Development of High Energy Density Li-Sulfur Cells

Donghai Wang
The Pennsylvania State University

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Project ID #ES125

OVERVIEW

Timeline

44% completed

Start: Sep. 30, 2011

End: Jan. 15, 2015

Barriers Addressed

- Power and energy density
- Cycle and calendar life
- Abuse tolerance

Budget

- FY 2012: $2,166,675
  - •DOE share:$$1,524,373
  - •Cos share: $642,302
- FY 2013: $2,405,452
  - •DOE Share: $1,642,452
  - •Cost Share: $763,000

Partners

- EC Power
- Johnson Controls
- Argonne National Lab

RELEVANCE - OBJECTIVES

Develop a **full lithium-sulfur battery system** for high energy density, efficiency, and good cycle life, and safe operation.

Project scope

Design of full lithium-sulfur cell:

- Nanocomposite Sulfur Cathode – high energy/power, stable
- Advanced Lithium- or Silicon-Based Anode – high energy/power, stable
- Electrolyte – nonflammable, stable, low self-discharge
- Optimized cell design

Performance targets

4Ah cells

600 Wh/L (cell level)

Cycle life 500+ cycles

Excellent safety characteristics

MILESTONES

1. **Advanced material development and characterization** (10/2011-09/2012)
   - Evaluate baseline cells
   - Develop and test 1st-generation cathode, anode, electrolyte
   - Thermal and failure mechanism studies
2. **Material scale up and 1Ah pouch cell development** (10/2012-09/2013)
   - Cathode and anode scale-up, continued improvement, and 1 Ah pouch cell design and testing
   - Continued investigation of electrolytes and failure mechanisms
3. **Large format prismatic cell design** (10/2013-09/2014)
   - Continued scale-up, failure mechanism analysis, and 4 Ah prismatic cell design and testing
   - Cell modeling and optimization

KEY DELIVERABLES

- 1st set (NCM Baseline Cells): Cell size: ~ 1Ah pouch cells. **[**Completed**]**
- 2nd set (Li-S Cells): Cell size: ~ 1Ah pouch cells. **[**Sep. 2013**]**
- 3rd set (Li-S Cells): Cell size: ~ 4Ah pouch cells. **[**Sep. 2014**]**

Approach - Overview

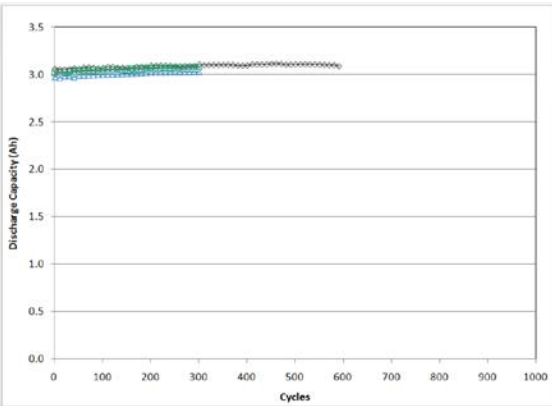
Anode	Investigating/optimizing Li and Si composite anodes Exploring polymer electrolytes
Cathode	Investigating sulfur-carbon nanocomposites Pursuing methods for increased sulfur loading
Electrolyte	Determining new electrolytes and additives Assessing and developing novel solvents Optimizing electrolytes for high capacity and low self-discharge
Cell design	Optimizing cells design for chemistry requirements Conducting modeling and experimental testing

Technical Accomplishment and Progress

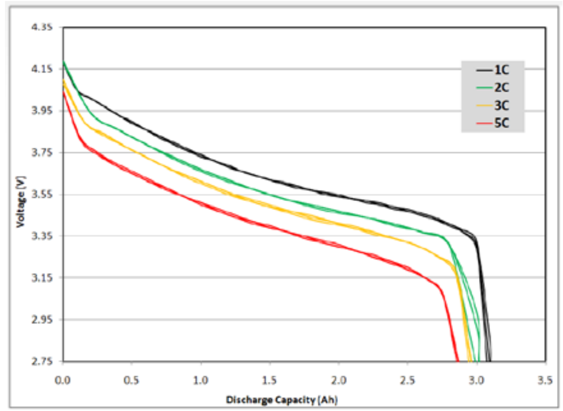
- Scaled up cathode material production to 50g level, with plans for further scale-up to 500g level
- Developed cathode composites for improve polysulfide adsorption, high sulfur loading, and improved rate performance
- Developed electrolytes capable of stable cycling with 1200 mAh/g capacity
- Developed improved Li powder-based and Si-based anodes
- Characterized thermal safety of many Li-S cell components
- Delivered baseline cells for independent testing

Submitted Baseline Cells for Independent Testing

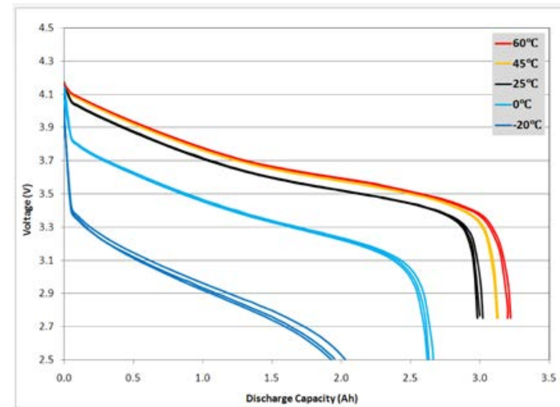
Cycling Performance



Rate Performance

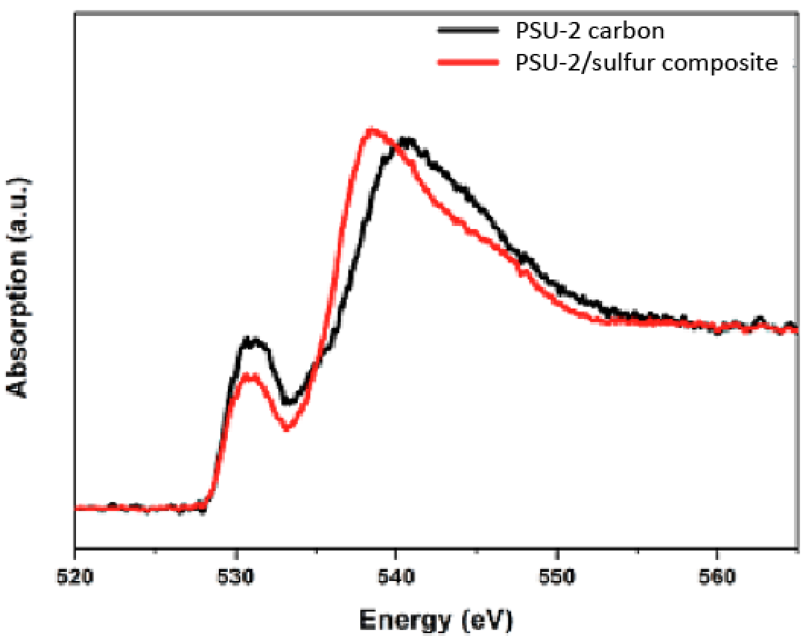


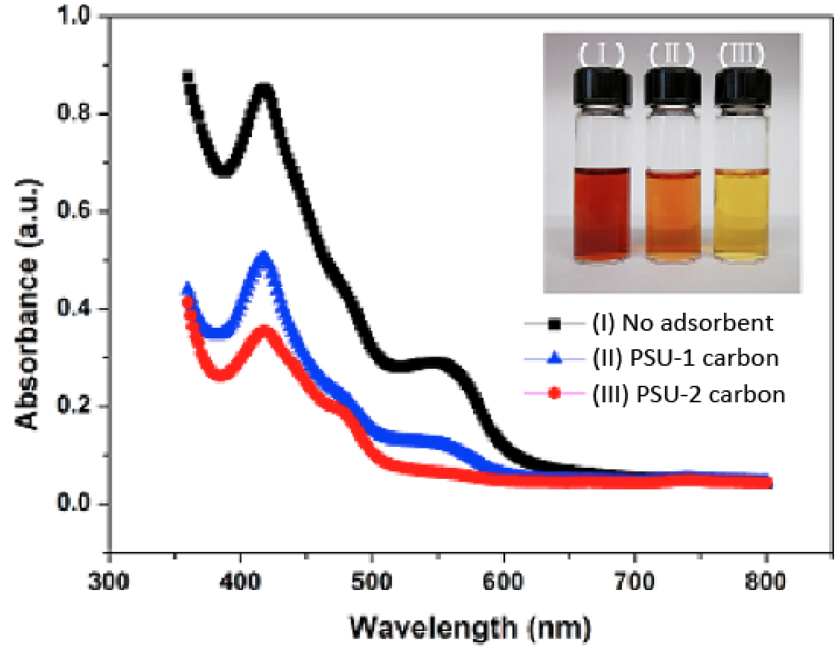
Temperature Performance



- 3Ah baseline NMC/graphite cells were tested and showed 100% capacity retention after 600 cycles at 1C rate and 92.7% retention after 300 cycles at 5C rate.
- Cells were submitted for independent testing by Idaho National Lab.

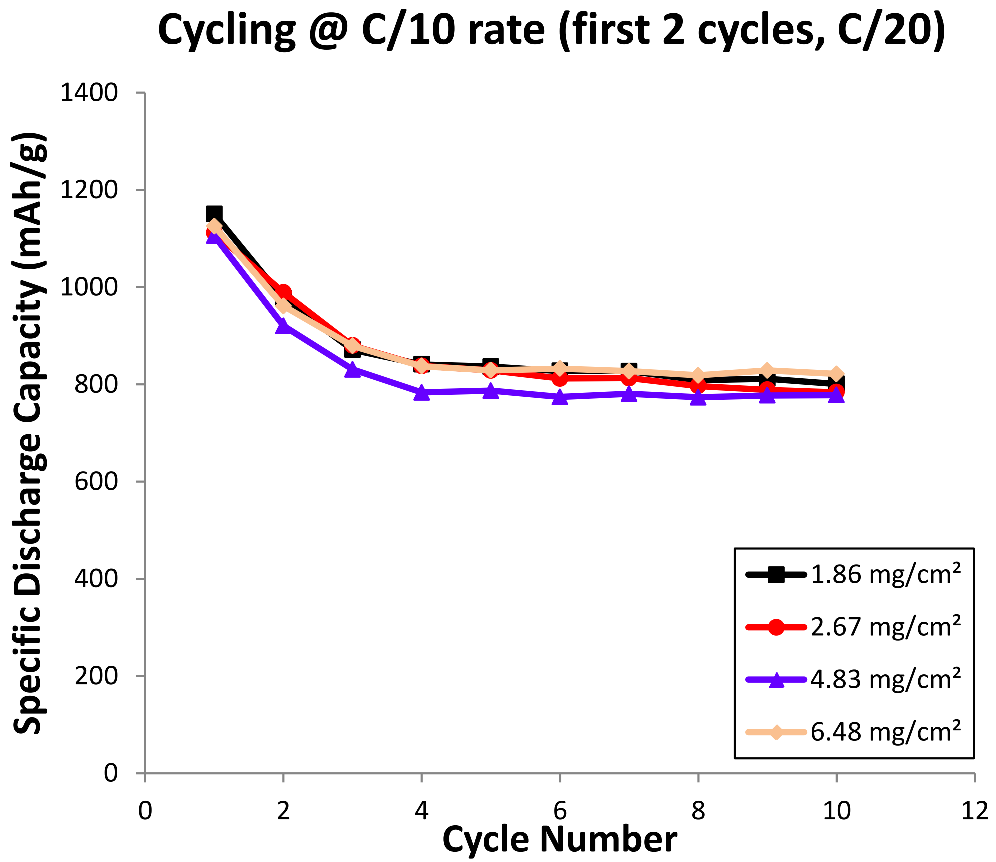
PSU-2 Sulfur Cathodes with Improved Sulfur Adsorption





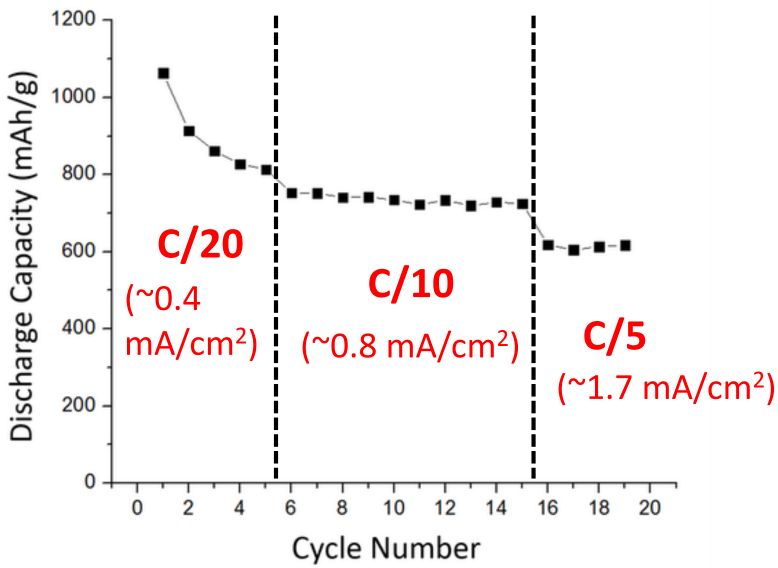
- UV-vis spectroscopy (right) shows that PSU-2 cathode material traps sulfur better than the baseline PSU-1 cathode material.
- XANES (left) shows interaction between oxygen and sulfur in PSU-2 carbon.

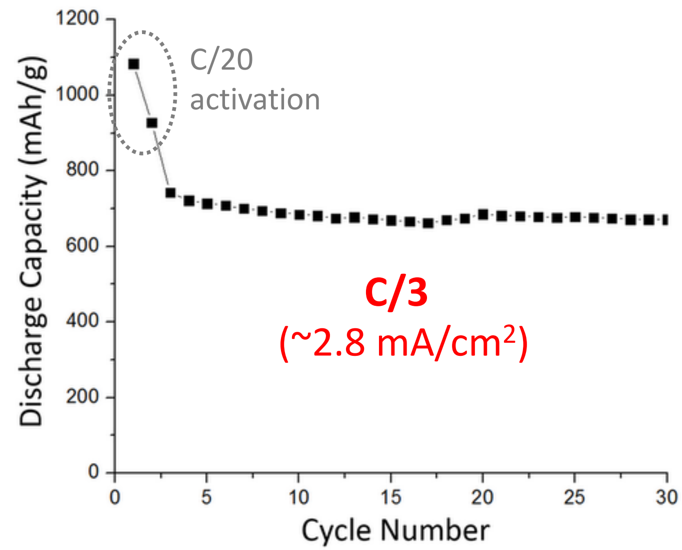
PSU-3 Sulfur Cathodes with High Sulfur Loading



- PSU-3 cathodes are able to achieve much higher loading than the baseline PSU-1 cathodes while maintaining good performance.

High-Loading PSU-4 Sulfur Cathodes with Improved Rate Performance



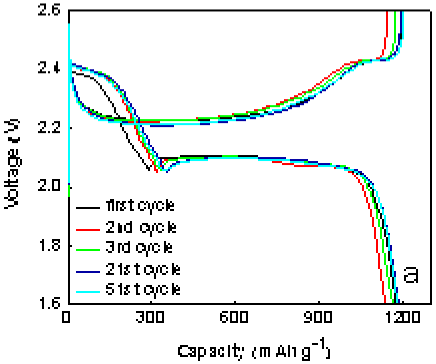


- PSU-4 cathodes have a high sulfur loading of 5 mg/cm^2 and greatly improved rate performance over previous cathode designs.

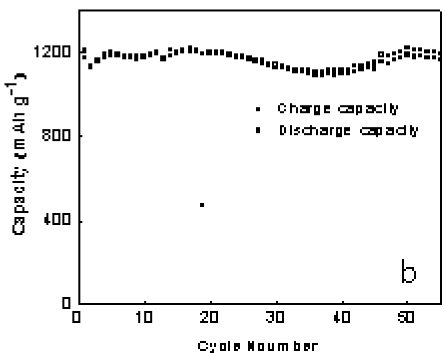
HIGH-PERFORMANCE ELECTROLYTES

ANL-E-1

Charge/Discharge Curves

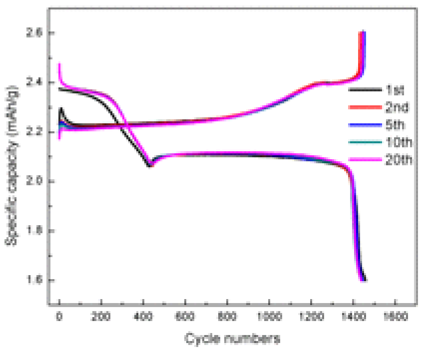


Cycling Performance

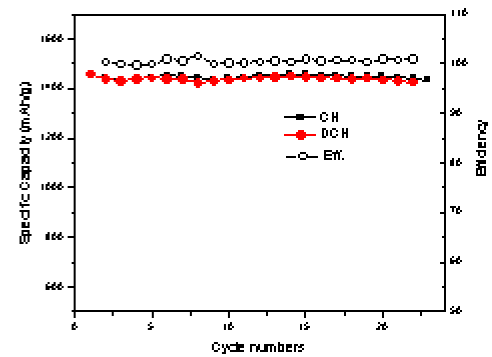


PSU-E-1

Charge/Discharge Curves

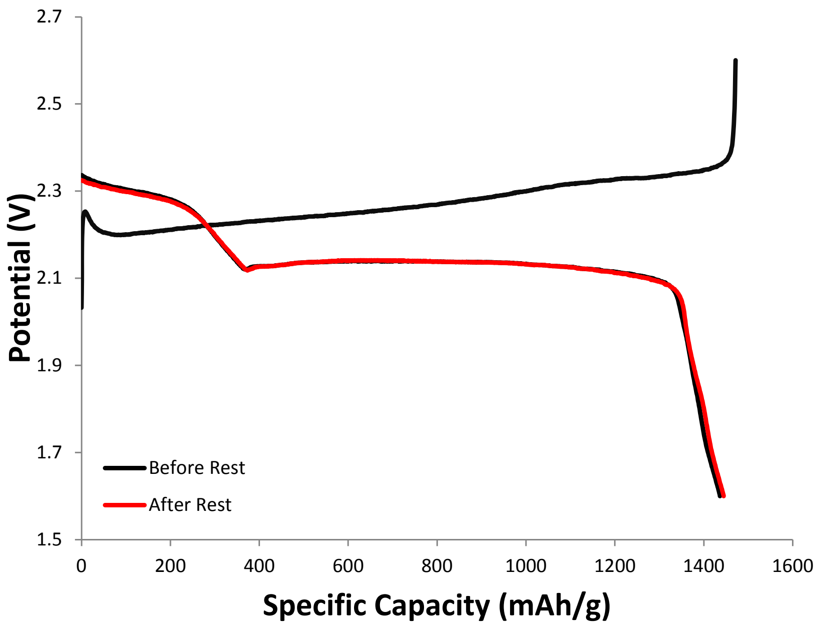


Cycling Performance



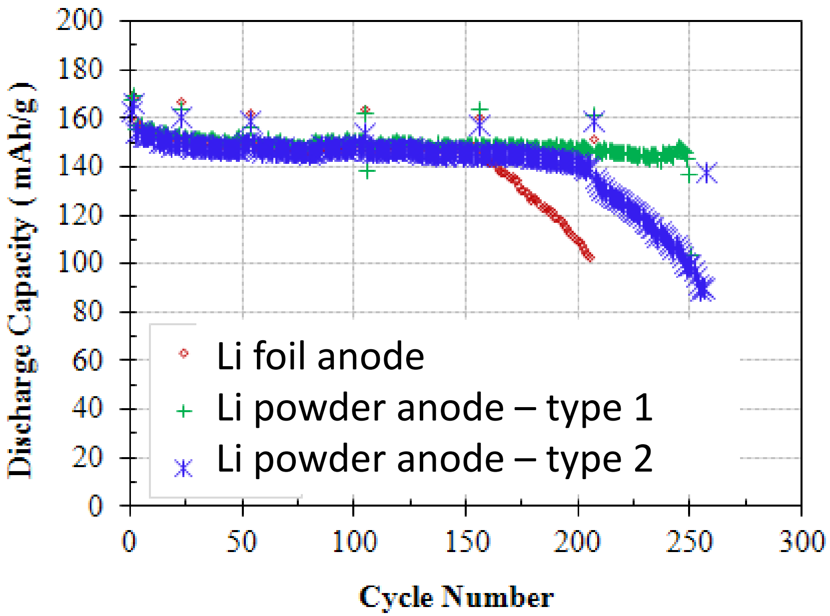
- New ANL-E-1 and PSU-E-1 electrolytes showed excellent cycling performance and coulombic efficiency with both PSU-1 and simple ball-milled sulfur cathodes.

Self-Discharge of Li-S Batteries



- Self-discharge of Li-S cells with baseline electrolyte was found to be as high as high as 60% in 10 h at 40°C.
- With new PSU-E-2 electrolyte, self-discharge of cells with simple ball-milled sulfur cathodes with loading ~1 mg S/cm^2 was found to be less than 1% (shown above).

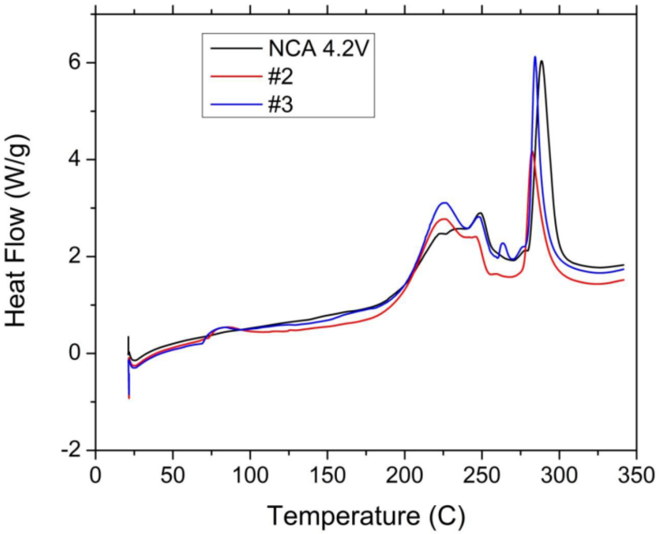
Li Powder-Based Anode



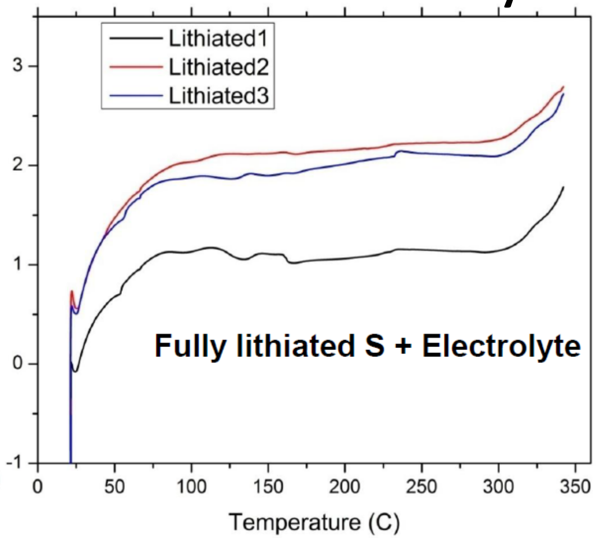
- Li powder-based anode shows cycling stability superior to that of Li foil.

Thermal Safety of Li-S Batteries

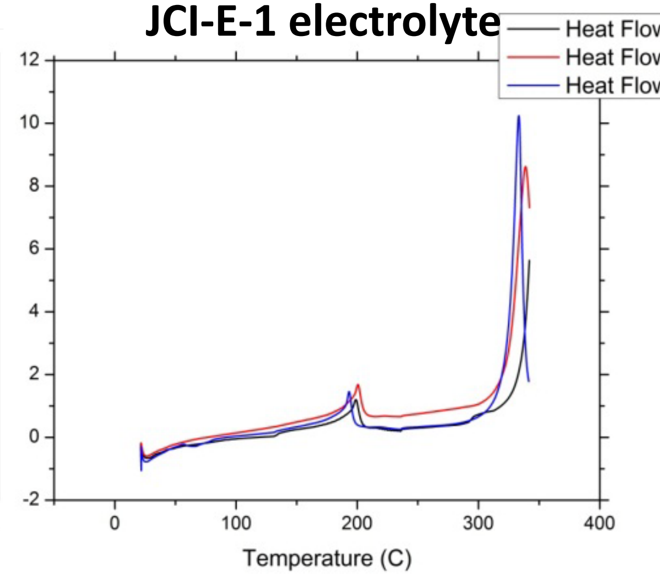
Comparison: NCA cathode



Lithiated PSU-1 cathode with baseline electrolyte

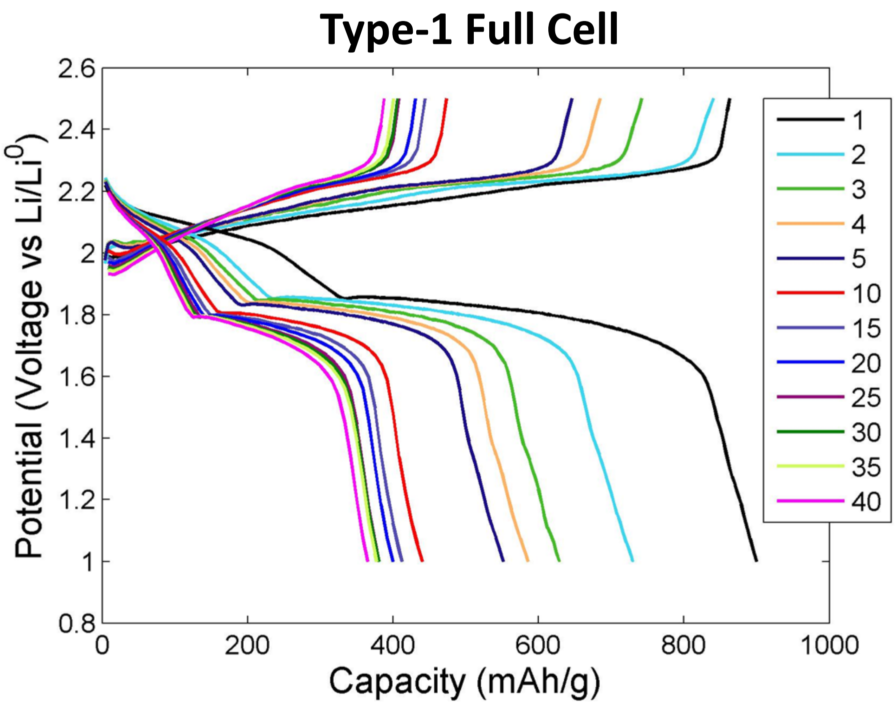


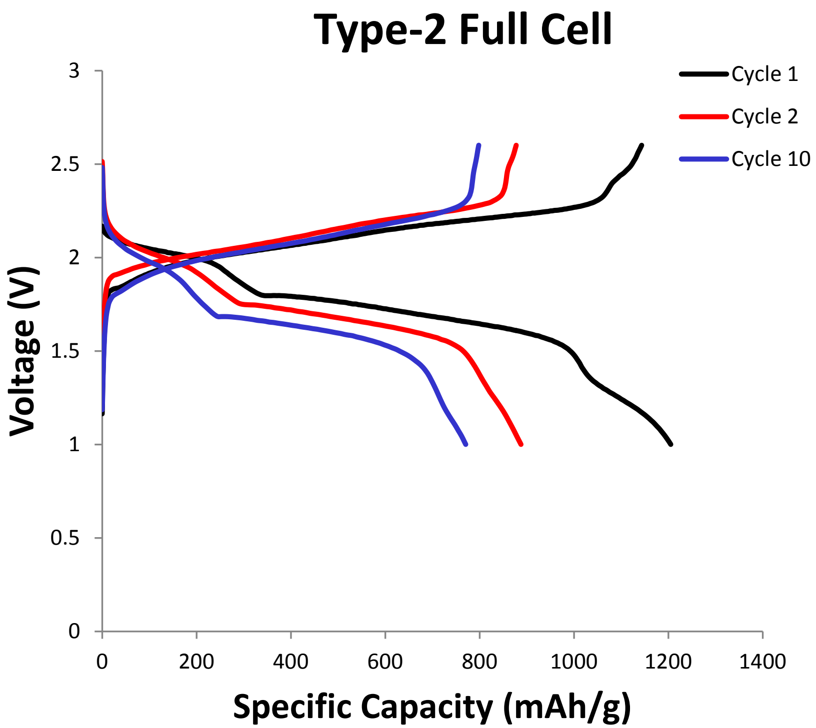
Si-based anode with JCI-E-1 electrolyte



- The PSU-1 sulfur cathode has excellent thermal stability in electrolyte even after cycling - no major thermal events up to at least 350°C.
- The Si-based anode with JCI-E-1 electrolyte has very good thermal stability - no major thermal events up to 330°C.

SILICON/SULFUR FULL CELLS





- Silicon/sulfur full cells were successfully cycled.
- Cell disassembly and separate half-cell testing for type-1 cells showed that capacity loss was primarily related to sulfur loss from the cathode.

COLLABORATION

- Worked with Johnson Controls, Argonne National Lab, and EC Power to establish strong project baselines.
- Working with Argonne National Lab on concurrent electrolyte development and testing.
- Working with Johnson Controls on silicon-based anode development, self-discharge testing, and overall cell testing and design.
- Working with EC Power on lithium powder-based anode development and overall cell design and testing.
- Independent testing of baseline cells is being conducted by Idaho National Laboratory.

Future Work

- Continue development of electrolyte systems for better overall battery performance, particularly in terms of lowering self-discharge and improving full-cell performance
- Further scale up cathode material production and improve cathode rate performance
- Perform extensive safety tests (nail penetration, oven testing, etc)
- Optimize full cell design and determine key parameters
- Design and test full 1 Ah pouch cells

Summary

- Scaled up cathode material production
- Developed cathode composites for high sulfur loading and improved rate performance
- Developed electrolytes capable of stable cycling with high capacity
- Characterized and addressed battery self-discharge
- Developed improved Li powder-based and Si-based anodes
- Characterized thermal safety of many Li-S cell components
- Delivered baseline cells for independent testing