Low Temperature Molten Sodium Batteries

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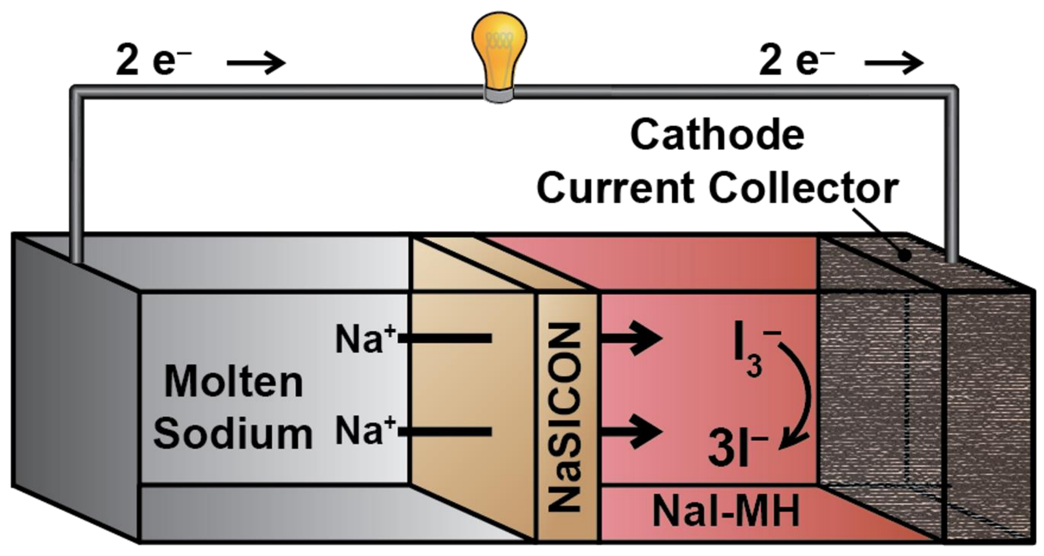
Motivation & Objective: High temperature operation restricts adoption of traditional molten sodium batteries due to increased material costs, lower battery lifetimes, and issues with safety. We are developing low temperature (<150 °C), high performance molten sodium batteries that promise cost-effective, safe energy storage for a resilient electric grid. This year we focused on increasing current density to decrease battery costs.



Overview: Low Temperature Molten Sodium Batteries

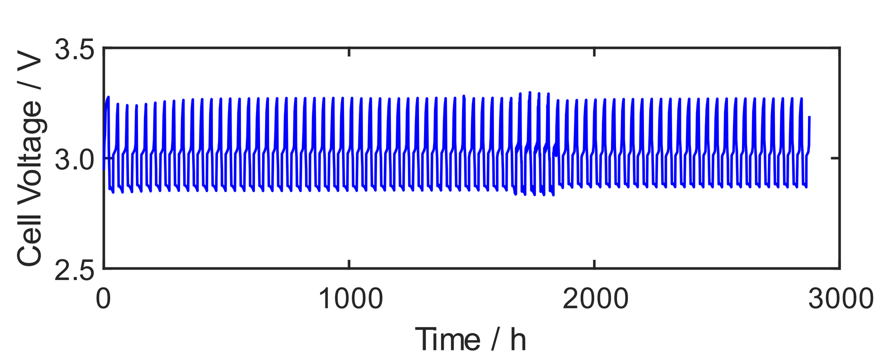
Goals
- Temperature < 150 °C
- Low-cost materials
- Performance similar to or exceeding that of high temperature Na batteries

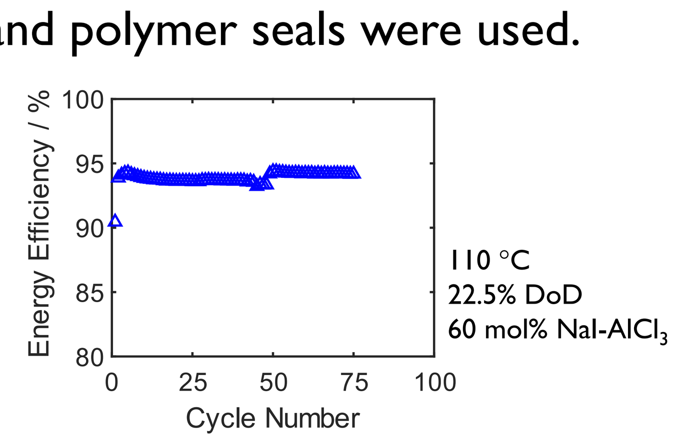
Components
- Molten sodium (Na) anode
- NaSICON solid electrolyte separator
- Inorganic NaI – MH (metal halide) catholyte, NaI – $AlCl_3$.

Redox Chemistry
$$Na \rightarrow Na^+ + e^-$$
$$I_3^- + 2e^- \rightarrow 3I^-$$
$$2Na + I_3^- \rightarrow 2Na^+ + 3I^-$$
E^0_{cell} ~ 3.1 V

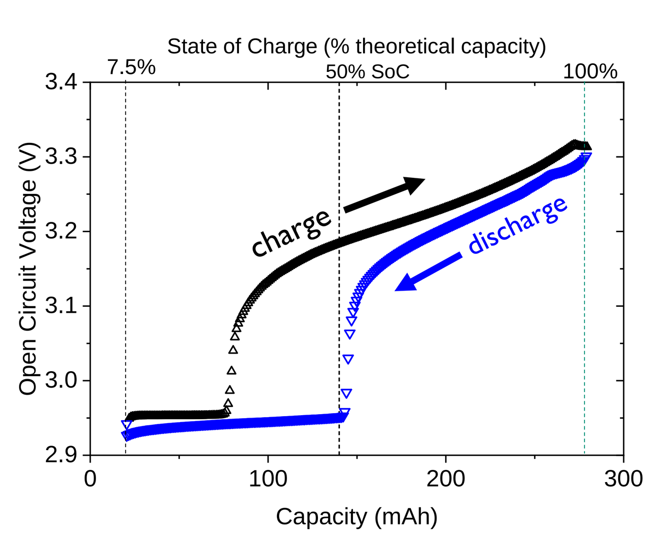
Long Term Cycling Using an Inexpensive, Energy Dense Metal Halide Catholyte

Long term cycling at 110 °C, low current (2.5 mA cm^{-2}), and moderate depth of discharge (22.5% of theoretical) yielded high energy efficiencies >93%. An inexpensive $AlCl_3$-NaI catholyte and polymer seals were used.





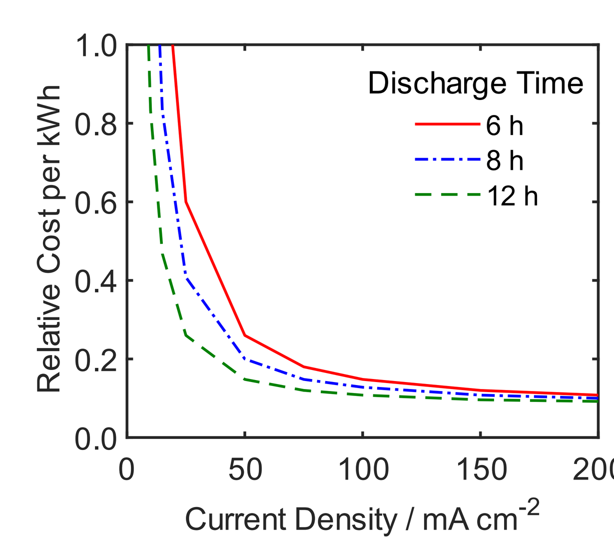
In other experiments, 92.5% of theoretical capacity was cycled at low currents (2.5 mA cm^{-2})



200 Wh kg^{-1} demonstrated at 2.5 mA cm^{-2}, 110 °C.

A.M. Maraschky et al. *J. Phys. Chem. C*, **127** (2023) 1293-1302. ***Invited Paper***.

High Current Drives Down Costs

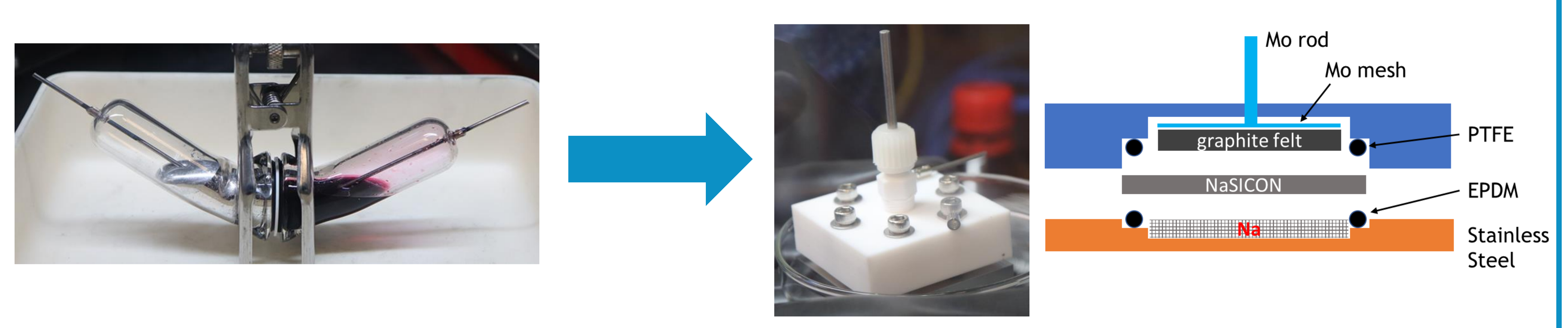


- Present applications for molten sodium batteries require 6-12 hour discharge times.
- The higher the current density, the more active material needed in each cell.
- More active material lowers overall cell cost per kWh by minimizing the relative amount of inactive material (insulation, wiring, housing, etc.).

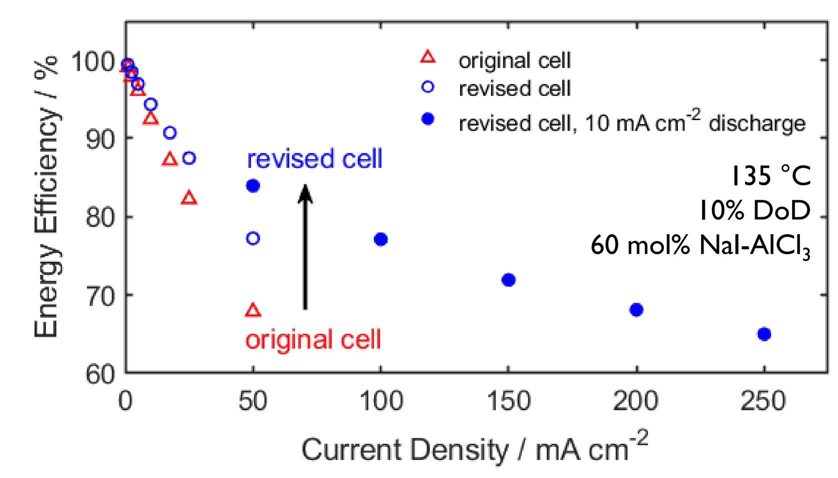
Higher Current Density Needed!
Goal: ≥50 mA cm^{-2}

Cell Redesign Enables 20× Improvement in Current Density

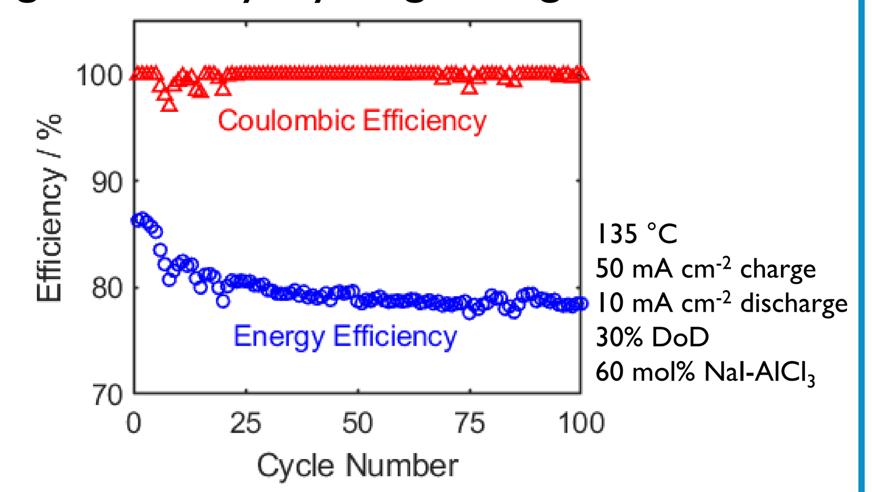
The cell was redesigned to align graphite felt parallel to NaSICON and more uniformly compress the felt, decreasing cell resistance, and providing further design flexibility.



Improved Rate Capability and Efficiency



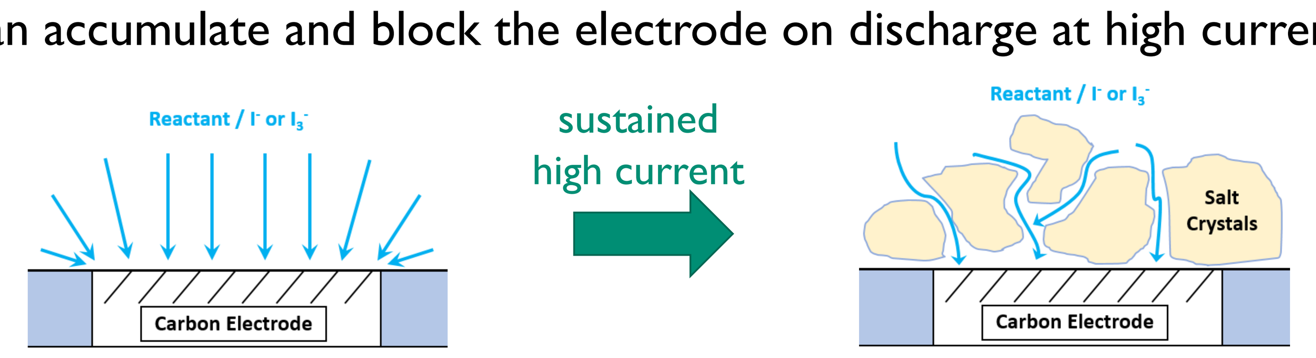
High Efficiency Cycling at Higher Current



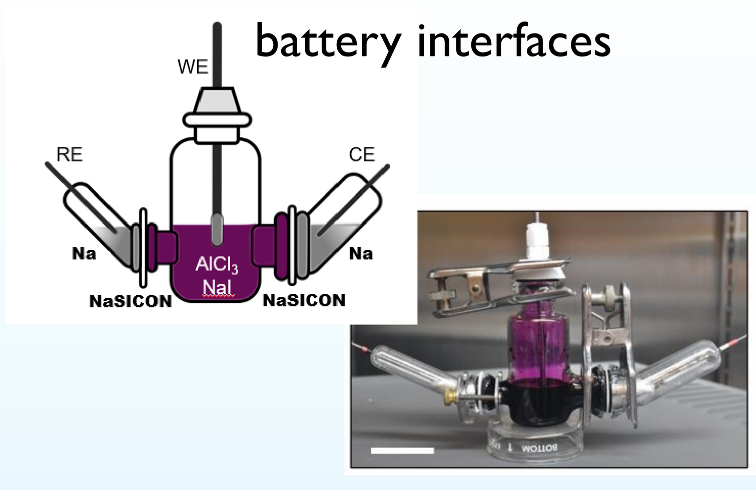
Successfully cycled at 50 mA cm^{-2} with charging currents as high as 250 mA cm^{-2} possible at 135 °C!

NaI Precipitation Limits Discharge Performance

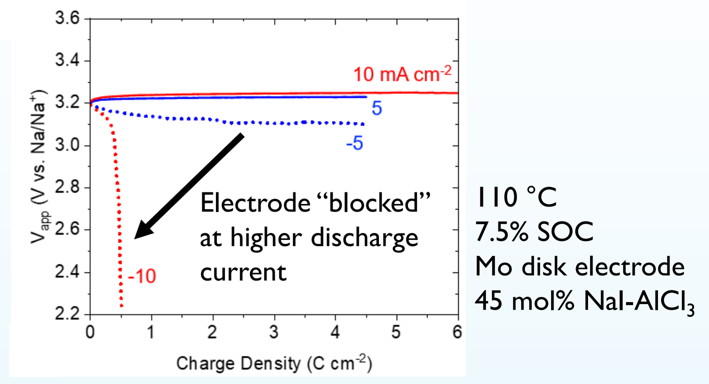
We leveraged a custom-designed 3-electrode cell to isolate battery interfaces and understand what was preventing high currents on battery discharge. From these experiments we inferred that NaI precipitation, from reduction of I_3^- containing species, can accumulate and block the electrode on discharge at high current.



3 Electrode cell used to isolate battery interfaces



Constant Current Experiments



Electrode blocking is reversible and can be avoided at low ***electrode*** currents. Optimization of electrode area to NaSICON area is needed.

A.M. Maraschky et al. *J. Electrochem. Soc.*, **170** (2023) 066504.
S.J. Percival et al. *J. Electrochem. Soc.*, **165** (2018) A3531-A3536.

Conclusions & Future Work

- **NaI – $AlCl_3$ catholyte delivers excellent performance at low currents, but higher currents are needed to drive costs lower.**
  - NaI precipitation on discharge limits max discharge current.
  - Revised cell design increases max achievable current density >20x, with more optimization possible.
- 4 Publications (3 published, 1 in review)
- **Future work**: Optimization of planar cell design to (1) increase energy efficiency at >50 mA cm^{-2}, and (2) enable deep discharge at >50 mA cm^{-2}.

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