



2025 OE Peer Review Meeting
Session 7: Na Batteries
McLean, VA

Intermediate Temperature Sodium-Metal Halide Battery Technologies for Grid Energy Storage Applications

Guosheng Li, Ph.D.

Battery Materials & Systems Group
Pacific Northwest National Laboratory



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



Project Overview

- **Project Goal:** Developing low-cost, safe, and long cycle life molten sodium-based battery technologies.
- **Current Practice:** Development of cathode materials utilizing abundant resources (Na, Fe, and Al) and well-established domestic supply chains, alongside innovative redox chemistry and materials aimed at reducing battery cell manufacturing and operating costs.
- **Why <PNNL>:** PNNL excels in molten sodium battery advancement through innovative research (IPs and publications), cutting-edge facilities, industry collaborations, and transitioning lab innovations to scalable, cost-effective energy storage solutions.
- **Innovation:** Introducing cost-effective cathode materials, leveraging abundant resources and lowering operational temperatures.
- **Impact:** Battery manufactures and utilities. Safe and low-cost energy storages for various grid applications.
- **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.

Intermediate Temperature Na-Metal Halide Battery

- **Project Team:**

Han Henry, Mark Weller, and Guosheng Li

- **Objective:**

- (1) Developing a novel low-cost surface treatment method to enhance Na wettability and reduce interface issues at lower operating temperatures.
- (2) Developing cathode additives to significantly reduce Na cathode activation.

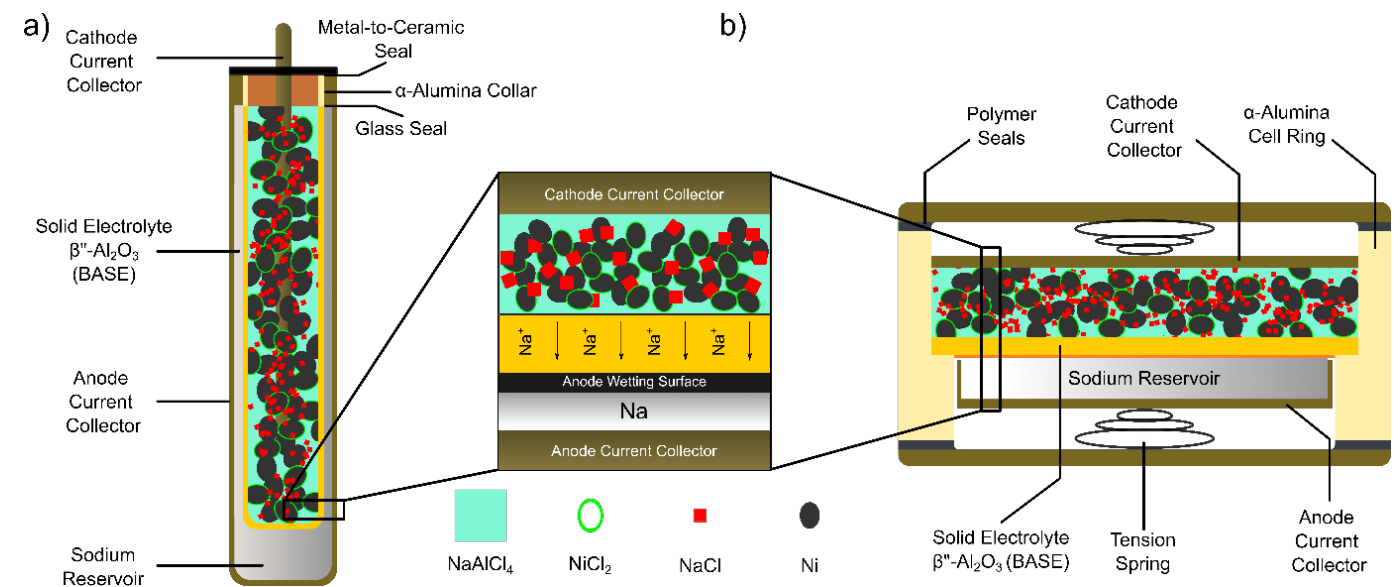
FY25	Milestones and Technical Achievements
Journal Publications	Polikarpov, et al. <i>ACS Appl. Energy Mater.</i> (accepted) Han, et al. <i>Battery Energy</i> (in preparation)
Invited Presentations	247 th ECS meeting; ICNaB 2024; Sodium-ion Battery Conference
IDR/Patent Applications	Carbon based surface treatment on substrates to improve wettability (<i>U.S. Non provisional patent application</i>)

Molten Na Battery Technologies

Batteries	Temp.(°C)	OCV(V)	Duration (hours)	SSE	Cycle life	Safety	Cost (\$/kWh)
Na-Ni	260	2.58	4-6	β'' -alumina	>1,000	No thermal runaway	500-1,000

- Advantages:

- No dendrite formation (molten Na anode)
- No thermal runaway
- No need of HVAC due to the elevated operating temperature
- Assemble/shipping at discharge state
- High specific capacity (~100 Wh/kg)
- Long cycling and calendar life (>10 years)



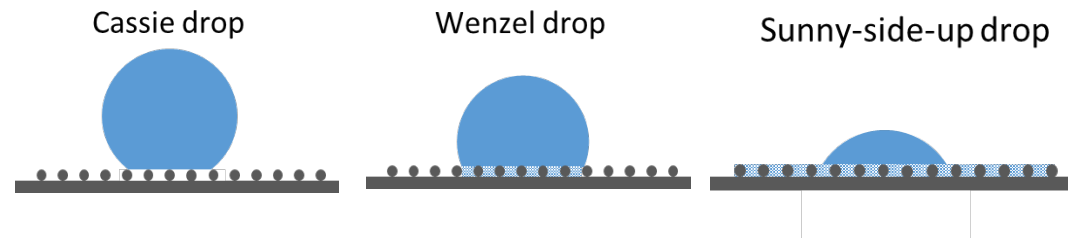
Weller et al. (in preparation)

#1: Low Operating Temperature (<200 °C)

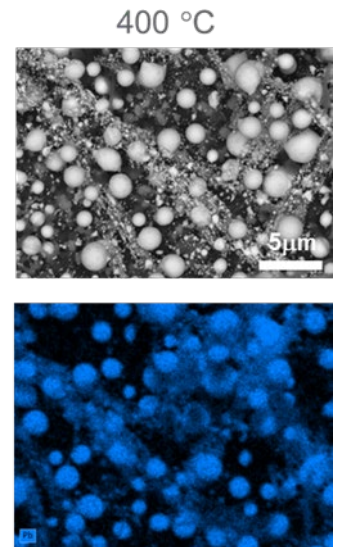
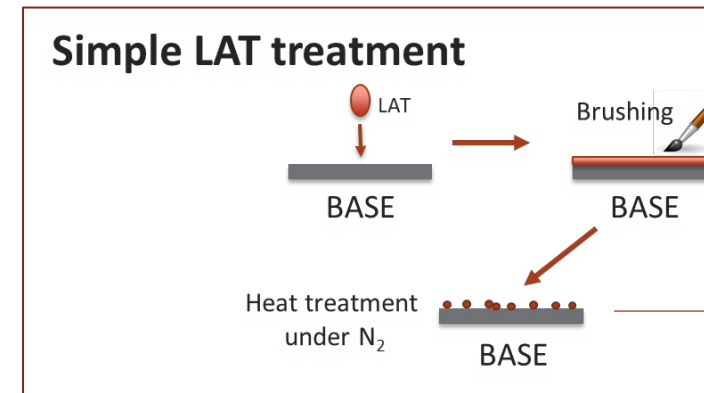
#2: Low-Cost Cathode

#1: Na Wetting on BASE Substrates

Na wetting on rough surface

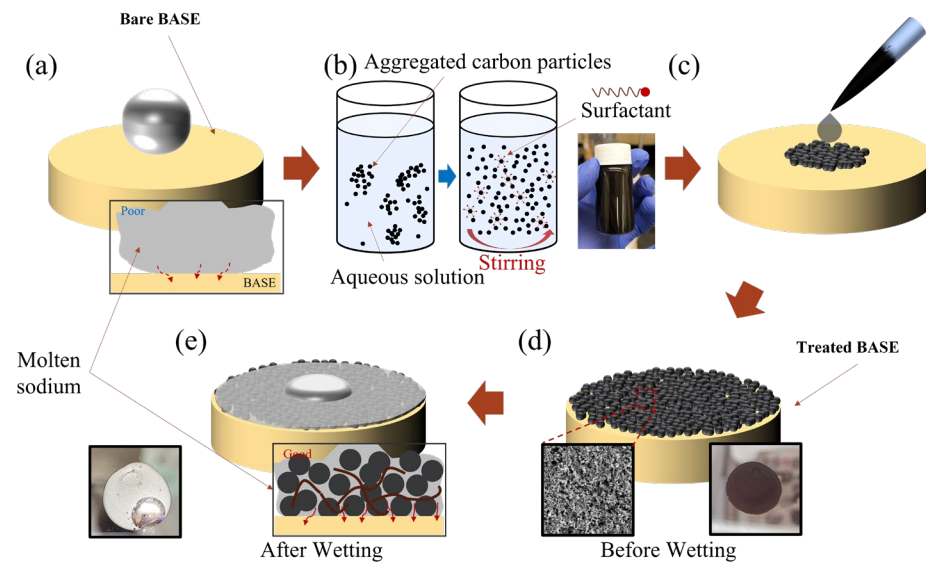


Gen 1 (metal based)



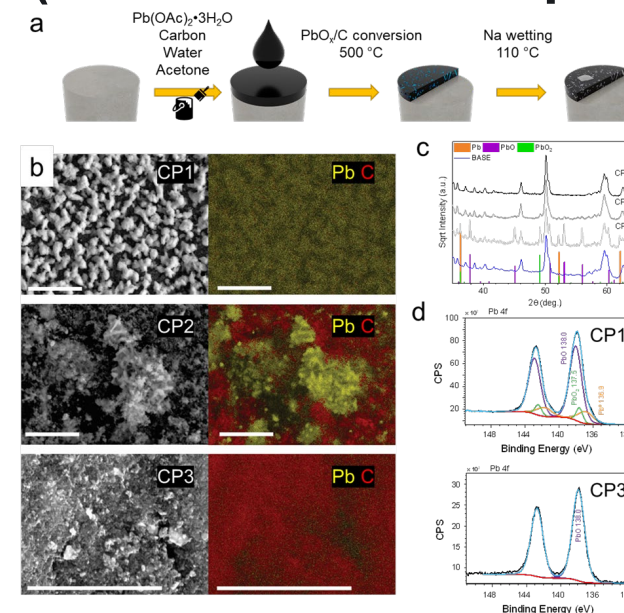
J. Mater. Chem. (2018)
Chem. Comm. (2021)

Gen 3 (metal free carbon layer)



Nano Energy (2024)

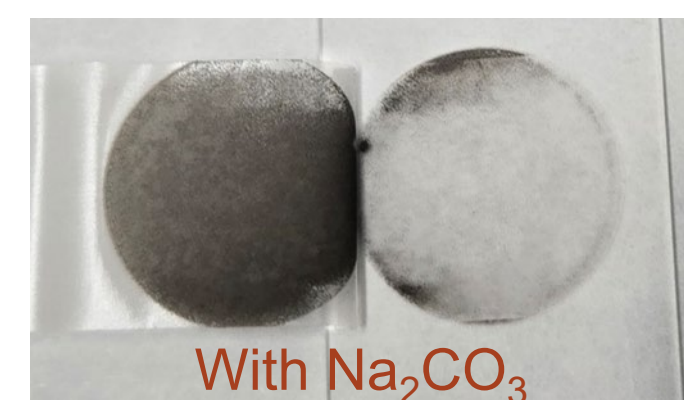
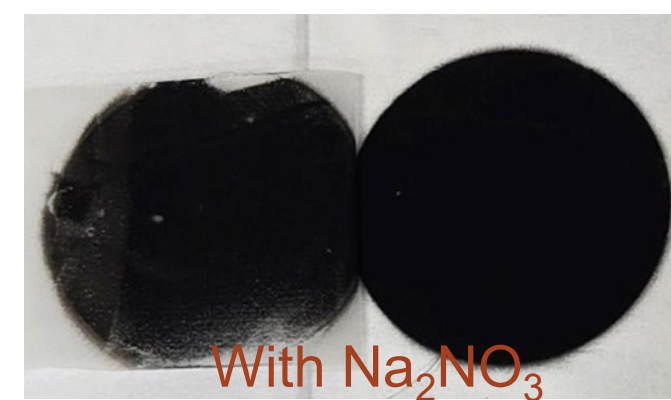
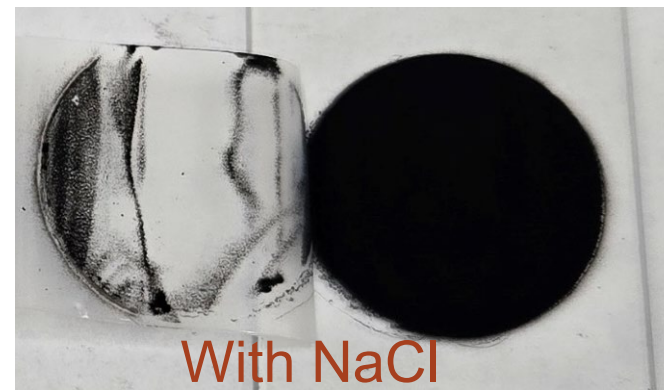
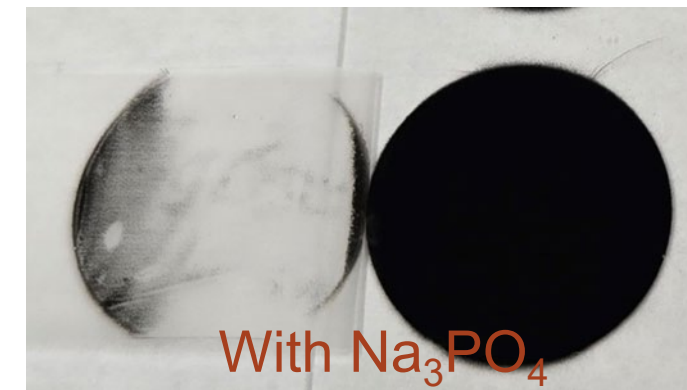
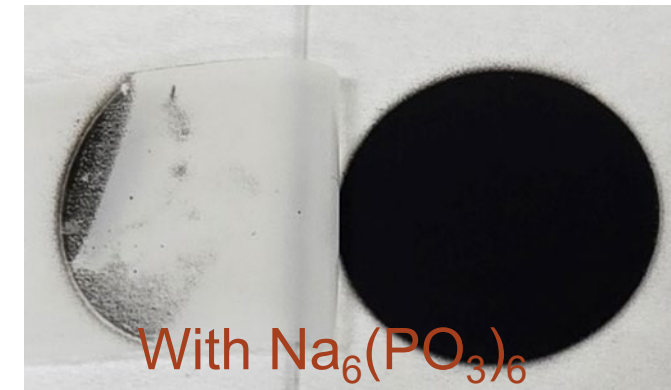
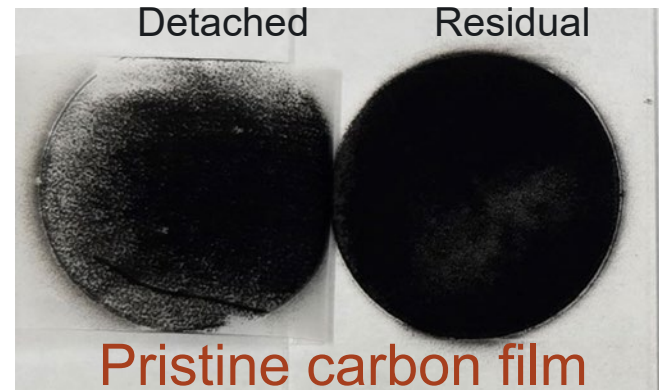
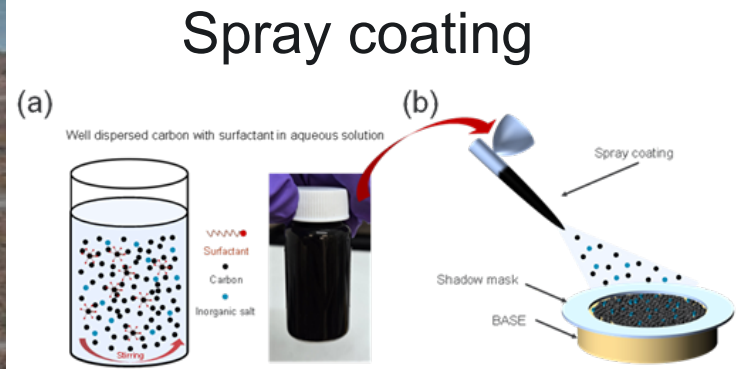
Gen 2 (carbon/metal composite)



ACS Appl. Mater. & Inter.
(2022)

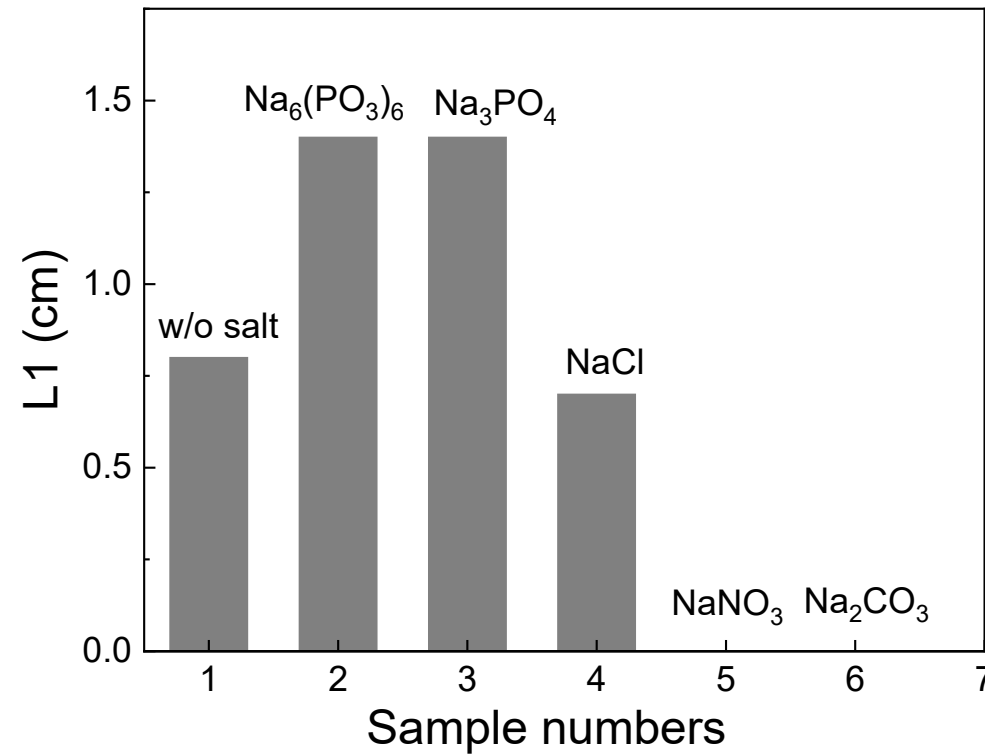
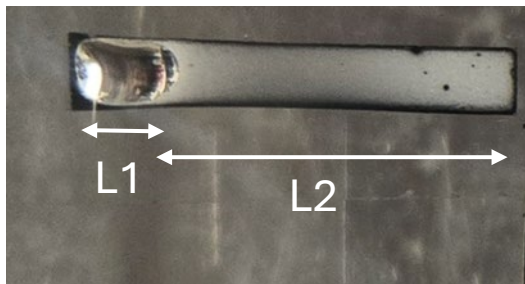
Gen 4: Carbon Coating with Salts

Peel test

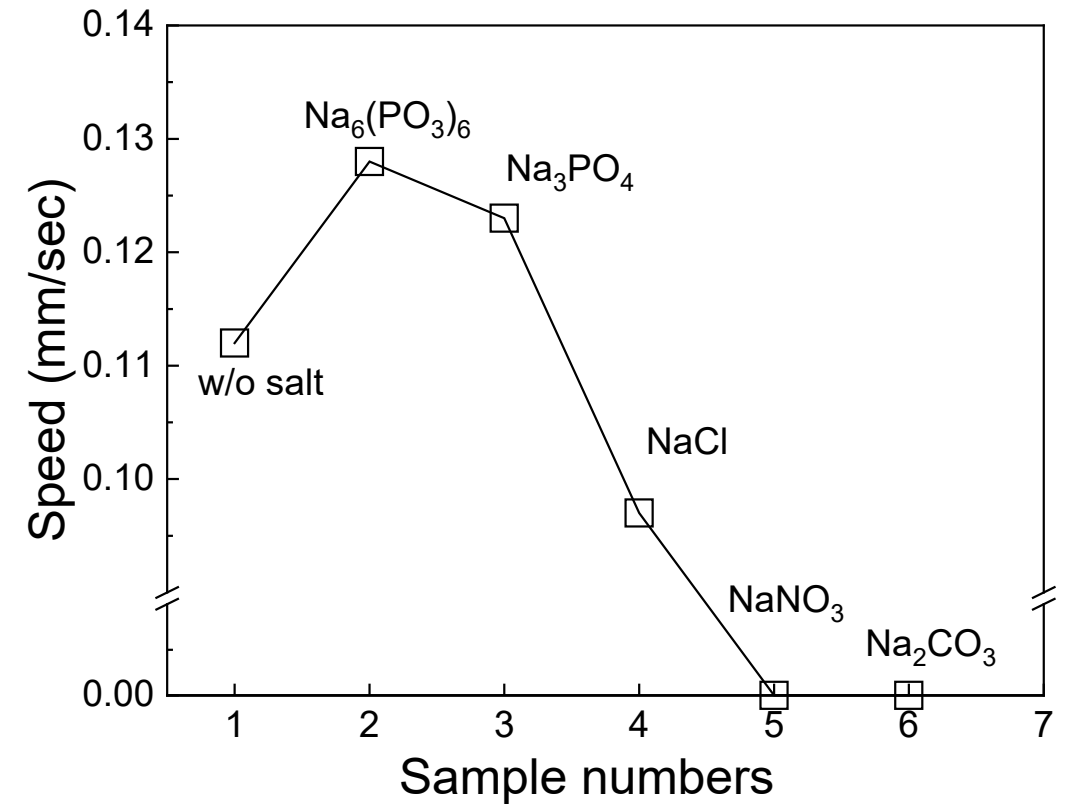


$\text{Na}_6(\text{PO}_3)_6$, Na_3PO_4 , NaCl > No salt > NaNO_3 > Na_2CO_3

Superior Na Wetting for $\text{Na}_6(\text{PO}_3)_6$ as an Inorganic Binder



Na spreading speed = $L2 / t$



More details can be found in the poster presentation...

#1: Low Operating Temperature (<200 °C)

#2: Low-Cost Cathode

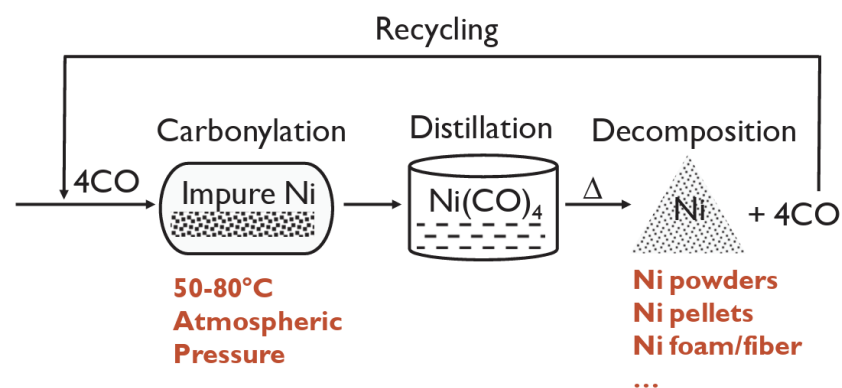
#2: Low-cost Fe/Ni Alloy Cathode

Ni cathode: $2\text{NaCl} + \text{Ni} \rightleftharpoons 2\text{Na} + \text{NiCl}_2$

Fe cathode: $8\text{NaCl} + 4\text{Fe} \rightleftharpoons \text{Na}_6\text{FeCl}_8 + 2\text{Na} + 3\text{Fe} \rightleftharpoons 4\text{FeCl}_2 + 8\text{Na}$

Commercial Cathode

- Lower cost (70% Ni / 30% Fe)
- Better kinetics vs 100% Ni



Carbonyl Ni powder

Carbonyl Fe powder

Ni/Fe cathode

?

Byproduct

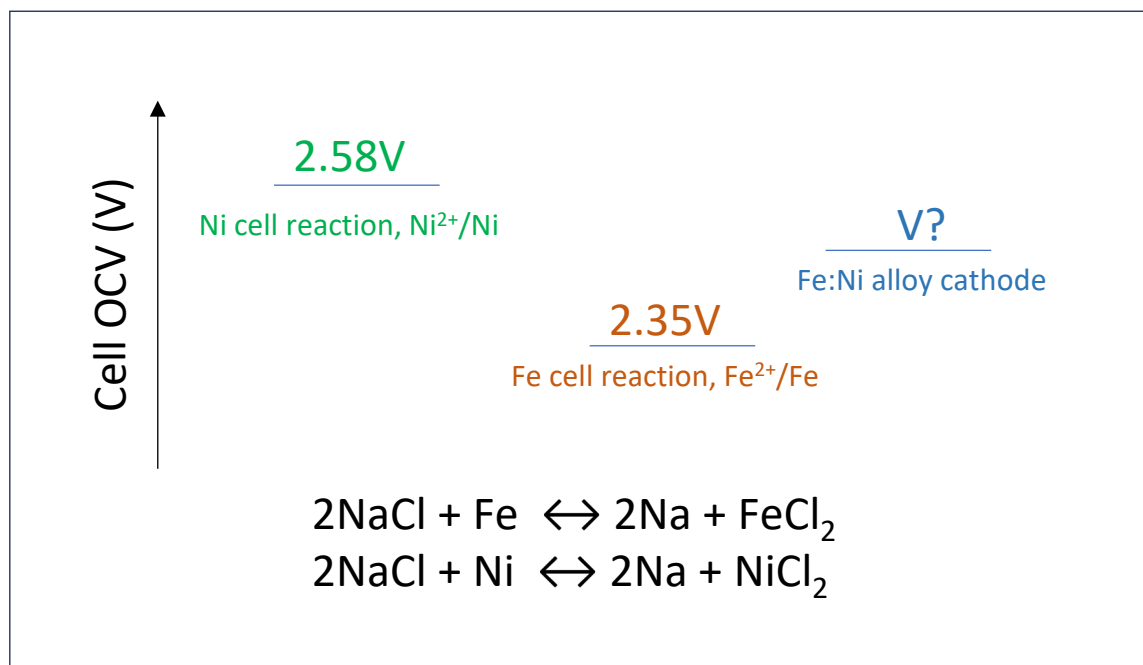
Lower cost



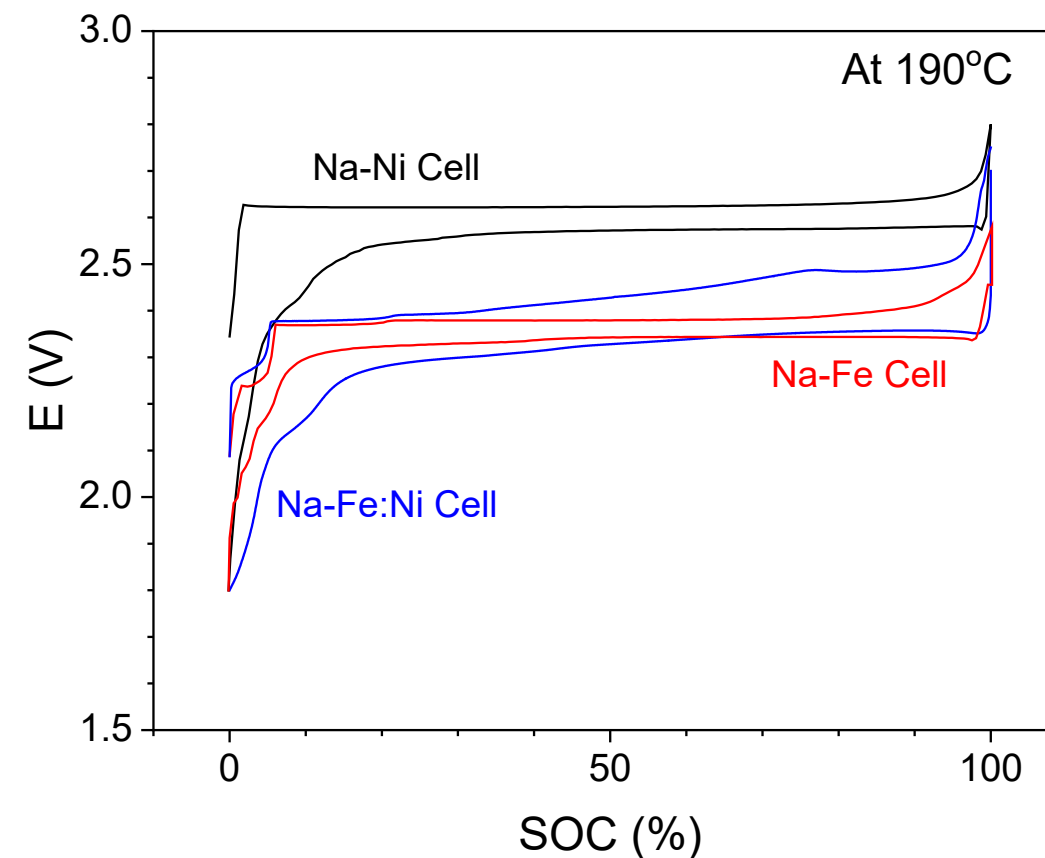
Steel Plant

Fe/Ni Alloy (Invar) as Model Cathode

Invar: Fe/Ni = 64:36 atomic%, -325 mesh (~45 um)

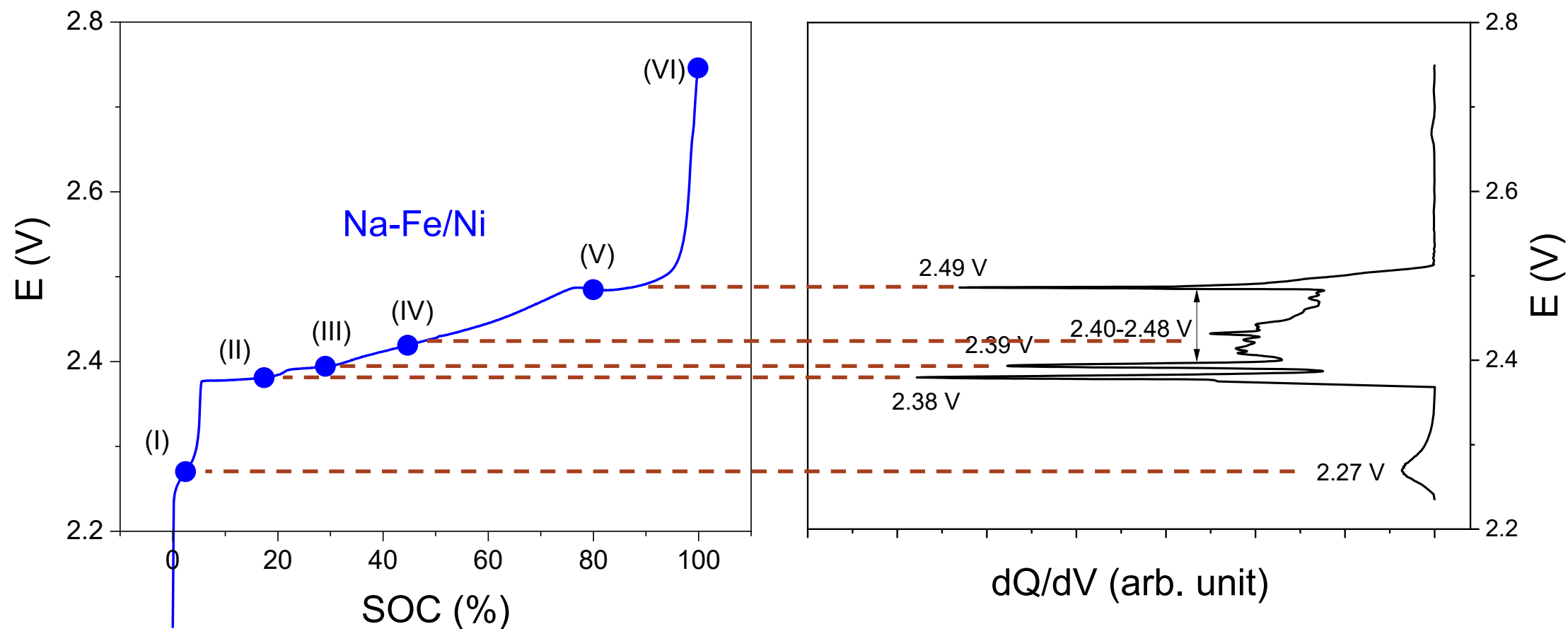


1. Voltage
2. Reaction mechanism



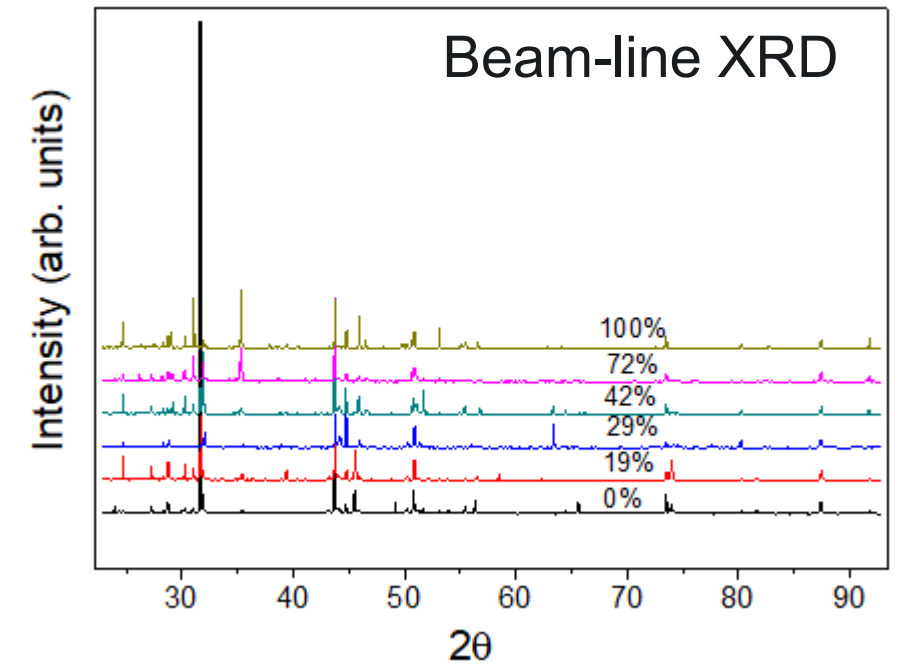
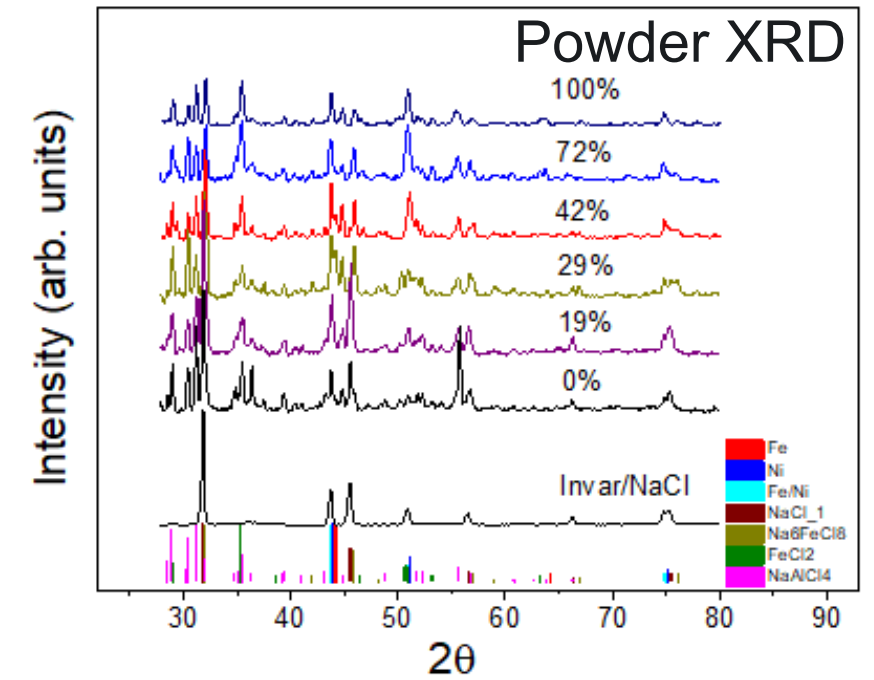
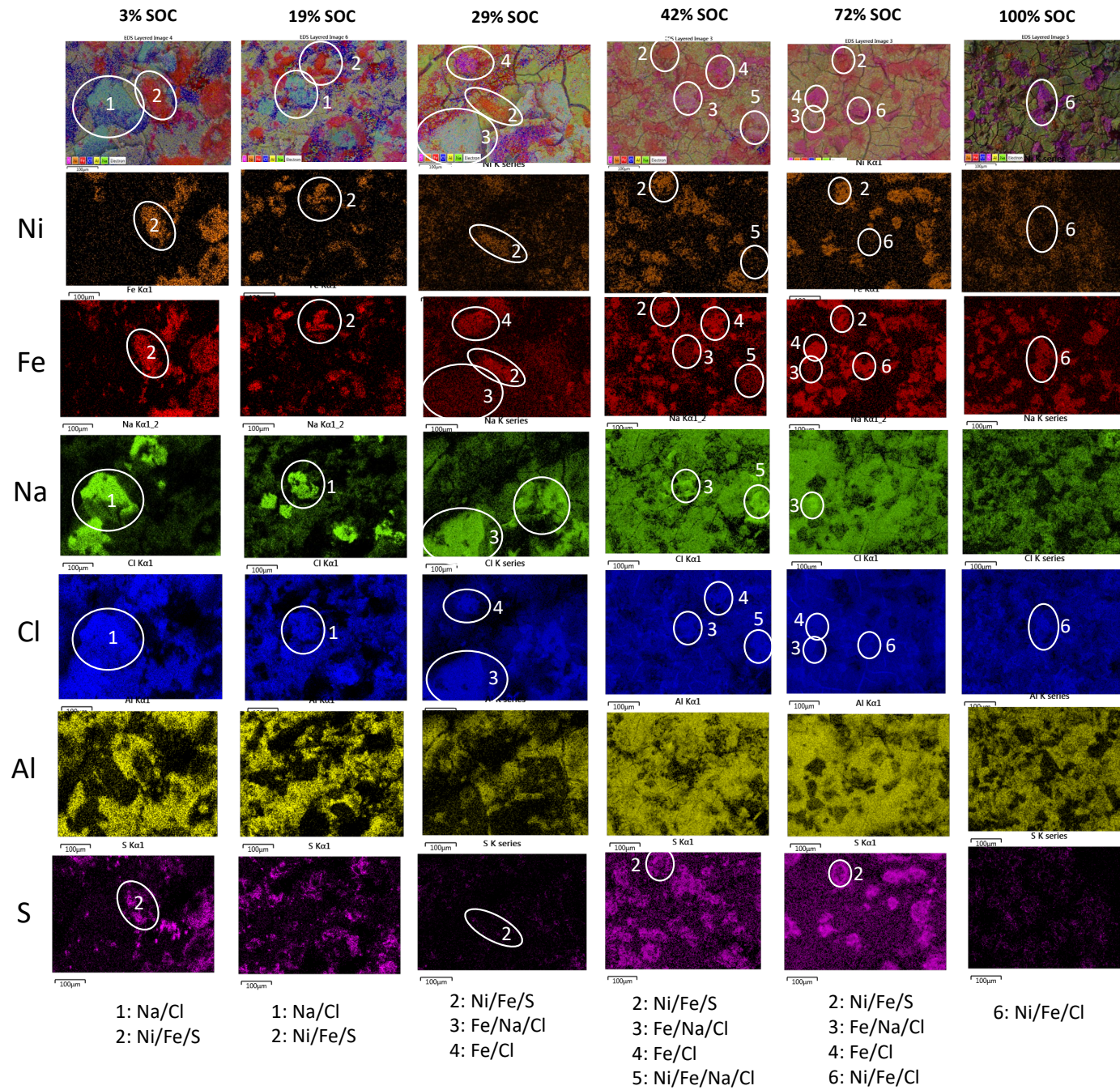
- The voltage is comparable to that of the Fe cathode
- Differs significantly in specific details

dQ/dV for the Charge Voltage of Invar Cathode

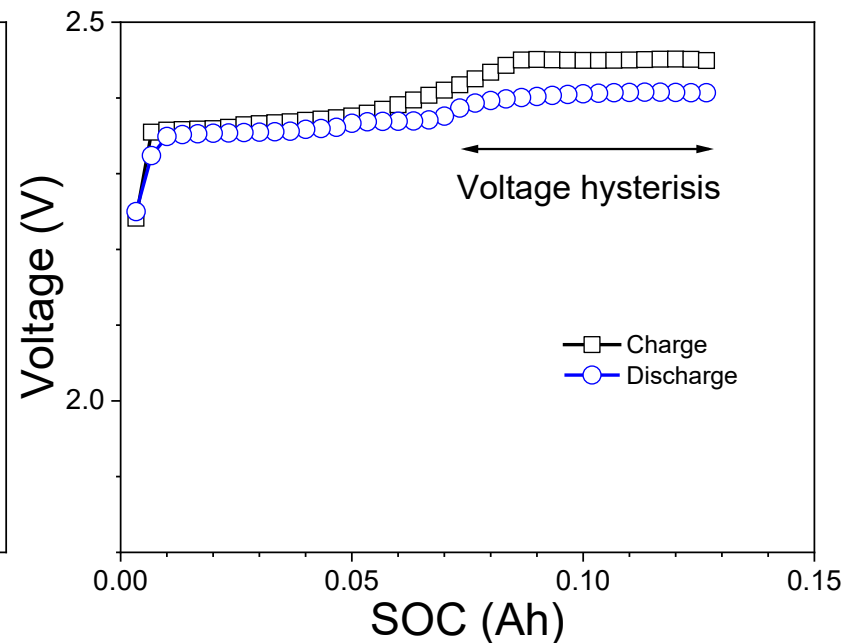
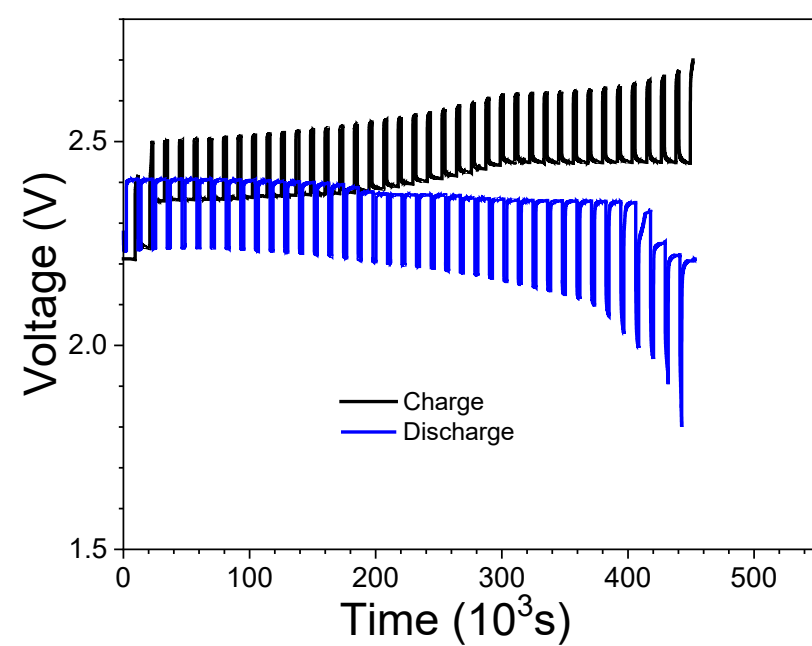
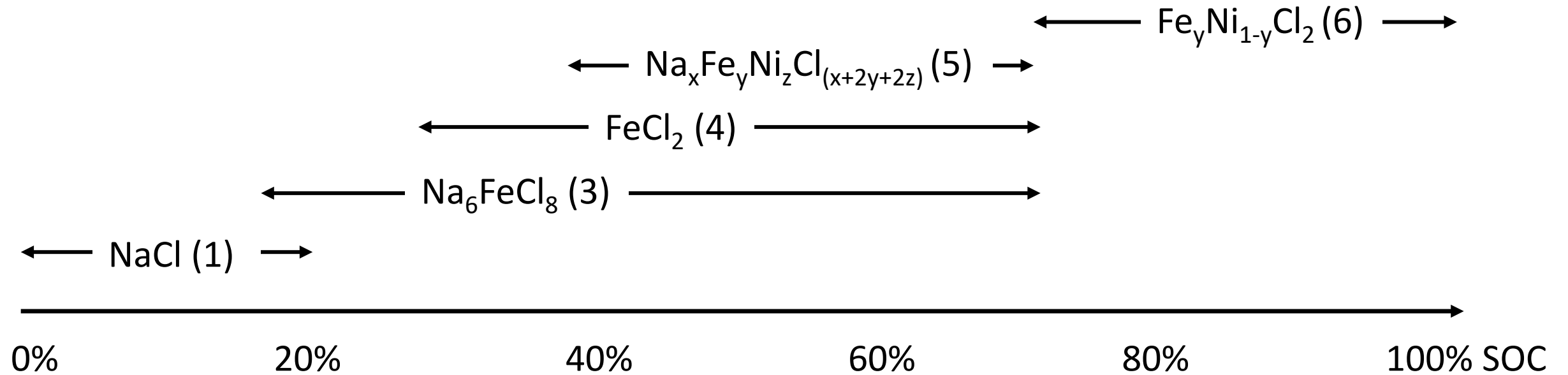


- I (2.27 V) : Sulfur based redox
- II and III (2.38 & 2.39 V): Na_6FeCl_8 & FeCl_2
- IV and V (2.40-2.48V & 2.49 V): Possible contributions from both Fe and Ni

SEM & XRD Measurements



Reaction Mechanisms



1. Significant difference between Fe/Ni cathode vs Fe or Ni cathode
2. Complicated hybrid phases
3. Voltage hysteresis toward higher SOC.

Summary and Future Works

- Molten sodium batteries present a promising solution owing to their abundant materials, exceptional safety, high energy density, and extended cycle life.
- Advancing technology for lower-temperature operation, including Na wetting and battery design.
- Developing cost-effective cathode materials like Fe and Al.
- Fostering collaborations with industry.



Acknowledgement

Pacific Northwest National Laboratory is a multiprogram national laboratory operated by Battelle Memorial Institute for the DOE under Contract DE-AC05-76RL01830

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division.

Thank You !

POC: Guosheng Li, Ph.D.
Email: guosheng.li@pnnl.gov