Pacific Northwest NATIONAL LABORATORY

FY23 DOE OE Energy Storage Program Peer Review Meeting
Oct. 24-26 (Santa Fe)
Na Battery Session
ID: 403

Intermediate Temperature Na Battery Technologies

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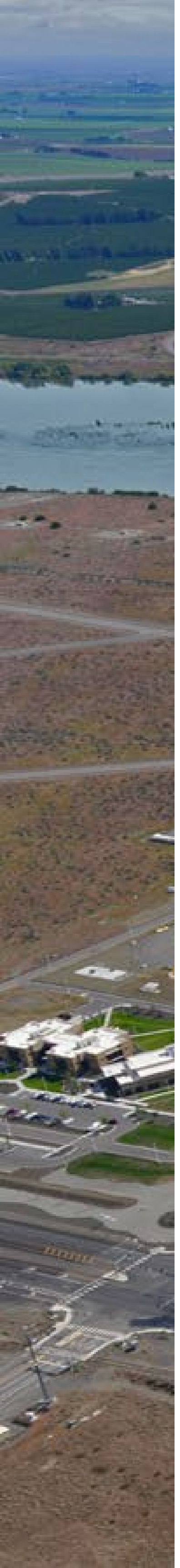


Project Objective and Outline

- Development of **intermediate temperature Na battery** includes advancing crucial materials synthesis and battery technologies to demonstrate **low cost, long cycle & duration, and reliable** energy storage system.

- ❑ Brief introduction of intermediate temperature (>100° C) Na battery
- ❑ Cathode chemistries
  - Fe cathode (SBIR & Adena/Nexceris, Poster)
  - Ferronickel alloy cathode (Poster)
  - Al cathode (Poster)
- ❑ Interface between molten sodium and solid-state electrolytes (Poster)
- ❑ DOE/KETEP collaboration (Phase 2)
- ❑ Freeze-thaw battery (Seasonal storage)
- ❑ Summary & Future works

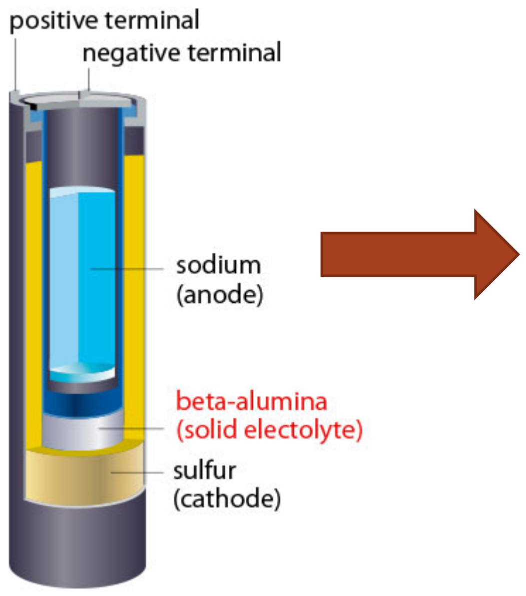
Challenges & Opportunities for High Temperature Na Batteries

Batteries	Temp. (°C)	OCV (V)	Duration (hours)	SSE	Cycle life	Safety	Cost ($/kWh)
Na-S	350	2	**4-6**	β″-alumina	> 3,000	Thermal runaway, limited thermal cycle	**500**
$Na-NiCl_2$	280	2.58	**4-6**	β″-alumina	>1,000	No thermal runaway	**1,000**

Tubular type

Increase tube diameter for larger cathode loading (LDES).

1. Manufacturing cost /challenges of large β″-tubes.
2. Cell processing cost & technical difficulties. Glass seal, TCB, etc.



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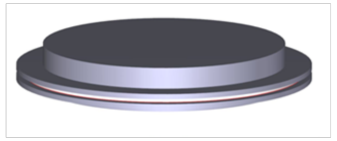
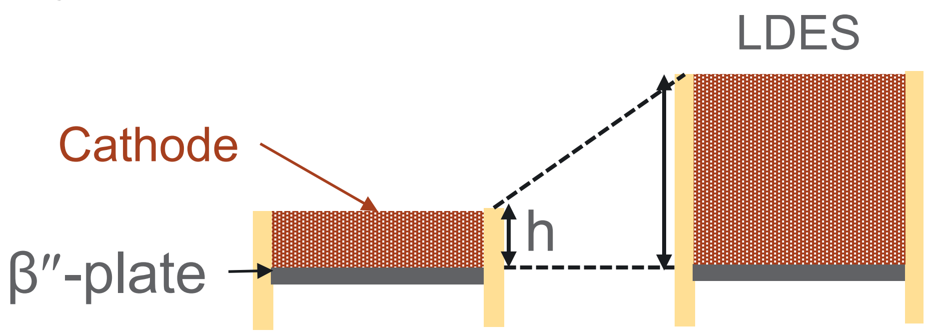


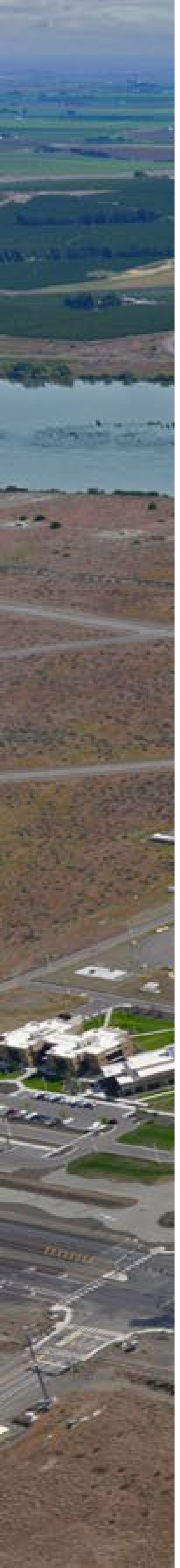
IT Na-MH: 190°C (< $100/kWh)

Planar type

Increase cathode thickness for larger cathode loading (LDES).

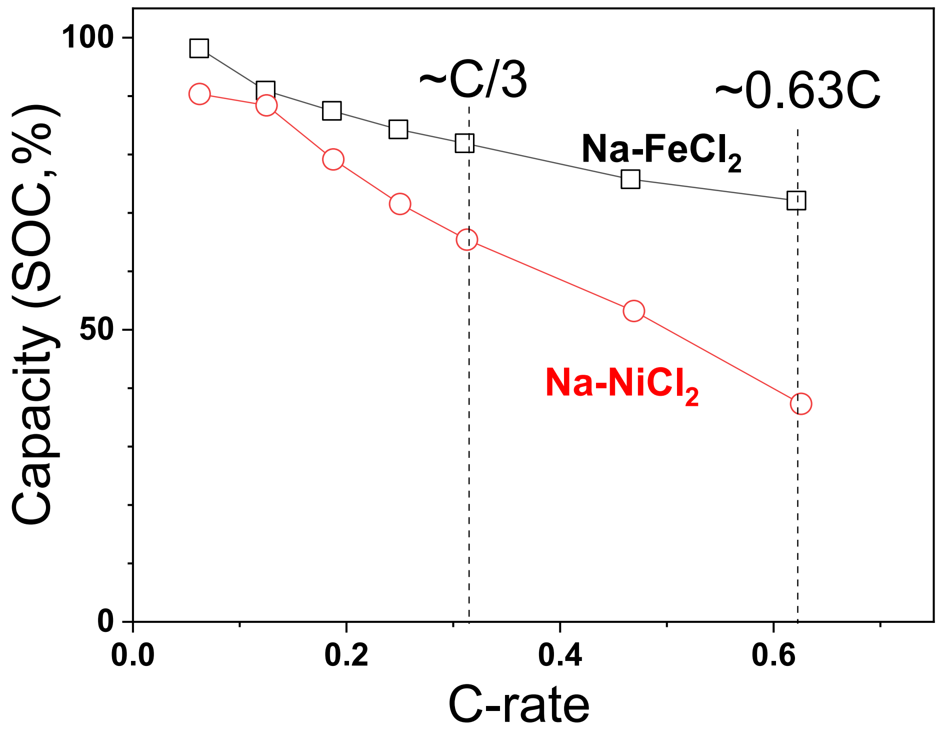
1. No size change for β″- plates.
2. Similar cell assembly.



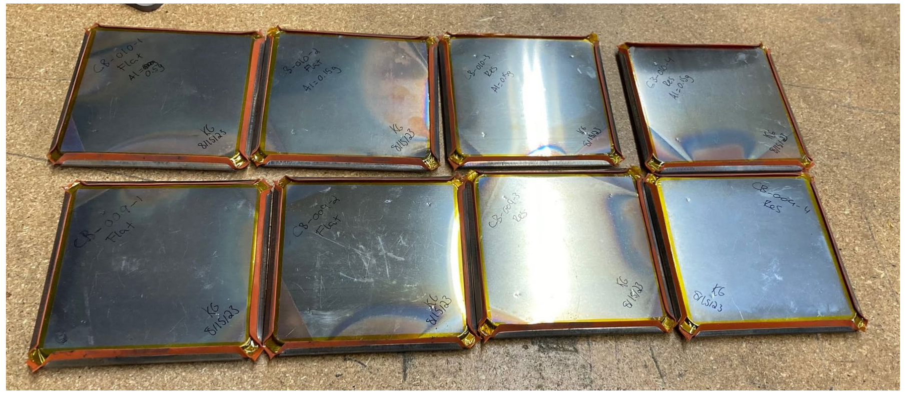


Low-Cost Fe Cathode (Neil, Poster)

	$Na\text{-}NiCl_2$	$Na\text{-}FeCl_2$
Cathode	Ni/NaCl	Fe/NaCl
E (V)	2.58	2.35
Materials cost ($/kWh)	**<100**	**<5**
Duration (Hours)	6-8	~15



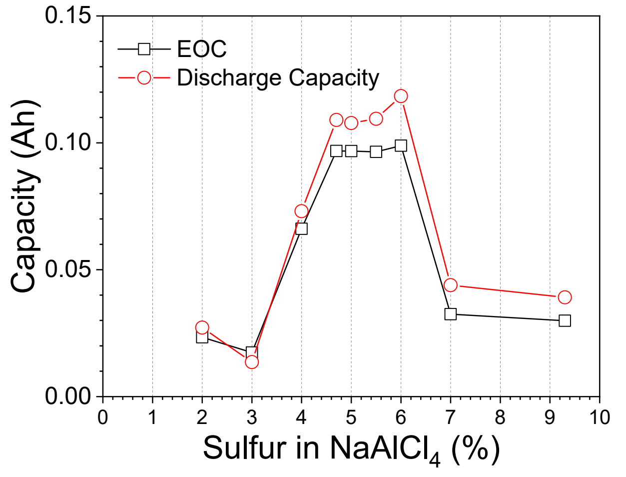
- ❑ Patent licensing agreement with Adena/Nexceris (OH)
- ❑ SBIR phase #2 to demonstrate $Na\text{-}FeCl_2$ battery technology in a module level.



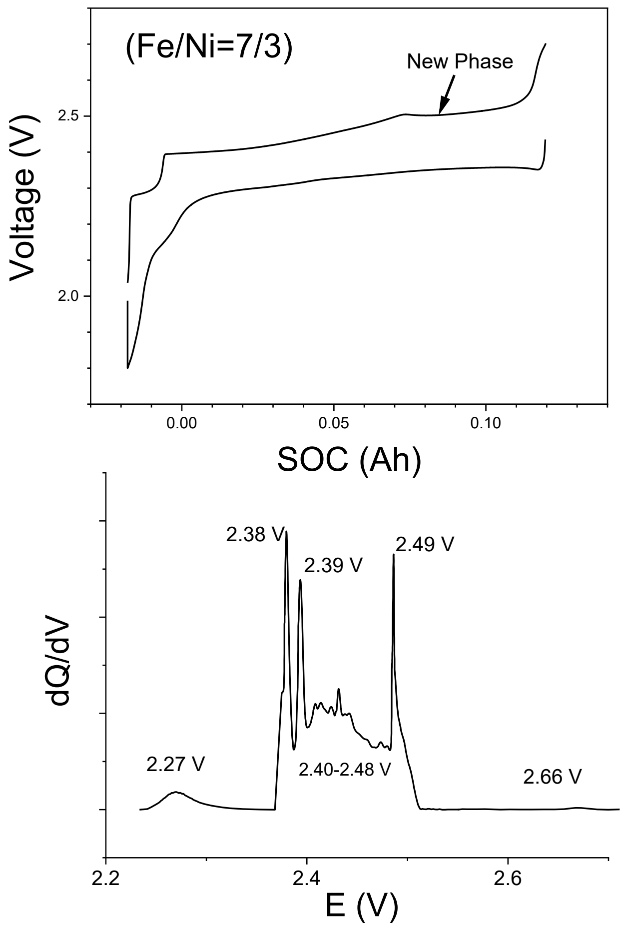
Li et al. *Adv. Energy Mater.* 5, 1500357 (2015): Zhan et al. *Adv. Energy Mater.* 10, 1903472 (2020);
Li et al. "$Na\text{-}FeCl_2$ Zebra type battery" US patent 10,615,407 (2020).

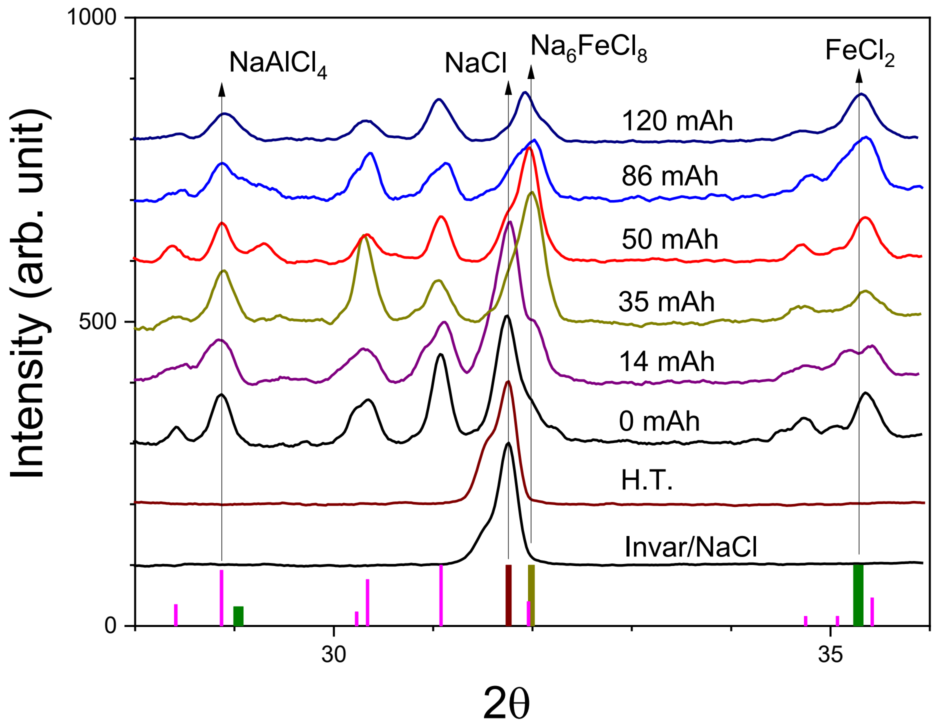
Ferronickel Alloy (Fe/Ni) Cathode (Eugene, Poster)

- Utilizing ferronickel byproduct of the steel industry (Interests from POSCO, 6^{th} largest steel manufacturing company)
- Benefits of both fast kinetics associated with Fe and the extended cycle life characteristic of Ni cathode



- Sulfur additive for Initial activation.
- Particle size of ferronickel powder (Fe/Ni=7/3) is important.





- Unique reaction mechanism
  - Intermediate states
  - Further study using HR-XRD (beamline)

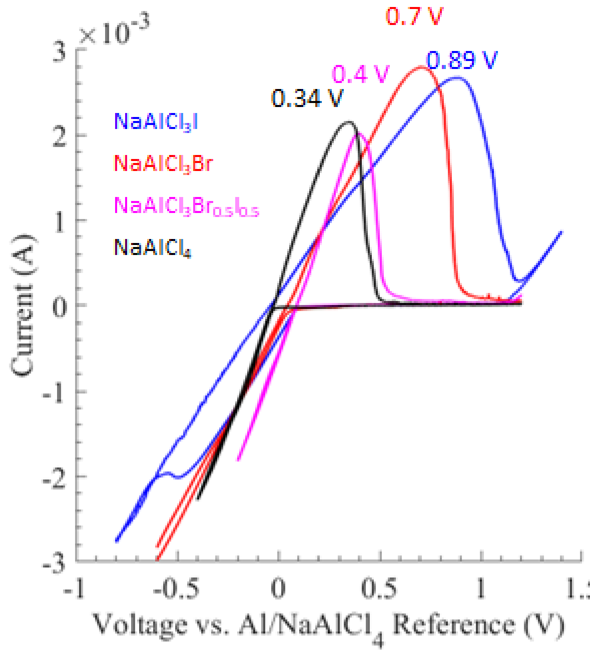
Polikarpov et al. (manuscript in preparation)

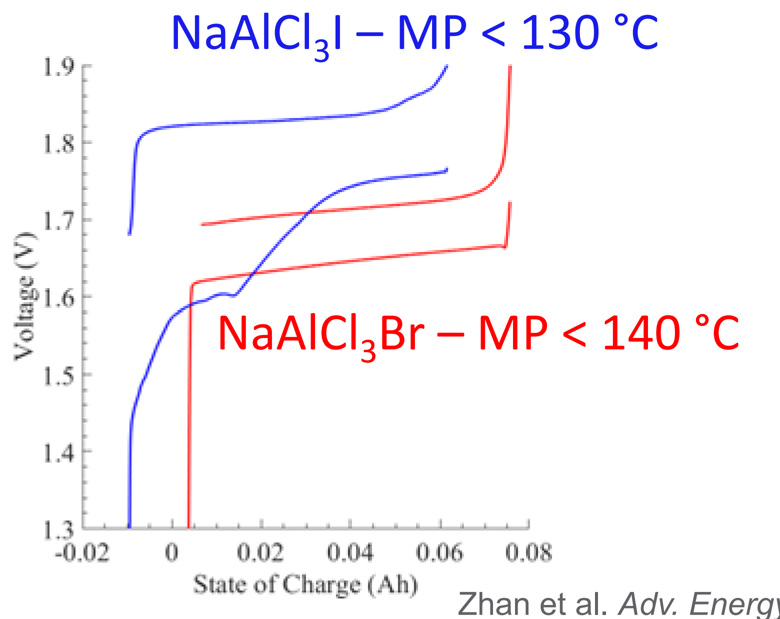
Exploring Halide-substituted Chloroaluminates (Mark, Poster)

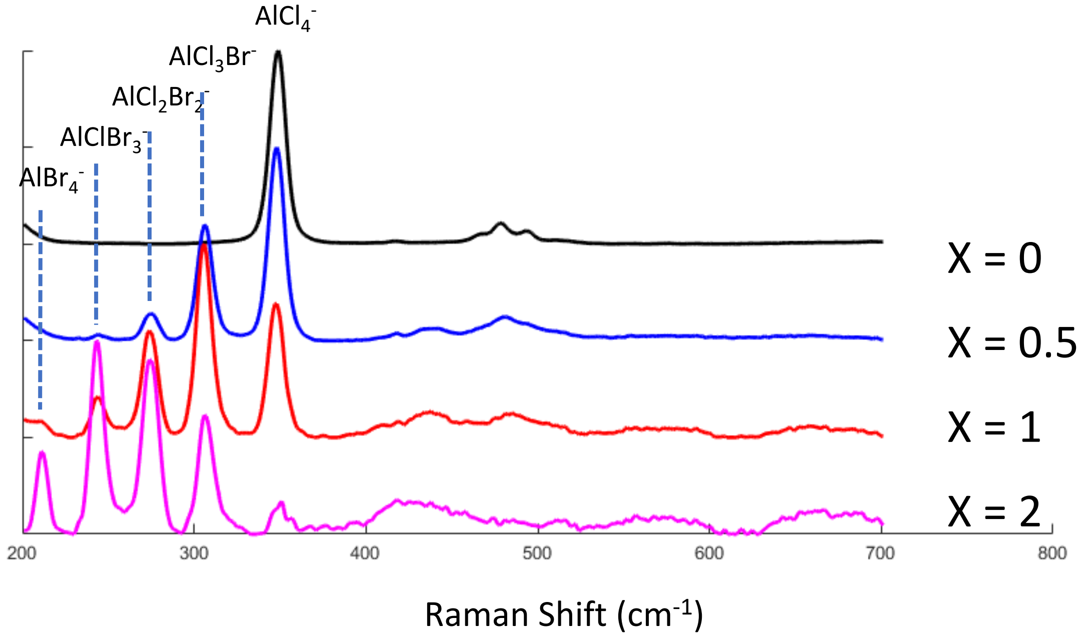
$3Na + NaAlCl_4 = 4NaCl + Al$

	$Na\text{-}NiCl_2$	Na-Al
Cathode	Ni/NaCl	Al
E (V)	2.58	1.6
Materials cost ($/kWh)	**<100**	**<5**
Duration (Hours)	**6-8**	**>20**

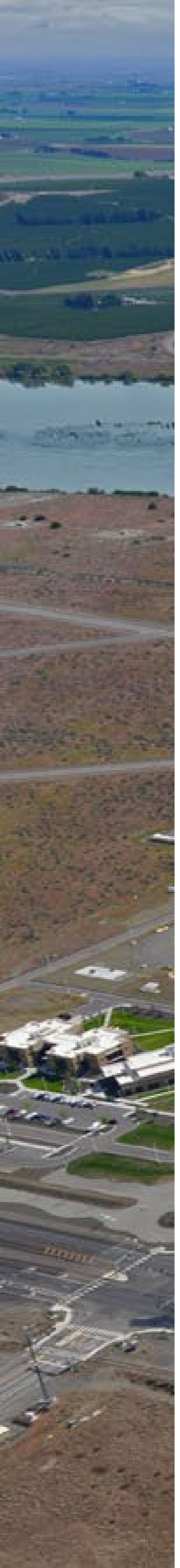
- Substitution of some Cl^- for Br^- or I^-
- Lowered MP & higher cell voltage
- Focusing on $NaAlCl_3Br$ initially
- Can we gain large benefit from small amount of substitution of Cl^-?







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



Interface between Molten Na and SSE (Henry, Poster)

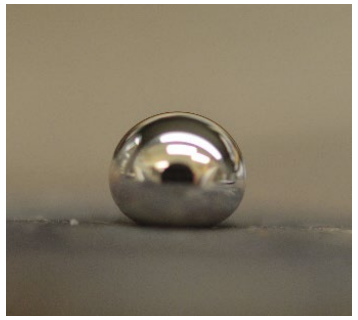
- ❑ Improve Na wetting on SSE to reduce interfacial resistance & cathode utilization.
- ❑ Fundamental understandings of Na wetting on various surfaces.

Na wetting on **smooth** surface

Young–Dupré relation

$W_{adh} = \gamma_m (1+\cos\theta)$

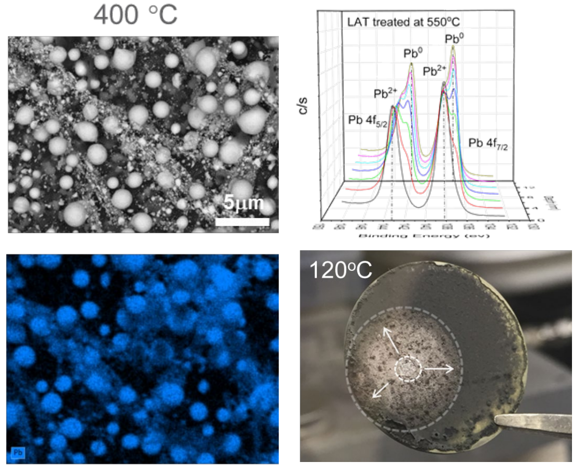
γ_m of Na = 200 mN/m
(3X higher than water)

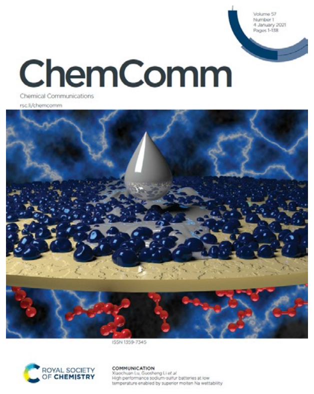


Na wetting on **rough** surface

Sunny-side-up drop

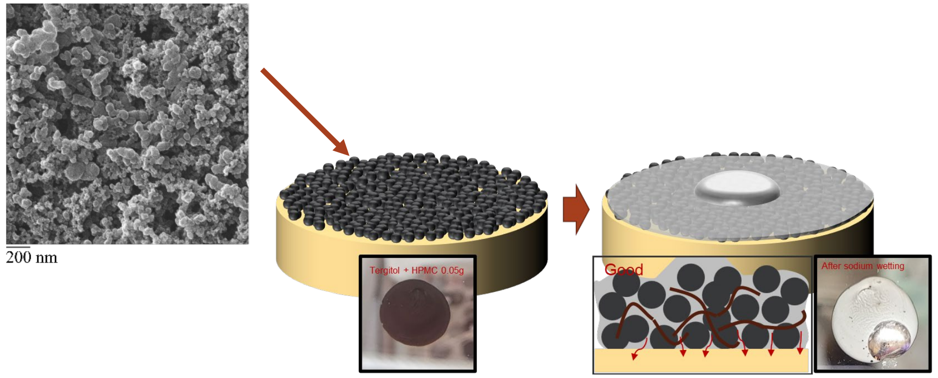
J. Mater. Chem. A 6, 19703 (2018).





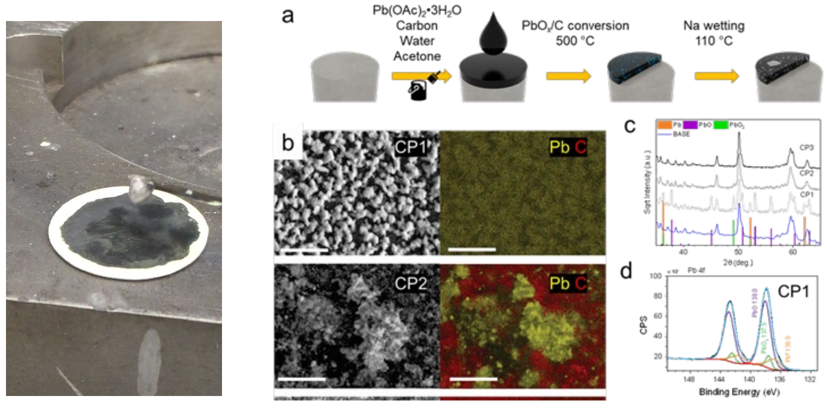
Chem. Comm. 57, 45 (2021).

Metal free/carbon treatment



New Na wetting agent (Manuscript in preparation)

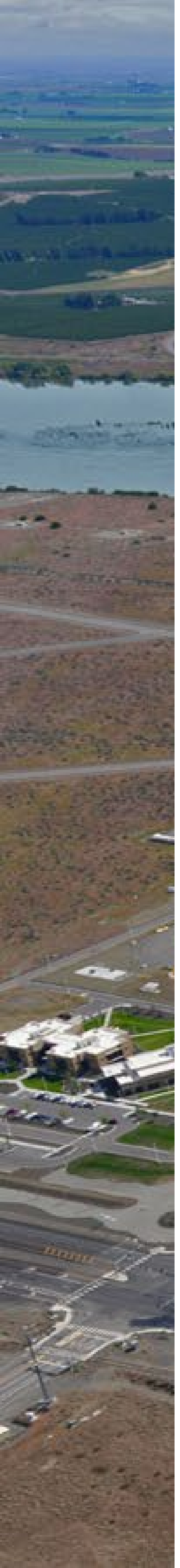
Metal nanoparticle/carbon composite



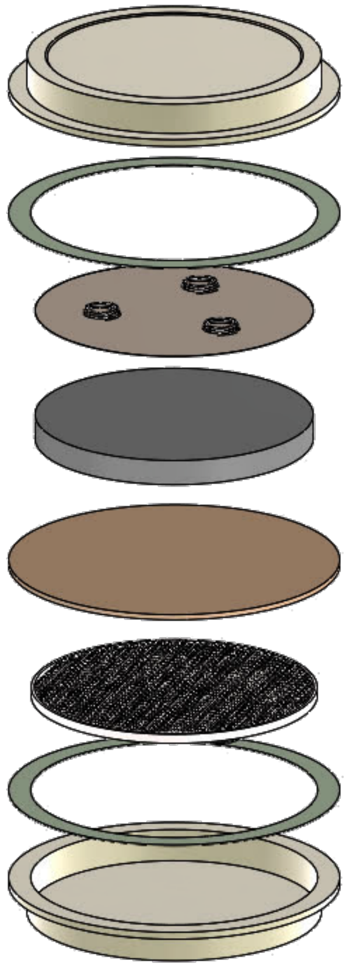
ACS Appl. Mater. & Inter. 14 (22), 25534 (2022).

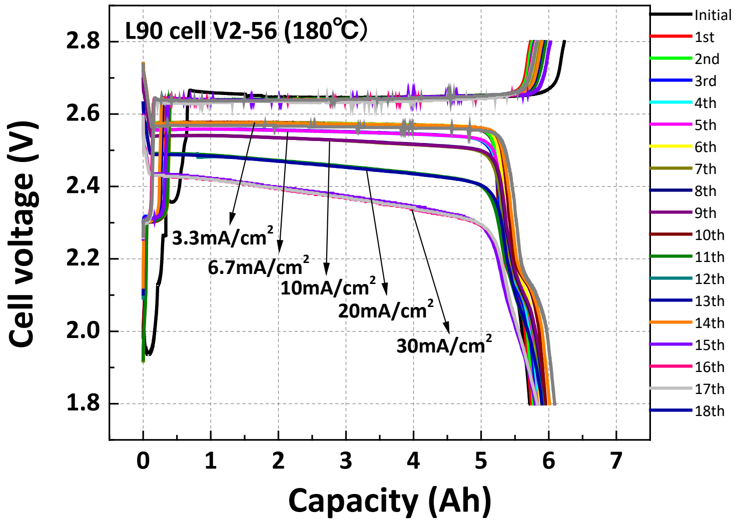
DOE/KETEP Collaboration on Intermediate Temperature Na-Metal Halide Battery

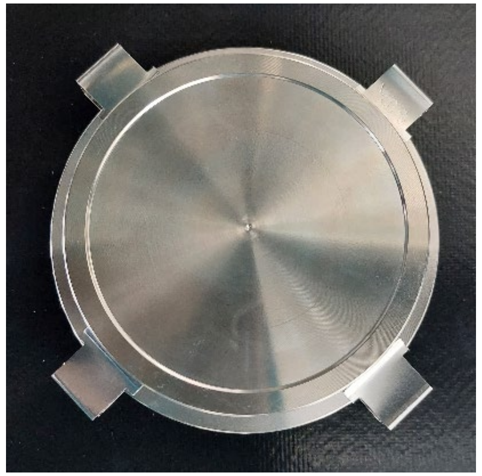
Phase 2: Nov. 2019−July 2023
Goal: Demonstrate planar-type Na-metal halide battery large single cell and module (1 kWh)



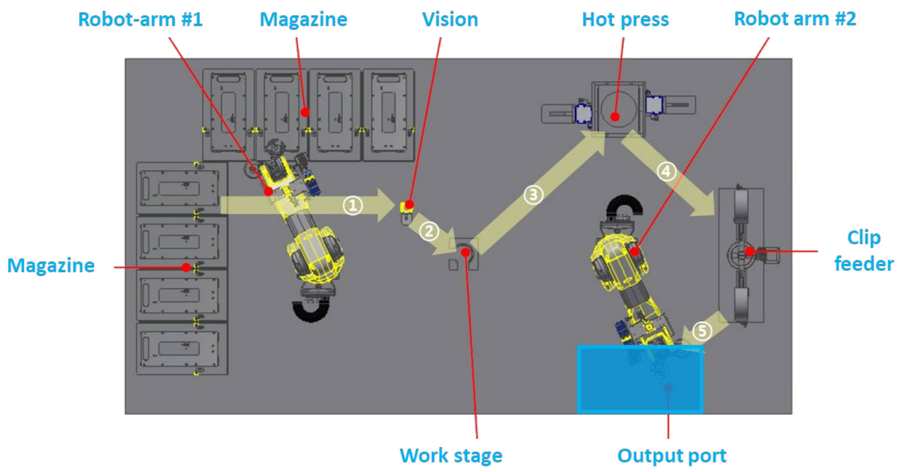
15 Wh cell

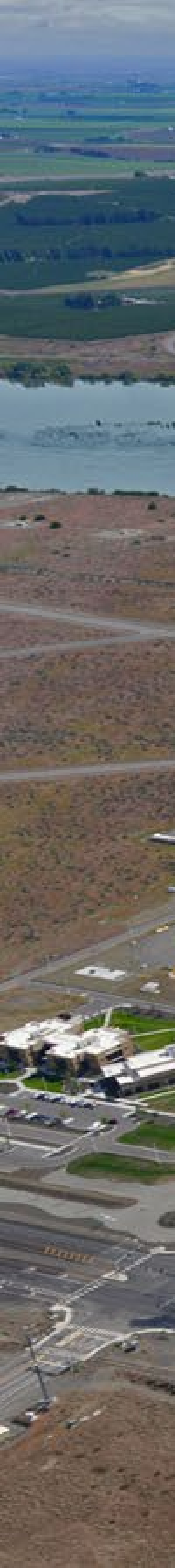






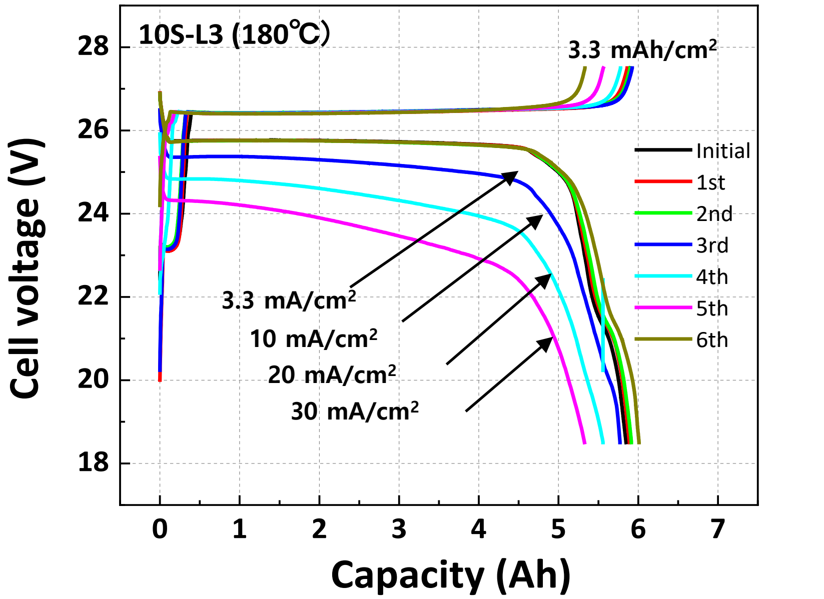
Semi-automated cell manufacturing





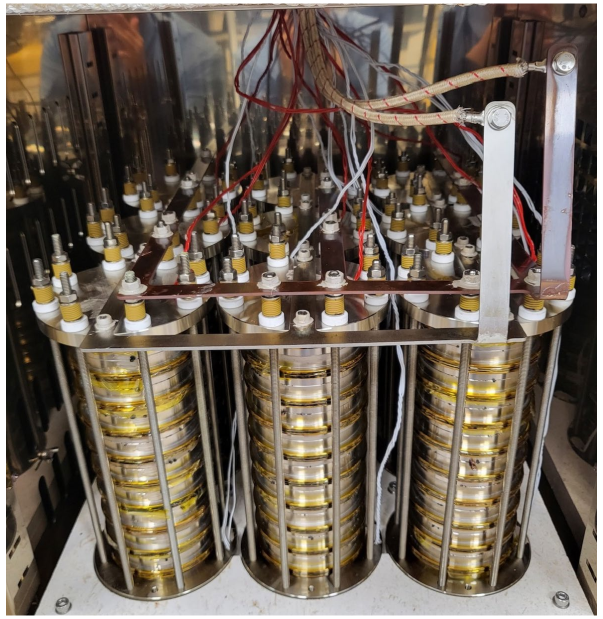
10s Stack and 1 kWh Module Demonstration

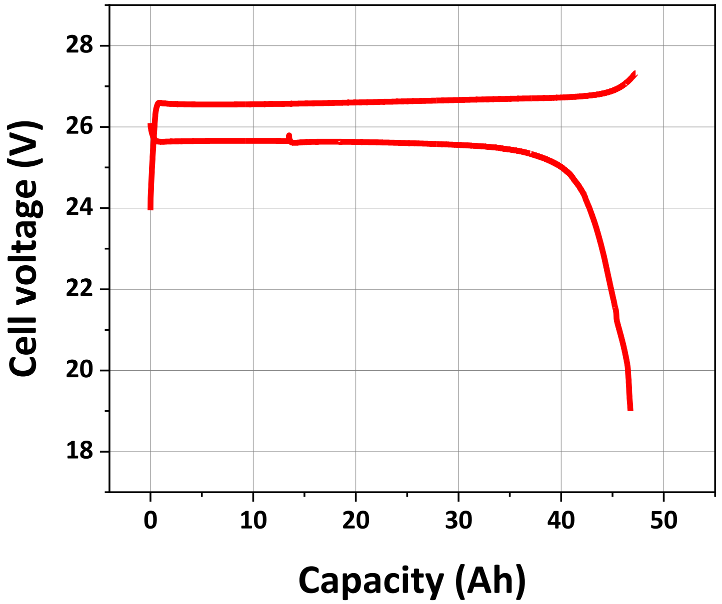
- Chemistry: Ni/NaCl=1.8
- Cathode loading: 156 mAh/cm^2
- Solid electrolyte: β''-Al_2O_3
- Temperature: 180^{o}C
- Voltage window: 19-27V
- DC current densities: 3.3~30 mA/cm^2



10s Stack (26 V, 150 Wh)

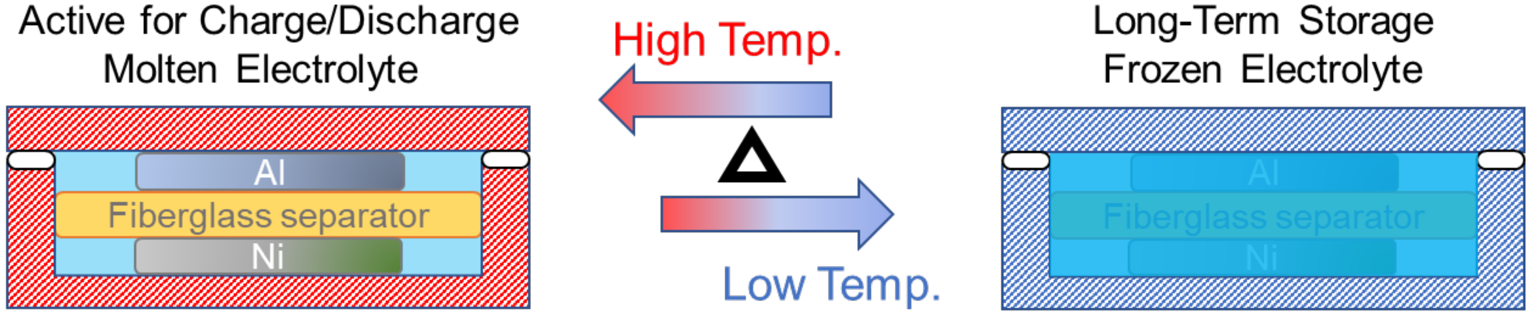
10s x 9 (90 cells) Module (26V, 1.3 kWh)

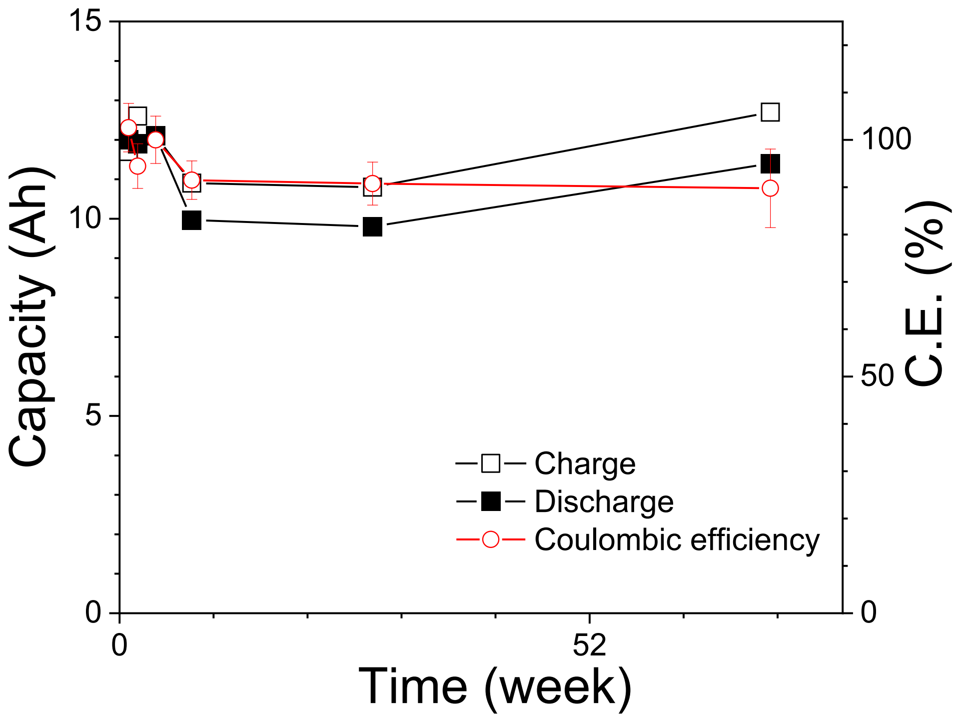




Freeze-Thaw Battery Technology for Seasonal Application

- Utilizing battery technology based on **freeze-thaw** electrolytes for long-term capacity retention (seasonal) to store and hold charges.





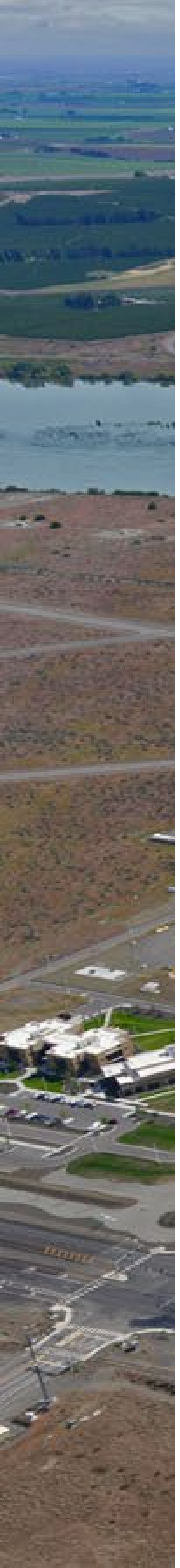
Anode: $Al + NaCl + 3Cl^- \rightarrow NaAlCl_4 + 3e^-$

Cathode: $NiCl_2 + 2e^- \rightarrow Ni + 2Cl^-$

Overall: $2Al + 2NaCl + 3NiCl_2 \rightarrow 2NaAlCl_4 + 3Ni$,

Specific capacity: 287.3 mAh/g (E = 0.910V (180 °C)

>90% capacity after 78 weeks (1.5 year)

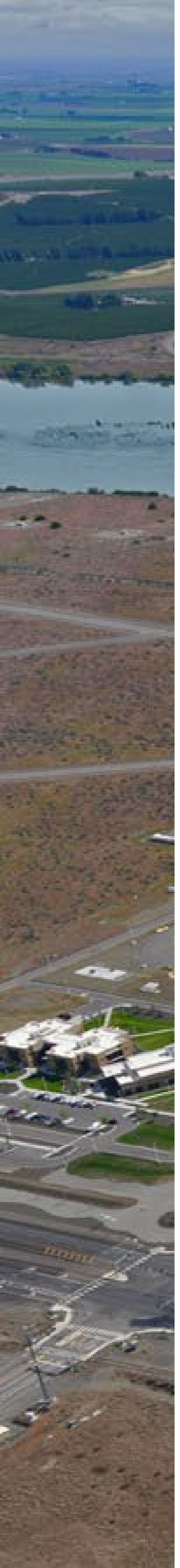


Summary and Future Plan

Journal publications & Milestone	• All milestones are achieved. • **TV interview** and numerous **news releases** for Na-Al battery technology published recently. • “Unlocking the $NaCl-AlCl_3$ Phase Diagram for Low-Cost, Long-Duration Na-Al Batteries.” ***Energy Storage Materials*** (2023). • “Directing High-efficiency Na plating with Carbon-Aluminum Junction Interface for Anode-free Na Metal Batteries” ***ACS Applied Energy Materials*** (2023). • “Thermally Activated Batteries and Their Prospects for Grid-Scale Energy Storage” ***Joule*** (2023).
IP& Invention Reports	• One provisional IP application filed (Advanced Na wetting agent)
Collaboration	• DOE/KETEP project phase #2 completion. • SBIR project (Nexceris, OH)

FY 24:

- Demonstration of low-cost Na based battery chemistries for long duration application.
- Develop low-cost freeze-thaw battery chemistries.
- Continue to participate/support on SBIR project (Adena, OH).
- Planning for DOE/KETEP phase #3.



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Thank you

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