Low Temperature Sodium Batteries

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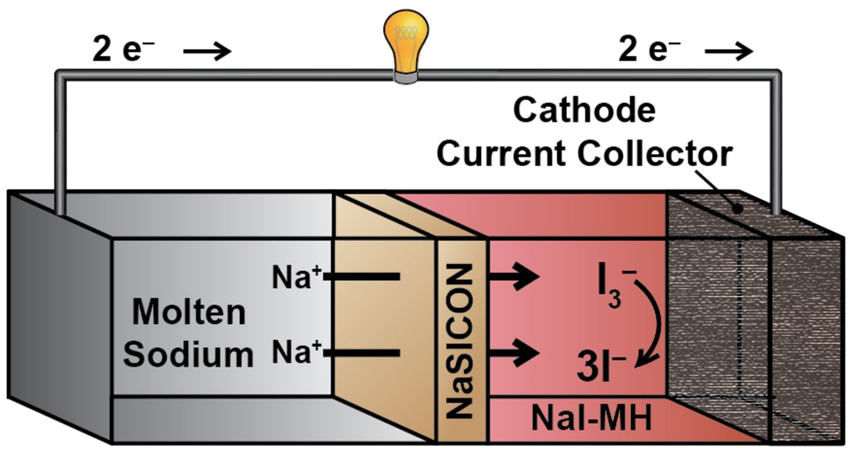
Motivation & Objective: High temperature operation restricts adoption of traditional molten sodium batteries due to increased material costs, lower battery lifetimes, and issues with safety. We are developing low temperature (<150 °C), high performance molten sodium batteries that promise cost-effective, safe energy storage for a resilient electric grid. This year we focused on increasing accessible capacity at high current 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, 60 mol% NaI – 40 mol% $AlCl_3$.

Redox Chemistry

$Na \rightarrow Na^+ + e^-$

$I_3^- + 2e^- \rightarrow 3I^-$

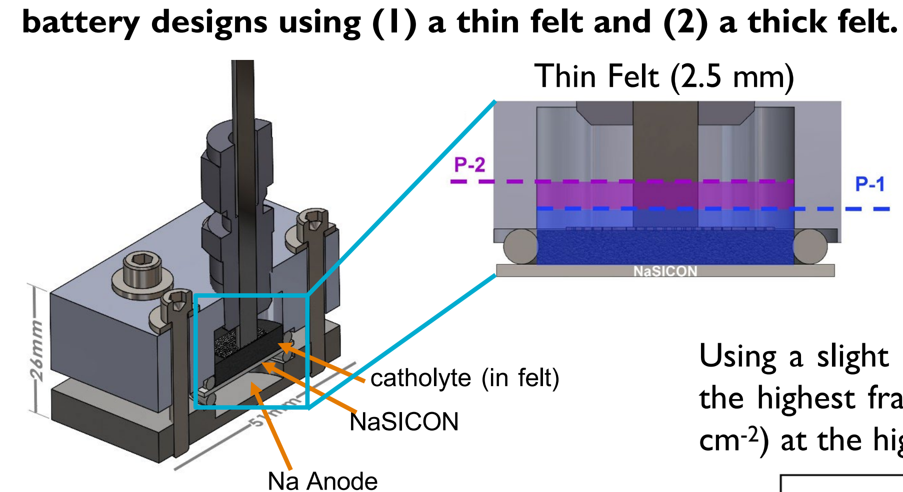
$2Na + I_3^- \rightarrow 2Na^+ + 3I^-$

$E^0_{cell} \sim 3.1$ V

Optimizing Battery Components to Increase Accessible Capacity

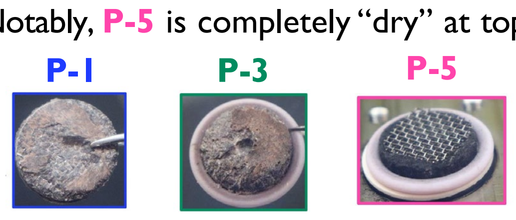
We evaluated different ratios of catholyte to cathode current collector (graphite felt) to understand how these ratios influence accessible capacity at high current. Five different ratios were investigated at 135 °C: P-1, P-2, P-3, P-4, P-5.

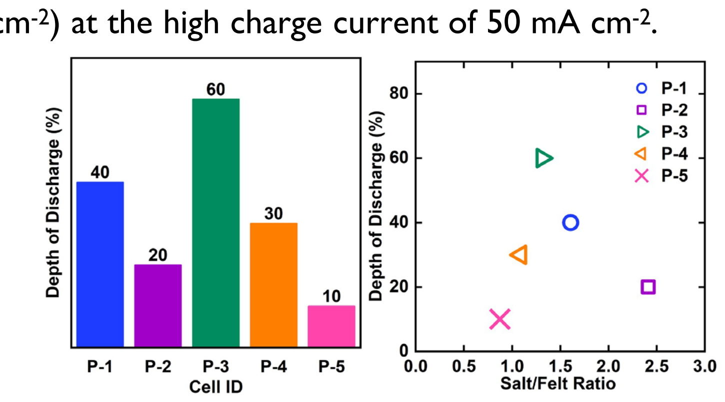
A sodium battery Solidworks model was used to calculate liquid heights for different battery designs using (1) a thin felt and (2) a thick felt.



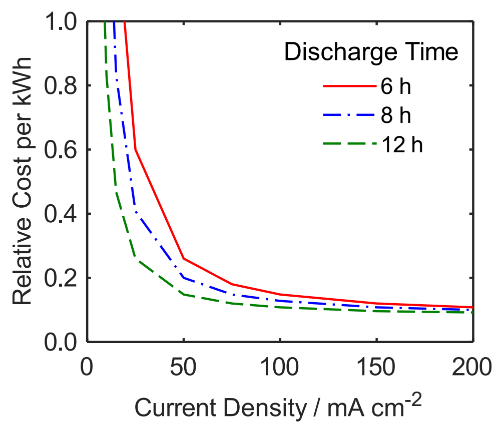
Using a slight excess volume of catholyte, P-3 accessed the highest fraction of theoretical capacity (60%, 0.1 Ah cm^{-2}) at the high charge current of 50 mA cm^{-2}.

Photographs of graphite felt current collectors upon disassembly agree with model predictions. Notably, P-5 is completely "dry" at top.





High Current Drives Down Costs

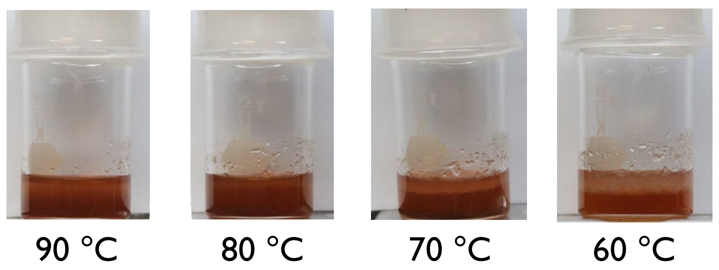


- Present applications for molten sodium batteries require 6-12 hour discharge times.
- The higher the current density, the more active material needed in each cell.
- More active material lowers overall cell cost per kWh by minimizing the relative amount of inactive material (insulation, wiring, housing,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

Current Densities ≥50 mA cm⁻² Are More Cost Competitive

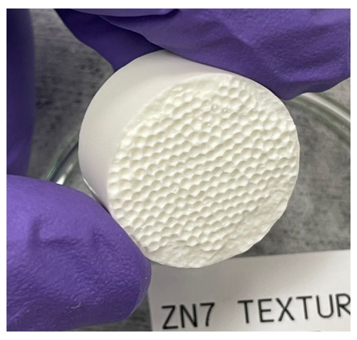
Lowering Battery Temperature <100 °C

Widespread interest in sodium-ion batteries led us to investigate if these sodium batteries could be operated at <100 °C using solid sodium.



We screened >12 inorganic molten salt systems to determine melting point and phase stability. Adding select Lewis bases at 10-20 mol% enables our $AlCl_3$-NaI based salt to remain molten at 60 °C.

To achieve our high current goal with solid sodium, significant increases in surface area will be needed between the solid sodium and NaSICON. We are developing structured sodiophilic NaSICON surfaces to increase this interfacial area. See poster by I.D. Dyer for more information.

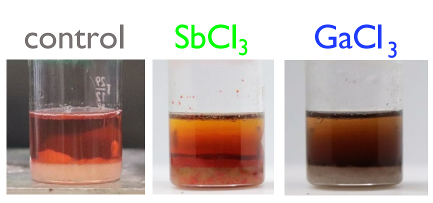


These anode and cathode materials are being combined and tested in a battery.

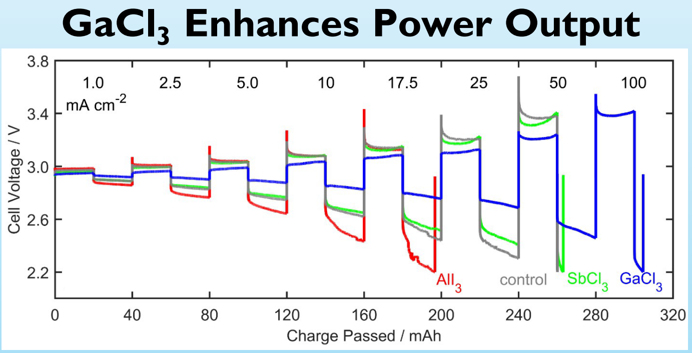
Trace Additives Enhance Efficiency and Power Output

Using the optimal ratio of catholyte to cathode current collector determined above (P-3), we evaluated the ability of trace amounts (1 mol%) of 6 Lewis acids to increase the power output of the molten sodium batteries, by minimizing the "electrode blocking" effects previously seen at high power and long times.

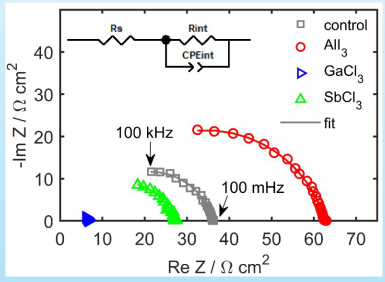
Additives screened (control (no additive), AlI_3, $BiCl_3$, $GaCl_3$, $SbCl_3$, $SnCl_2$, SnI_2) produced obvious visual changes despite being present at only 1 mol%. Electrochemical screening lead to down selecting to $SbCl_3$ and $GaCl_3$ for incorporation into 0.3 Ah (0.17 Ah cm^{-2}) batteries at 135 °C. Additionally, a control and poor performer (AlI_3) were run.



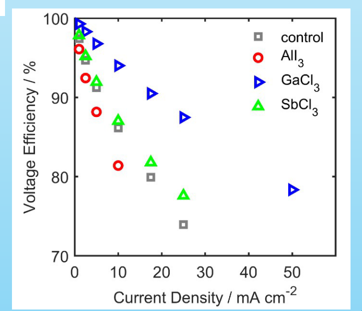
$GaCl_3$ Enhances Power Output



Max power output: AlI_3<control<$SbCl_3$<$GaCl_3$



1 mol% $GaCl_3$ decreases the battery's impedance, as measured by impedance spectroscopy.



Decreased impedance for the $GaCl_3$ additive results in higher voltage and energy efficiency.

Conclusions & Future Work

- **NaI – $AlCl_3$ catholyte delivers excellent performance at high currents necessary for cost competitive operation, using optimized cell design and select additives.**
  - Accessible capacity increased from 40 to 60% of theoretical at 50 mA cm^{-2}, 135 °C.
  - >100 mA cm^{-2} charge current possible, more work needed to increase discharge current
- 3 publications in review

Future work
- Long term cycling of additive batteries (in progress) to assess stability
- Integration of low temperature molten salt and high surface area NaSICON to operate a high power sodium battery at 60-80 °C.

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