Pacific Northwest
NATIONAL LABORATORY

Our Journey Towards Sustainable Na-Ion Batteries

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NAATBatt Sodium-Zinc Workshop

Nov. 30, 2023

U.S. DEPARTMENT OF ENERGY BATTELLE

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

The focus is on Grid

Jul. 2023

FORTUNE

Two-thirds of the U.S. is at risk of power outages this summer—but it's not stopping Americans from electrifying everything in their homes

The Department of Energy recently warned that two-thirds of the U.S. is at risk of losing power this summer. It's an increasingly common refrain: Homeowners want to be less reliant on the aging power grid and don't want to be at the mercy of electric utilities due to rising energy costs and dwindling faith in the power grid's reliability.

THE WALL STREET JOURNAL.

Nov. 2023

REUTERS®

Two-thirds of North America could face power shortages this winter -NERC

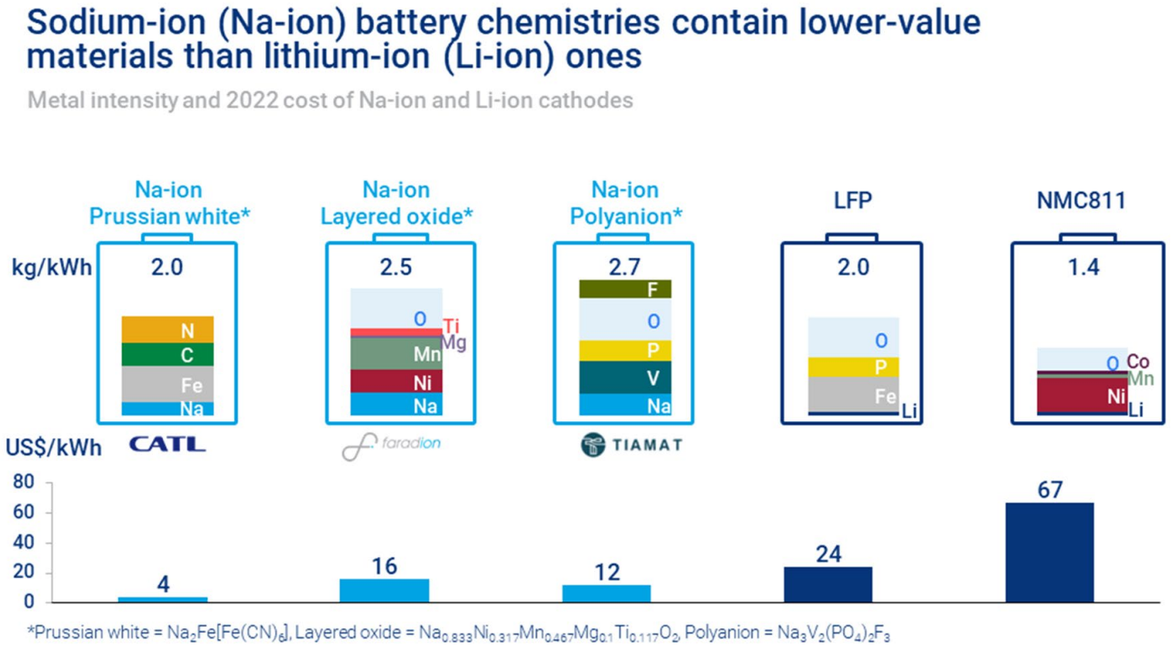
A robust energy (electricity) market requires a balance between **supply** and **demand.**

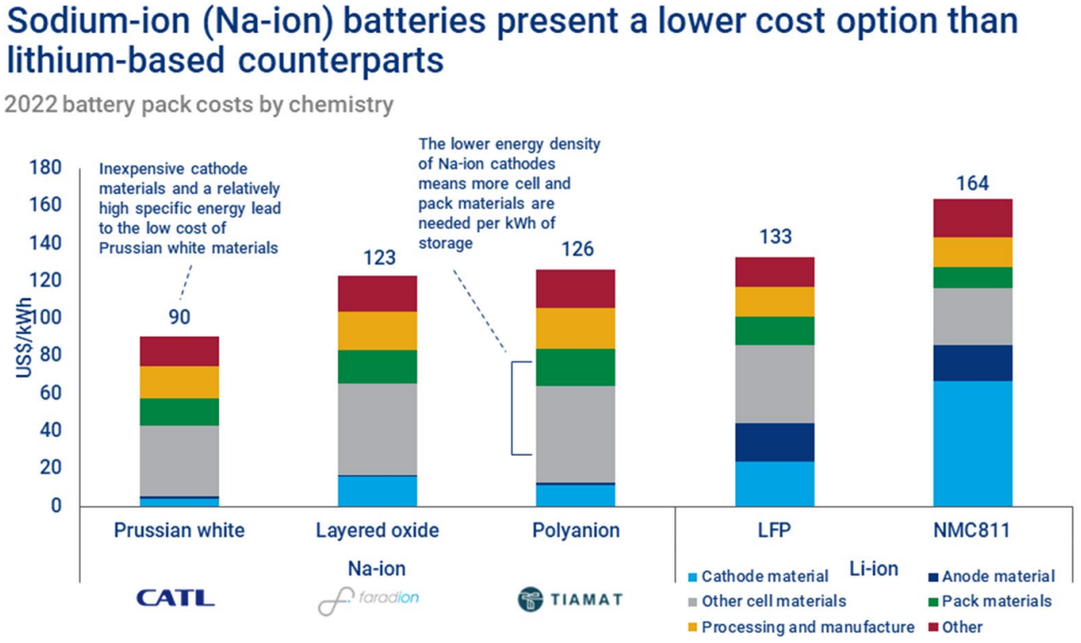
"Character traits" of electric grid infrastructure: **sustainable** and resilient, reliable, smart, secure, …

https://fortune.com/2023/07/03/two-thirds-usa-risk-of-power-outages-this-summerbut-americans-electrifying-everything-energy-environment/
https://www.eia.gov/todayinenergy/
https://www.wsj.com/articles/elon-musks-latest-mission-rev-up-the-electricity-industry-1583a184
https://www.reuters.com/world/us/north-america-faces-power-reliability-challenges-again-this-winter-nerc-2023-11-08/
https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2023.pdf

Sustainable energy storage

“Sodium-ion batteries: disrupt and conquer?”





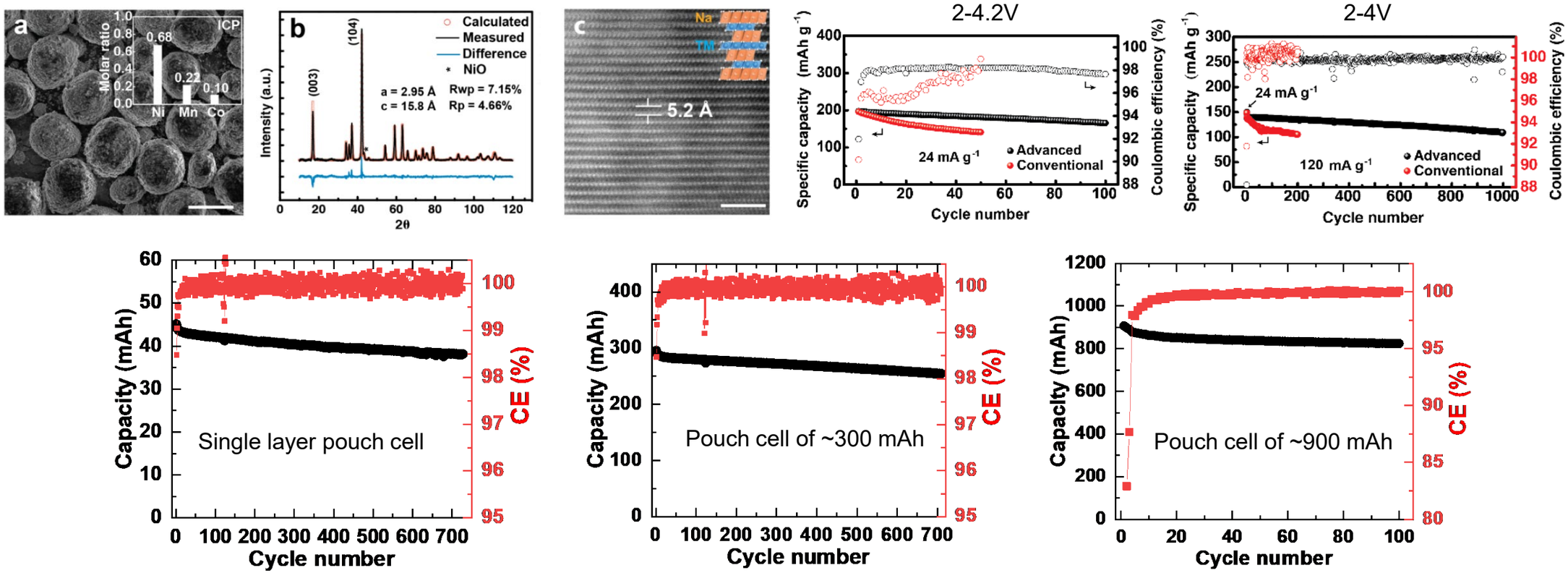
The Na-ion market outlook (Wood Mackenzie 02-21-2023)

“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/

Our journey: viability demonstration

O3-$NaNi_{0.68}Mn_{0.22}Co_{0.10}O_2$ cathode

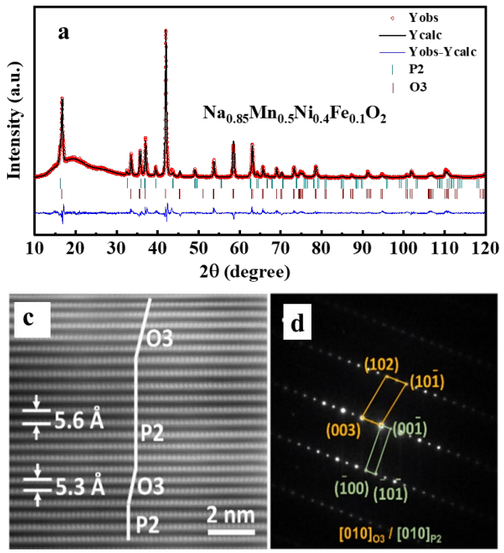


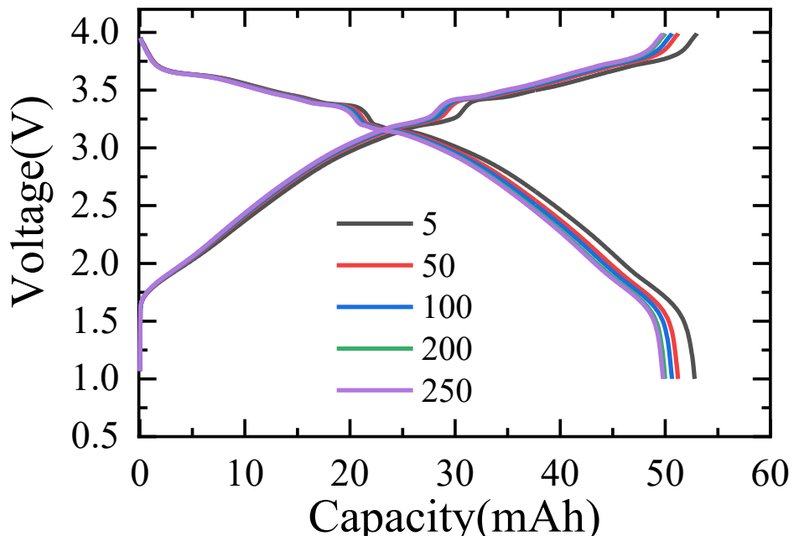
- Na-ion battery can delivery high specific capacity (~196 mAh/g at 4.2 V cutoff) and long cycling stability (~80% retention over 1000 cycles with a specific capacity of ~151 mAh/g at 4.0 V cutoff).
- Pouch cells demonstrated good cycling stability (i.e., the ~300 mAh cell has ~88% retention over 700 cycles).

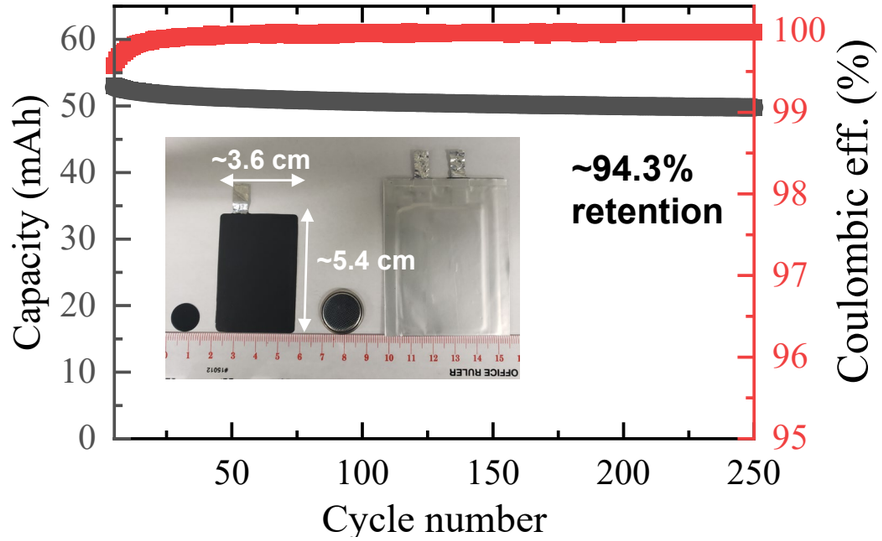
J.H. Song et al. ACS Energy Lett. 2020, 5, 1718

Our journey: towards practical devices

P2/O3 $Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$ cathode







- The $Na_{0.85}Mn_{0.5}Ni_{0.4}Fe_{0.1}O_2$ ($Na_{0.85}$NMF) cathode material has a mixed P2/O3 structure.
- Single layer 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%.

B. Xiao et al., Nano Energy, 2021, 89, 106371
DOE OE energy storage peer review, October 2023

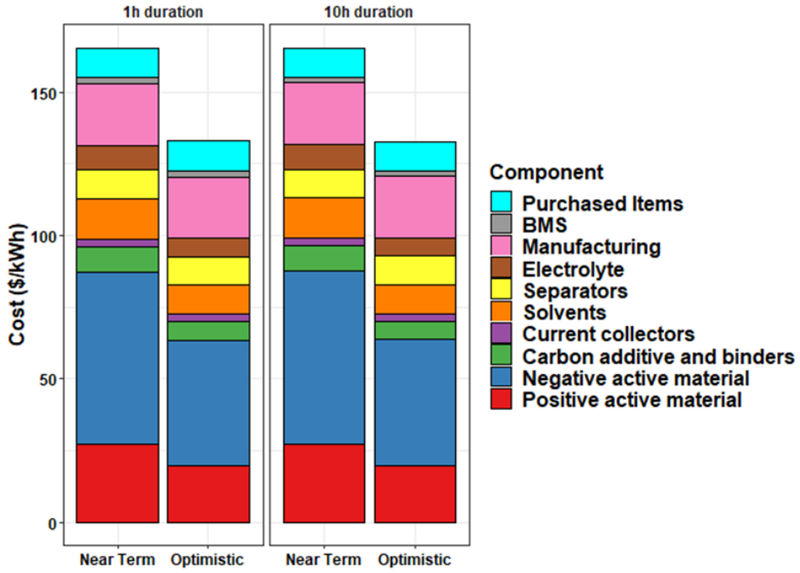
Our journey: economic analysis

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

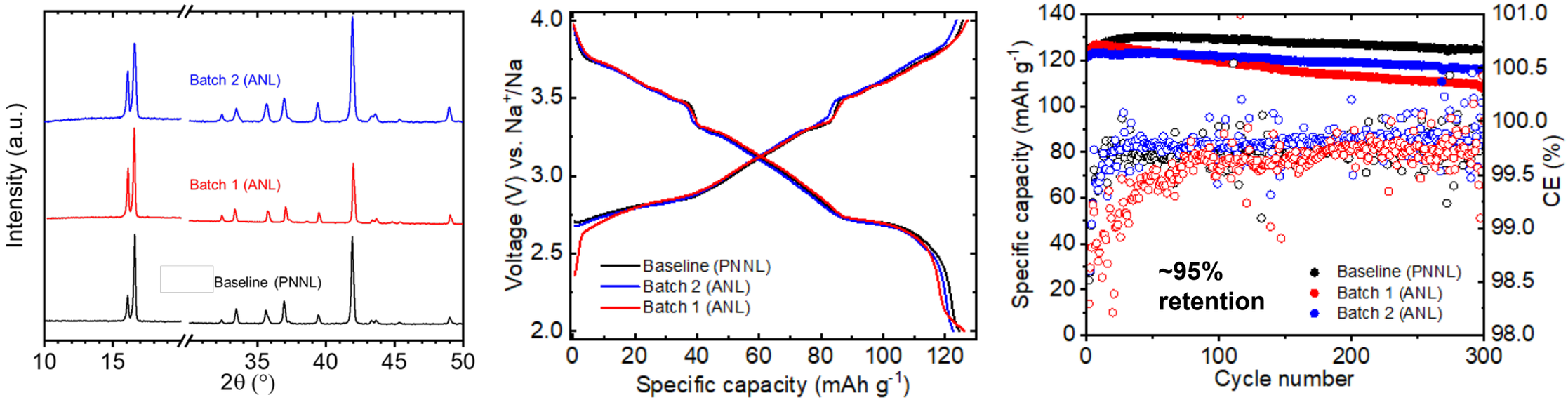
Total cost and cost breakdown



- The material cost of the $Na_{0.85}$MNF-hard carbon Na-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 or 10 hr duration system, the overall system cost, including manufacturing, battery management system, and additional components such as cables and sensors, is ~$133/kWh.

Our journey: material scale up

Validation of the scale up syntheses

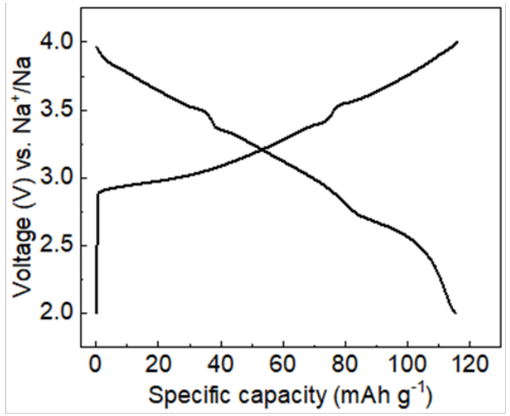


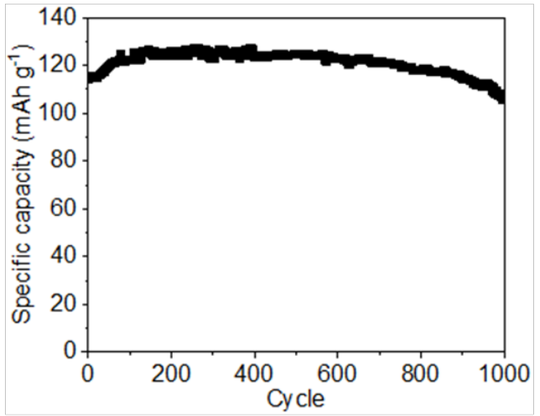
- The material scaled up by ANL has very similar composition and battery performance to the lab-scale baseline material prepared at PNNL. The half cells demonstrated ~95 % retention over 300 cycles. The average coulombic efficiency is ~99.8%.
- Further refinement of the scale up parameters are underway.

What's next

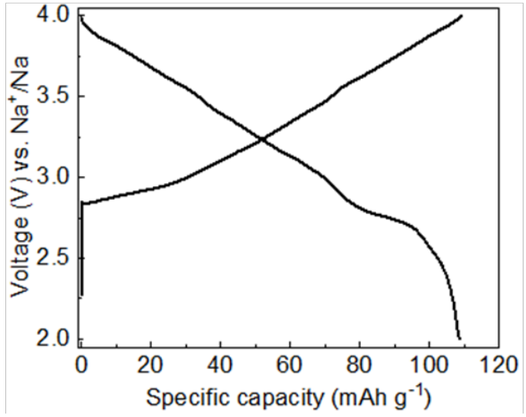
Next generation cathode materials

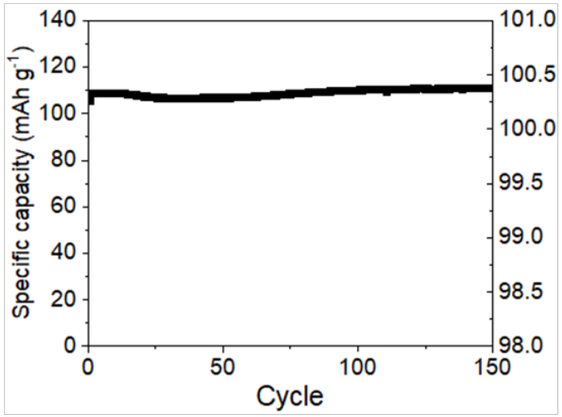
30% Ni





20% Ni





Sustainability

- Next-generation cathode materials with less critical materials are under developing. One material with ~30% Ni demonstrated a specific capacity of 125 mAh/g and > 80% retention over 1000 cycles.

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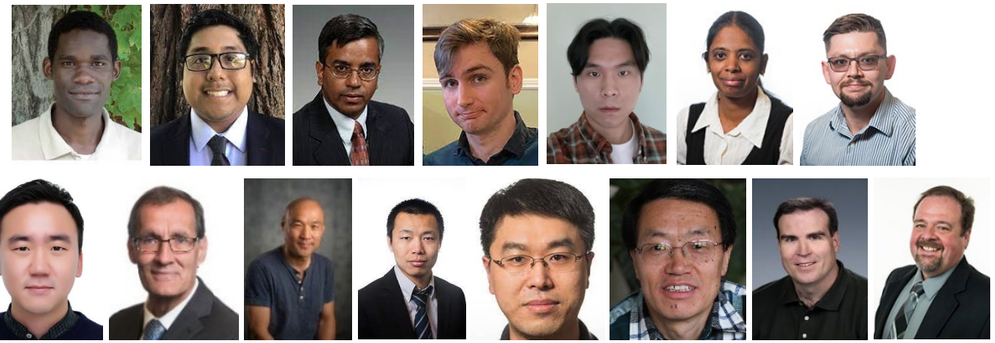

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