2026 OE Peer Review Meeting
Session 7: Na Batteries
Dallas, TX

Sodium-Metal Halide Battery Technologies for Grid Energy Storage Applications (#703)

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Project Overview

- **Goal:** Developing low-cost, safe, and long cycle life molten sodium-based battery technologies.
- **Current Practice:** Development of a sodium battery that leverages abundant resources (Na, Fe, and Al) and well-established domestic supply chains, together with innovative redox chemistry and materials to reduce cell manufacturing and operating costs.
- **Why <PNNL>:** PNNL excels in advancing molten sodium batteries through innovative research (IP and publications), state-of-the-art facilities, industry collaborations, and the transition of laboratory innovations into scalable, cost-effective energy storage solutions.
- **Innovation:** Introducing cost-effective cathode materials, leveraging abundant resources and lowering operational temperatures.
- **Duration:** FY25-FY26, Al cathode development and carbon-based Na wetting agent.

Project Overview (Continue)

- **Impact:** Battery manufactures and utilities. If successful, bring safe and low-cost energy storages for various grid applications.
- **Vertical/Investment Area:**
  - ✓ Materials and Systems Innovation
- **Alignment/Supports strategic pathway:** 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.

Na-Metal Halide Battery Project

- **Project Team:**

  Mark Weller (Al cathode), Henry Han (Al cathode and Na wetting), Eugene Polikarpov (Ceramic processing), and Guosheng Li

- **Objective:**

  (1) Developing cathode additives to significantly improve Al cathode activation.

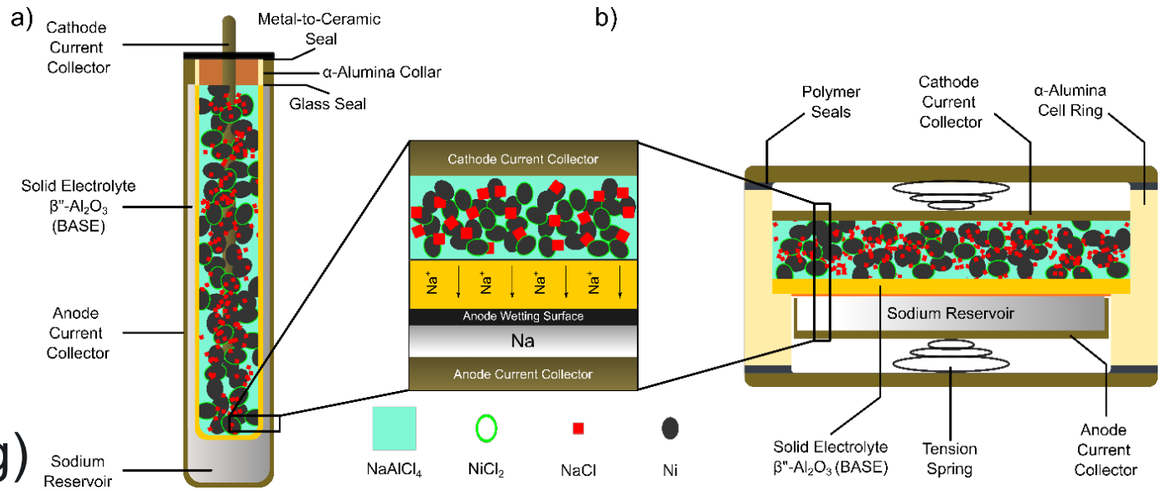
  (2) Developing a novel low-cost surface treatment method to enhance Na wettability and reduce interface issues at lower operating temperatures.

FY26	Milestones and Technical Achievements
Journal Publications	"Designing carbon wetting layers with inorganic salts as additives for enhanced adhesion and molten sodium wettability in electrochemical application" *Frontiers in Batteries and Electrochemistry* 5, 1759353 (2026)
Presentations	2026 ECS Spring meeting
IP	Provisional patent application under preparation

Molten Na Battery Technologies

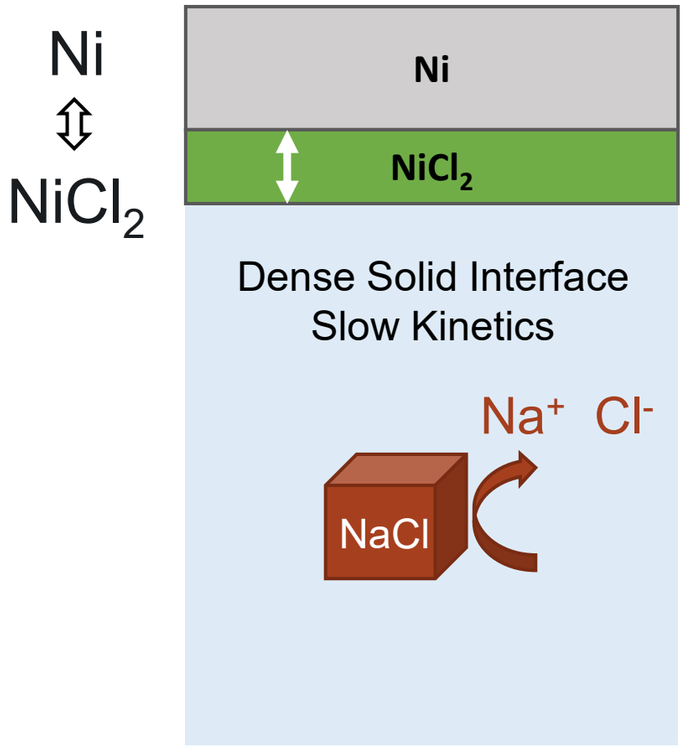
Batteries	Temp.(°C)	OCV(V)	Duration (hours)	SSE	Cycle life	Safety	Cost ($/kWh)
Na-MCl_x (M=Ni)	260	2.58	4-6	β″-alumina	>10 years	No thermal runaway	500-1,000

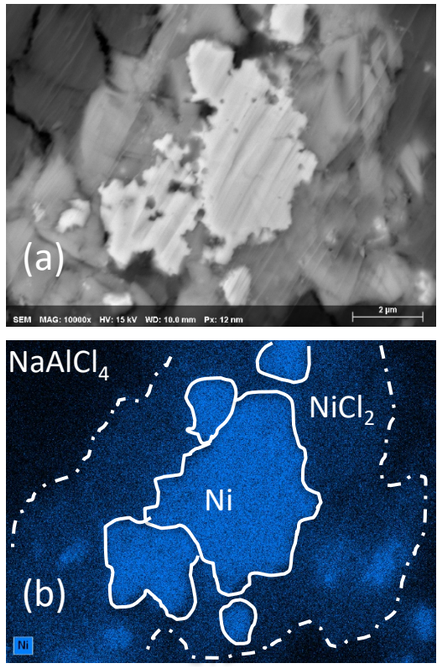
- Advantages:
  - No dendrite formation (liquid Na anode)
  - No thermal runaway (no organic or oxygen sources)
  - No need of HVAC (elevated operating temperature)
  - Assemble/shipping at discharge state
  - High specific module capacity (~100 Wh/kg)
  - Long cycling and calendar life (>10 years)



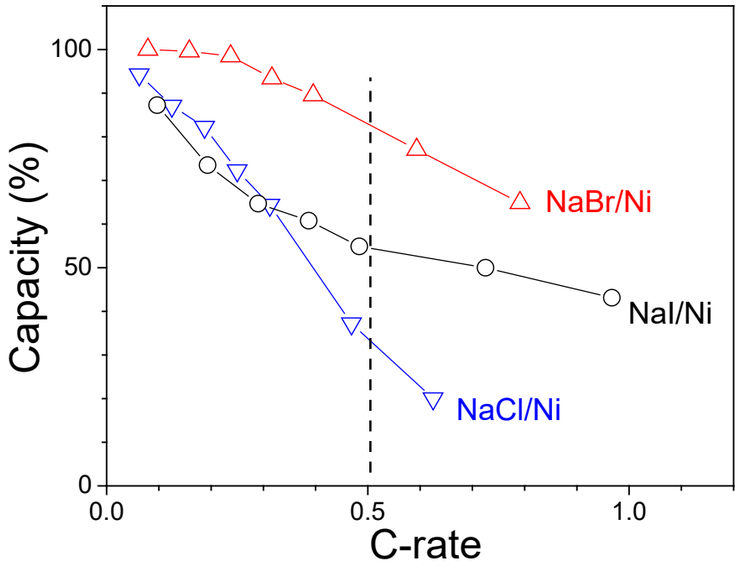
Technical Challenges Na-$NiCl_2$ Batteries

Na-$NiCl_2$: $2Na + NiCl_2 \Leftrightarrow 2NaCl + Ni$





Energy Storage Mater. 24, 177 (2020).



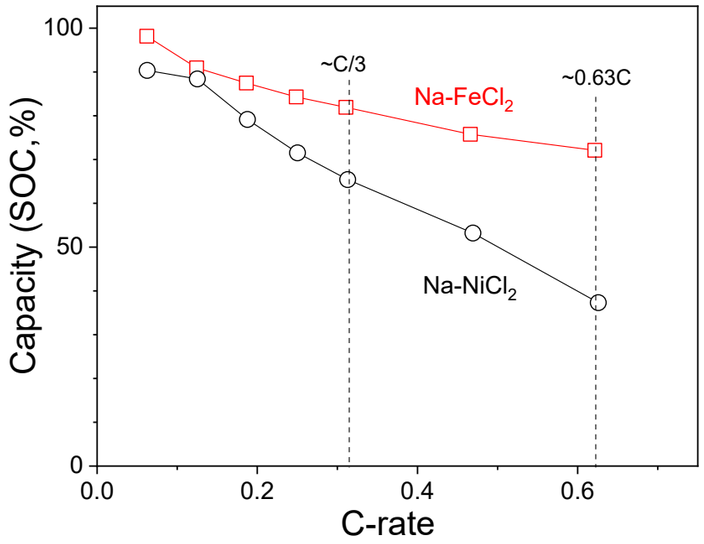
NaBr/Ni cathode shows faster kinetics via Mixed halide reaction mechanism

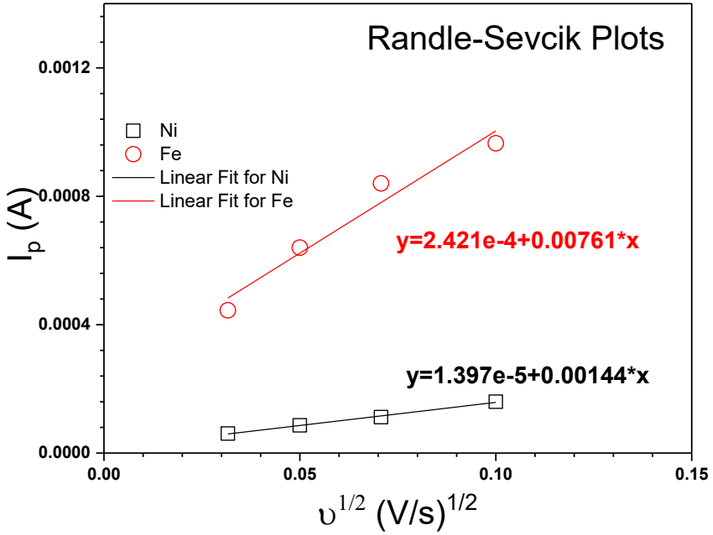
Li et al. *Nat. Commun.* 7, 10683 (2016). Zhan et al. *Energy Storage Mater.* 24, 177 (2020)

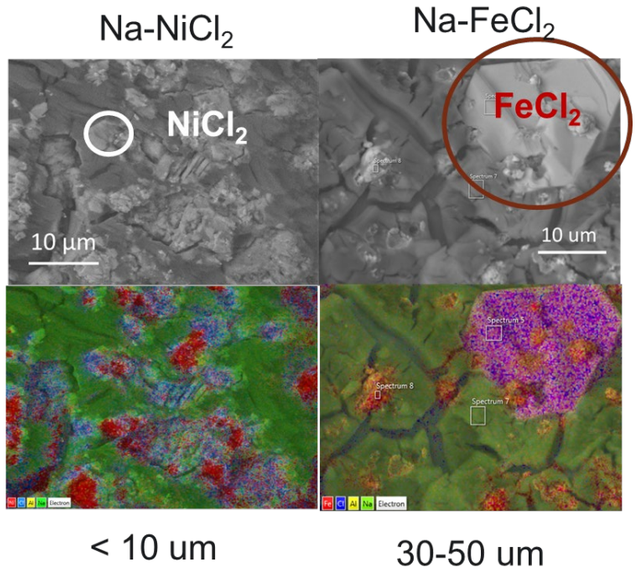
Replacing Ni with Fe Cathode

$8NaCl + Fe \text{ (discharge)} \Leftrightarrow 2Na + Na_6FeCl_8$ (25% capacity)

$Na_6FeCl_8 + 3Fe \Leftrightarrow 6Na + 4FeCl_2$ (75% capacity)







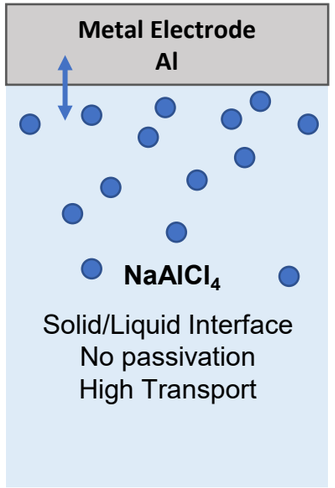
- Fast kinetics for $Na\text{-}FeCl_2$
- vs $Na\text{-}NiCl_2$
- Higher diffusion for Fe^{2+} ions

Zhan et al. Adv. Energy Mater. 10, 1903472 (2020).
"Na—FeCl2 ZEBRA type battery" US Patent 10, 615, 407 (2020).

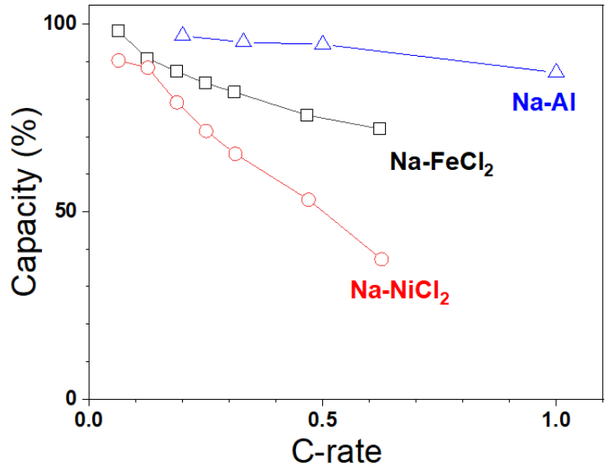
Project Details

- Problem
  - Na + $NiCl_2$ (S) = NaCl + Ni (S)
  - Slow kinetic of Ni^{2+} solid state diffusion and NaCl dissolution
  - Require large surface area cathode (processing cost)
    - Ni cathode (1-2 um carbonyl Ni powders)
    - Fe cathode (10 um carbonyl Fe powders)

- Approach
  - 3Na + $NaAlCl_4$ (L) = Al (S) + 4NaCl
  - Faster kinetics of $AlCl_4^-$ liquid phase diffusion
  - Faster NaCl + $AlCl_3$ reaction
  - Aluminum wools instead of powders

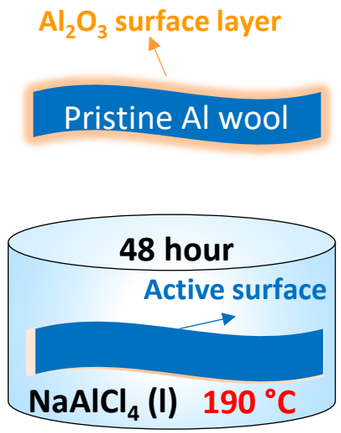


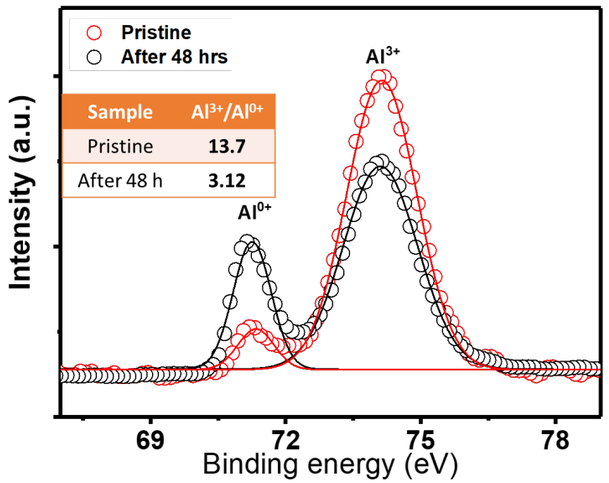
Al
⇳
$NaAlCl_4$

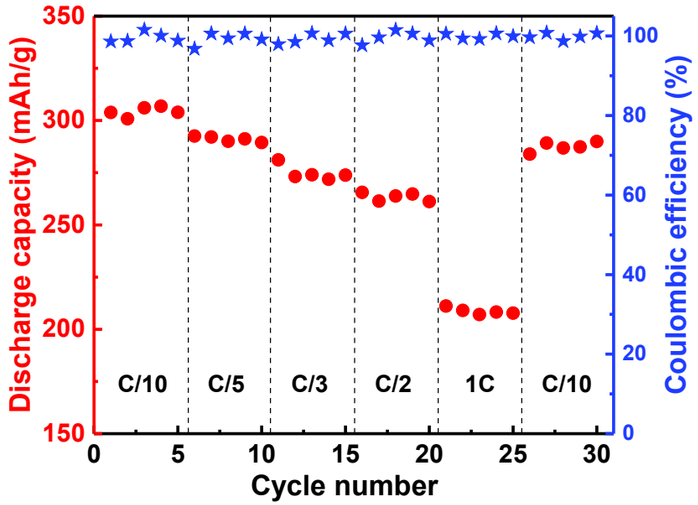


Approaches

- Previous approach: precondition process (> 24 hours) is required to activate Al cathode duo the dense alumina passivation (Al_2O_3).





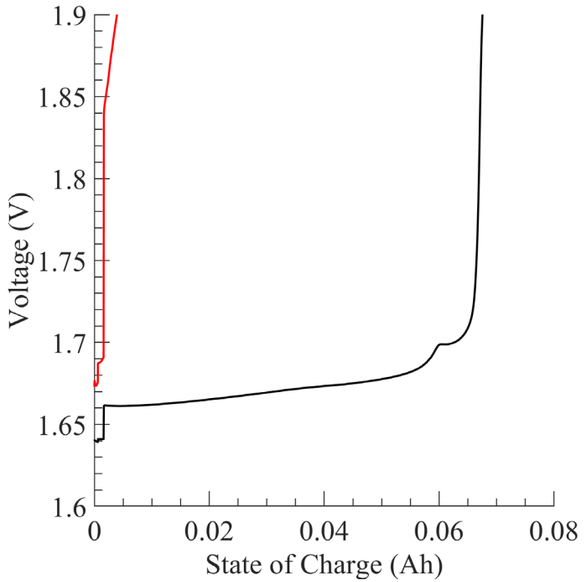


- Currently applying activation additive (future disclosure, on-going patent process) to allow immediate/more consistent activation. Full capacity on 1st charge.
- More consistent Al cathode activation could be important for practical applications, particularly for modules with many cells in serial or parallel configuration.

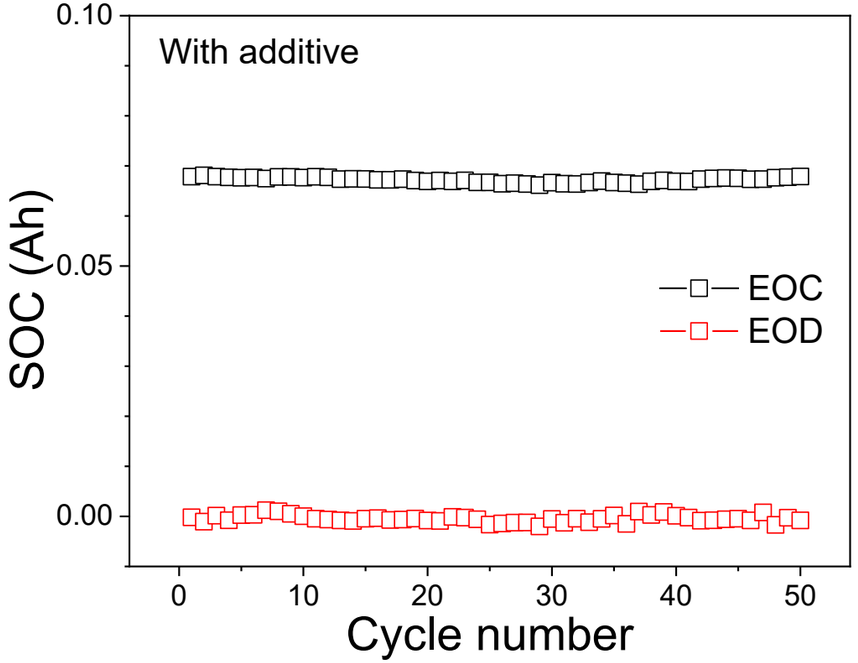
Zhan et al. Adv. Energy Mater. 10, 2001378 (2020).
Weller et al. *Energy Storage Mater.* 56, 108 (2023).

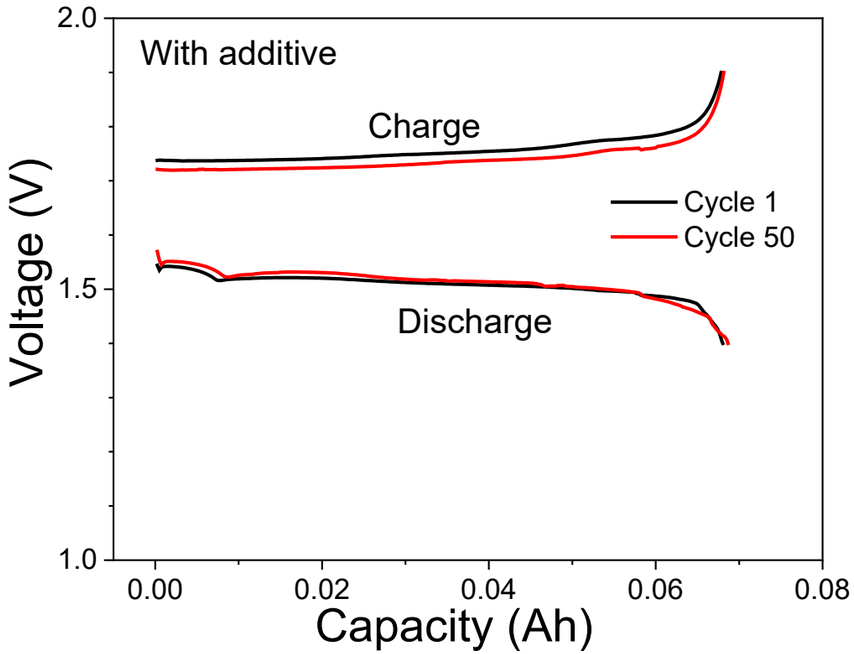
Results

without



with additive





- Without additive Na-Al battery experiences large overpotential and shows no capacity at the 1st charge.
- <0.5 % of additive in Na-Al battery enables full charge capacity at the 1st cycle.
- Initial testing indicates stable battery cycling after the activation.

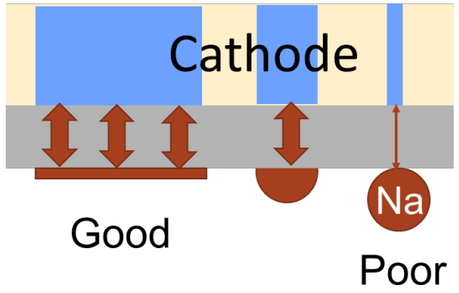
Provisional patent application under preparation.

Conclusion & Impact

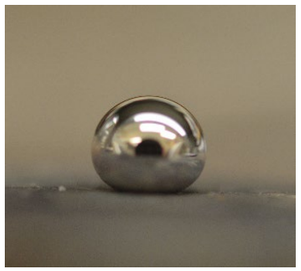
- Na-Al battery offers a viable solution for low cost and longer duration battery applications.
- In-situ activation of Al cathode provides solution for simpler BMS in practical application.
- Clear understandings of the activation mechanism are underway.

More Works on Na Wettability (Poster session for details)

- Na wetting on BASE is critical for battery performance



Young-Dupré equation : $W_{adh} = \gamma_m (1+\cos\theta)$



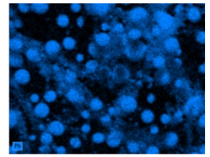
Smooth surface

γ_m of Na = 200 mN/m
(3x higher than water)

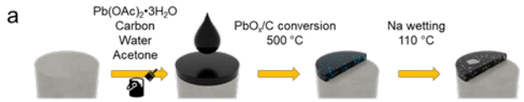
Sunny-side-up drop

Rough surface

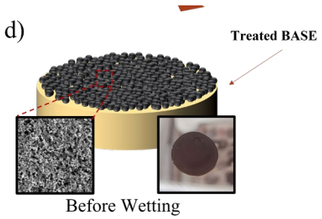
Metal based (Pb)



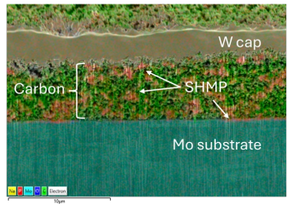
Carbon/metal (Pb/Sn) composite



Metal free carbon layer



Carbon layer/ Salt binder



Han et al. *Frontiers in Batteries and Electrochemistry* 5, 1759353 (2026)

Acknowledgements

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Thank you !