Advanced Intermediate Temperature (IT) Na-Metal Halide Batteries

Guosheng Li, Xiaochuan Lu, Hee-Jung Chang, Jeff Bonnett, Nathan Canfield and Vince Sprenkle

Electrochemical Materials and Systems Group, Pacific Northwest National Laboratory, Richland, WA

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Dr. Hee-Jung Chang, Dr. Xiaochuan Lu, Mr. Jeff Bonnett,
Dr. Nathan Canfield and Dr. Vince Sprenkle

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Ms. Sonri Son, Dr. Yoon-Cheol Park, and Dr. Keeyoung Jung

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FY18 Milestones and Publications

	FY18	Achieved
Energy Capacity (Wh)	>15	√
Discharge Current (mA/cm^2)	>30	√
Energy Efficiency (%)	>80	√
Capacity Utilization (%)	> 70	√
Cycle Number	>100	√
2-stack Cell (Wh)	> 15	√
Publications	3 SCI	3 (published), 1 (revision)
Presentation	5	10 presentations (3 invited)

2018

1. "An intermediate-temperature high-performance Na-$ZnCl_2$ battery" *ACS Omega* (revision)
2. "Decorating beta″-alumina solid-state electrolyte with submicron Pb spherical particles for improving Na wettability at lower temperatures" *J. Mater. Chem. A* (web published)
3. "′Ni-less′ cathodes for high energy density, intermediate temperature Na-$NiCl_2$ batteries." *Adv. Mater. Interfaces* 5, 1701592 (2018).
4. "An advanced Na-$NiCl_2$ battery using bi-layer (dense/micro-porous) β″- alumina solid-state electrolytes" *J. Power Sources* 396, 297 (2018).

Outline

- Introduction
- Cathode development
- Polymer durability
- Na wettability
- Large cell testing

Pros & Cons of Na-Metal Halide Batteries

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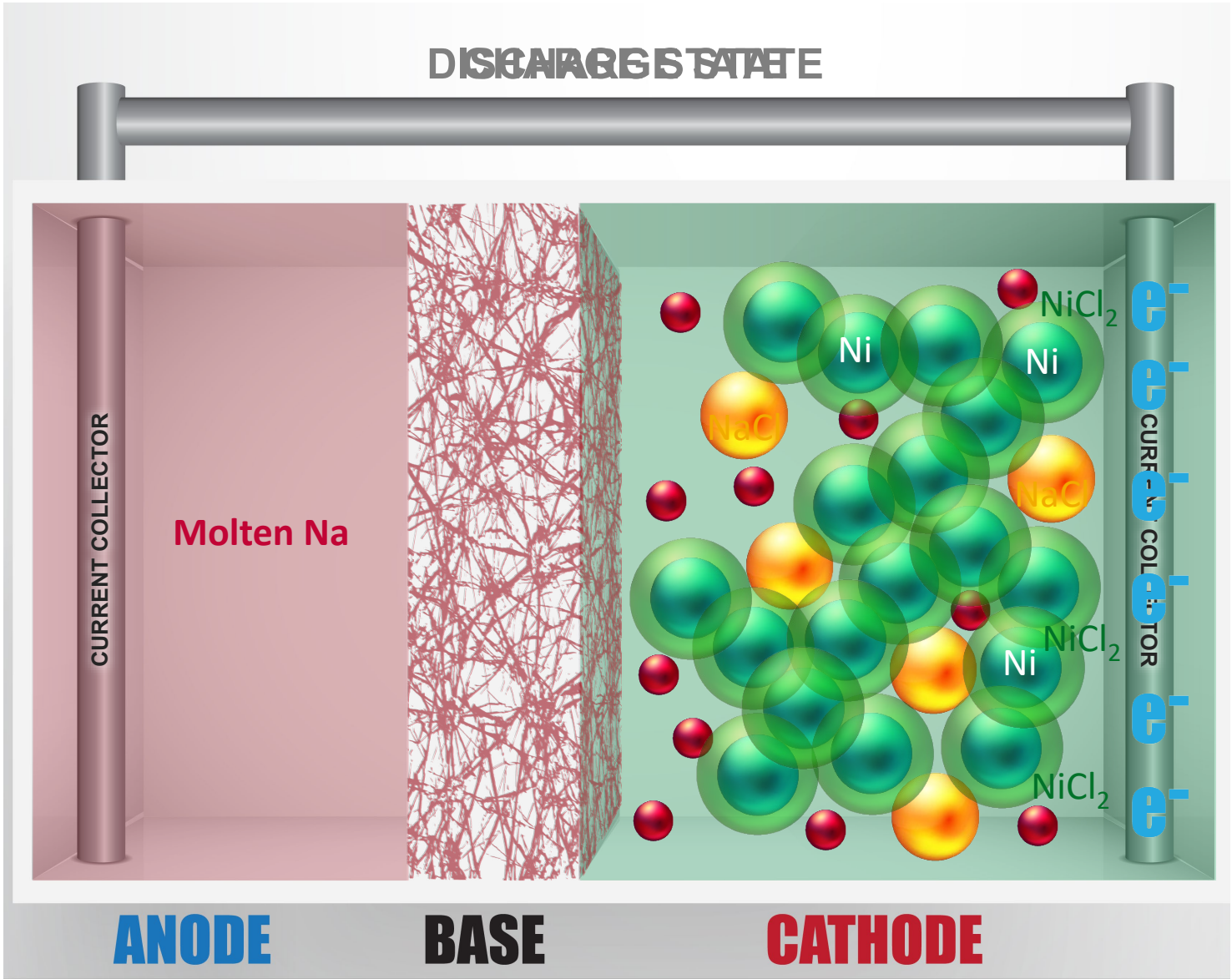
- Na-Metal Halide (Na-MH or Zebra) Battery: (FZ Sonic, GE, Chaowei, etc.)
  $2Na + NiCl_2 \Leftrightarrow 2NaCl + Ni$ (T=280 °C, 2.58 V)

	Zebra (280°C)	IT Na-MH (~190°C)
Pros	○ **Easy cell assembly**: No need of metallic sodium ○ **Low fire hazard**: All inorganic compounds ○ **Safe cell failure mode**: $3Na + NaAlCl_4 \Rightarrow 4NaCl + Al$	○ Easy cell assembly ○ Low fire hazard ○ Safe cell failure mode ○ **Lower operating temperature** ○ **Low cost (~$100/kWh)** ○ **Simple BMS** ○ **Longer cycle life**
Cons	○ High operating temperature ○ High cost (~$1000/kWh) ○ Complicated BMS	○ New technology ○ Maturity

Schematic View of Na-$NiCl_2$ Batteries



2NaCl + Ni (D)

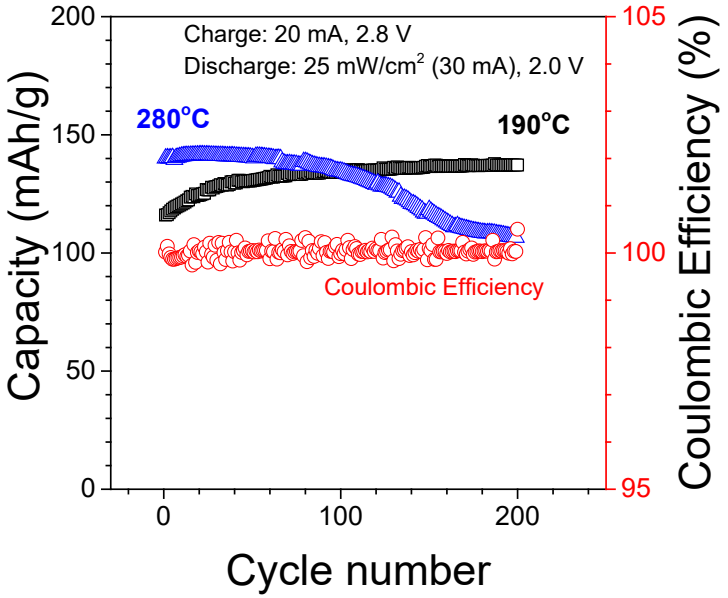
⇕

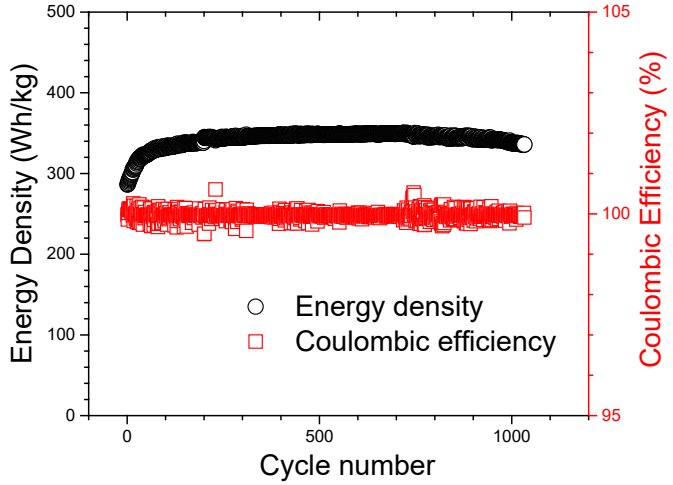
2Na + $NiCl_2$ (C)

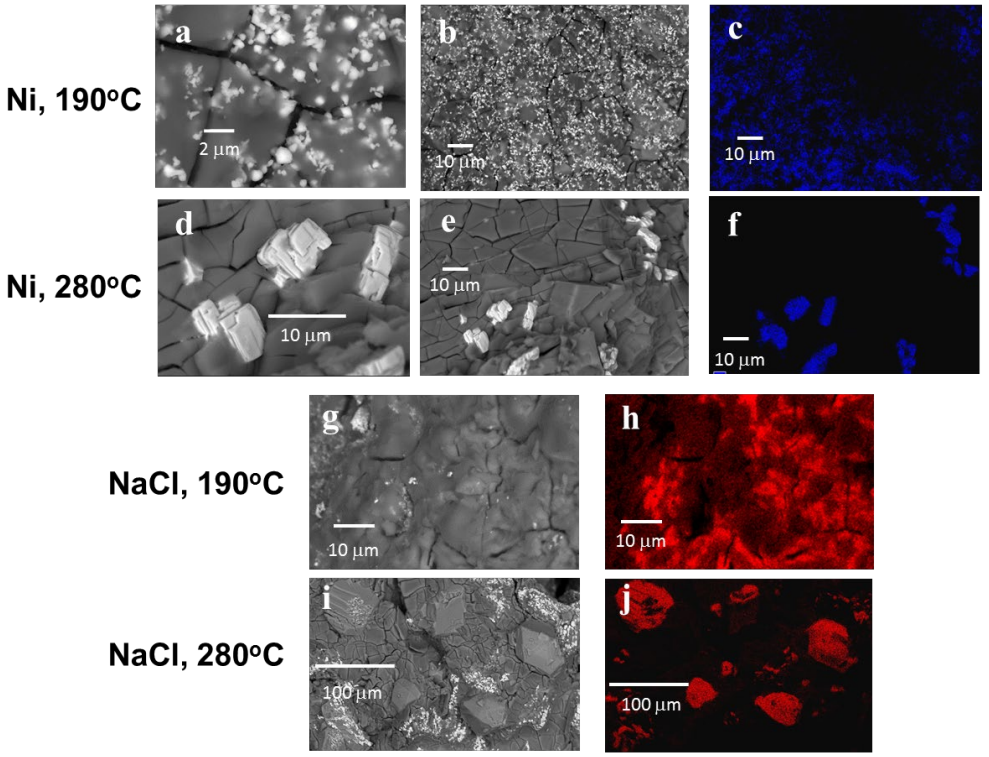
Ni and NaCl particle sizes

- ❑ Surface area
- ❑ Electron pathway
- ❑ NaCl dissolution

Na-$NiCl_2$ Batteries Operated at 190 vs 280°C







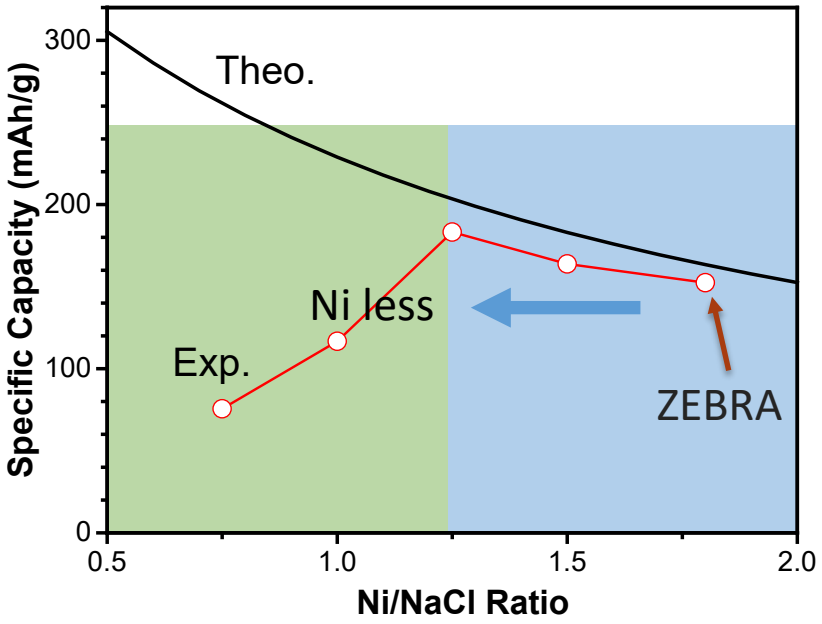
Testing time: Over 1000 cycles (1 year and 6 months)

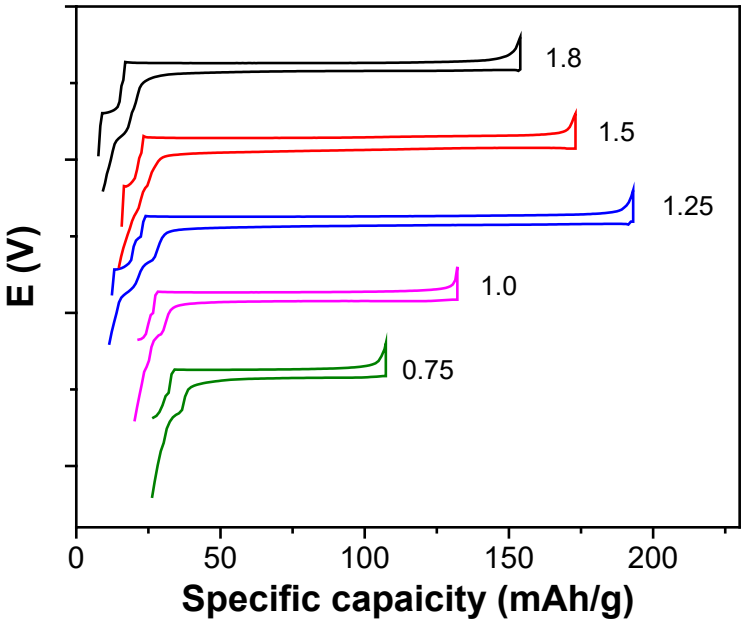
Capacity retention:

- ❑ No degradation was observed at 190°C
- ❑ Fast capacity degradation at 280°C
- ❑ Rapid particle growth observed for Ni and NaCl at 280°C
- ❑ No significant changes observed for the cathode at 190°C

Nat. Commun. 7, 10683 (2016).

Lowering Ni Contents at 190°C



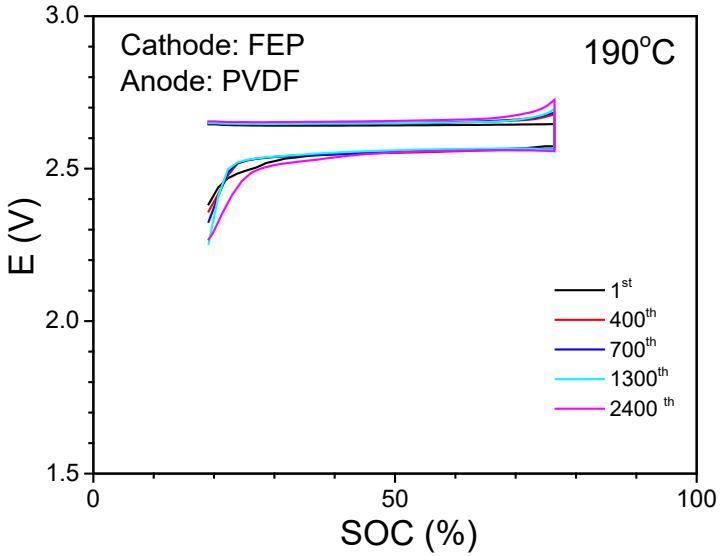


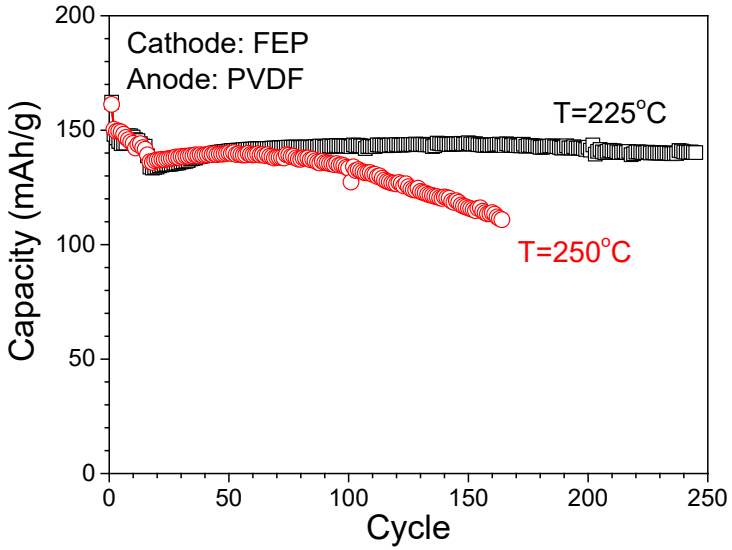
Ni/NaCl Ratio	Energy Density (Wh/kg)	Ni (kg/kWh)	Ni Saving (%)
1.8	330	1.89	0
1.5	380	1.52	20
1.25	**405**	**1.31**	**31**
1.0	200	2.38	-26

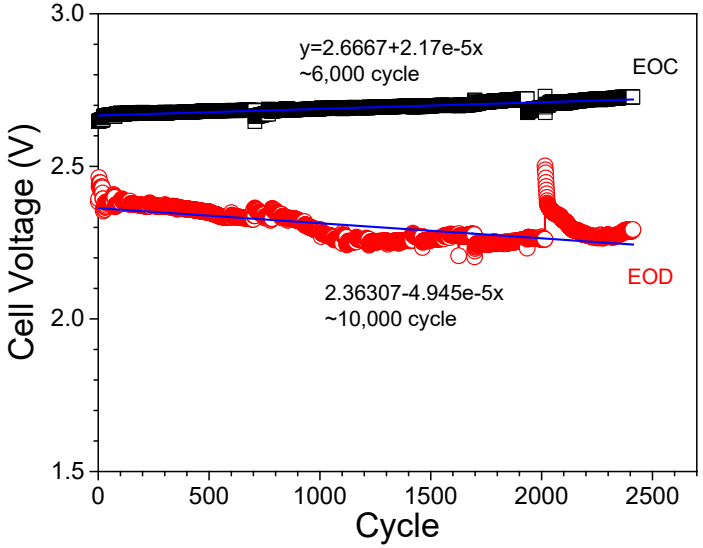
- Ni/NaCl ratio of 1.25 shows the highest Ni utilization.
- Cathode formulas with Ni/NaCl ratios of 1.5 and 1.25 use 20% and 31% less Ni.

Adv. Mater. Interfaces 1701592 (2018).

Long Term Cycling of Cells Sealed with Polymers





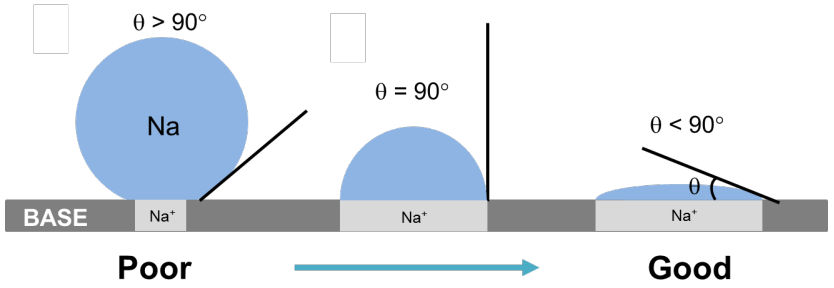


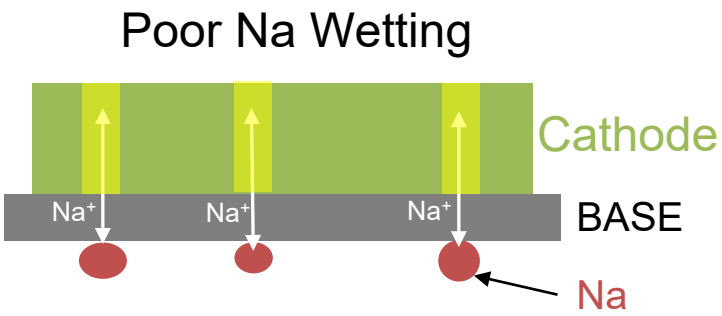
- Current cycle number > 2400 cycles (~3 years)
- Extrapolated cycle number > 6000 cycles for remaining 60% capacity
- Stable cell performance for the operating temperature of 225°C

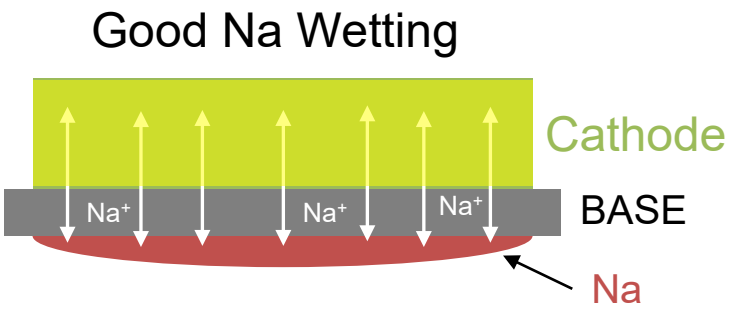
Improving Na Wettability at Lower Operating Temperatures

Young-Dupré Relation: $\frac{W_{adh}}{\gamma_l} = 1 + \cos\theta$

- Surface tension of Na (200 mN/m) >> H_2O (73 mN/m)

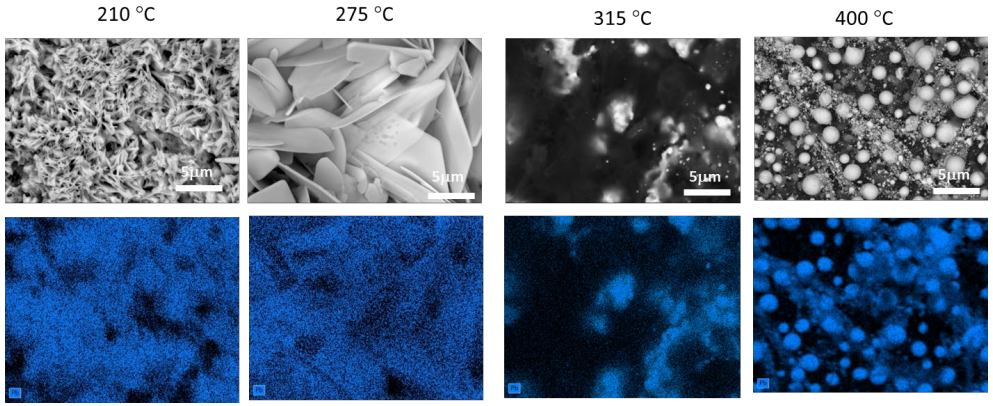






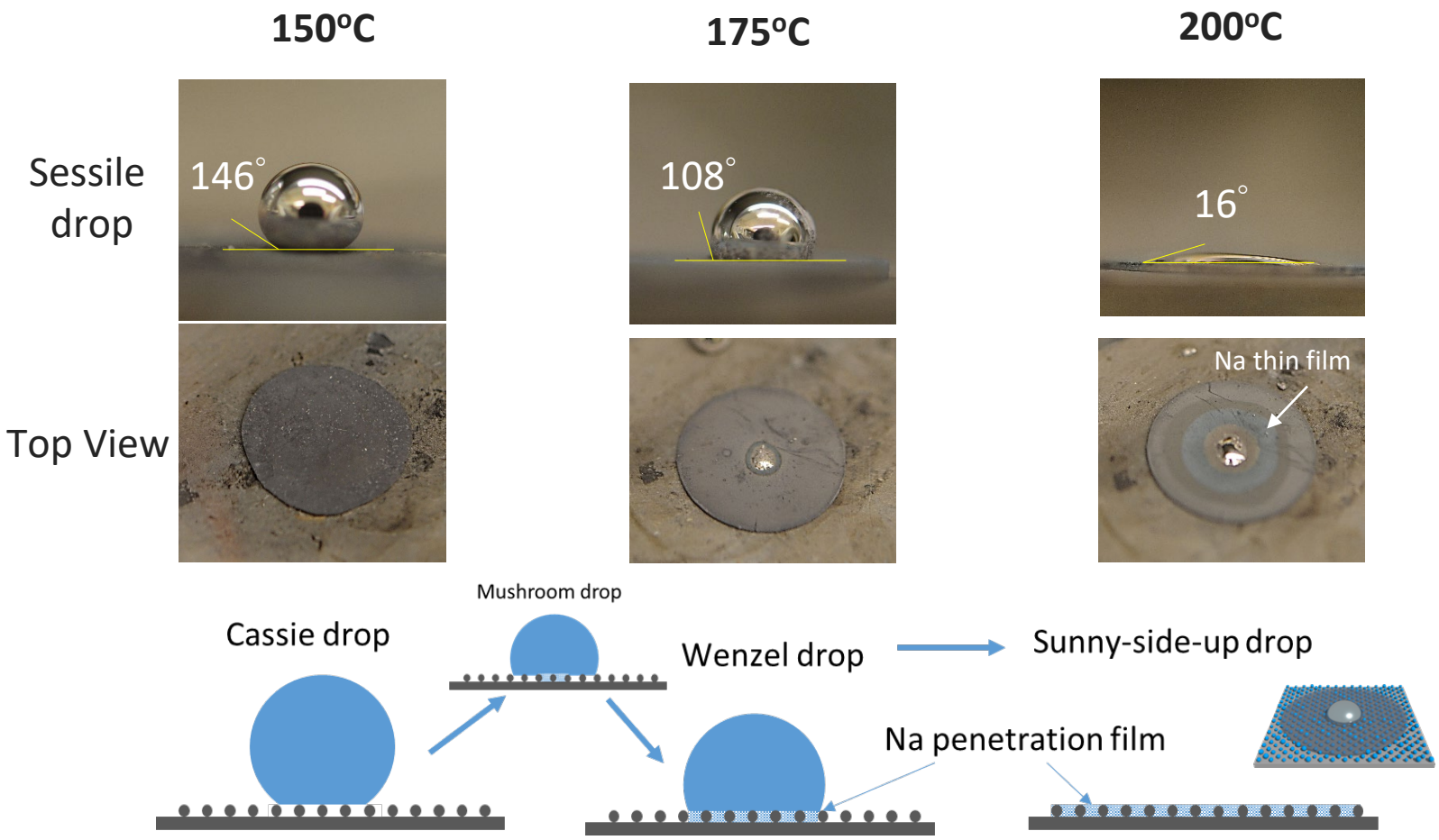
Surface modification:

- Pb acetate heat treatment (N_2)
- Superior Na wettability for 400°C treatment
- Spherical micron Pb particles



J. Mater. Chem. A (in press)

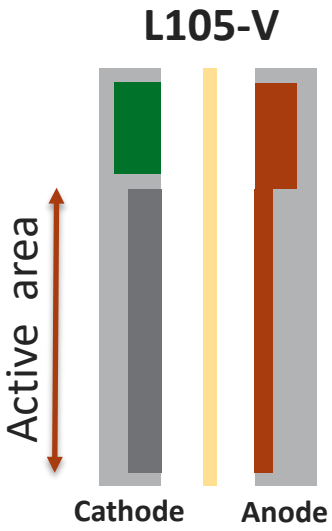
Na Wetting via “Sunny-side-up” Model



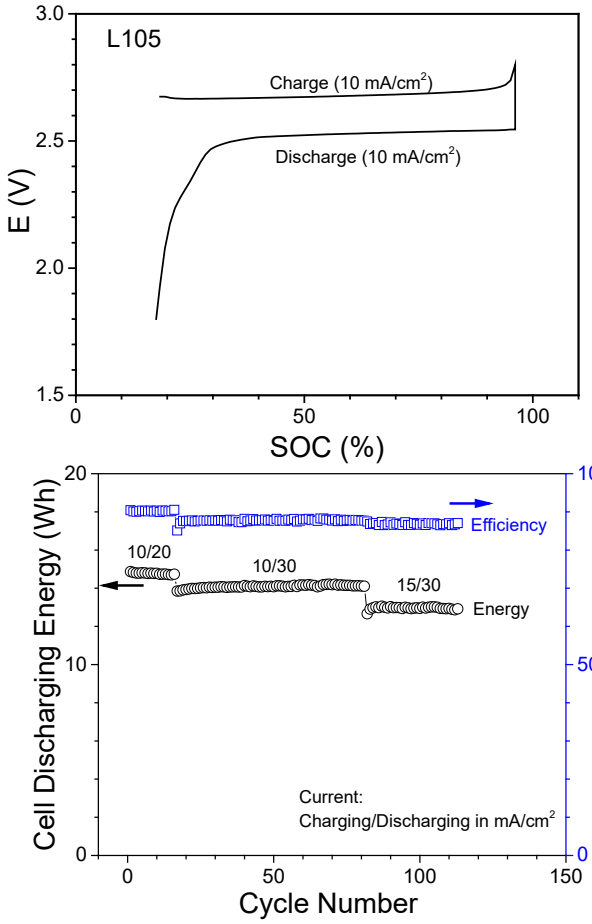
- Na wetting in “sunny-side-up” shape is responsible for high battery performances

Large Cell Testing (L105-V)

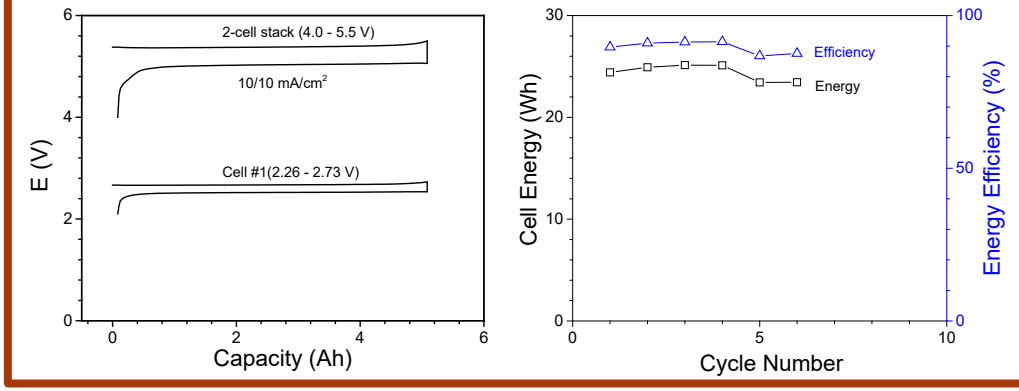
Cell	L105-V (PNNL)	L105-H (PNNL&RIST)
Orientation	Ver.	Hor.
BASE (mm)	105 (4”)	105 (4”)
Active Area (cm^2)	45	60
Capacity (Ahr)	7.1	9.4
Energy (Whr)	18	24
Case	Machining	Pressing



Single Cell (L105-V)



2-stack Cell



Large Cell Testing (L105-H)

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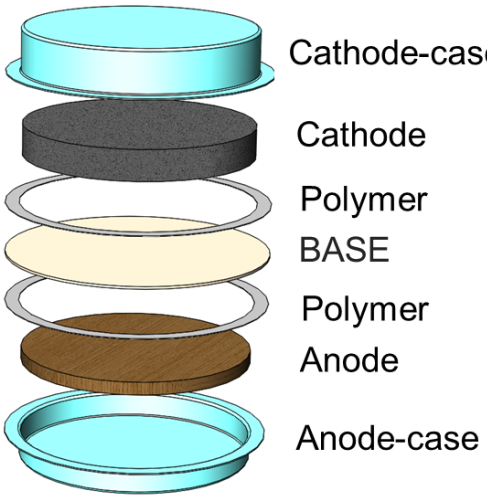
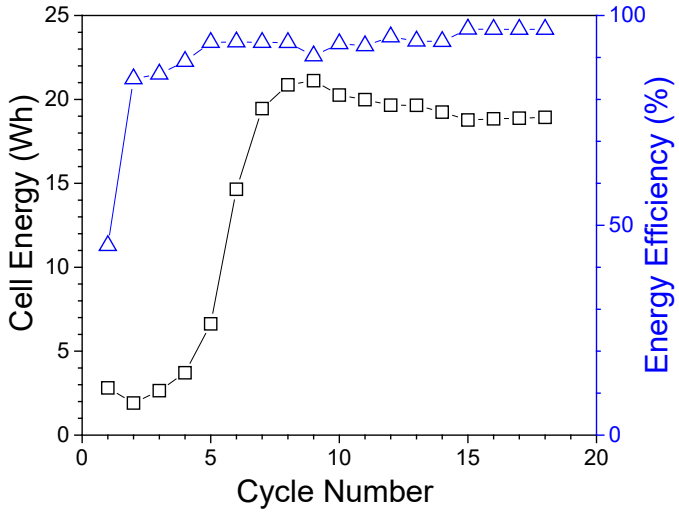
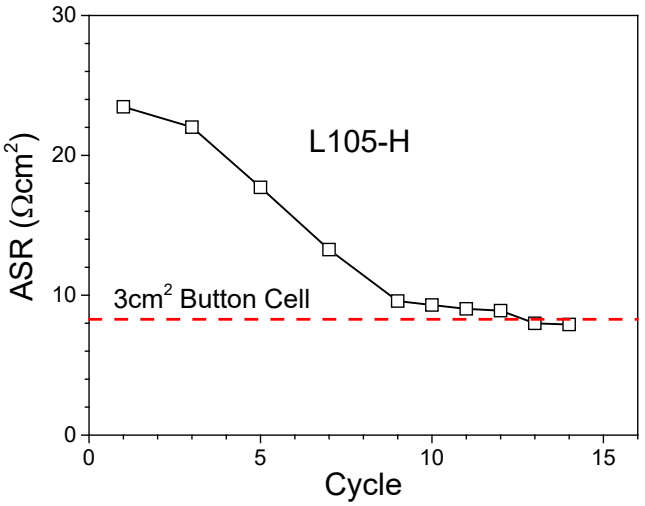
Exploded View of L105-H

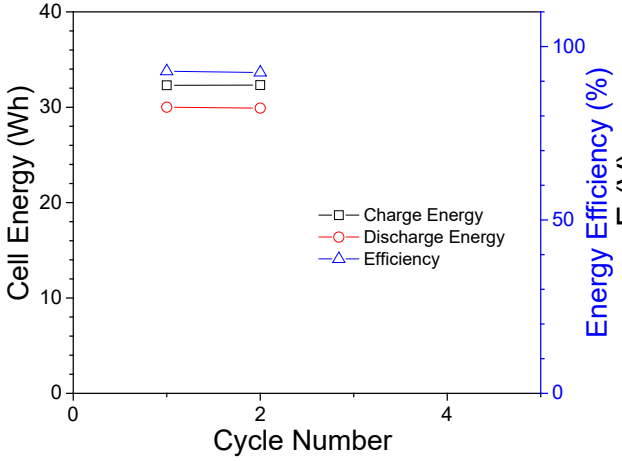


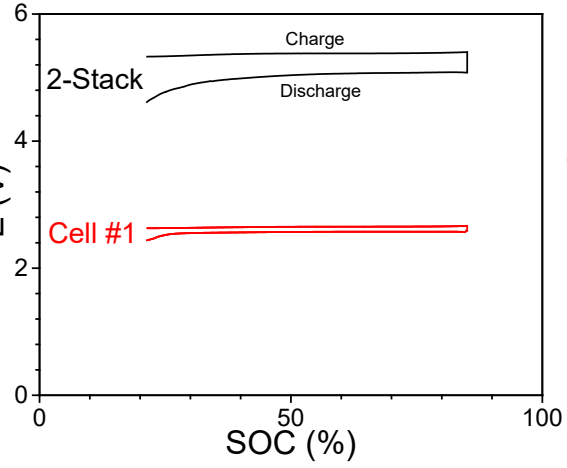
Single Cell (L105-H)





2-Stack Cell





Poster Section:

"Toward comprehensive cell design & testing for low cost Na-metal halide batteries"

Summary & Future Work

- **IT Na-MH Batteries** present great opportunities for ESS applications due to its potential lower cost, higher safety, and longer cycle life.
- Lowering the **operating temperature** to ~ 200^{o}C provides tremendous advantages of lower manufacturing cost, thermal management and reliability of batteries.
- Developing **novel cathodes** (lower Ni amount) helps to further reduce the materials cost of Na-MH batteries.
- New approach (sunny-side-up model) for the surface treatment on the BASE promoted the **Na wettability** at lower temperatures.
- Demonstrations of **large unit cell** and **2-stack cells** provide opportunities for investigating cell performances and assembly at the practical scale.

Future Work

- Continue to improve large cell performances, including the shorter conditioning cycle and higher current densities.
- Improving Na wettability via surface treatment (Pb or other materials) for larger cells.

Thank you for your kind attention!