Low Temperature Na-Metal Halide Batteries: Low Cost, Long Cycle Life, and Safe ESS for LDES

Guosheng Li, J. Mark Weller, Henry H. Han, Evgueni Polikarpov, Kee Sung Han, David M. Reed, and Vincent L. Sprenkle

Battery Materials & Systems Group, Pacific Northwest National Laboratory, Richland, WA 99352

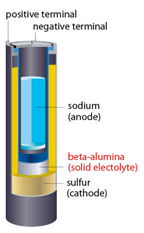
Pacific Northwest NATIONAL LABORATORY

❑ Conventional Molten Na Battery Technologies

Batteries	Temp. (°C)	OCV (V)	Duration (hours)	SSE	Cycle life	Safety	Cost ($/kWh)
Na-S	350	2	4-6	β″-alumina	> 3,000	Fire hazard	350
Na-Ni	280	2.58	4-6	β″-alumina	>1,000	No thermal runaway	1,000

❑ Innovation in Battery Design

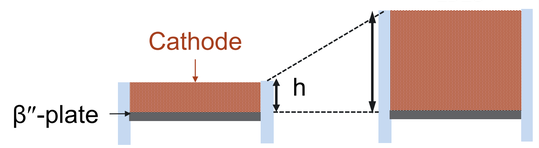
Tubular Type (Conventional)



1. Increase tube diameter for larger cathode loading.
2. Manufacturing cost /challenges of large β″- tubes.
3. Cell processing cost & technical difficulties. Glass seal, TCB, etc.

VS.

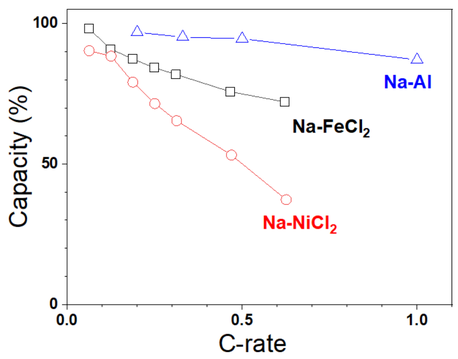
Planar-Type (PNNL)



1. Increase cathode thickness for larger cathode loading (LDES)
2. No size change for β″ SSEs.
3. Minimize the cost of cell manufacturing.

❑ Advances in Low-cost Battery Materials

	Na-Ni[1]	Na-Fe[2]	Na-Al[3,4]
Cathode	Ni/NaCl	Fe/NaCl	Al/NaCl
E (V)	2.58	2.35	1.6
Temperature (°C)	180	180	180
Materials cost ($/kWh)	<100	**<5**	**<5**
Duration (hr)	4-6	**12**	**20**
Redox Chemistry	$Ni/NiCl_2$	$Fe/Na_6FeCl_8/FeCl_2$	$Al/NaAlCl_4$



1. Low materials cost for Fe and Al cathode
2. Fe and Al cathodes offer faster redox kinetics vs Ni cathode
3. Longer duration discharge

❑ Collaborations for Scaling Up

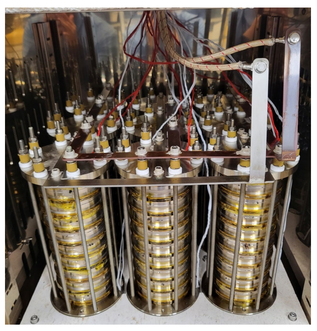
- *DOE/KETEP International Collaboration (Phase 1, 2015-2018)*

  Goal: Demonstrate planar-type Na-metal halide battery large single cell
  Cell Chemistry: Na-Ni, $NaAlCl_4$, 180°C
  Cell Specification: 15 Wh, 80% SoC utilization, 1.8-2.8 V, 3-30 mAh/cm^2

- *DOE/KETEP International Collaboration (Phase 2, 2019-2023)*

  Goal: Demonstrate planar-type Na-metal halide battery module (1 kWh)
  Cell Specification: 1.3 kWh, 80% SoC utilization, 19-27 V, 3-30 mAh/cm^2

1.3 kWh module (10sx9)



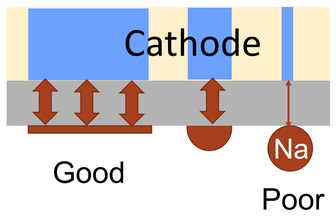
Semi-automated Battery Assembly

- *DOE/SBIR with Adena Power (Phase 1&2, 2020-2023)*

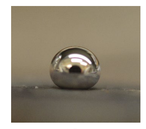
  Goal: Na-Fe battery demonstration
  Patent licensing agreement on PNNL's Na-Fe battery technology (2022)
  Cell Chemistry: Na-Fe, $NaAlCl_4$, 200°C
  Low-cost Cell Assembly: Stamping metal cases and polymer sealing method

❑ Na Wettability

- Crucial for molten Na battery operation at lower temperatures
- Intrinsically inferior Na wettability on SSEs



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

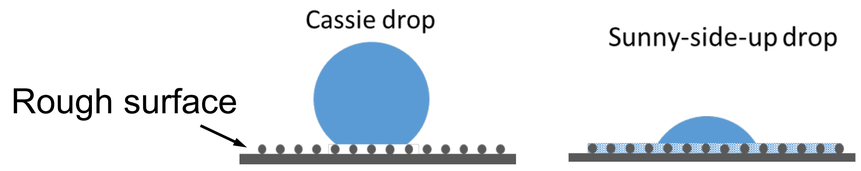


γ_m of Na = 200 mN/m (3x higher than water)

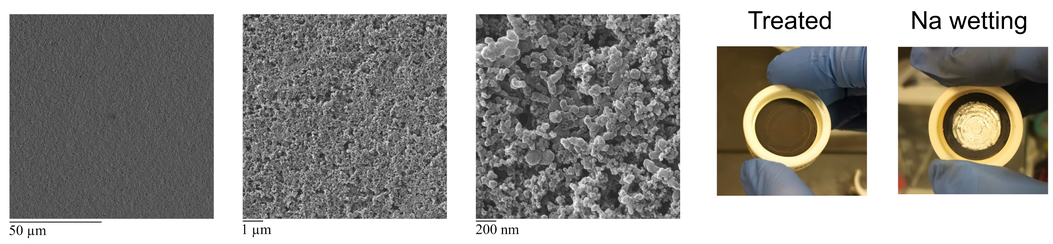
Smooth surface

❑ New Strategy for Superior Na Wetting

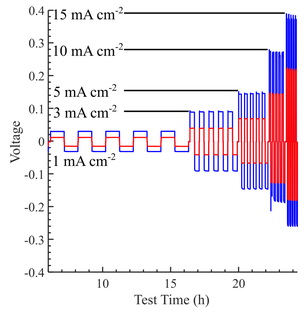
- Strategical surface modification to improve Na wettability beyond Young-Dupré wetting angle



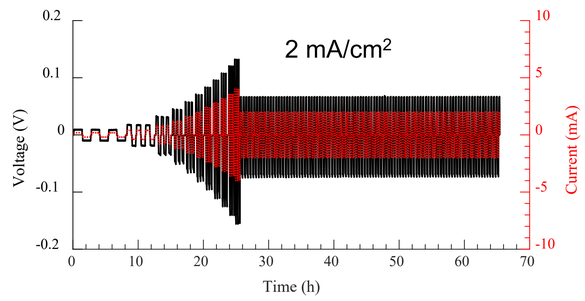
- Patented (iEdison No. 0685901-23-0141) carbon black based ink for surface treatment [5]



Moten Na symmetric cell (110°C)



Solid Na symmetric cell (30°C)



Summary and Future Works

- Planar-type molten sodium battery can provide a viable solution for LDES applications due to their low cost, no dendrite formation, and fast battery kinetic, etc.
- Pursuing fundamental understanding of Na wetting phenomena to promote its applications for molten sodium as well as solid-state Na battery development.
- Continue seeking industrial collaboration to demonstrate technology viability at scale.

Acknowledgments

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Contact: Guosheng Li, Ph.D.
Battery Materials & Systems Group
Pacific Northwest National Laboratory
Email: guosheng.li@pnnl.gov

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