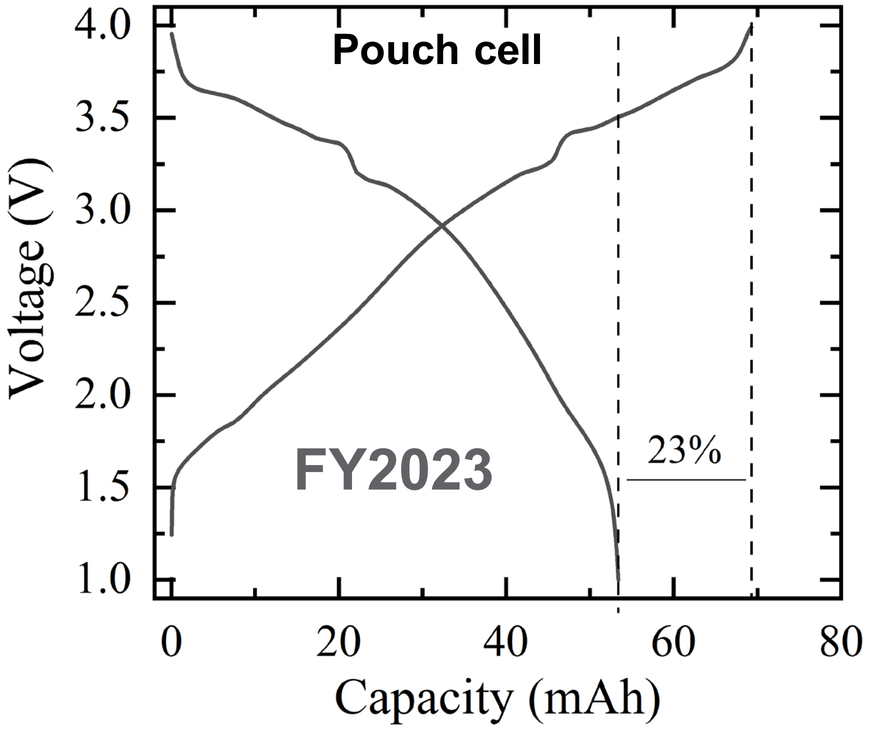


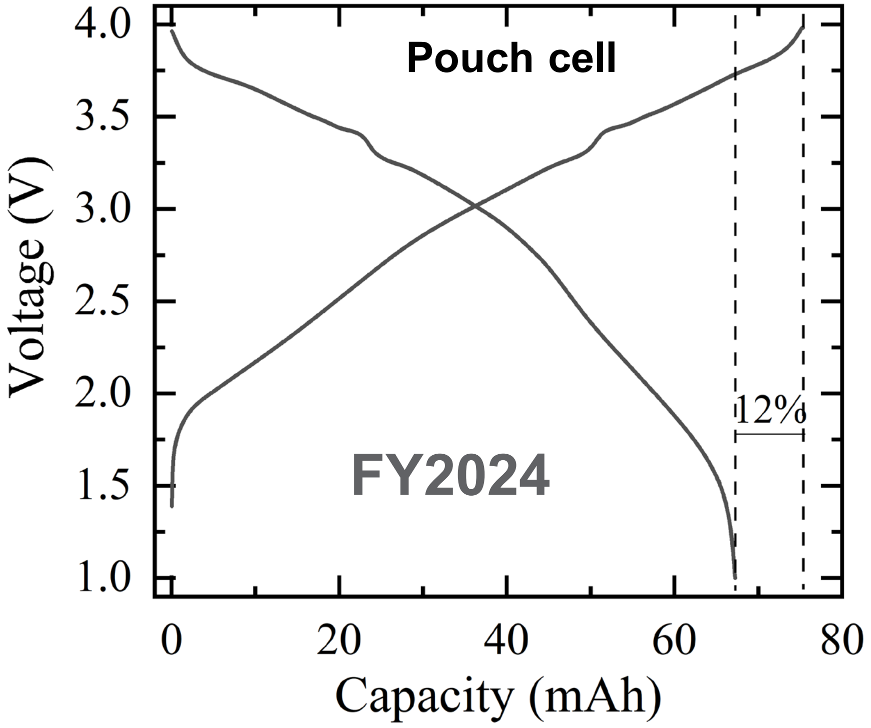
- Both the MNF541-hard carbon and MNF5311-hard carbon pouch cells demonstrate good rate performance.
  - The cells delivers 97.3%, 95.7%, 93.5% and 91.3% of the 0.1C capacity at 0.3C, 0.5, 1 and 2C rate, respectively.

Project achievements in FY24(2)

Performance optimization







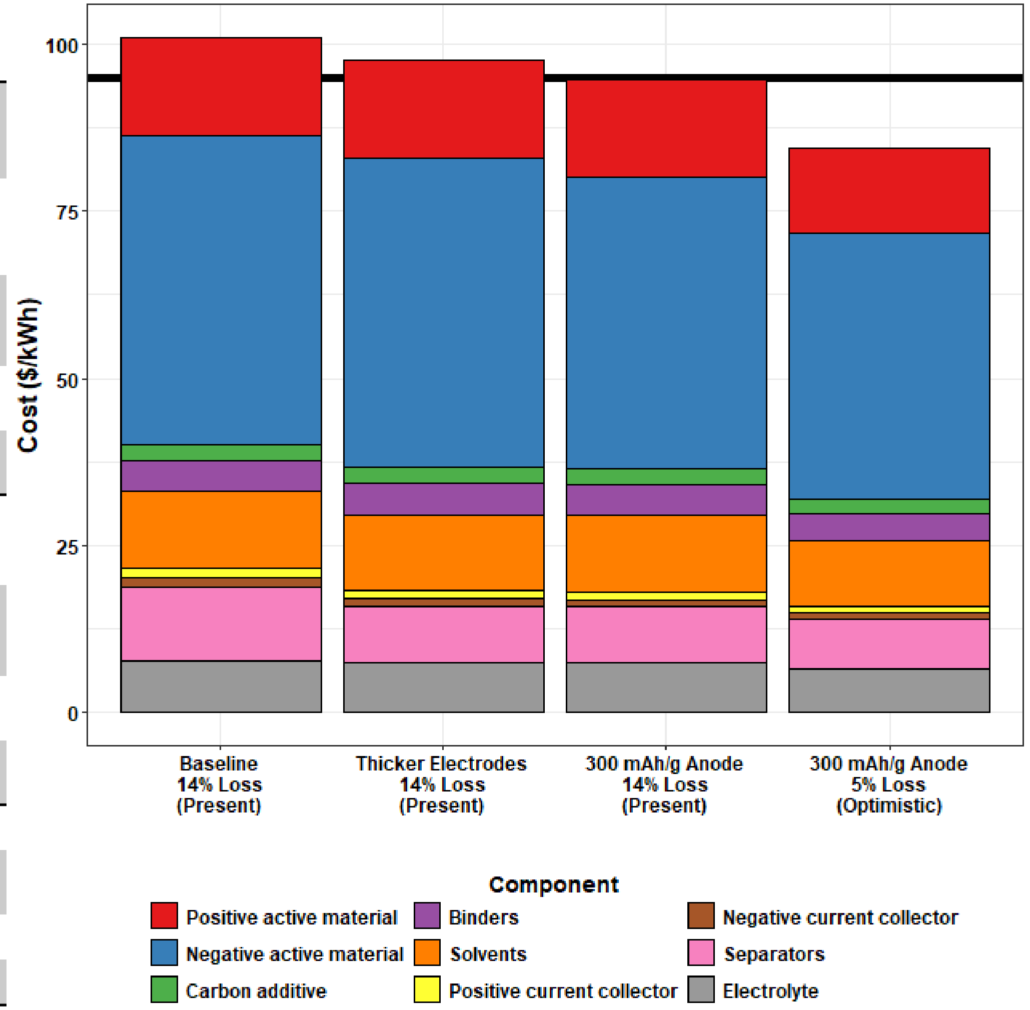
- Optimization of the electrode (hard carbon) through electrode engineering procedure the performance first cycle capacity loss can be improved From ~92% to ~95%
- The NMF541-HC pouch cell ICE can be improved from 23%(FY23) to 12%(FY24)

Project achievements in FY24(3)

Cell component cost input

Quantity	Value	Units	Notes
Cost of active material for NMF-541, positive electrode	4.32	$/kg	Calculated from metals prices and 20% synthesis cost
Cost of active material for NMF-5311, positive electrode	3.84	$/kg	Calculated from metals prices and 20% synthesis cost
Cost of carbon additive for positive electrode	7	$/kg	BatPaC default
Cost of binder for positive electrode	15	$/kg	BatPaC default
Cost of solvent of positive electrode	2.7	$/kg	BatPaC default
Cost of active material for negative electrode	30	$/kg	Average cost from market analysis, floor of 0.4 $/kg
Cost of carbon additive for negative electrode	7	$/kg	BatPaC default
Cost of binder for negative electrode	10	$/kg	BatPaC default
Cost of solvent of negative electrode	0	$/kg	BatPaC default
Positive current collector foil	0.2	$/m^2	Aluminum
Negative current collector foil	0.2	$/m^2	Aluminum
Separators	0.9	$/m^2	Aluminum
Electrolyte	8.1	$/L	BatPaC default

Total cost and cost breakdown



- The material cost of the $Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$-hard carbon sodium-ion battery by the BatPaC model is ~$95/kWh when the cathode active material is priced at $4.32/kg and the hard carbon cost at $30/kg.

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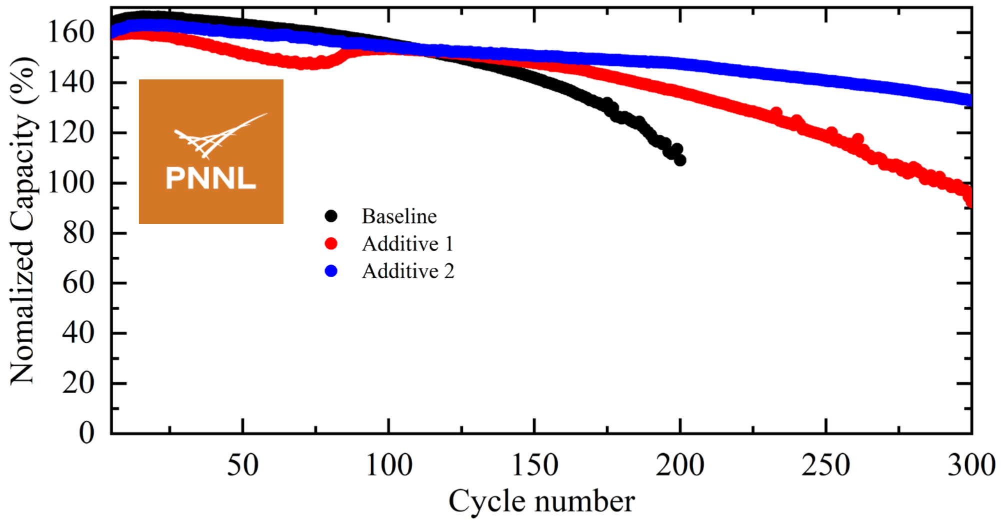
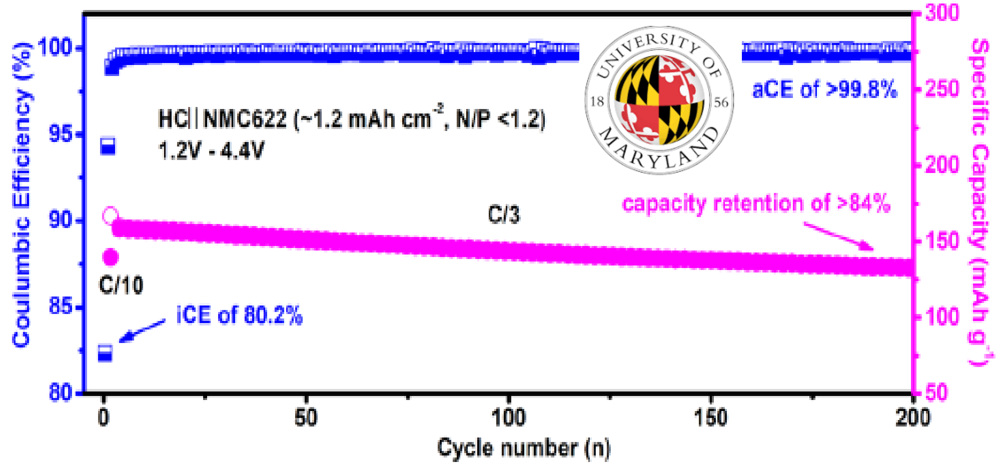
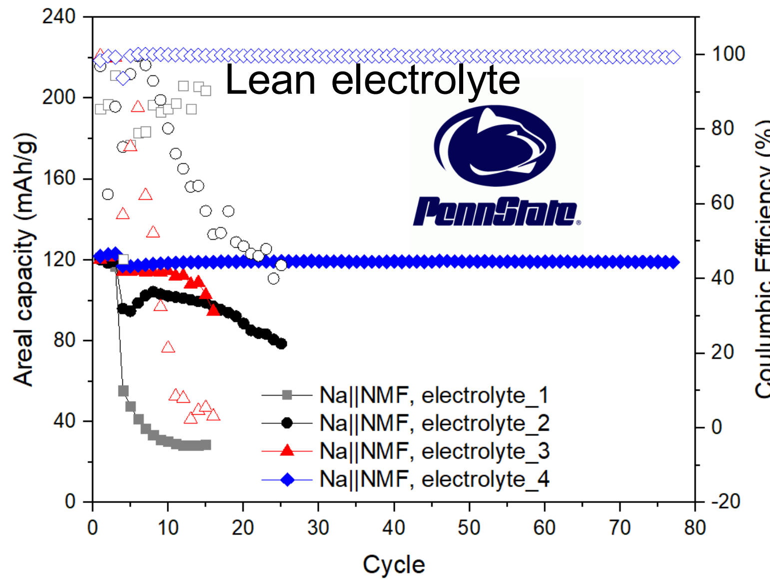
Electrolyte Development

High voltage electrolyte development

Safe Electrolyte







Focus

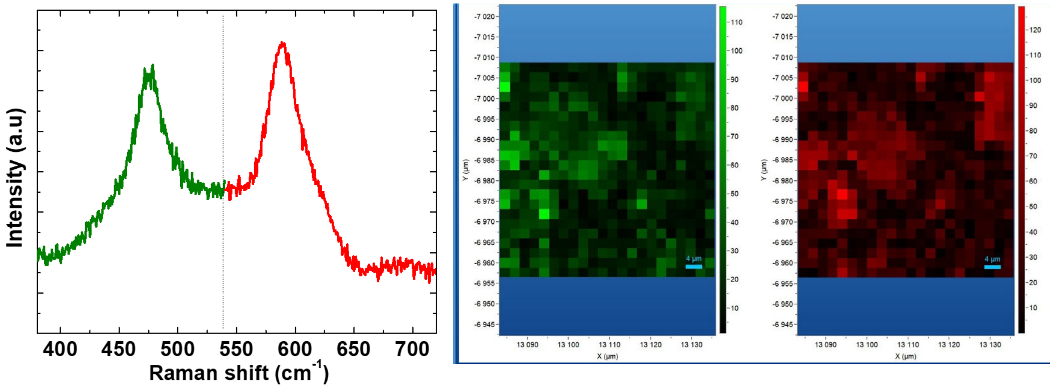
- PNNL: Electrolyte modification significantly boosts the cycle life of layered cathodes in sodium-ion batteries.
- UM: Developed high voltage for sodium ion battery to achieve high energy density.
- Pennstate: A novel electrolyte/Solid-state electrolyte enabling long cycle life under lean electrolyte conditions.

Posters

- *Impact of Additives on Cycle Life of Layered Metal Oxide Cathode in Localized High Concentration Electrolyte; Marcos Lucero*
- *High-voltage Electrolyte Design for Sodium-ion Batteries; Chunsheng Wang's group*
- *Design of Materials for Interface Manipulation in Na Batteries; Donghai's group*

Materials Understanding and Development

Microstructural and morphological evolution of Na-ion electrodes



Raman mapping suggests a random distribution of O3 and P2 phases within the electrode

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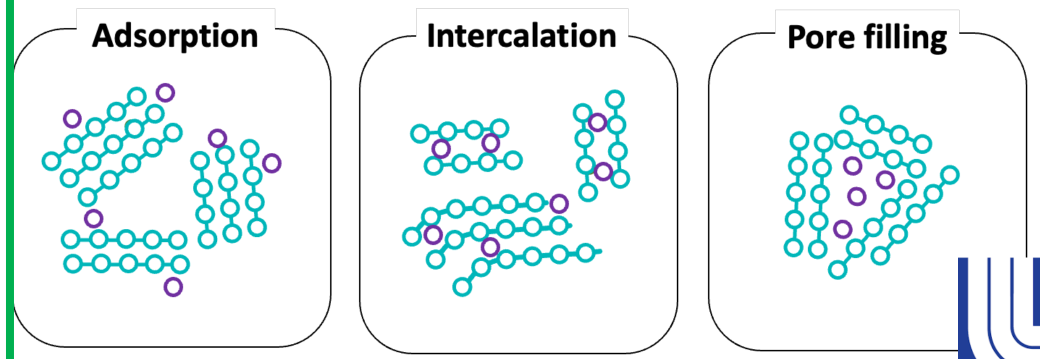
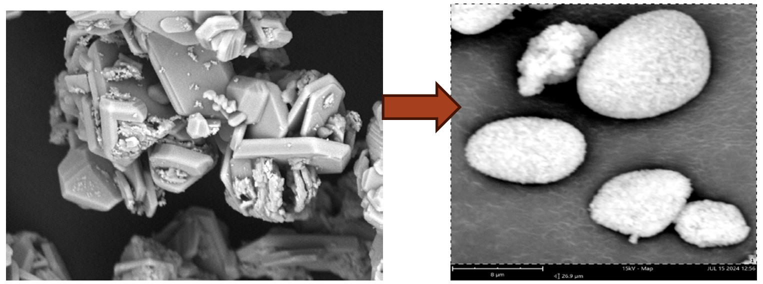
Atomistic simulation to understand local structure and chemistry evolution



Scale-up synthesis

- Scale-up PNNL cathode materials
- Morphology control: secondary particles

Delivered 1st generation 100 g to PNNL.



Element	At. %
Mn	48.4
Ni	42.1
Fe	9.6

TVR: Successful formation of secondary particles

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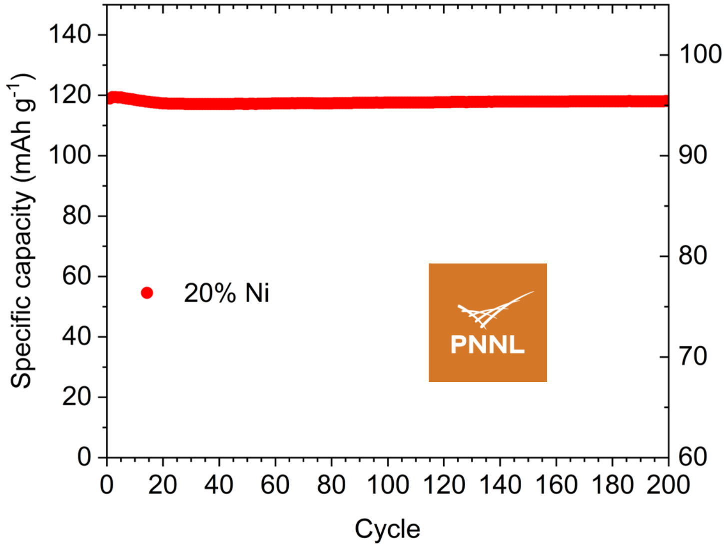
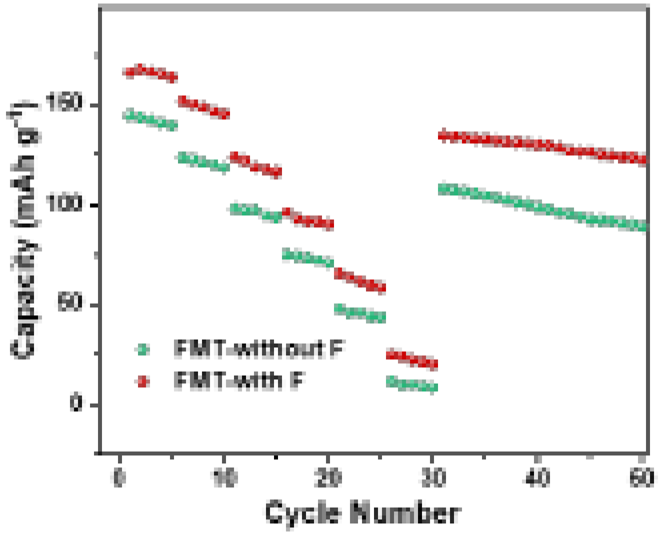
Material Development



Reducing Ni amount



Nickel-free cathode materials

Summary

- The baseline pouch cell MNF-541/HC and new generation cathode Na_xMNF-5311/HC achieved over 88% capacity retention after 900 cycles.
- Optimized the HC performance by improving the initial coulombic efficiency from 92% to 95.6% through electrode engineering.
- Using our optimized pouch cell data, We demonstrated the material cost of the MNF541-hard carbon sodium-ion battery can achieve ~$95/kWh.
- Lowered Ni content in the New generation cathode material to 20% Ni, delivering a specific capacity of ~120 mAh/g and high-capacity retention.

Proposed work for FY25

- Scale-up PNNL materials.
- Demonstrate pouch cells with ~500 mAh capacity capable of achieving $95/kWh materials cost.
- Developing Next generation cathode material with lower Ni content can deliver a specific capacity.

Acknowledgements and contributors

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- **PNNL contributors**

  - Fredrick Omenya
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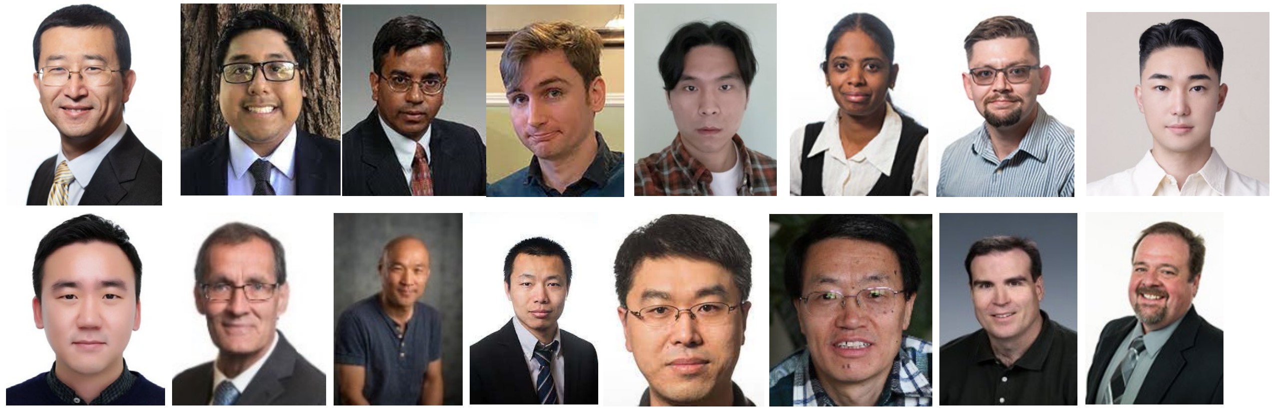
  - Chongmin Wang
  - David Reed
  - Vincent Sprenkle



- **External collaborators**

  - Dr. Kris Pupek

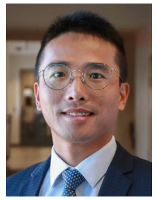
  - Dr. Jagjit Nanda

  - Dr. Jonathan Lee & Sabrina Wan

  - Prof. Donghai Wang

  - Prof. Chunsheng Wang

  - Prof. Feng Lin



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Thank you!