Progress and Status of Battery500 Consortium

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Pacific Northwest National Laboratory

2020 DOE Vehicle Technologies Office Annual Merit Review
June 1-4, 2020

Project ID bat317

BATTERY 500 CONSORTIUM

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

Overview

Timeline

- Project start date: 10/01/2016
- Project end date: 9/30/2021
- Percent complete: 70 percent

Barriers

- Barriers addressed
  - Increasing the energy density of advanced lithium (Li) batteries beyond what can be achieved in today's Li-ion batteries is a grand scientific and technological challenge.

Budget

- Total project funding: DOE share $50M
- Funding received in FY 2019: $10M
- Funding for FY 2020: $10M

Partners

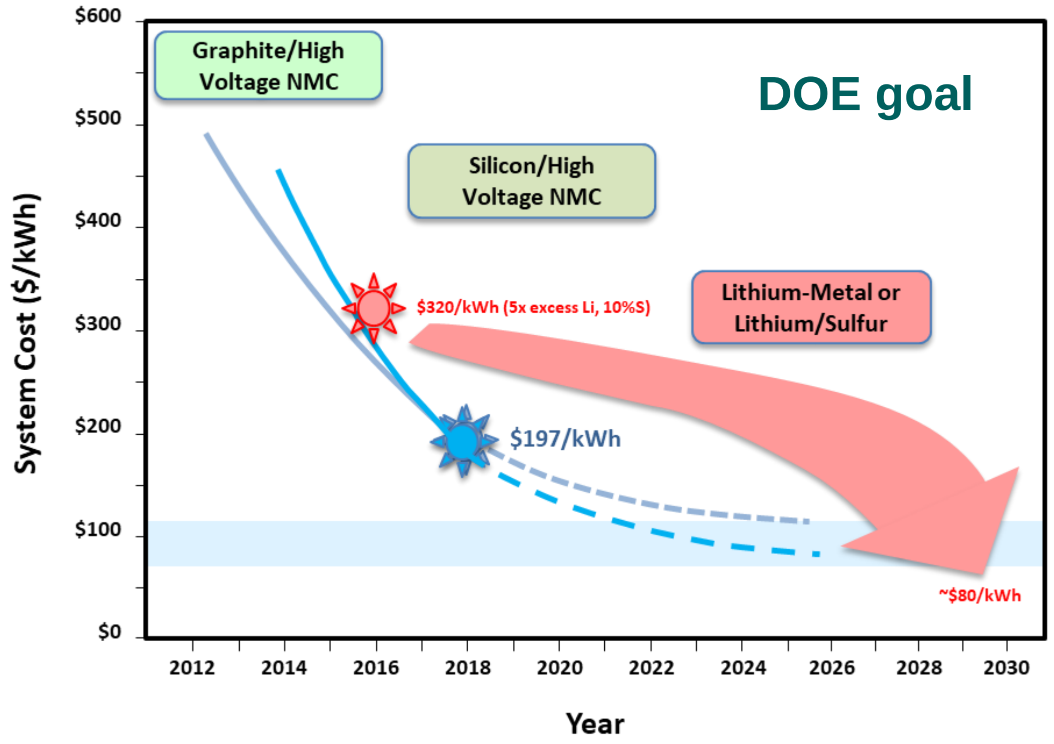
- Project lead: PNNL
- Battery500 Core Team: Binghamton Univ., BNL, INL, Stanford Univ./SLAC, UC San Diego, Univ. of Texas Austin, Univ. of Washington
- 10 seedling projects

Core Team:

Advisors:

Project Objectives

- The Battery500 Consortium aims to increase the specific energy (up to 500 Wh/kg) relative to today's battery technology and achieve 1,000 charge/discharge cycles.
- The consortium aims to overcome the fundamental scientific barriers to extract the maximum capacity in electrode materials for next generation Li batteries.
- The consortium leverages advances in electrode materials and battery chemistries supported by DOE.
- Focus on two battery chemistries: Li anode combined high nickel NMC ($LiNi_xM_{1-x}O_2$, M = Mn or Co and x > 0.7) and sulfur.



Key Cell Level Milestones

Date	Milestones	Status
FY2020 annual	Fabricate and test a pouch cell capable of 350 Wh/kg and 350 cycles	***Completed***
FY2020 annual	Fabricate and test a pouch cell capable of 400 Wh/kg and 100 cycles	***On track***

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Approach: Three Keystone Projects - Integration from Materials to Cells

Keystone Project 1: Materials and Interfaces (Stan Whittingham, Jason Zhang, Arumugam Manthiram, Jihui Yang, Yi Cui, Wu Xu, Will Chueh)
Develop and optimize cathode materials and novel electrolytes to improve the stability of the cathode materials, enhance the stability of the Li metal anode, increase the Li metal deposition/stripping efficiency, reduce the dendrite formation, widen the electrochemical window of the system, and improve the performance of the full cells.

Keystone Project 2: Electrode Architectures (Ping Liu, Zhenan Bao, John Goodenough, Jie Xiao, Peter Khalifah, Venkat Subramanian)
Increase electrode thickness and maximize active materials utilization; Develop new nanocomposite membranes and 3D Li architectures to stabilize the metal anode.

Keystone Project 3: Cell Integration, Fabrication and Diagnosis (Eric Dufek, Jie Xiao, Jun Liu, Xiao-Qing Yang, Shirley Meng, Peter Khalifah, Mike Toney, Boryann Liaw), Venkat Subramanian)
Develop design rules and principles to achieve the energy density, as well as standard methodology protocols to perform diagnostic evaluation and performance validation of the battery.

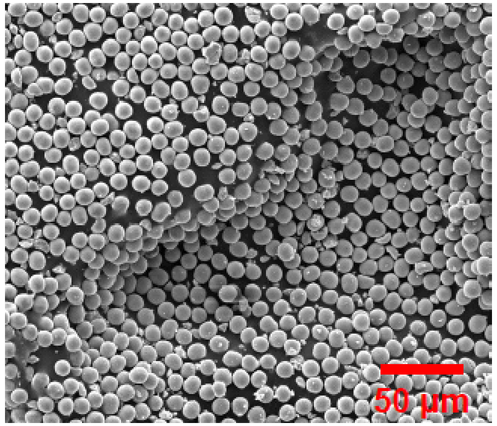
Accomplishment: synthesis of high Ni-NMC, understanding degradation of cathodes and improving cathode performance

Manthiram, 9:00 am
Cathode, BAT360

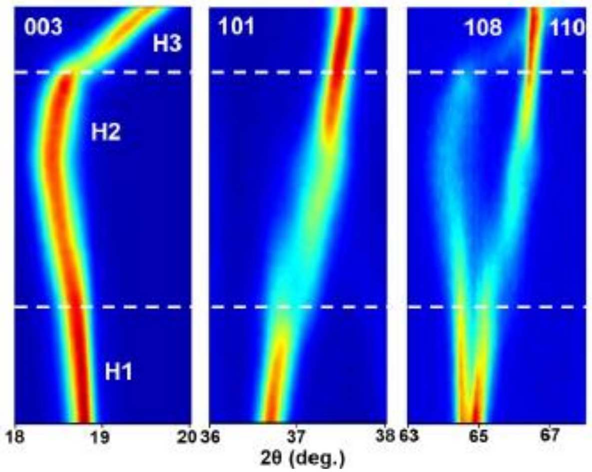
Whittingham,8:30 am
Keystone I, BAT359

Yang, 11:30 am
Coating, BAT364

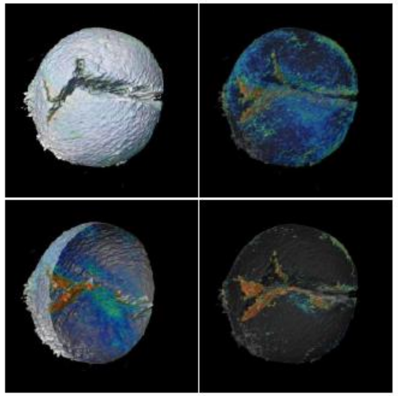
$LiNi_{0.8}Co_{0.1}Mn_{0.1}O_2$



In-situ study of cathodes

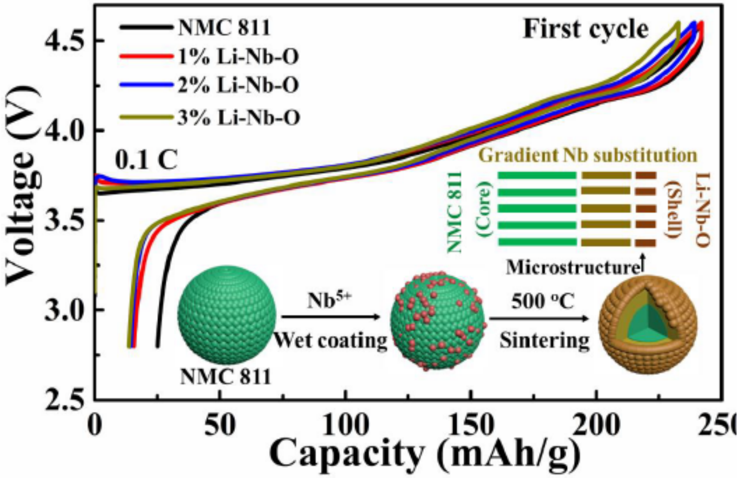


Element redistribution and cracking



Yang, BNL

Khalifah, 2:30 pm
Characterization, BAT367



First cycle loss/degradation over cycling through surface induced reaction:

- Phase transition.
- Microcracking.
- Element redistribution.
- Mitigation by surface coating

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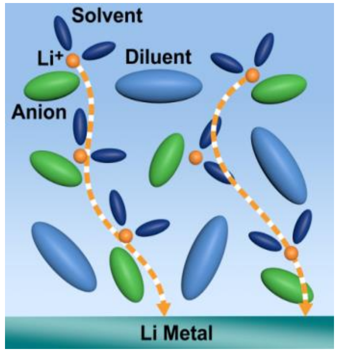
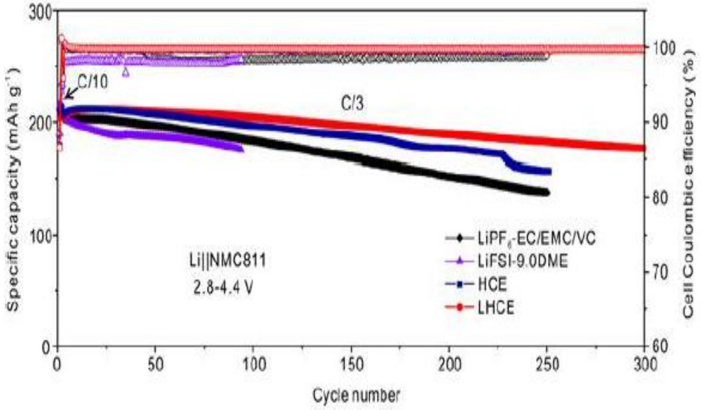
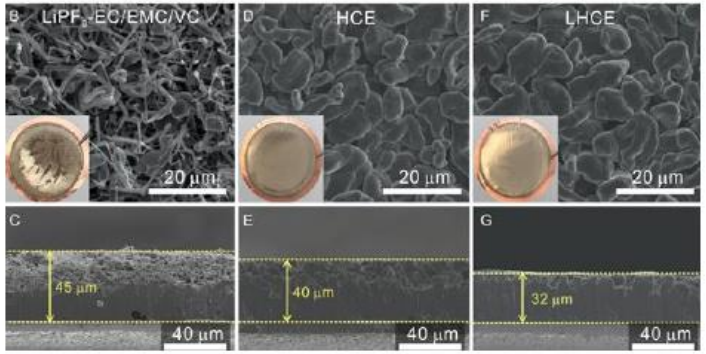
Accomplishment: development of new electrolytes-from highly concentrated (HCE) to localized concentrated electrolytes (LHCE)







LHCE leads to thinner and denser Li deposition.

Zhang, 2:30 pm
Li anode, BAT362

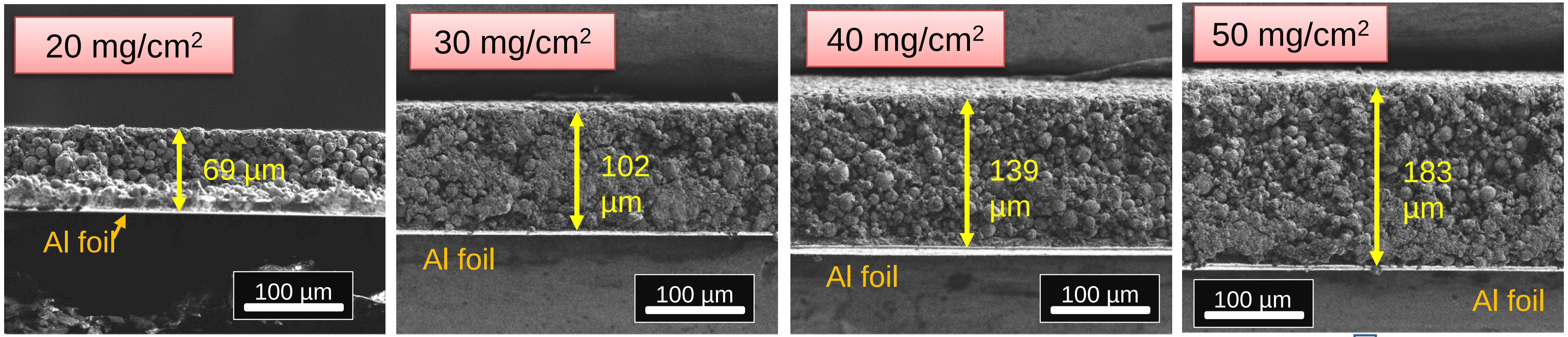
Xu, PNNL

Before 2015	2015	2016	2018	2020
Traditional electrolyte CE ~76%	Highly concentrated electrolyte CE 99.1~99.5%	Locally concentrated electrolyte • CE ~99.3%	Non flammable high voltage electrolyte CE – 99.3	Low vapor high voltage electrolyte CE - 99.5 %

LiFSI/DME-TTE based LHCE significantly reduced the SEI reactions with Li metal

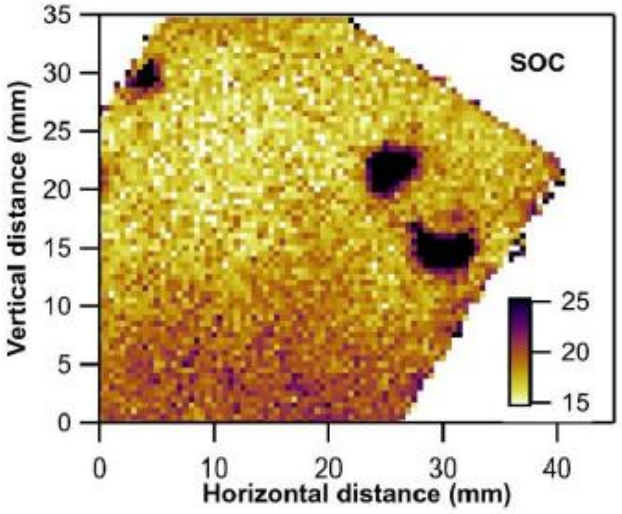
Accomplishment: characterization and optimization of thick cathode architectures

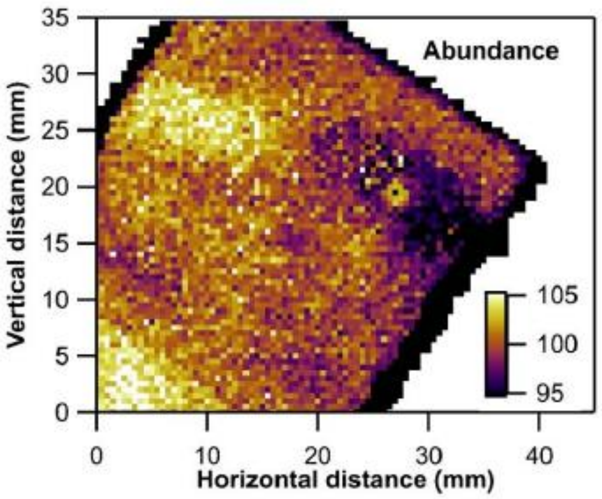
Liu, 11:00 am
Keystone II, BAT454



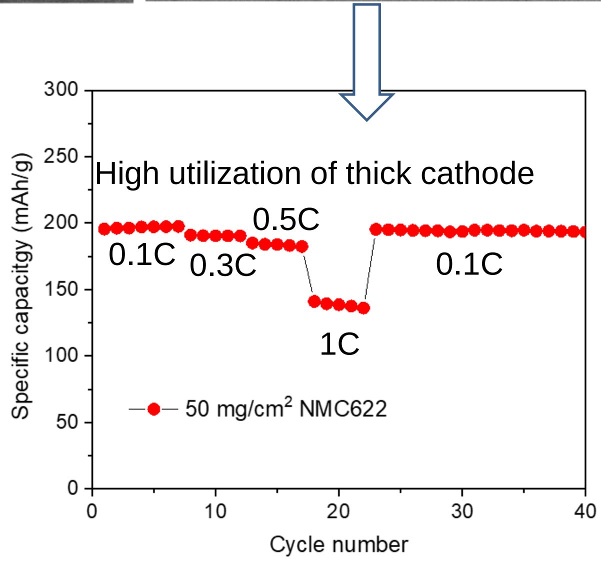
Xiao,
PNNL

Khalifah, 2:30 pm
Characterization, BAT367





Thick electrode reduces cathode utilization due to uneven reactions



New cathode preparation
enables very thick cathodes

Liu,
PNNL

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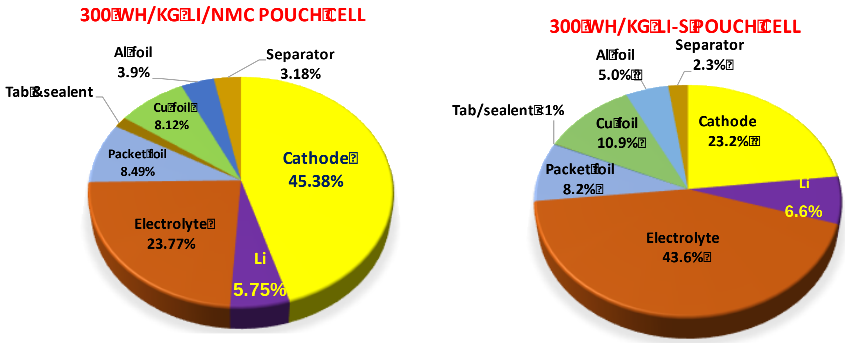
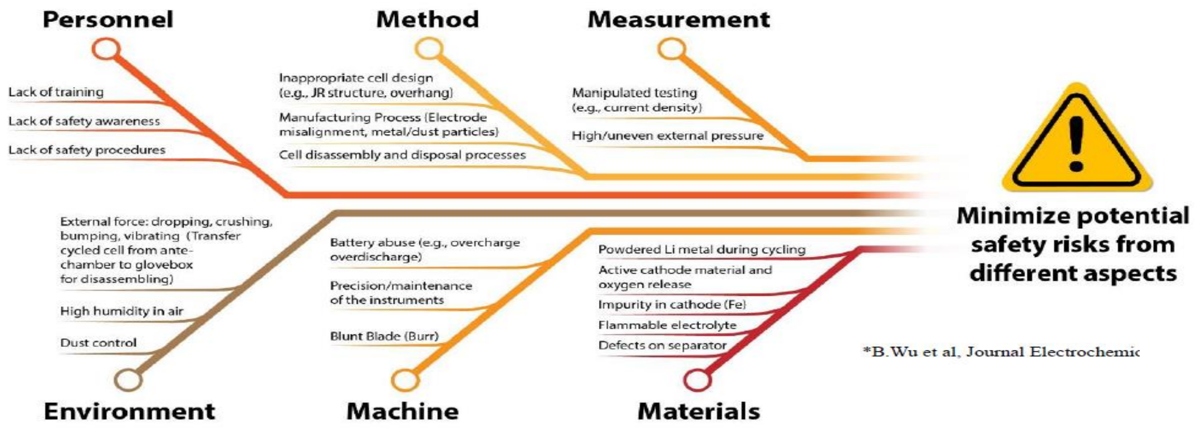
UC San Diego

Pacific Northwest NATIONAL LABORATORY

Accomplishment: optimization of cell design, fabrication, testing and safety to extend cycling life

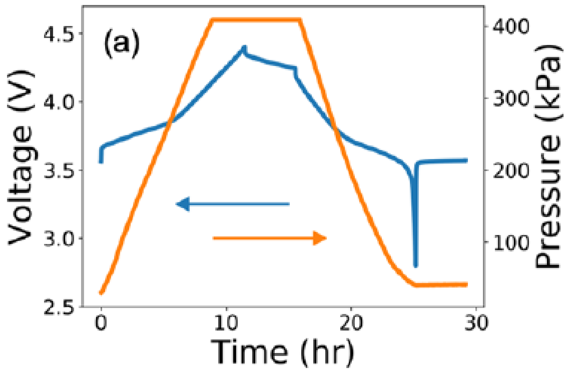
Standard cell parameters and testing conditions





Safe handling of cells

Optimized pressure effect



Liaw
INL

Xiao, 3:00 pm
Cell, BAT369

Dufek, 2:30 pm
Keystone III, BAT368

Whittingham
Binghamton

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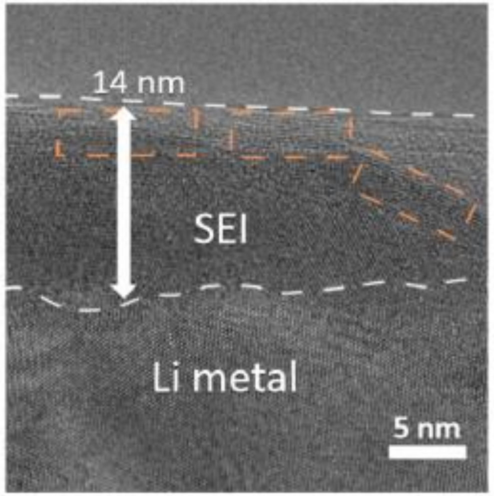
Idaho National Laboratory

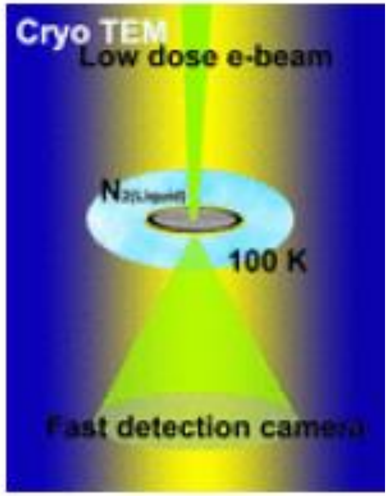
BINGHAMTON UNIVERSITY

Pacific Northwest NATIONAL LABORATORY

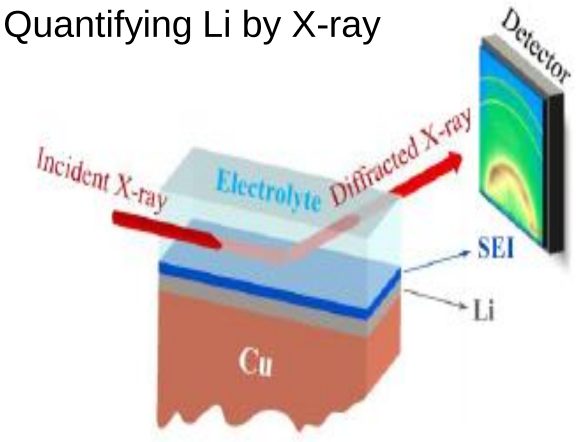
Accomplishment: developing and expanding new tool sets and obtaining atomistic understanding of SEI and Li failure

Xiao, 9:30 am
Interface, BAT361



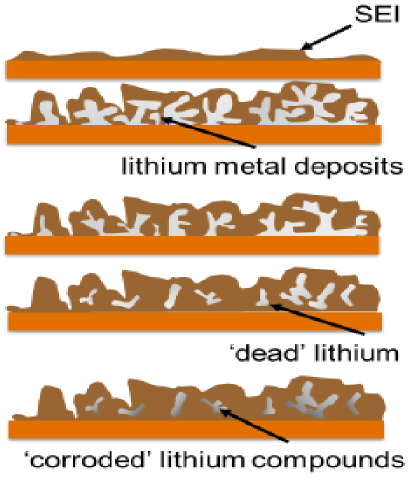


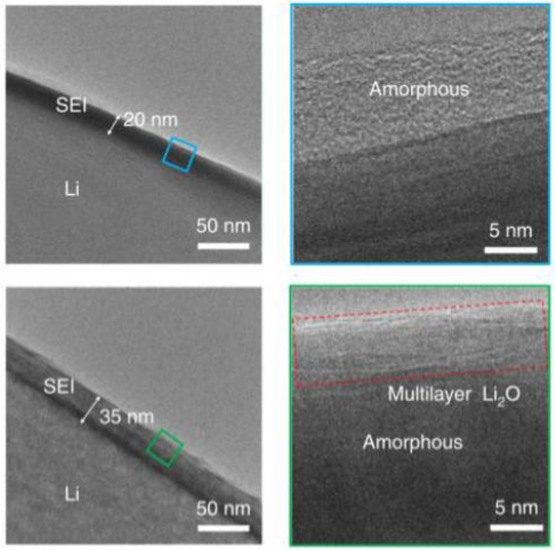
Quantifying Li by X-ray



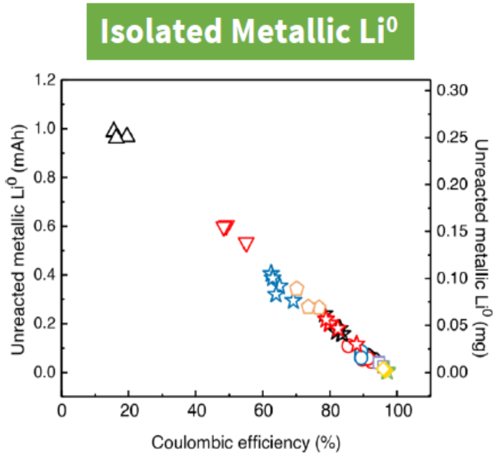
Toney, 4:00 pm
Ni rich oxides, BAT370

Chueh, 5:00 pm
Operando, BAT455





Li failure by dead metallic Li



Meng, 2:00 pm
Characterization,
BAT366

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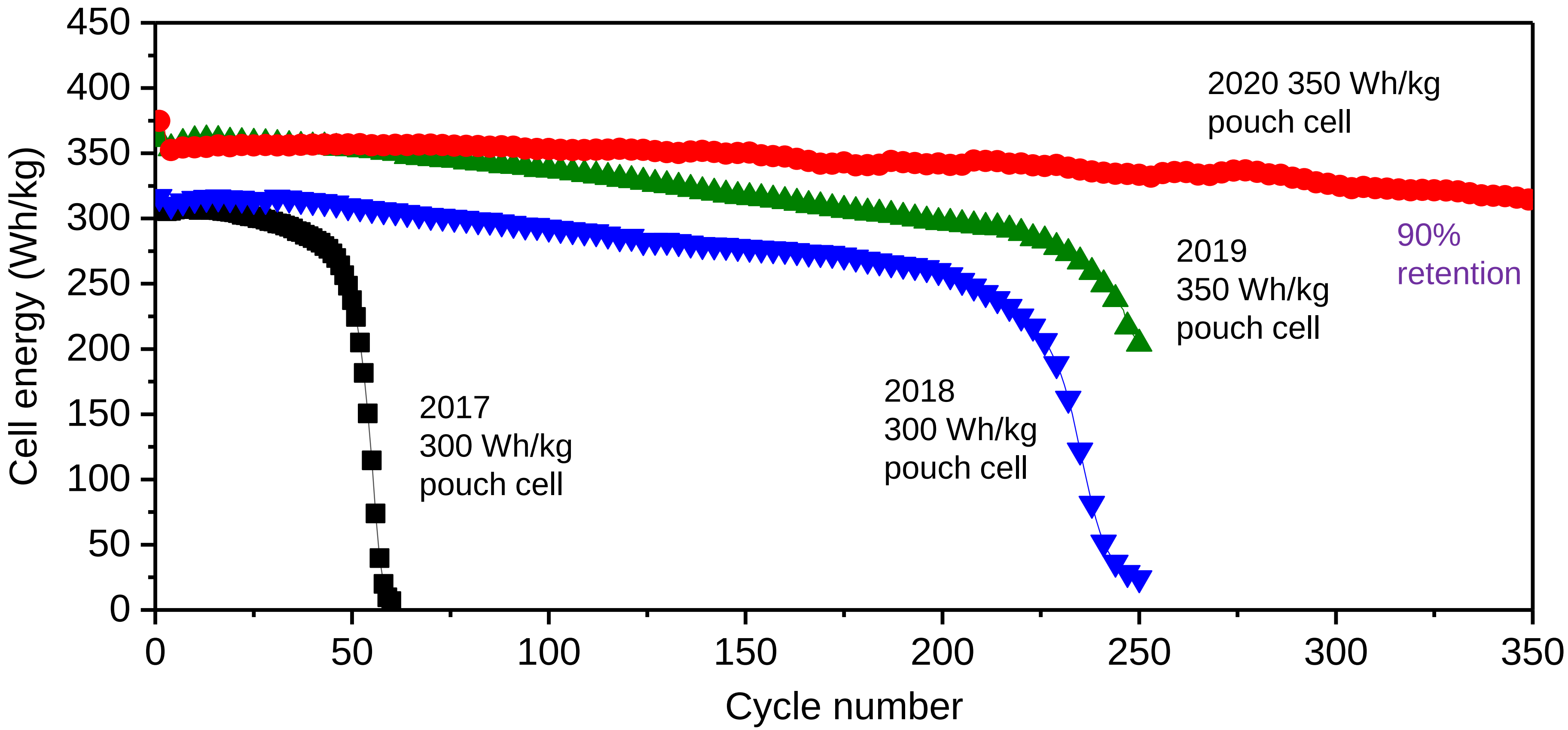
Accomplishment: Stable, long cycling with significantly reduced cell swelling (Li/NMC622 pouch cell, 350 Wh/kg 350 cycles)



Xiao, 3:00 pm Cell, BAT369

Liu, PNNL

2020 cell parameters:

0.1C charge
0.3C discharge

- Li/NMC622 pouch cell
- 4.0 mAh/cm^2
- N/P ratio: 2.45 (with 50 µm Li)
- E/C ratio: 2.2 g/Ah
- Two formation cycles at C/10
- Then C/10 charge, C/3 discharge

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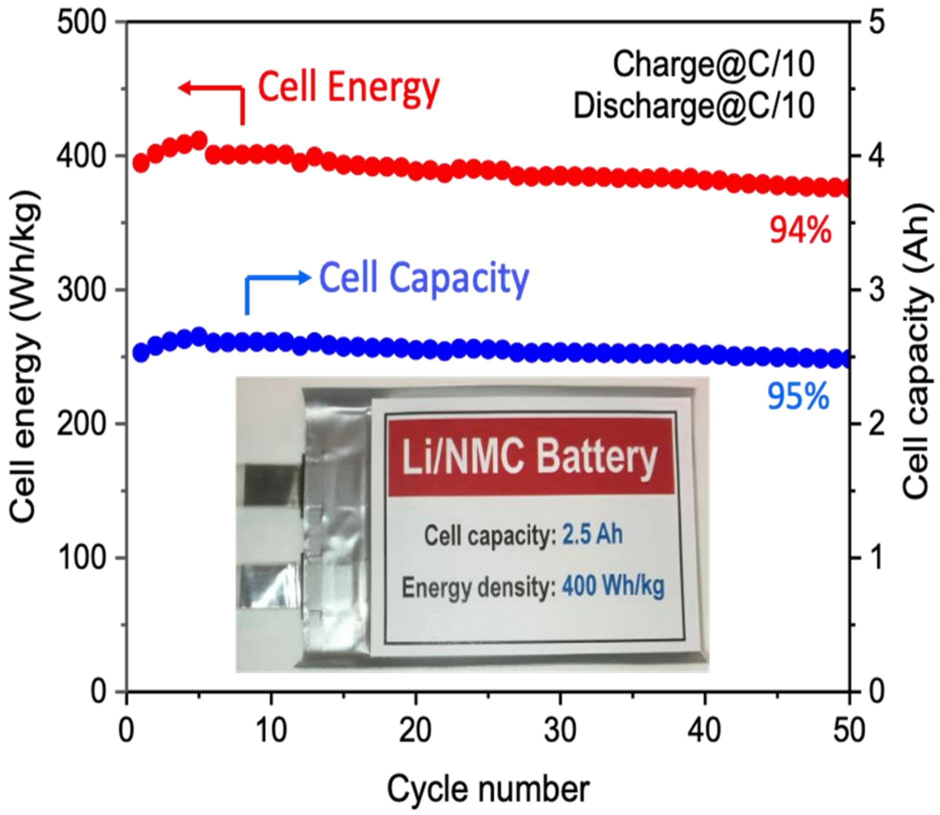
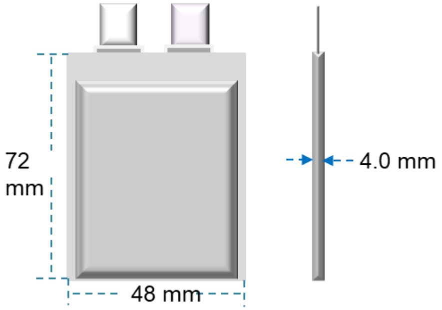
350 Wh/kg cell provides a critical platform to evaluate high energy cells, but a high specific energy can be obtained based on pouch cell designs.

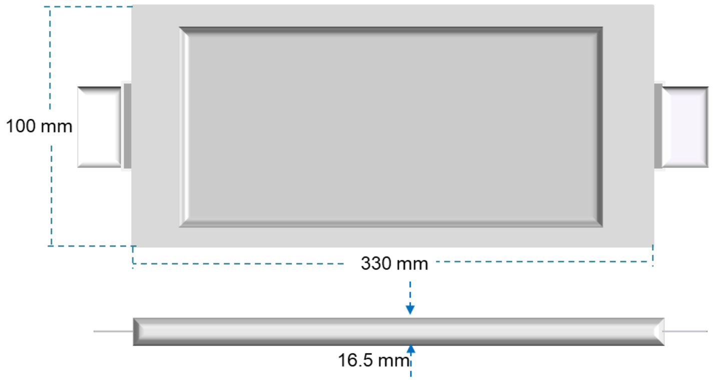


Stable cycling of 400 Wh/kg pouch cell (811, still under test).

PNNL: 350 Wh/kg (2.5 Ah) Li/NMC811



Increase cell size



Large Cell Estimate: 416Wh/kg (167.4 Ah) NMC811/Li

Increase cathode thickness

Cathode thickness	Specific Energy
70 μm	389Wh/kg
105 μm	427Wh/kg
140 μm	448Wh/kg

Xiao, PNNL

Liu, PNNL

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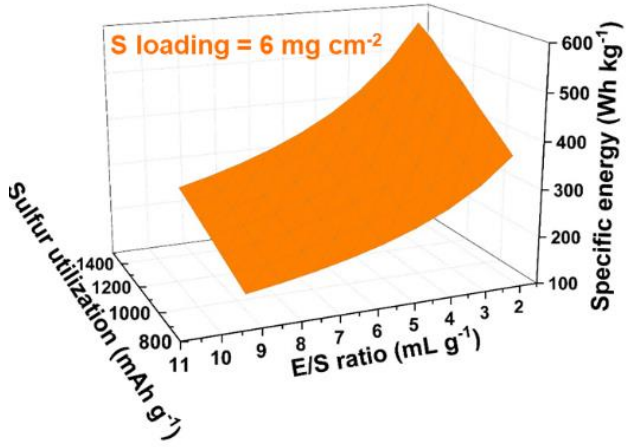
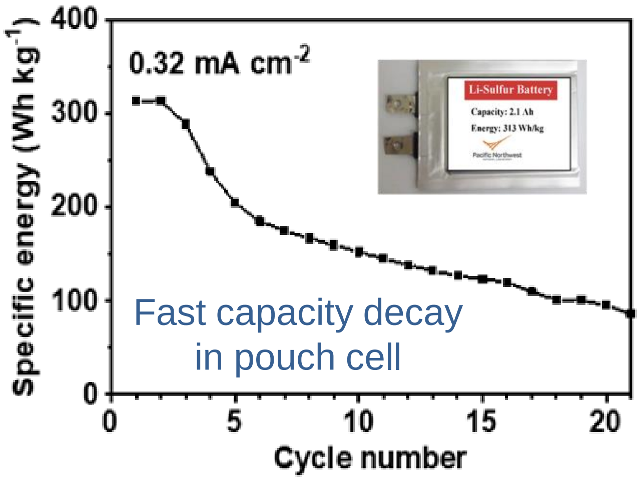
Li-S batteries have a much higher specific energy with earth abundant materials



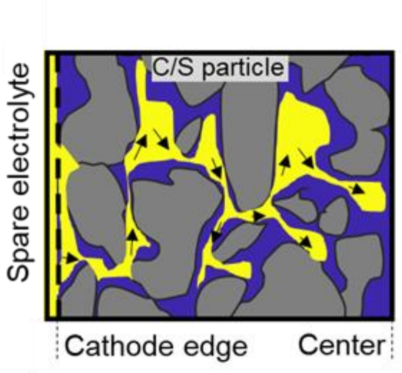


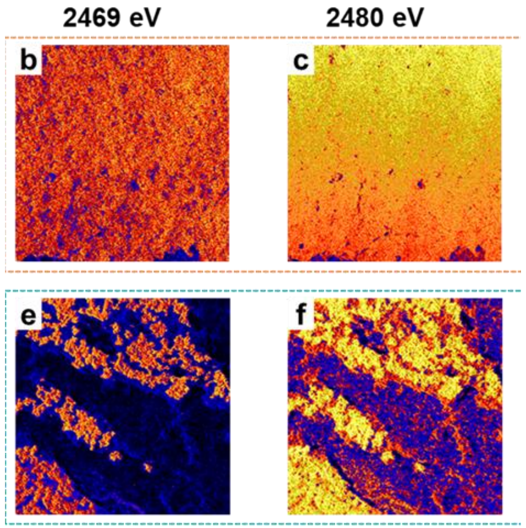
Mitigation strategy for Li-S:

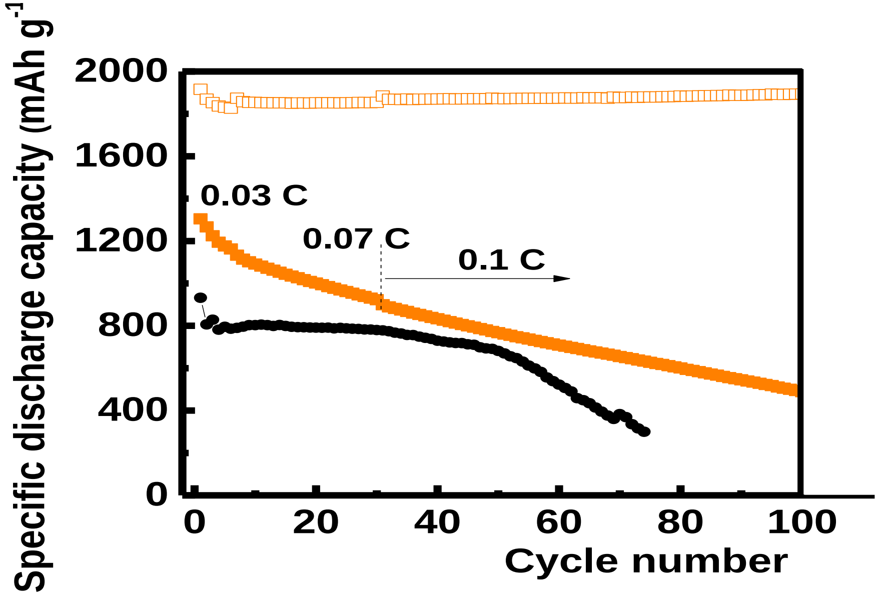
- New mechanism for high S utilization.
- Control electrode architectures.
- New electrolytes to reduce reactivity

Yang, BNL

Xiao, PNNL







Fast capacity decay in pouch cell is caused by poor electrolyte diffusion and uneven electrochemical reactions in the cathode.

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GM RESEARCH & DEVELOPMENT

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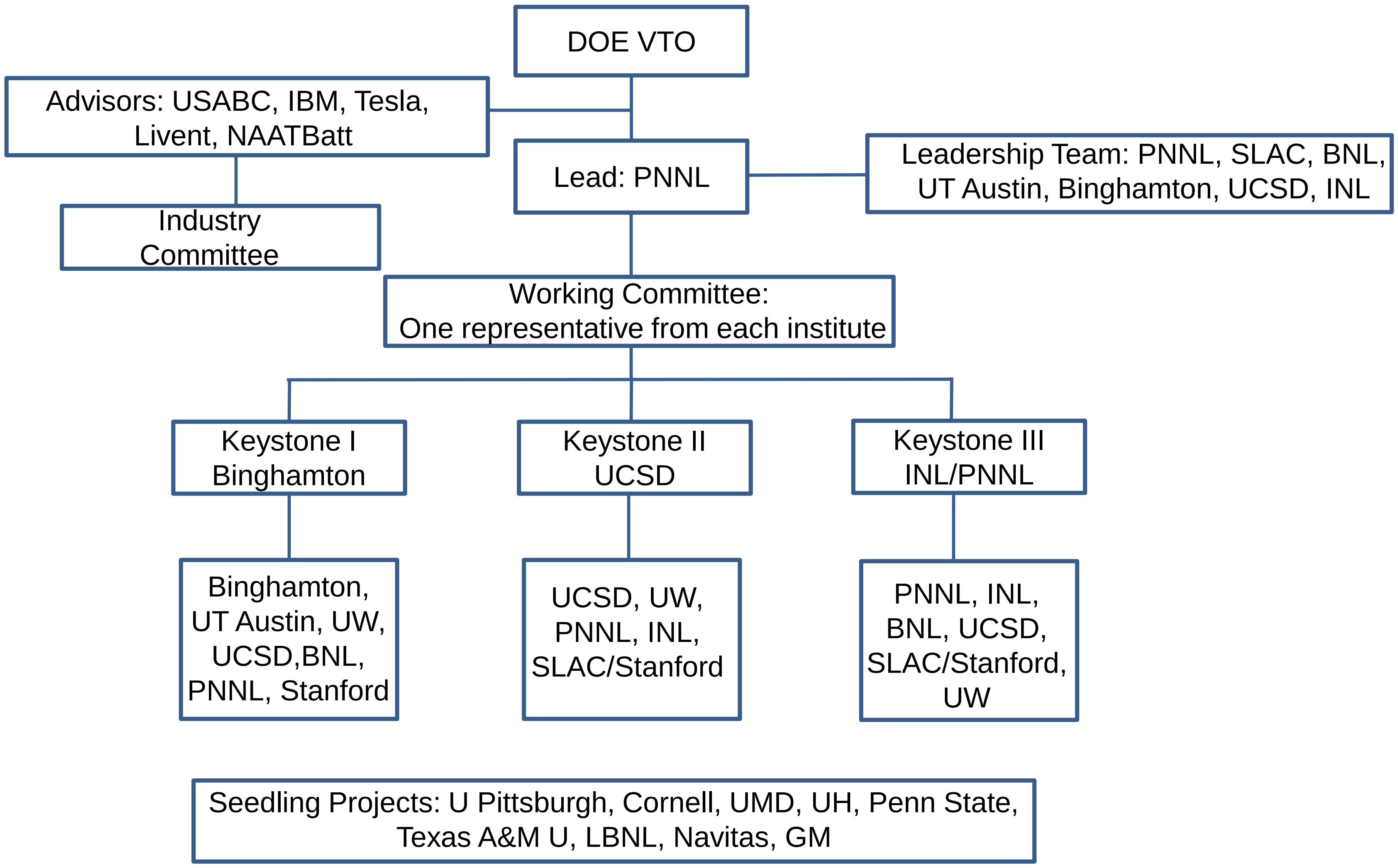
Responses to Previous Year Reviewers' Comments

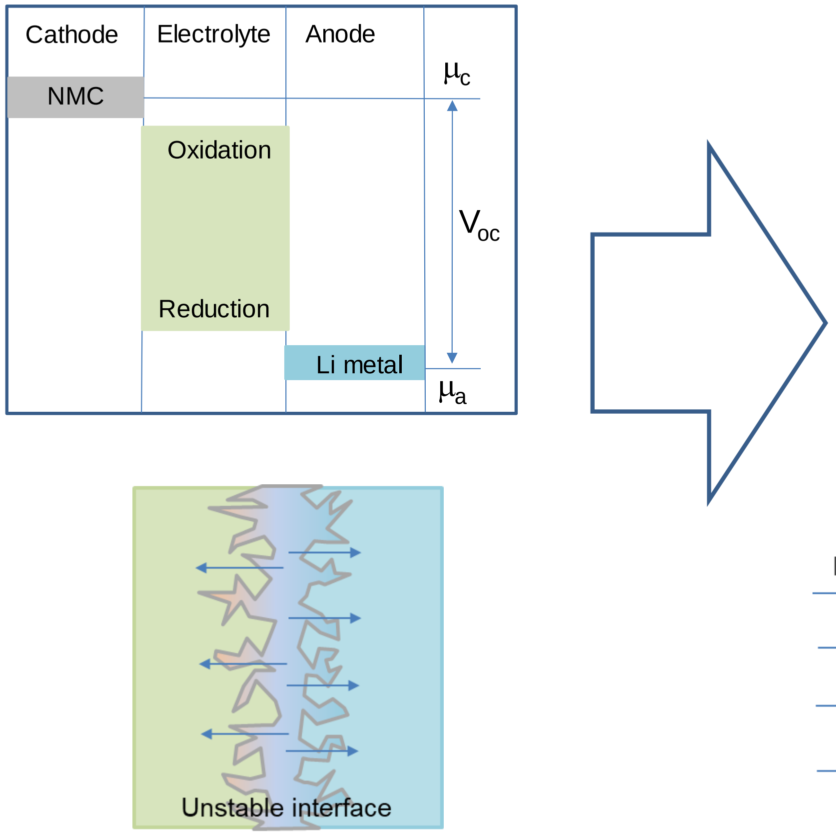
No comments from previous years

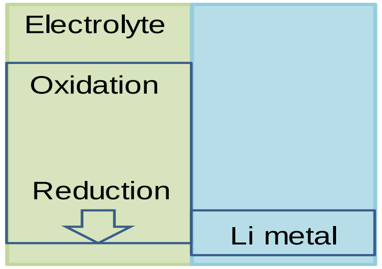
Collaboration and Coordination with Other Institutions



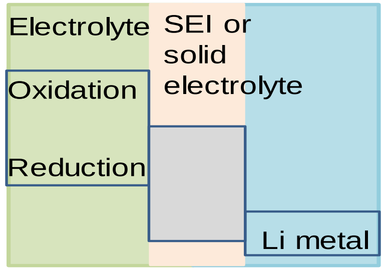
Remaining Challenges and Barriers

- Fundamental solutions to Li metal anode for long cycle life
- Fully utilization of active materials and optimize high energy cells
- Achieving > 500 stable cycling

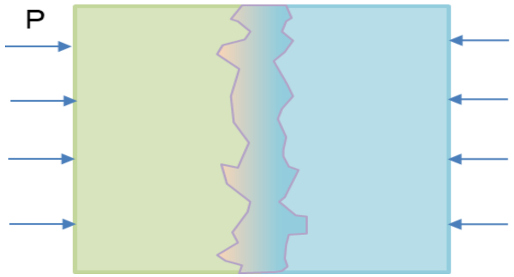




Widened electrolyte stability window



Quasi-stable SEI or solid electrolyte



Coupled electrochemical mechanical effects

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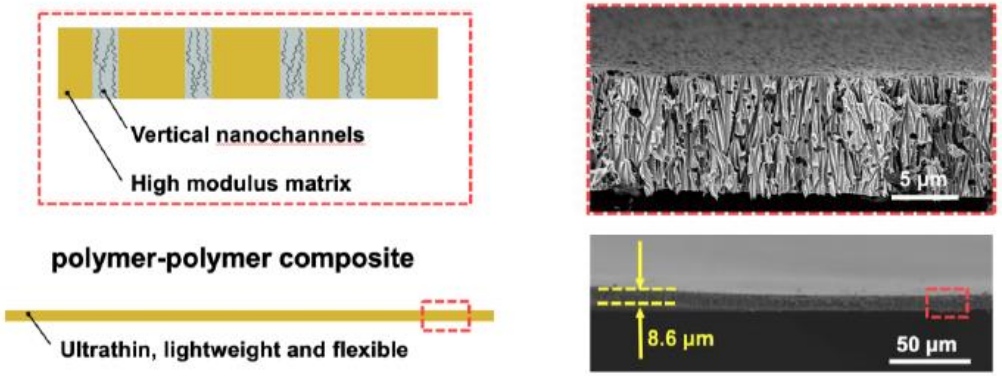
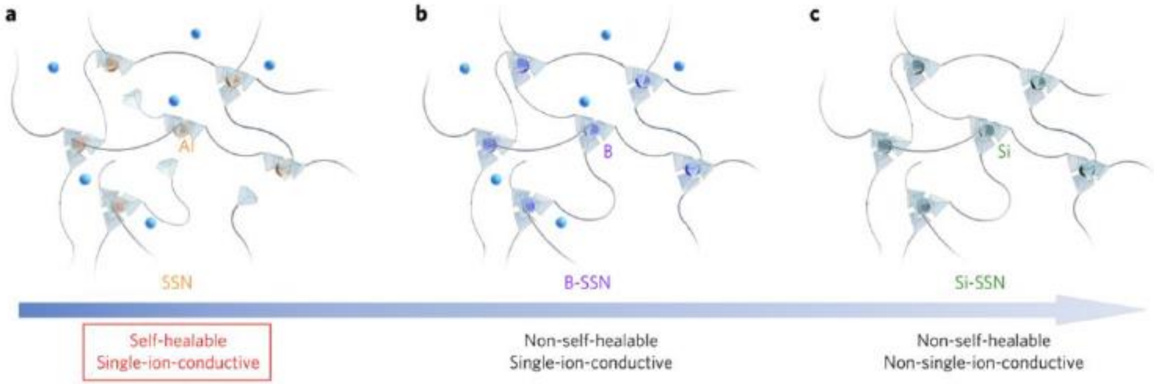
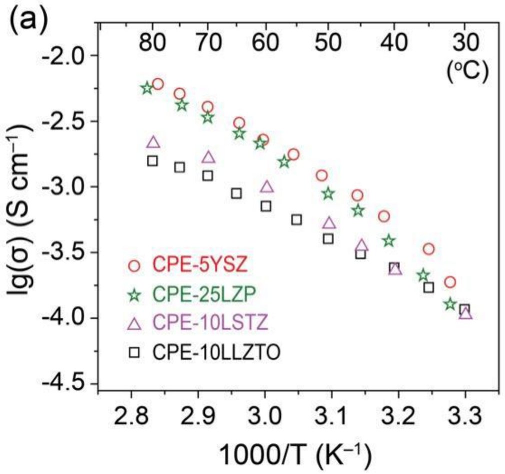
Proposed Future Work

- Integrate the multi-institute capabilities in battery materials and chemistry, electrode architecture, cell design and fabrication, and advanced diagnosis to push the limit of cell energy and cycling life.

Structure: composites with oriented channels; ultrathin and stable films.







Chemistry: rationally designed electrolytes with tunable electrochemical and mechanical properties

Bao, 12:00 noon
Polymer, BAT365

Goodenough,
UT Austin

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SLAC NATIONAL ACCELERATOR LABORATORY

STANFORD UNIVERSITY

W UNIVERSITY of WASHINGTON

THE UNIVERSITY OF TEXAS AT AUSTIN

Summary

- Established the cell level criteria and strategy to achieve the 500 Wh/kg goal for both high Ni NMC and sulfur systems.

- Demonstrated progress on the program and Keystone Projects.

- Significant progresses in mechanistic understanding of the failure on both materials and cell levels.

- Pouch cell level results:
  - ✓ Achieved more than 350 stable cycles for 350 Wh/kg pouch cell.
  - ✓ On track to achieve more than 100 cycles for 400 Wh/kg pouch cells.
  - ✓ Derived design principles for higher energy cells.

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