High Performance Na-ion Batteries

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Energy Storage Program

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Project Overview

Project Objective

- To develop low cost Na-ion batteries with comparable performance to Li-ion batteries (LIBs) and to utilize the existing facilities/capabilities for LIB manufacturing.

Accomplishments in FY18

- Research highlights
  - Developed advanced anodes (Sb@C microspheres ➡ Bi ➡ SnS) with a specific capacity of ~350 mAh/g and >80% retention over 200 cycles.
  - Developed high performance Na-ion battery cathodes. The O3 type layered metal oxide cathode can deliver ~150 mAh/g specific capacity between 2-4V and ~195 mAh/g between 2-4.2V. Excellent cycling stability with >90% retention over 1000 cycles between 2-4V was demonstrated.
- Publications: 2 papers published and 2 papers under review.
  - B.W. Xiao, et al. *Adv. Energy Mater.* 2018, 8, 1801441
  - J. Song, et al. *Adv. Energy Mater.* 2018, 8, 8, 1703082.
- Professional activities put DOE at the leading position in Na-ion battery research
  - The special issue organized on Na-ion batteries for Advanced Energy Materials was published https://onlinelibrary.wiley.com/toc/16146840/2018/8/17
  - Organized Nature Conference on Materials and Electrochemistry: Fundamentals and Applications and chaired the Na-ion battery session.

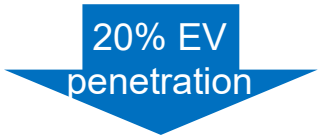
Why do we need Na-ion batteries

Dramatic increase in the consumption of Li compared to the limited reservation/production casts big concern on the price escalation of Li-ion batteries

Lithium consumption at ~90kWh battery

- Li -> $Li^+ + e^-$ (3860 mAh/g^{-1})
- 1 kWh = 270,000 mAh ≈ 70 g of Li
- 90 kWh ≈ **6.3 kg of Li**

- ~80 million auto sale in 2017



- 100.8k tons of Li will be needed

Lithium

Production of 2017: 43k tons

- ~50% of current production used in batteries
- Lithium price: ~2x increase since 2014

Reserves of 2017: 16 million tons

Sodium

6th most abundant element in earth crust

Reserves of 2017: 25 billion tons

Production of 2017: 54 million ton

- ~1000x annual Li carbonate production
- ~100x cheaper than Li carbonate

Na-ion battery, with comparable energy and cycle life to Li-ion battery and lower cost, is the best alternative to Li-ion battery at deep penetration of renewable energy storage

1. https://news.ihsmarkit.com/press-release/global-auto-sales-set-reach-935-million-2017-risk-greater-ever-ihs-markit-says
2. https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust
3. https://www.metalary.com/lithium-price/
4. https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2018-lithi.pdf
5. https://minerals.usgs.gov/minerals/pubs/mcs/2018/mcs2018.pdf

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Where do we need Na-ion batteries for

1. Stationary energy storage
Backup power etc

2. Low/medium speed vehicles
Electric bicycle/motorcycle, personal transportation etc

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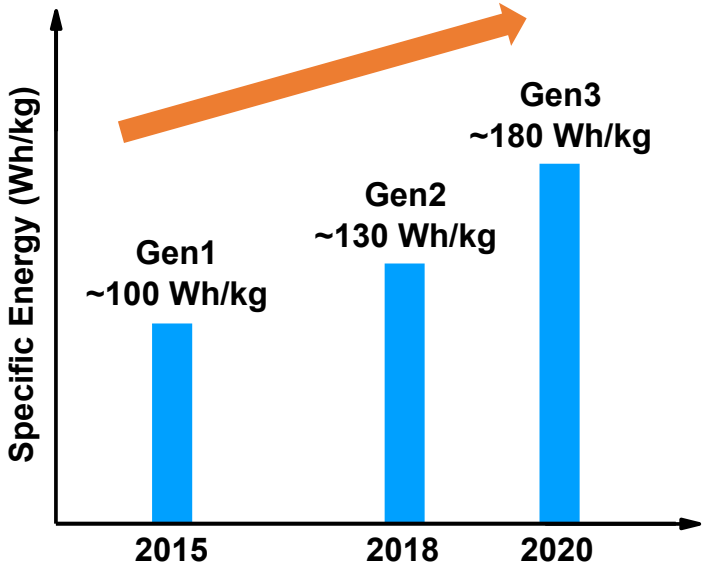
PNNL strategy and roadmap

Goal:
Comparable energy and cycle life to the range of Li-ion batteries with ~30% lower cost

Strategy

Na-ion battery development roadmap



Gen2 technology:

- High energy layered cathode: 1.5 times of the capacity of gen 1 cathode
- Hard carbon anode: >50% improvement of the capacity at high rate using advanced electrolyte

D. Larcher, J. M. Tarascon, Nature Chemistry 2015, 7, 19

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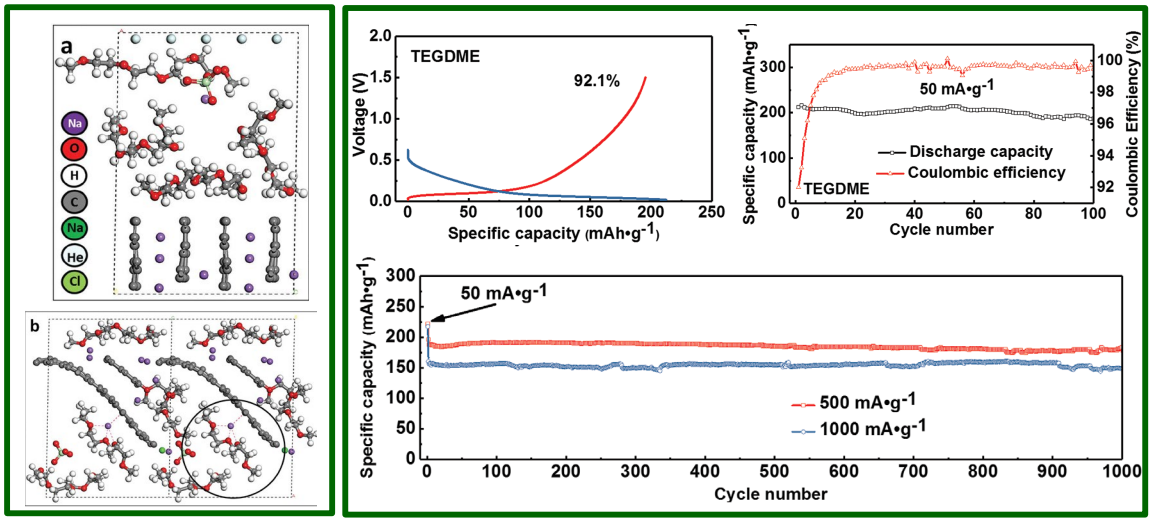
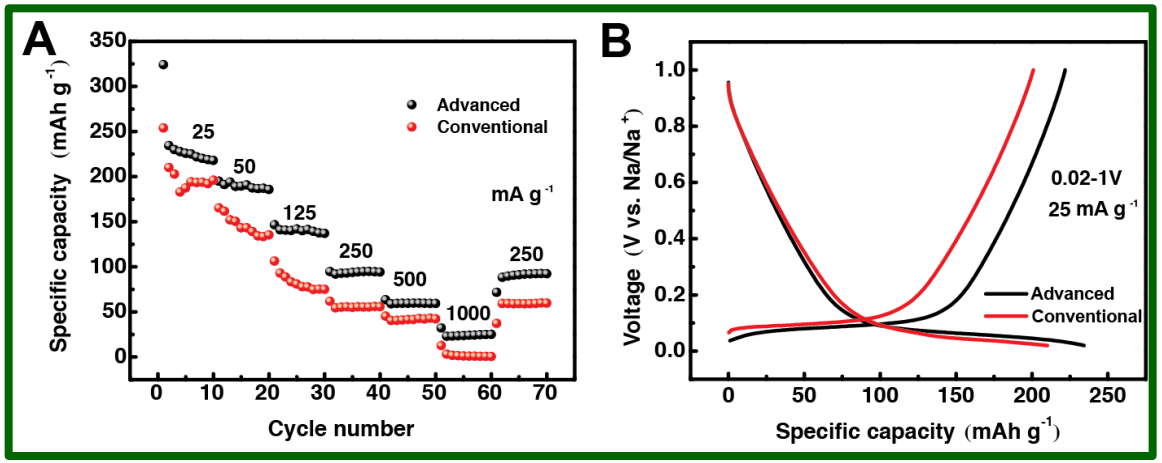
Gen2 hard carbon anode

TEGDME electrolyte



High voltage electrolyte



Advanced electrolyte enables >50% improvement of the capacity of hard carbon anode at high rate

B.W. Xiao, et al. Adv. Energy Mater. 2018, 8, 1801441
J. Song, et al. under preparation.

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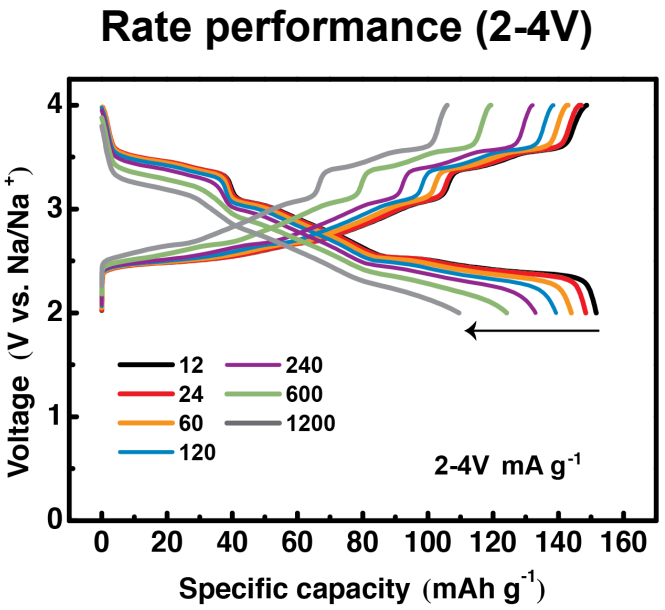
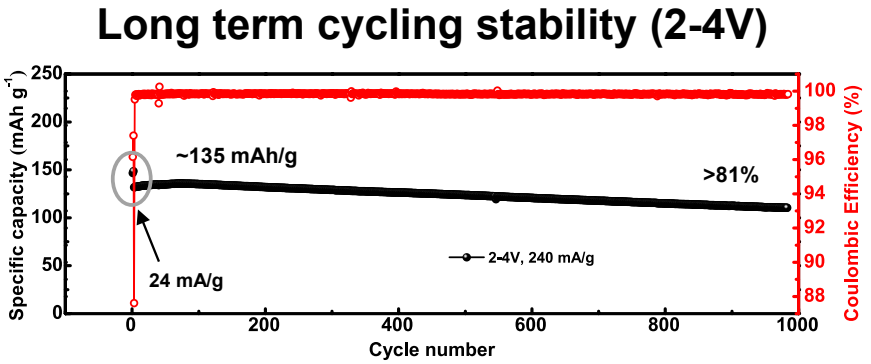
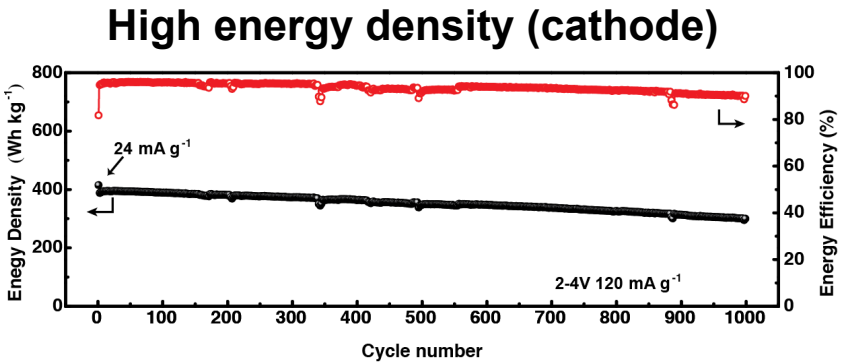
Gen2 cathode material







The new cathode material delivers high specific capacity, good rate performance and good cycling stability between 2-4V

- ~81% capacity retention over 1000 cycles at 240 mA/g current density.
- The specific capacity is 1.5 times of the Gen1 cathode.

J. Song, et al. under preparation.

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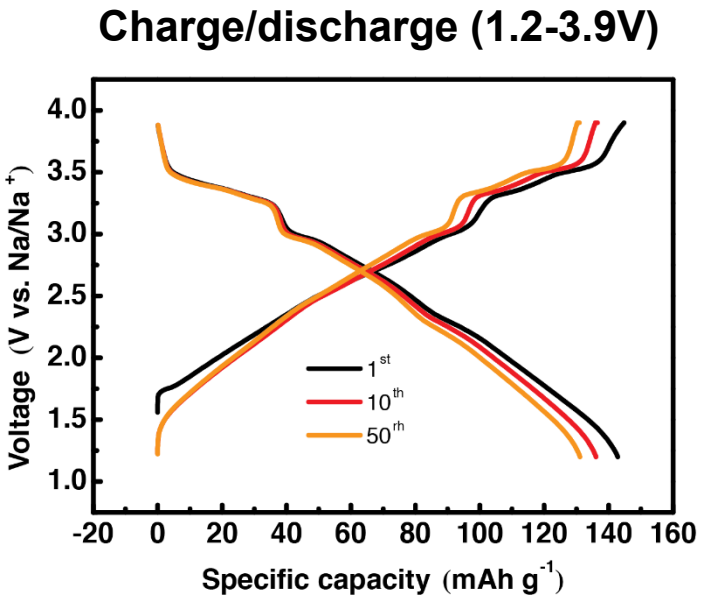
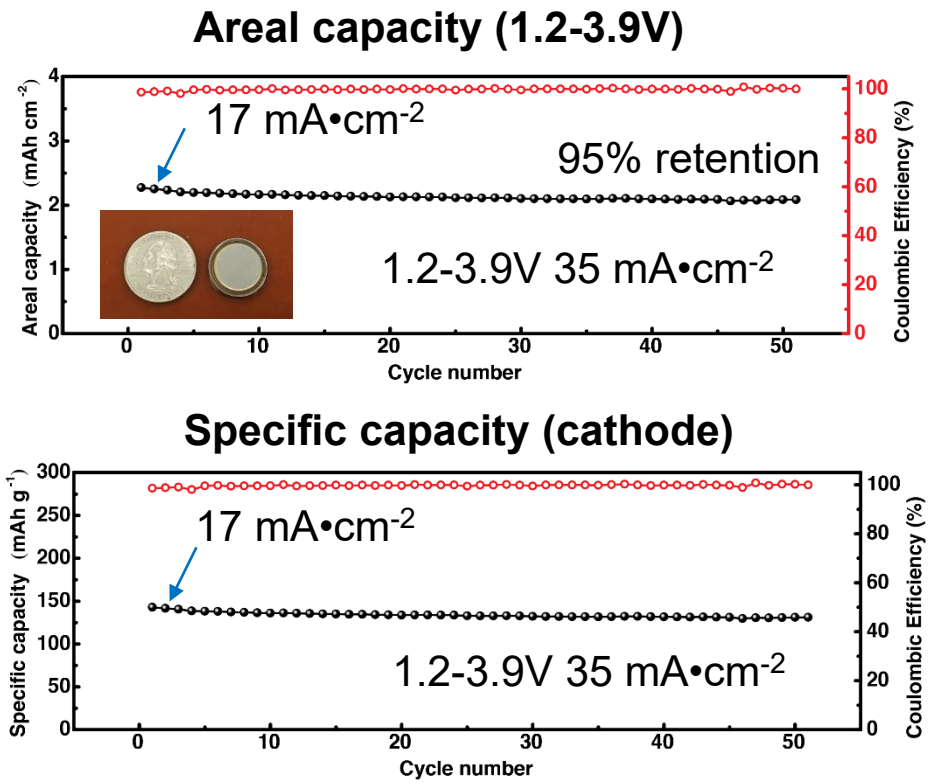
Gen2 coin cell full cell demonstration





- The coin cell full cell between 1.2-3.9V delivers good cycling stability even at ~2 mAh/cm^2 loading.
- The capacity retention is ~95% over 50 cycles.

J. Song, et al. under preparation.

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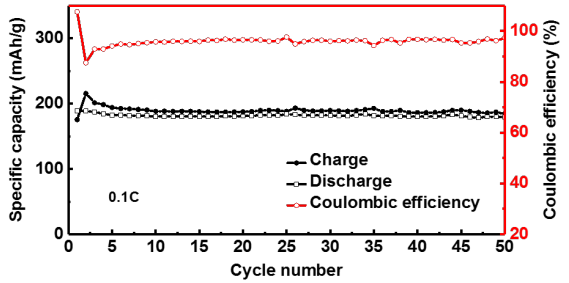
Efforts towards Gen3 technology

Gen3 Cathode material:

P2-Type $Na_{0.66}Mn_{0.75}Ni_{0.25}O_2$

- Lower cost by avoiding the use of Co and reducing of the Ni content
- High specific capacity of ~190 mAh/g between 1.5-4.4V
- >95% retention over 50 cycles

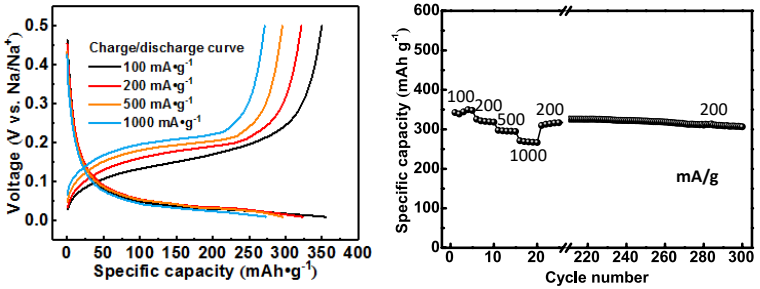


➢ See details in Dr. Biwei Xiao's poster

Gen3 anode material:

SnS anode

- Potentially low cost with the high abundance and large annual productions of Sn and S.
- Low voltage potential and high specific capacity of ~350 mAh•g^{-1} between 0.01 and 0.5V.
- The capacity retention @300 cycles is 94%.

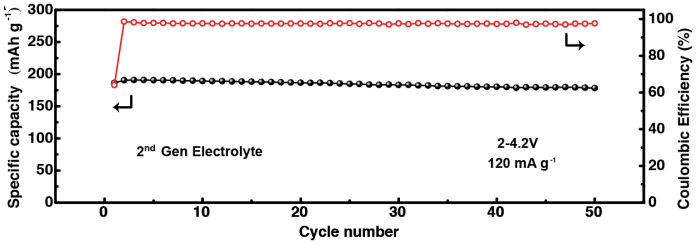


J. Song, et al. under preparation.

Gen3 advanced electrolyte development

2nd generation high voltage electrolyte

- Stable up to 4.5V with the new cathode material



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Summary

- Advanced electrolyte enables >50% improvement of the capacity of the Gen2 hard carbon anode at high rates.
- Developed high performance Gen2 Na-ion battery cathodes. The O3 type layered metal oxide cathode delivers ~150 mAh/g specific capacity between 2-4V and ~195 mAh/g between 2-4.2V. Excellent cycling stability with >90% retention over 1000 cycles between 2-4V was demonstrated.
- Demonstrated good performance of the Gen2 technology in coin cell full cell. The capacity retention is ~95% over 50 cycles at the electrode loading of ~2 mAh/cm^2.
- Developed Gen3 advanced anodes with a specific capacity of >350 mAh/g and >80% retention over 200 cycles.
- Developed Gen3 cathode. The P2 cathode has lower cost than Gen2 cathode while delivering high specific capacity of ~190 mAh/g between 1.5-4.4V.

FY19 proposed work

- Gen2 material scale up and performance validation in pouch cells
- Gen3 coin cell full cell demonstration using the high performance cathode and anode.

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- PNNL Contributors

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- External Collaborators

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  - Prof. Donghai Wang at Penn State University
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  - Dr. Guiliang Xu at Argonne National Laboratory
  - Prof. Meng Gu at Southern University of Science and Technology
  - Prof. Pengfei Yan at Beijing University of Technology

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