Pacific Northwest
NATIONAL LABORATORY

Sodium-Ion Battery Development

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Presentation 405

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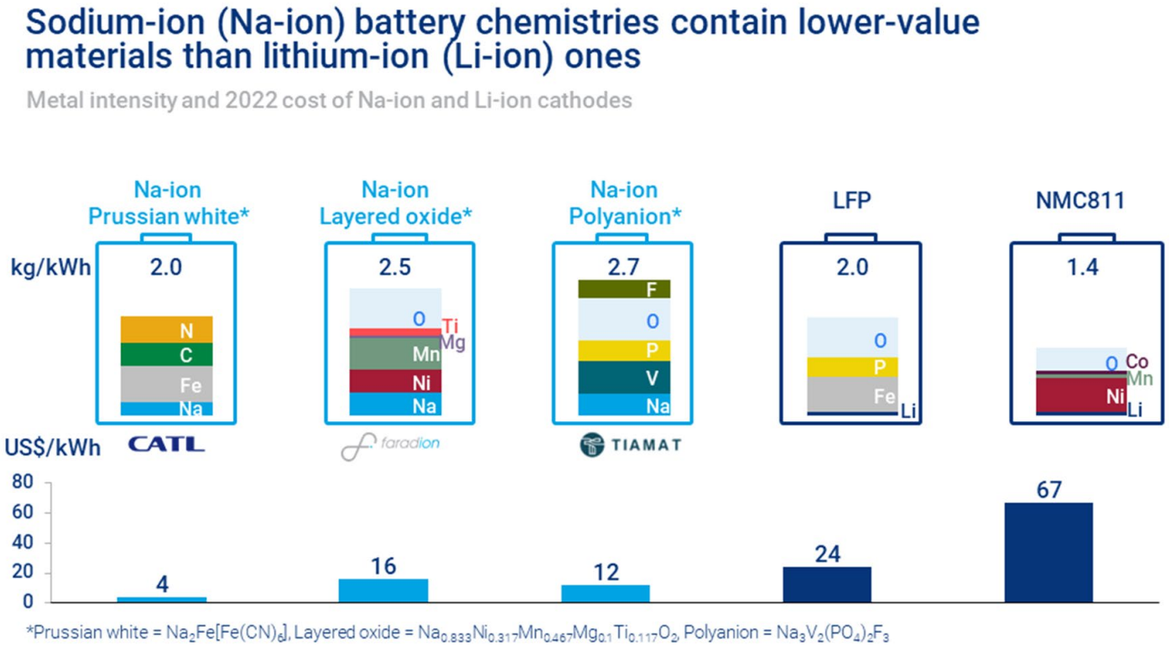
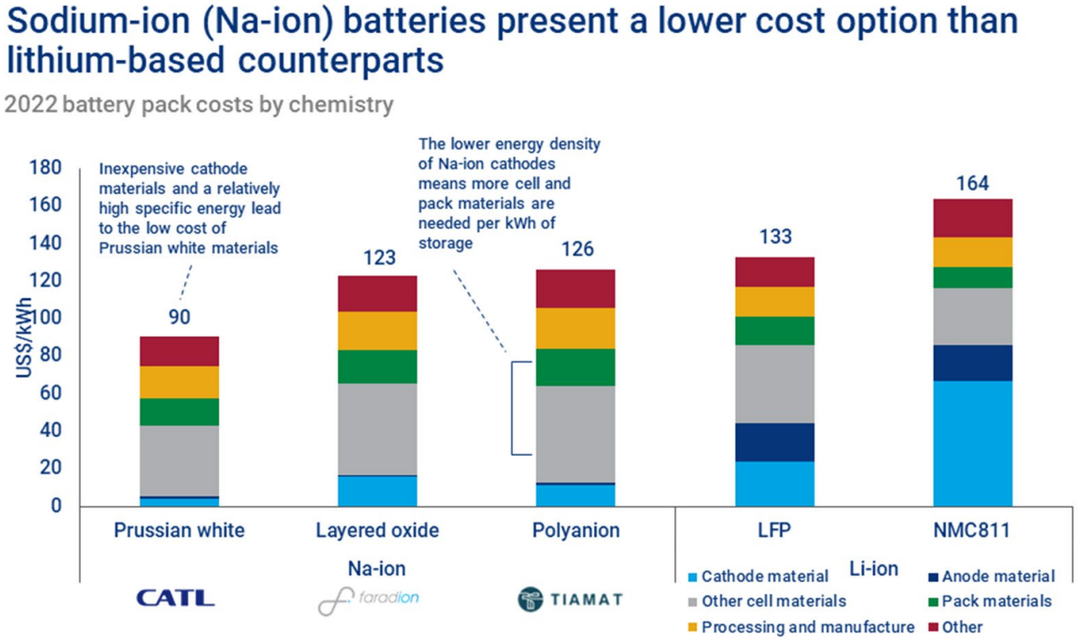
U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Project overview

“Sodium-ion batteries: disrupt and conquer?”





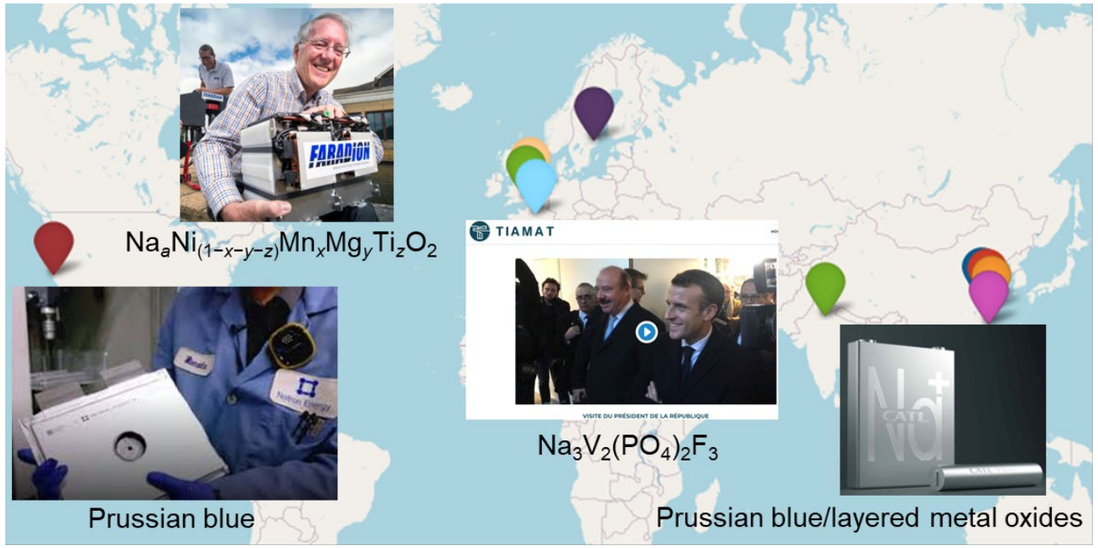
The Na-ion market outlook (Wood Mackenzie 02-21-2023)

“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.”

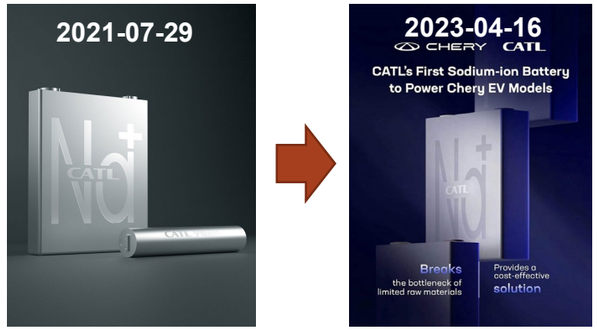
https://www.woodmac.com/news/opinion/sodium-ion-batteries-disrupt/

Project overview

Global prominent operators and challenges to “US”



Company name	Website	Country
Faradion Limited (Bought by Reliance Industries)	https://faradion.co.uk/	UK
AMTE POWER	https://amtepower.com/energy-storage/	UK
Contemporary Amperex Technology Ltd. (CATL)	https://www.catl.com/en/	China
HiNa Battery Technology Co.Ltd	https://www.hinabattery.com	China
TIAMAT Energy	http://www.tiamat-energy.com/	France
Natron Energy Inc.	https://natron.energy/	US
Altris	https://www.altris.se/	Sweden
Natrium Energy	http://www.natriumenergy.cn/	China
Nanjing Nasco Energy Technology Co. Ltd.	http://www.nasico.cn/	China



https://www.catl.com/en/news/665.html
https://www.catl.com/en/news/6013.html

BYD

2023-06-08

JAC MOTORS

https://electrek.co/2023/06/12/byd-joint-venture-mass-producing-sodium-ion-ev-batteries/
https://faradion.co.uk/first-faradion-battery-installed-in-australia/

The New York Times

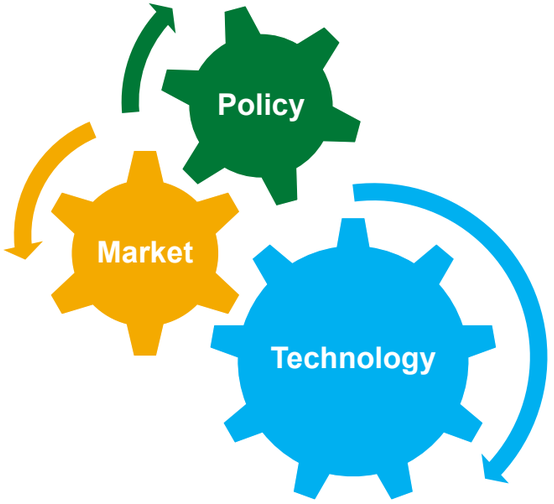
Why China Could Dominate the Next Big Advance in Batteries

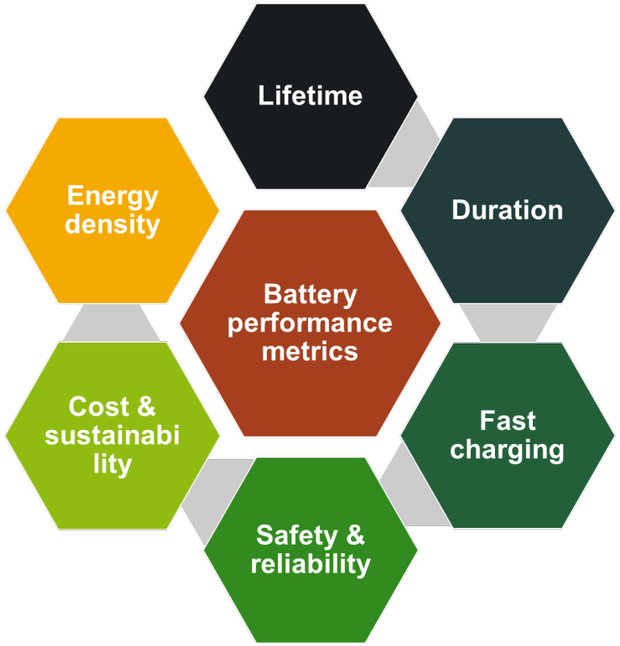
China is far ahead of the rest of the world in the development of batteries that use sodium, which are starting to compete with ubiquitous lithium power cells.

https://www.nytimes.com/2023/04/12/business/china-sodium-batteries.html?smid=em-share

Project overview

A great momentum





Na-ion batteries with desired performance metrics will play a pivotal role in energizing, mobilizing, and connecting the globe.

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 and demonstration of pouch cells

Project milestones in FY23

- **Milestone 1.**

  Demonstrate 50 mAhr capacity in single layer pouch cell with energy retention of > 80% over 100 cycle (12/31/2022, completed)
- **Milestone 2**

  Optimize electrode composition and density to achieve > 80% energy retention over 250 cycles. (03/31/2023, , completed)
- **Milestone 3.**

  Establish baseline materials cost for sodium ion battery technology and costs for selected 1, 10, and 100 MW scale systems at various durations (06/30/2023, completed)
- **Milestone 4.**

  Evaluate sodium ion pouch cell prototype with optimized electrode composition capable of achieving > 80% energy retention over 250 cycles with a projected MW scale materials cost of $100/kWh (09/30/2023, completed)

Achievements summary in FY23

Research highlights

- The baseline pouch cell with $Na_xNi_{0.4}Mn_{0.5}Fe_{0.1}O_2$ ($0.85 < x < 0.95$) cathode and hard carbon anode demonstrated ~94.3% retention over 250 cycles at a capacity of ~50 mAh/cm^2.
- Employing the BatPaC model with specific Na-ion battery performance parameters, the material cost of the $Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$-hard carbon sodium-ion battery is $100/kWh when the cathode active material is priced at $6.5/kg and the hard carbon cost at $30/kg.
- Preliminary modeling suggests that for a 1 to 100 MW system at 1-10 hr duration, the overall system cost, including manufacturing, battery management system, and additional components such as cables and sensors, is ~$133/kWh.
- Next generation cathode material with lower Ni content can deliver a specific capacity of ~125 mAh/g and > 80% retention over 1000 cycles in half cell test.

Publications

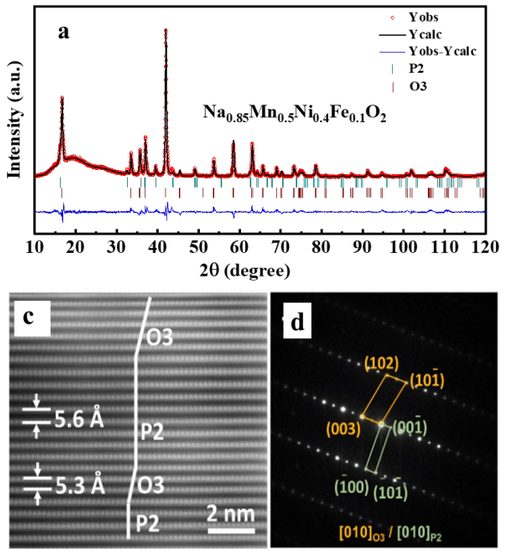
- F. Omenya, et al. Energy and power evolution over the lifetime of a battery. ***ACS. Energy Lett.*** 2023, 8, 2707.
- L.-J. Jhang, et al., Stable all-solid-state sodium-sulfur batteries for low-temperature operation enabled by sodium alloy anode and confined sulfur cathode. ***Nano Energy***, 2023, 105, 107995.

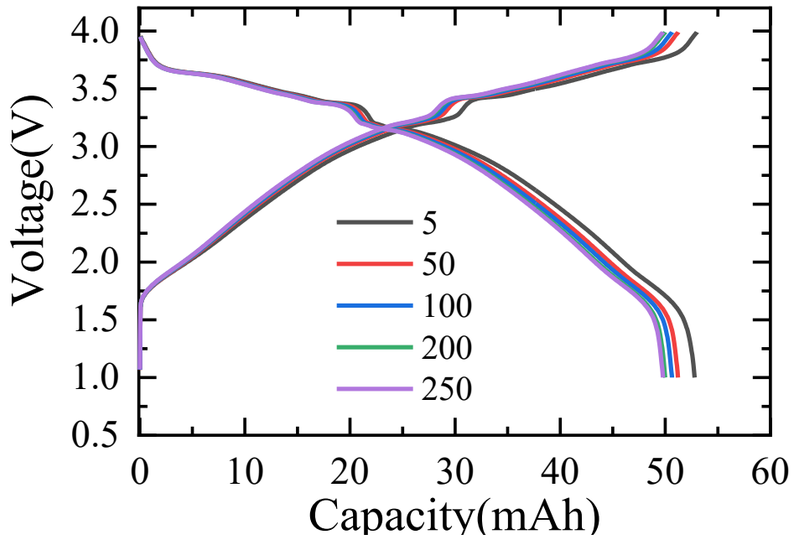
Professional activities

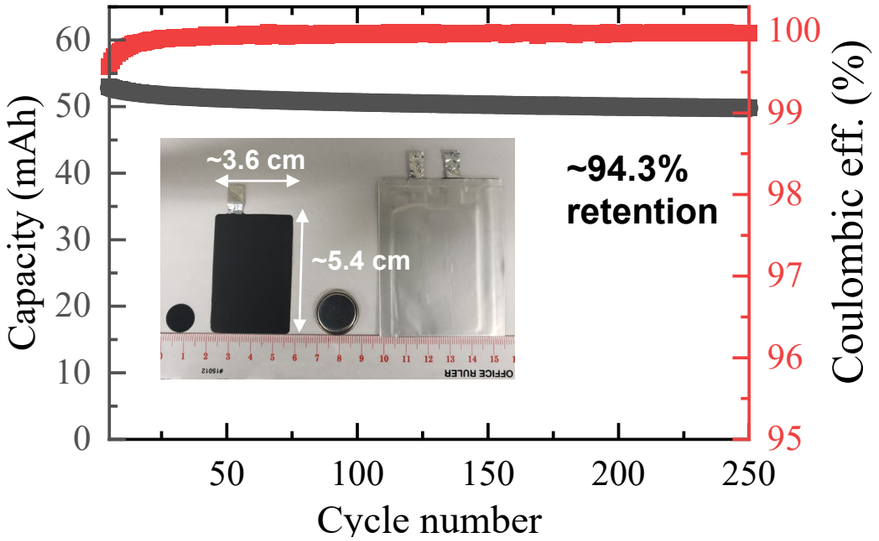
- One invited talk at the *7th International Conference on Sodium Batteries*
- One oral presentation and two posters at *the 243rd ECS Meeting*
- Two invited talks at the *2023 ACS Fall Meeting*
- Organized the symposium of "*Sodium and zinc batteries*" for the *243rd ECS meeting*

Project achievements in FY23 (1)

$Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$-hard carbon pouch cell







- Baseline $Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$ ($Na_{0.85}$NMF) material has a P2/O3 structure, the ratio of which is dependent to the synthesis parameters.
- Pouch cell of $Na_{0.85}$NMF-HC with a capacity of ~50 mAh has been demonstrated.
- The capacity retention after 250 cycles is ~94%.

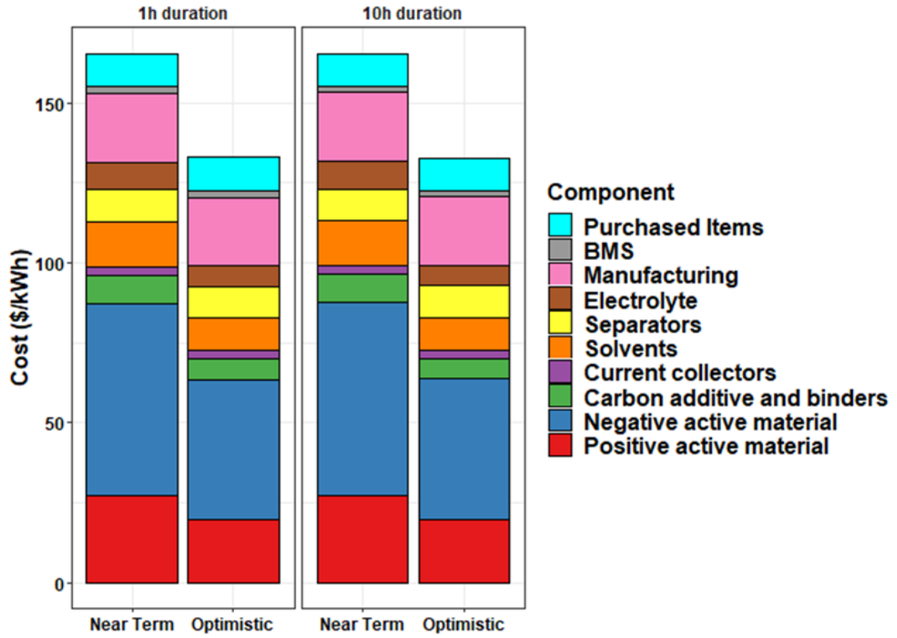
Project achievements in FY23 (2)

Cost estimation

Cell component cost input

Cost of active material for positive electrode, $/kg	6.5	$/kg	Regressed from list of Na-Ion layered oxide cathodes
Cost of carbon additive for positive electrode, $/kg	7	$/kg	BatPaC default
Cost of binder for positive electrode $/kg	15	$/kg	BatPaC default
Cost of solvent of positive electrode $/kg	2.7	$/kg	BatPaC default
Cost of active material for negative electrode, $/kg	30	$/kg	Average cost from market analysis, floor of 0.4 $/kg
Cost of carbon additive for negative electrode, $/kg	7	$/kg	BatPaC default
Cost of binder for negative electrode $/kg	10	$/kg	BatPaC default
Cost of solvent of negative electrode $/kg	0	$/kg	BatPaC default
Positive current collector foil, $/m²	0.2	$/m²	Aluminum
Negative current collector foil, $/m²	0.2	$/m²	Aluminum
Separators, $/m²	0.9	$/m²	BatPaC default
Electrolyte, $/L	8.1	$/L	BatPaC default

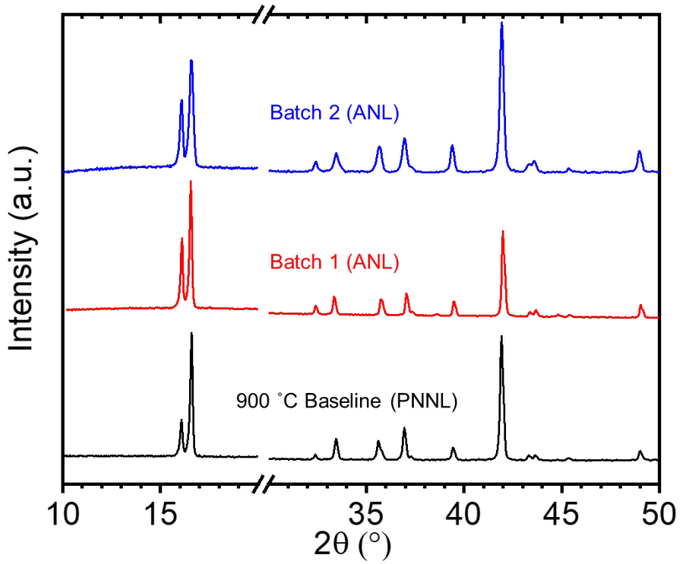
Total cost and cost breakdown

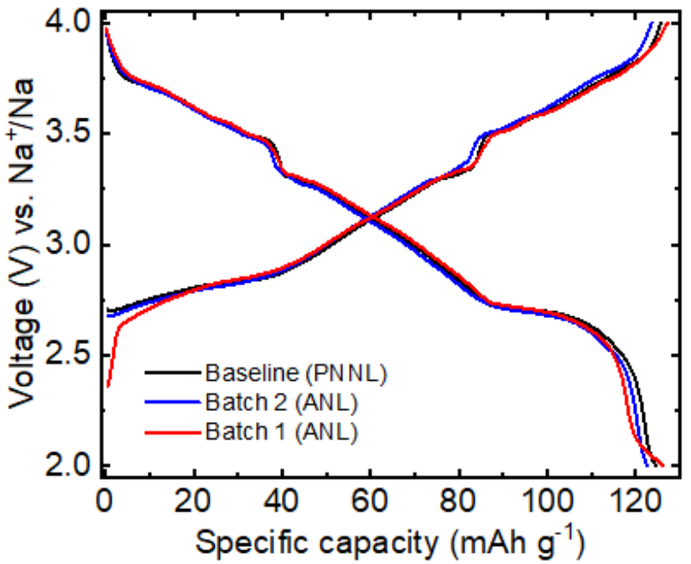


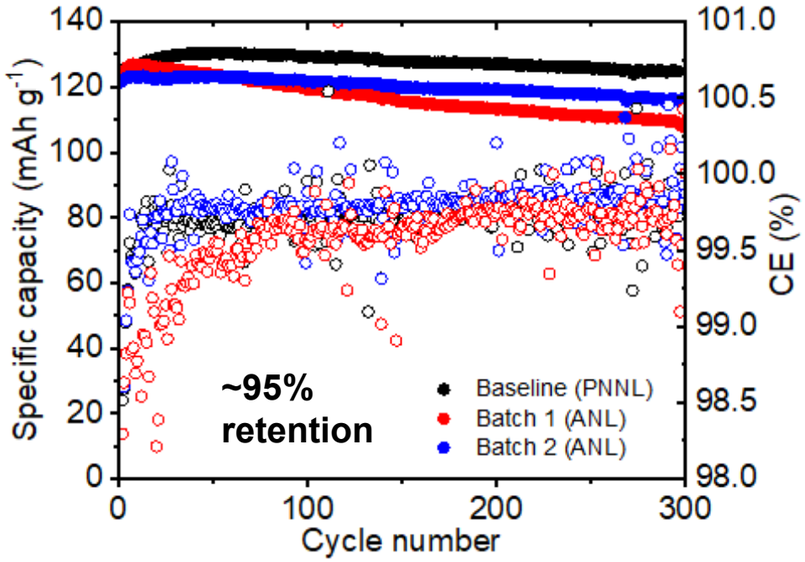
- The material cost of the $Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$-hard carbon sodium-ion battery by the BatPaC model is ~$100/kWh when the cathode active material is priced at $6.5/kg and the hard carbon cost at $30/kg.
- Using the design inputs from the 1MW, 4MWh Li-ion battery at horn rapids in Eastern Washington, for a 1 to 100 MW system at 1-10 hr duration, the overall system cost, including manufacturing, battery management system, and additional components such as cables and sensors, is ~$133/kWh.

Project achievements in FY23 (3)

Validation of the scale up syntheses





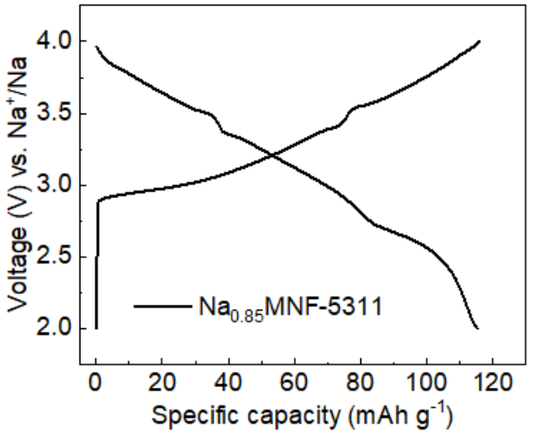


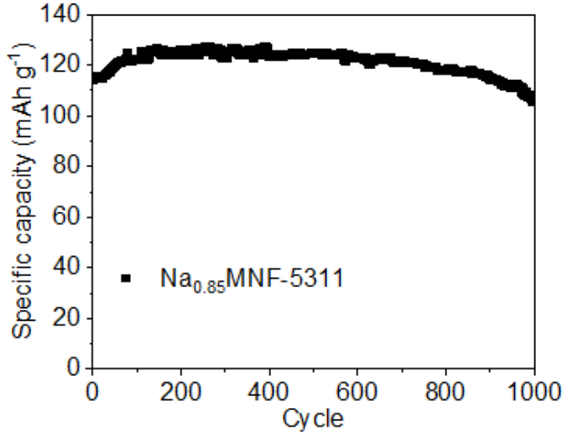
- The material scaled up by co-precipitation method at ANL has similar composition and battery performance to the lab-scale baseline material prepared at PNNL. The half cells demonstrated ~95 % retention over 300 cycles. The average coulombic efficiency is ~99.8%.
- Refining scale-up synthesis parameters and approaches may be needed.

Project achievements in FY22 (4)

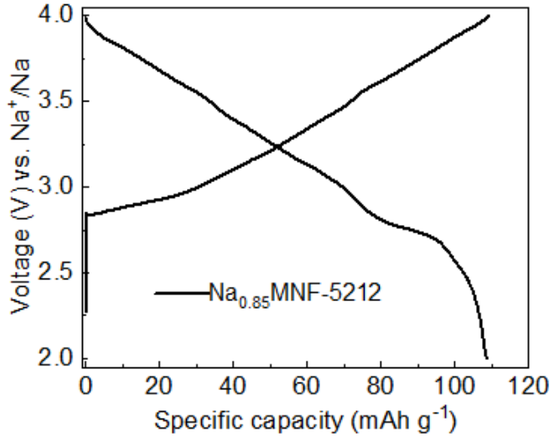
Next generation cathode materials

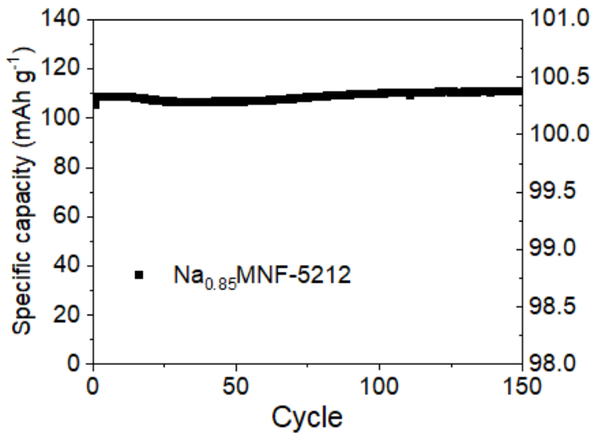
MNF-5311





MNF-5212





Sustainability

- Next-generation cathode materials with less critical materials are under developing.
- $Na_{0.85}$MNF-5311 demonstrated a specific capacity of ~125 mAh/g and > 80% retention over 1000 cycles.

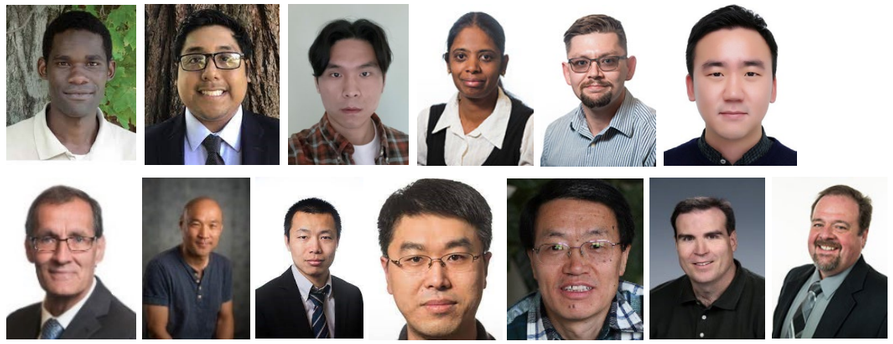
Proposed work for FY24

- Continue developing the next generation of more sustainable and high-performance electrode materials
- Systematically evaluate the material cost and cost reduction of the various types of sodium-ion batteries with market growth
- Scale up of materials and demonstration of pouch cells

Project team

- **PNNL contributors**

  - Fredrick Omenya
  - Marcos Lucero
  - Wonkwang Lim
  - Bhuvaneswari Sivakumar
  - Matthew Fayette
  - Hyungkyu Han
  - Mark H. Engelhard
  - Kee Sung Han
  - Yaobin Xu
  - Peiyuan Gao
  - Chongmin Wang
  - David Reed
  - Vincent Sprenkle



- **External collaborators**

  - Prof. Perla Balbuena
  - Prof. Donghai Wang
  - Dr. Kris Pupek, Guiliang Xu & Khalil Amine

  - Dr. Wanli Yang
  - Prof. Yanyan Hu

Acknowledgements

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Thank you!