Sodium-based Battery Development

A Family of Batteries for Large Scale Energy Storage

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US DOE Energy Storage Systems Research Program Peer Review, Washington, DC, Sept. 26-28, 2012

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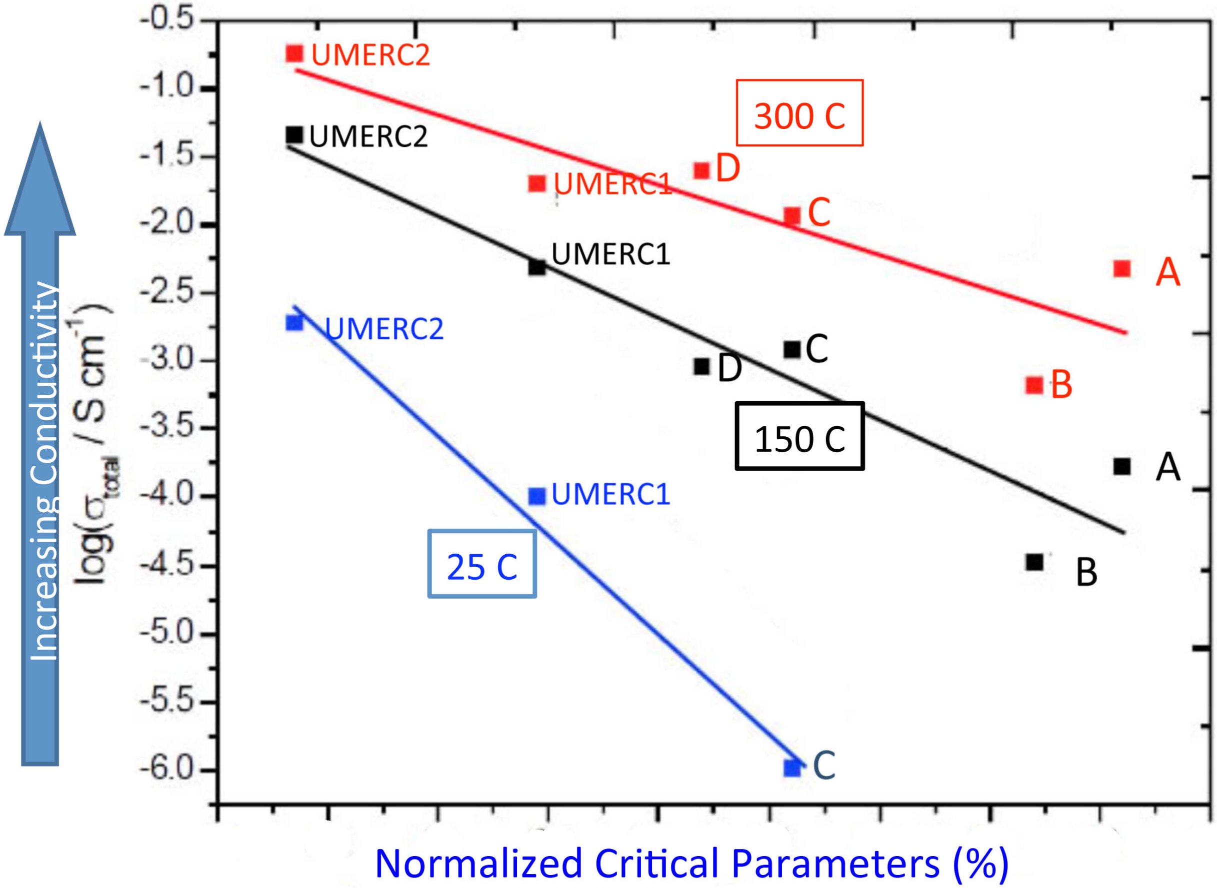
Sodium-based batteries

- Purpose
  - Demonstrate a family of sodium-based battery chemistries
    - sodium-iodine, sodium-bromine, sodium-air, sodium insertion, sodium-metal, etc
- Goals
  - reduce the cost of power to values consistent with large-scale application needs, e.g. load leveling, frequency regulation, UPS, etc.
  - reduce the cost of energy to < 100 $/kWh

- Approach – multi-organizational, multidisciplinary team encompassing both science and engineering
  - employ NaSICON as a solid ceramic separator/electrolyte
    - stable against molten sodium anode
    - high conductivity
    - variety of structures can/have been made, plates, tubes, supported membranes, etc
    - manufacturing demonstrated
  - demonstrate laboratory prototypes of various cell chemistries
  - utilize advanced *materials* diagnostics & and development to understand behavior and improve performance using laboratory prototypes

Toward improved materials

- Increasing the performance of NaSICON
  - developed hypothesis about what is necessary for Na^+ mobility, and what can be done to improve it
  - validated hypothesis - synthesized & measured several materials
  - made predictions to improve performance
  - demonstrated improved performance with new materials
- Other Predictions made about how to further improve performance, and new materials being prepared



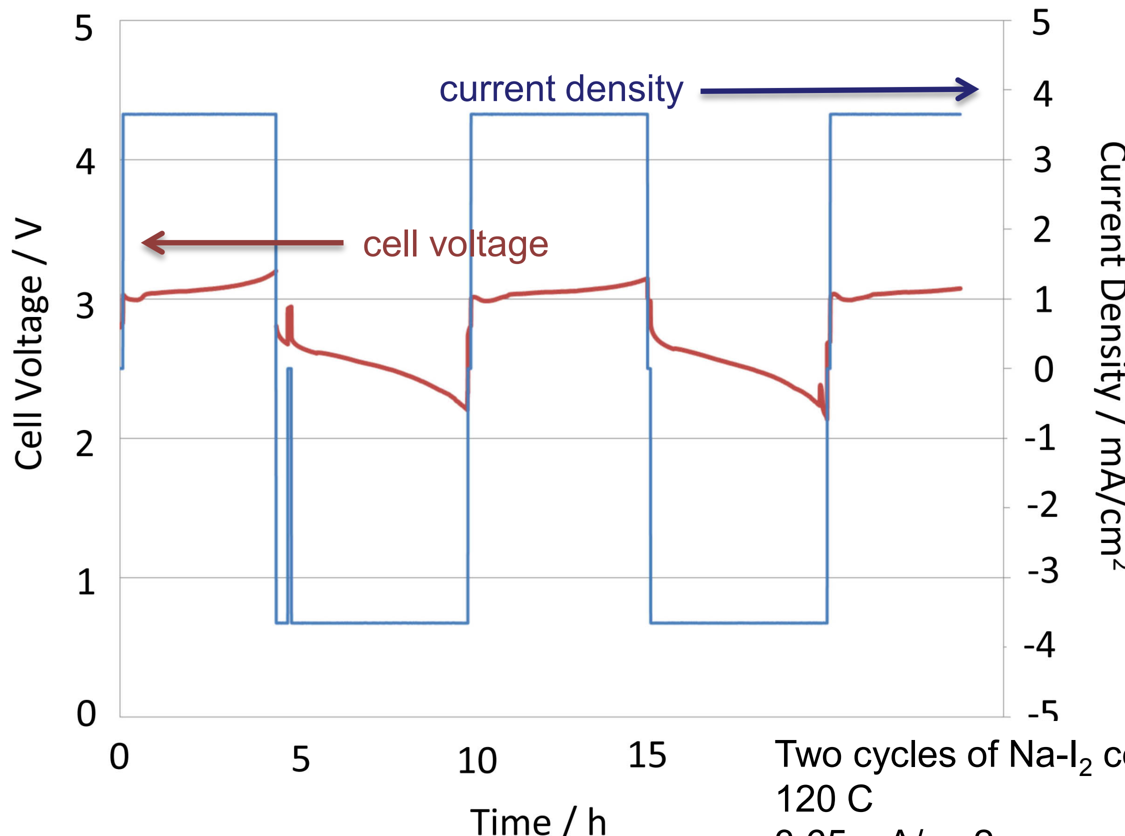
E. Wachsman, UMERC

Laboratory Prototypes

- Sodium-iodine - furthest along
  - sealed cell
  - thousands of cycles at high DOD
  - three catholytes developed and are being evaluated
    - I_2 vapor pressure not an issue
- Sodium-bromine – catholytes under development
- Sodium-metal (Zebra analogs) - have demonstrated cells
  - dendrites are an issue at the cathode
- Sodium-insertion – have developed cathodes and demonstrated cells
- Sodium-air – bifunctional catalyzed electrode at early stages of development

Redox Reactions

Anodic	Na	↔	$Na^+ + e^-$	-2.71V
Cathodic	$2I^- + 2e^-$	↔	I_2	0.54V
Overall	$2Na^+ + 2I^-$	↔	$2Na + I_2$	3.25V



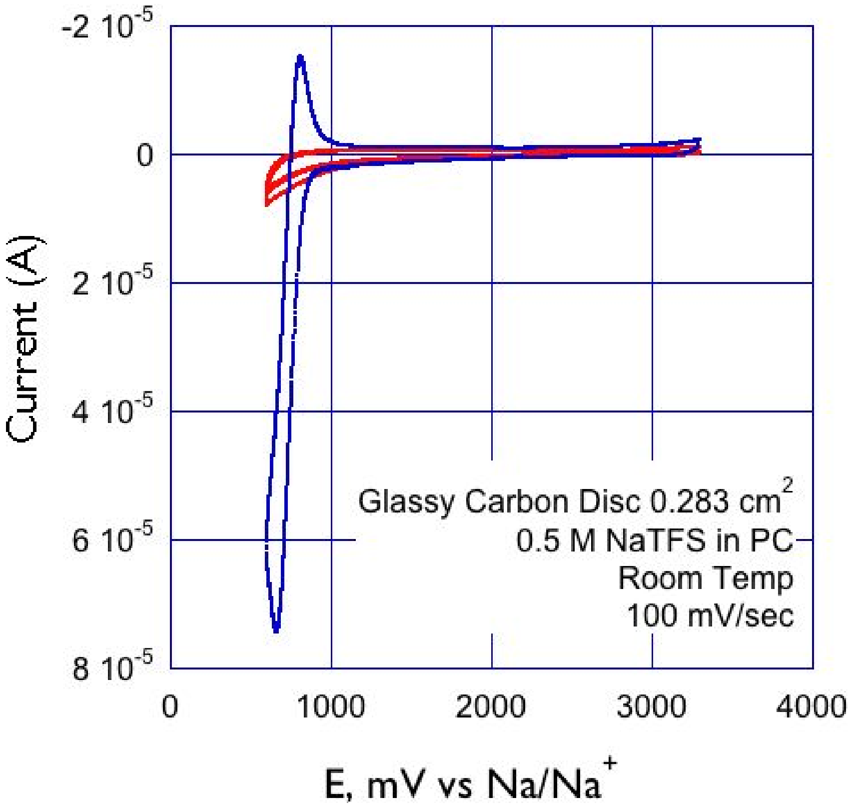
Two cycles of $Na\text{-}I_2$ cell
120 C
3.65 mA/cm2
50% DOD

S. Bhavaraju, Ceramatec

Alternative Anodes

- Baseline anode – sodium metal
  - high energy density
  - low cost
  - molten above 100 C
    - no dendrites
  - below 100 C, solid
    - employing secondary electrolyte
    - dendrites
- Other anodes being developed
- that allow:
  1. flow configuration
  2. eliminate/mitigate dendrite issues at temperatures below 100 C

➢ lower energy density, but:
  - ➢ can be more easily pumped than sodium metal
  - ➢ simplifies means for eliminating shunt current associated with molten sodium (metallic conductor)
  - ➢ engenders lower cost plumbing than sodium metal

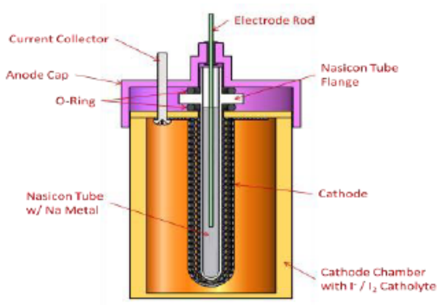


Cyclic Voltammogram showing redox behavior of possible alternative anode.

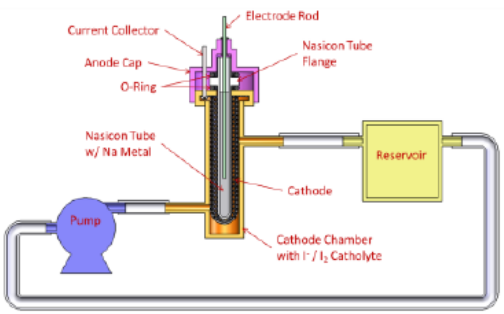
D. Ingersoll, SNL

Modeling as an Aid to Cell Design

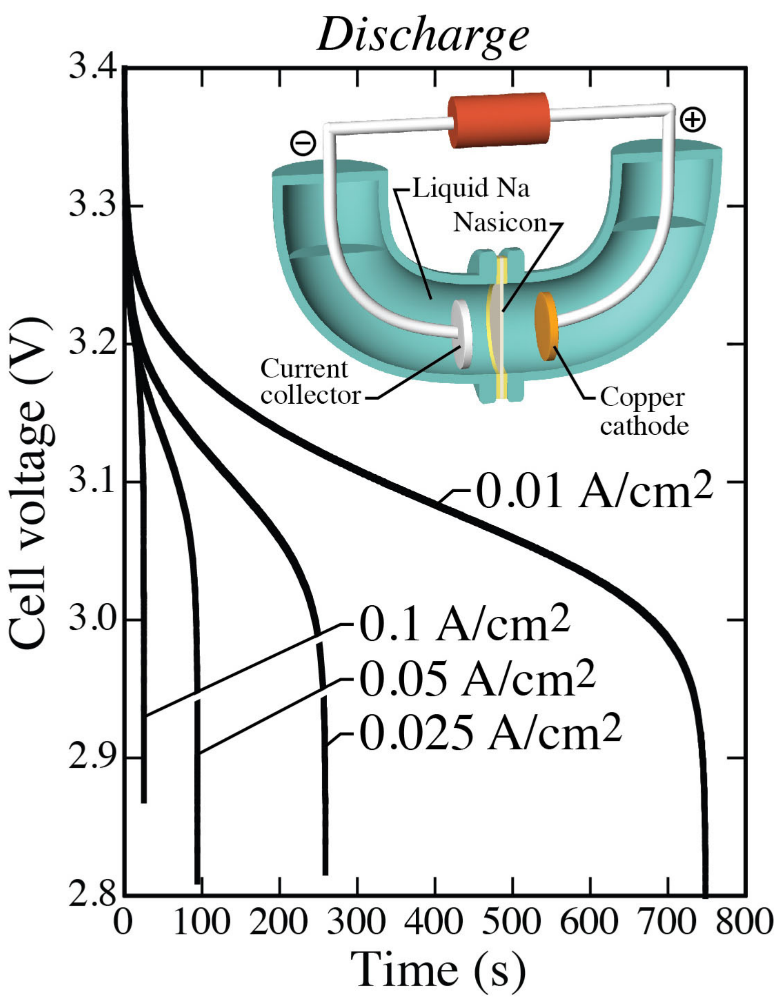
- Derive and implement physically based *predictive* models
- Apply models to aid in cell design and system development
  - Models to predict charge & discharge behavior as functions of:
    - geometry – cell design
    - operating conditions – temperature, cell operation, cell chemistry, etc
- Model for Sodium-metal (Zebra-analog) system developed
  - Ion transport limitations limit charge and discharge capacity at high rate
- Have begun to use the model for cell design for the sodium-iodine system



Non-flow design



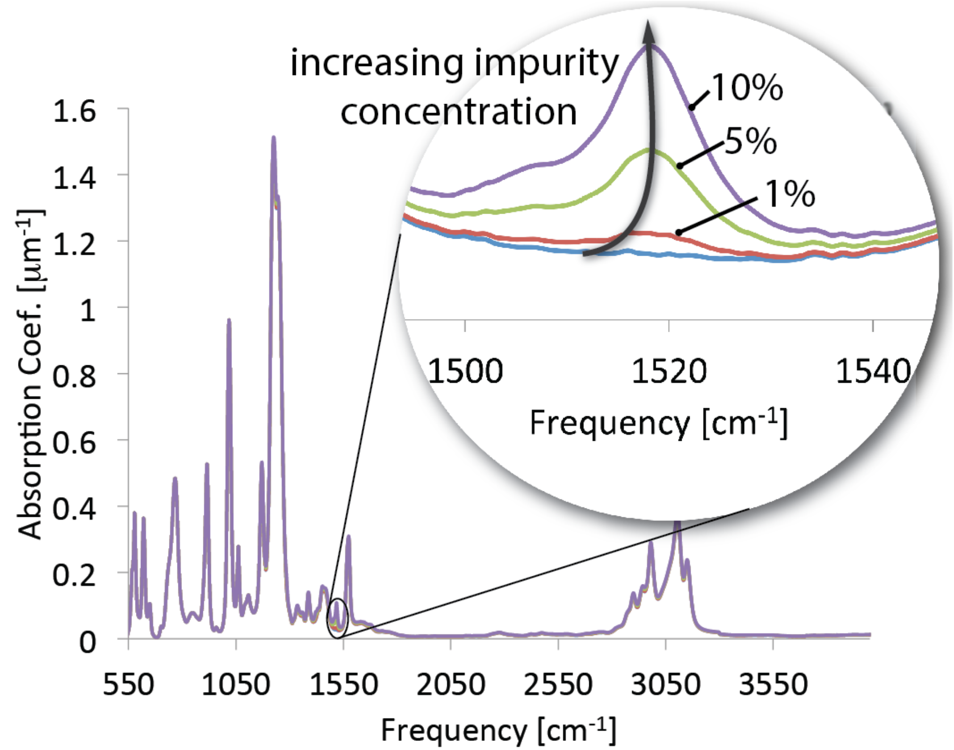
Hybrid design



R. Kee & Z. Hu, CSM

Advanced Diagnostics for Materials Development

- Develop and employ advanced diagnostics for materials characterization
  - NMR, TOF-SIMS, scanning probes, etc
  - includes for use in-situ to detect materials degradation and lifetime stability issues – e.g. long term stability of the catholytes or impurity detection in feedstocks
- We are currently using Room Temperature Ionic Liquids (RTILs) as a part of select catholyte formulations
  - low vapor pressure
  - thermally stable
  - electrochemically stable
  - but cost still high
    - cost reduction strategy - partnered (unpaid) with Boulderionics
- Techniques being developed, and baseline data being obtained using optical spectroscopies:
  - FTIR
  - UV-vis
  - fluorescence



FTIR of select RTIL used to quantitate impurities

J.M. Porter & C.B. Dreyer, CSM

FY13 Future Work

- Demonstrate sodium-air laboratory prototype
- Demonstrate sodium-bromine laboratory prototype
- Demonstrate improved solid ceramic membrane
- Continue materials development
  - improved ceramic
  - cathodes and electrolytes
  - We also have a poster that describes some of the other materials development activities

Acknowledgements

- Dr. I. Gyuk
  - DOE Office of Electricity