Progress and Status of Battery500 Consortium

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2021 DOE Vehicle Technologies Office Annual Merit Review
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Project ID bat317

Pacific Northwest NATIONAL LABORATORY
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Overview

Timeline

- Project start date: 10/01/2016
- Project end date: 9/30/2021
- Percent complete: 90 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 on the pouch cell level.
- 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
FY2021 annual	Fabricate and test a pouch cell capable of 350 Wh/kg with more than 450 cycles	***Completed***
FY2021 annual	Fabricate and test a pouch cell capable of 400 Wh/kg with more than 100 cycles	***Completed***

Approach: Three Keystone Projects - Integration from Materials to Cells

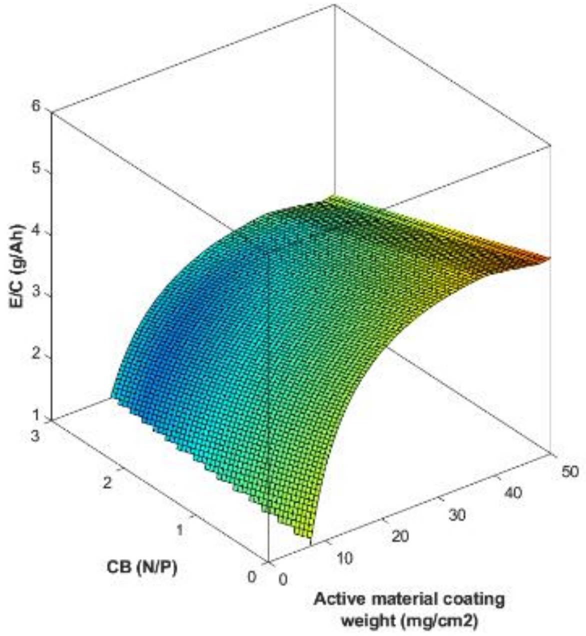
Keystone Project 1: Materials and Interfaces (Stan Whittingham, Jason Zhang, Arumugam Manthiram, Jihui Yang, Yi Cui, Wu Xu, Will Chueh)
Develop and optimize cathode materials and novel electrolytes to improve the stability of the cathode materials, enhance the stability of the Li metal anode, increase 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.

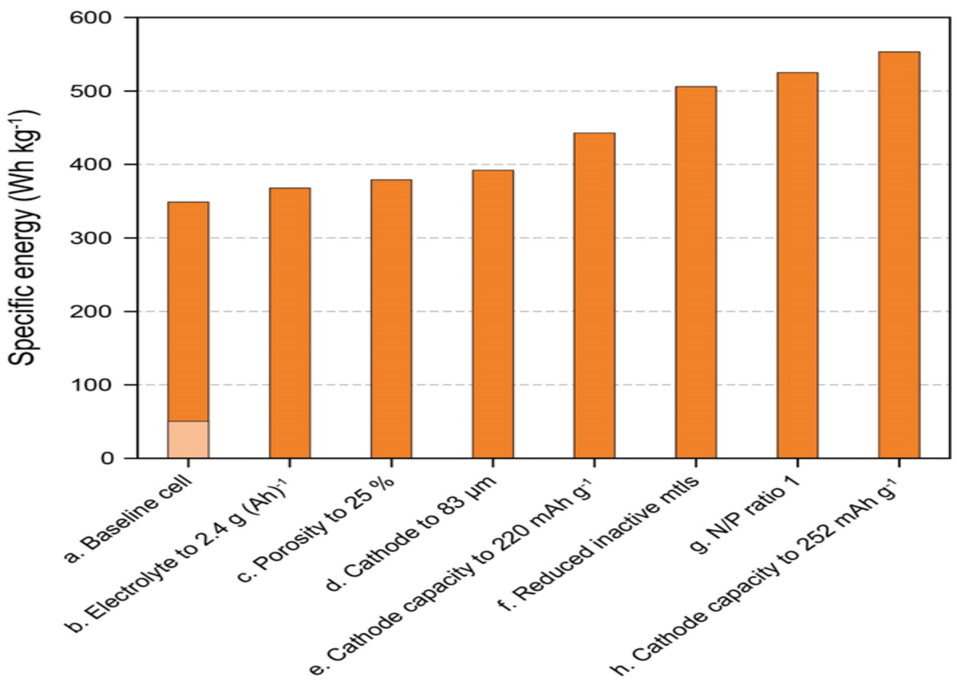
Keystone Project 3: Cell Integration, Fabrication and Diagnosis (Eric Dufek, Jie Xiao, Jun Liu, Xiao-Qing Yang, Shirley Meng, Peter Khalifah, Mike Toney, Boryann Liaw, Venkat Subramanian)
Develop design rules and principles to achieve the energy density, as well as standard methodology protocols to perform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

B500 integrated strategy for high energy cells

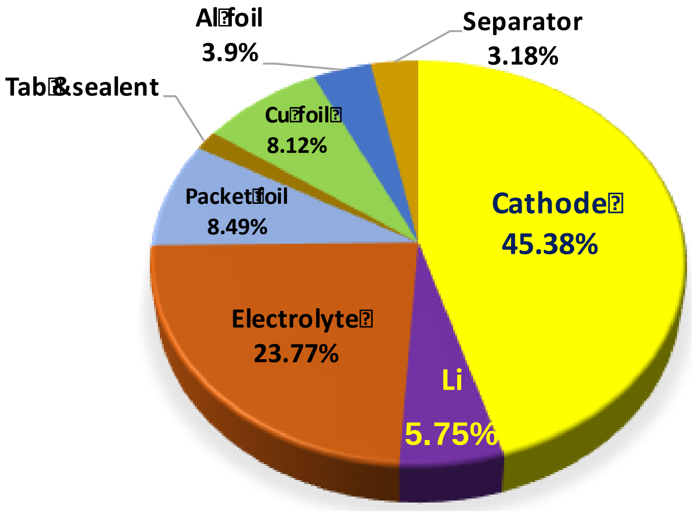
Cell level design



Pathway for high energy



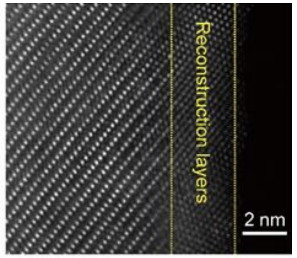
Standard protocols for validation



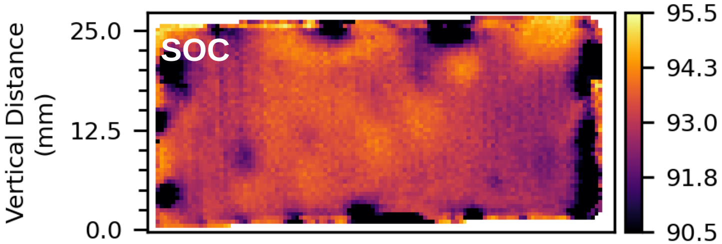
- Pouch cell level design, integration and optimization of advanced electrode and electrolyte materials.
- Rapid prototyping and validation using standard protocols.

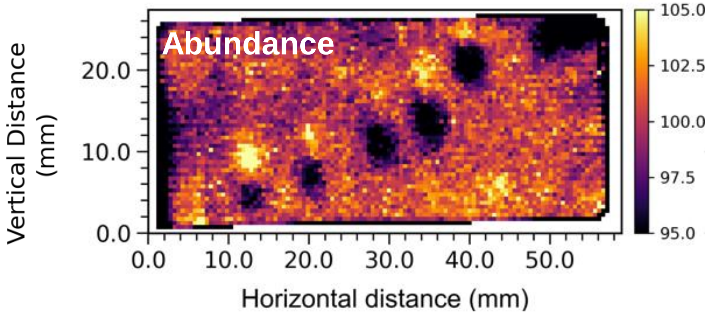
Accomplishment: pushing the limit of the electrode materials.

Reduce cathode degradation from particle to electrode levels

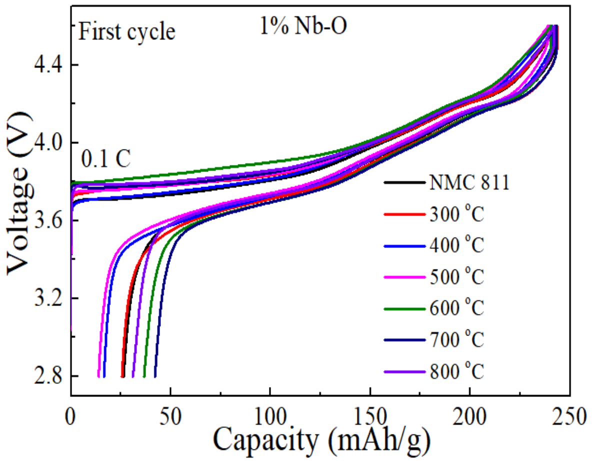


Surface degradation

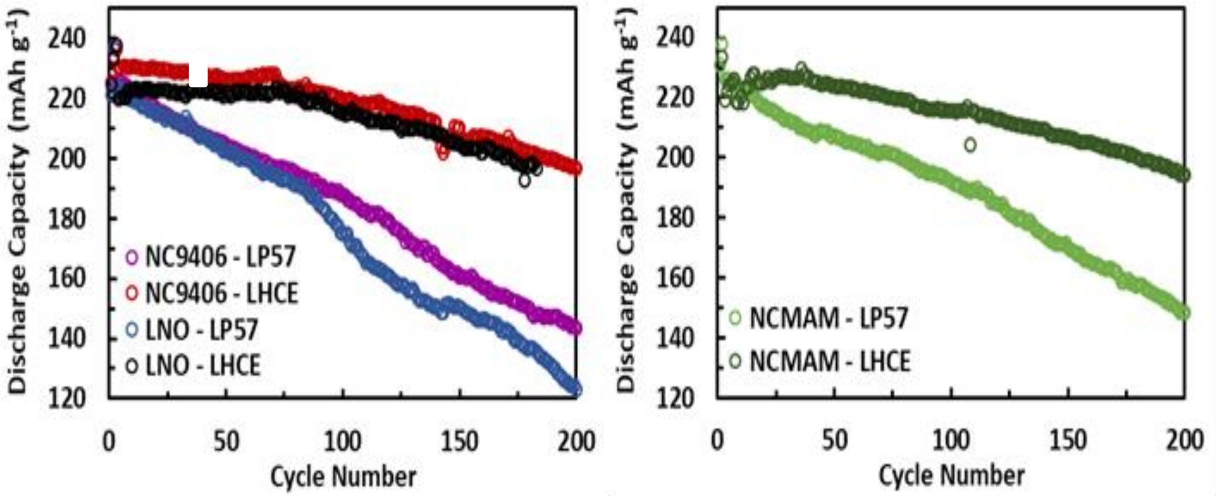




Spatial variation in electrodes



Reduce first cycle loss of NMC811 with Nb-O coating.



Increases stability of $LiNi_{0.94}Co_{0.06}O_2$ (NC9406), and $LiNi_{0.95}Co_{0.02}Mn_{0.015}Al_{0.01}Mg_{0.005}O_2$ (NCMAM) using LHCE.

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BINGHAMTON UNIVERSITY

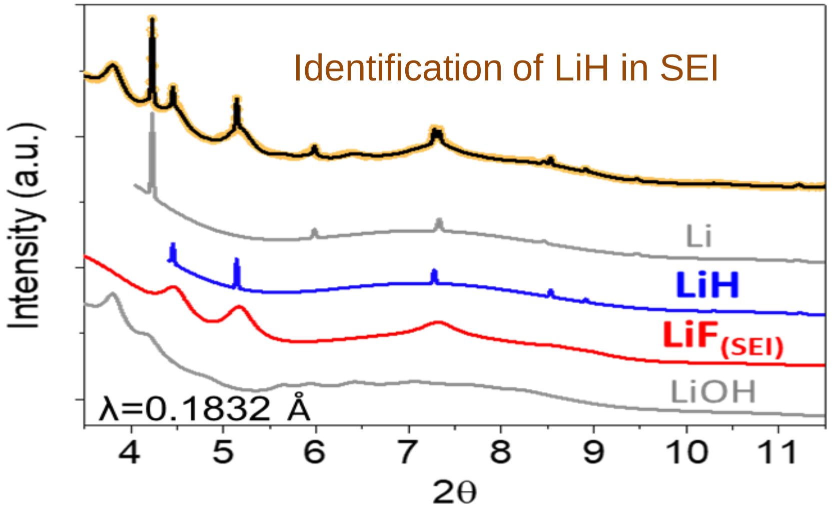
BROOKHAVEN NATIONAL LABORATORY

W UNIVERSITY of WASHINGTON

THE UNIVERSITY OF TEXAS AT AUSTIN

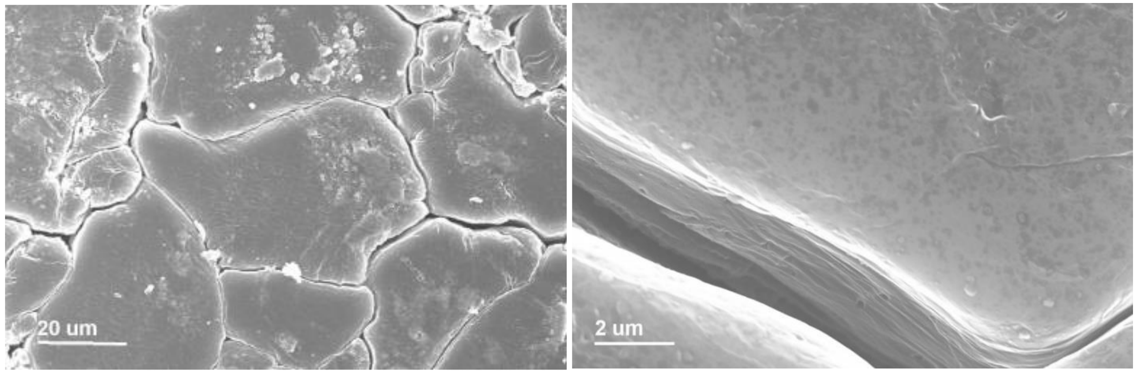
Accomplishment: new knowledge of SEI and achieving high efficiency Li deposition

- Compositions and structures of SEI.
- Li degradation mechanisms in real cells.
- Causes for cell death.
- Quantification of dead Li and reaction rates.
- Ideal interfaces for Li cell.

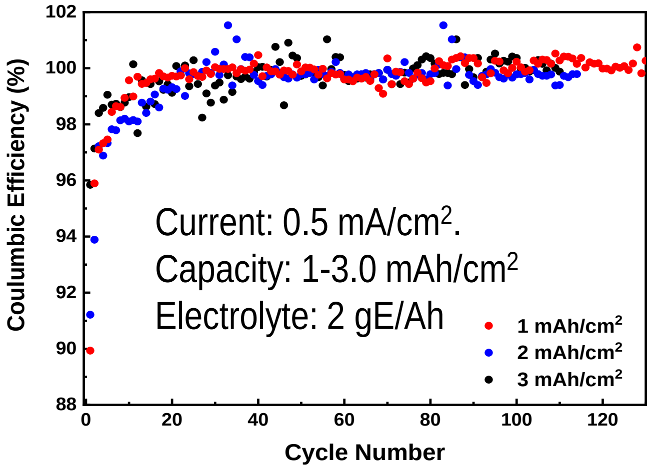


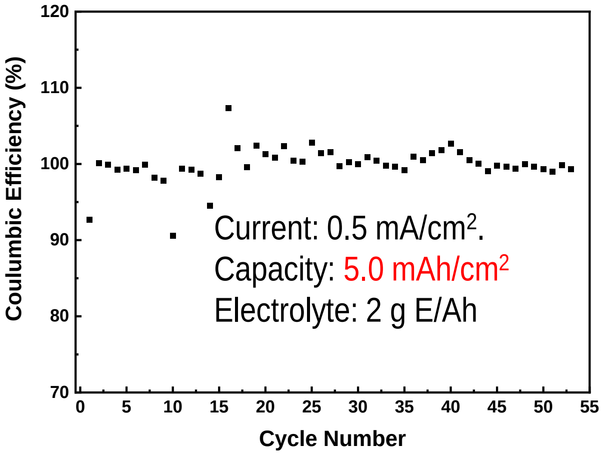
Z. Shadike, H.-K. Lee, O. Borodin, X. Cao, X. Fan, X. Wang, R. Lin, S.-M. Bak, S. Ghose, K. Xu, C. Wang, J. Liu, J. Xiao, X.-Q. Yang & E. Hu, "Identification of LiH and nanocrystalline LiF in the solid–electrolyte interphase of lithium metal anodes", *Nature Nanotechnology* (2020), 10.1038/s41565-020-00845-5.

Enabling more than 99.9% Coulombic efficiency



Morphologies of Li deposit on Cu at current of 0.5 mA cm^{-2}, capacity of 5.0 mAh/cm^2, 2 g E Ah^{-1}





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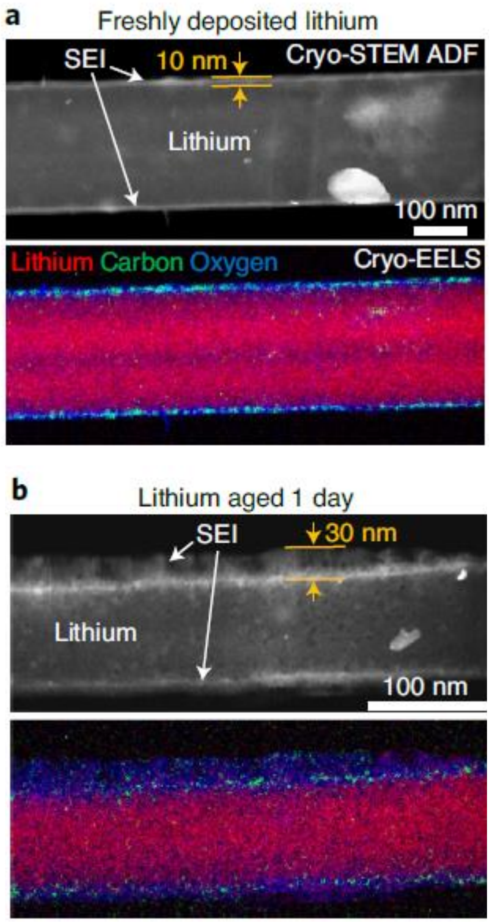
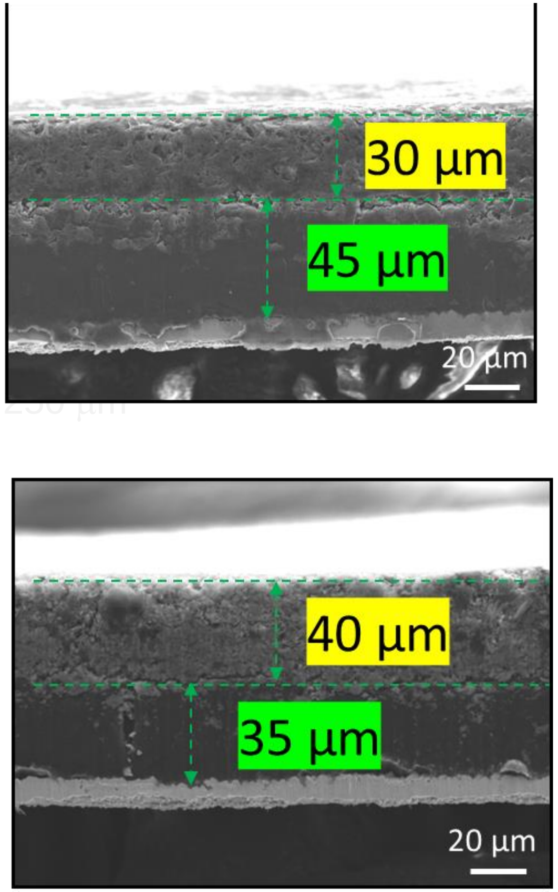
Accomplishment: control interfacial reactions on all levels and improve cell stability

SEI formation due to corrosion

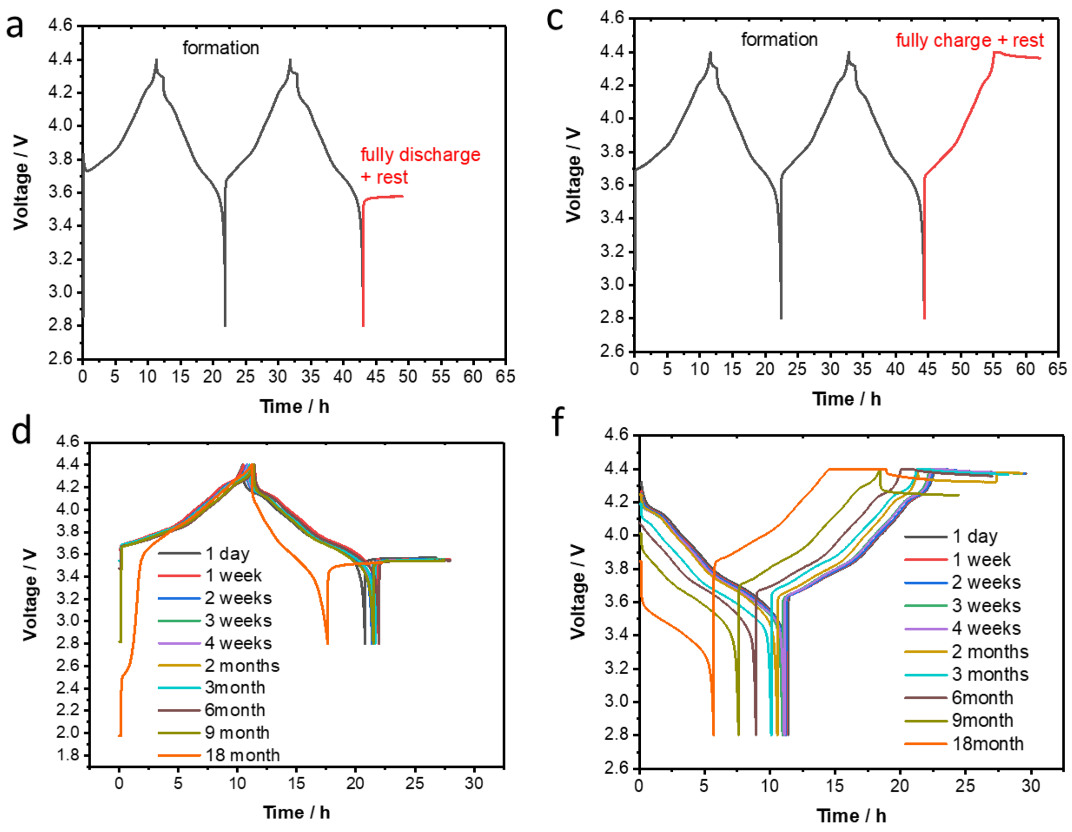


Stable interfaces with good electrolytes



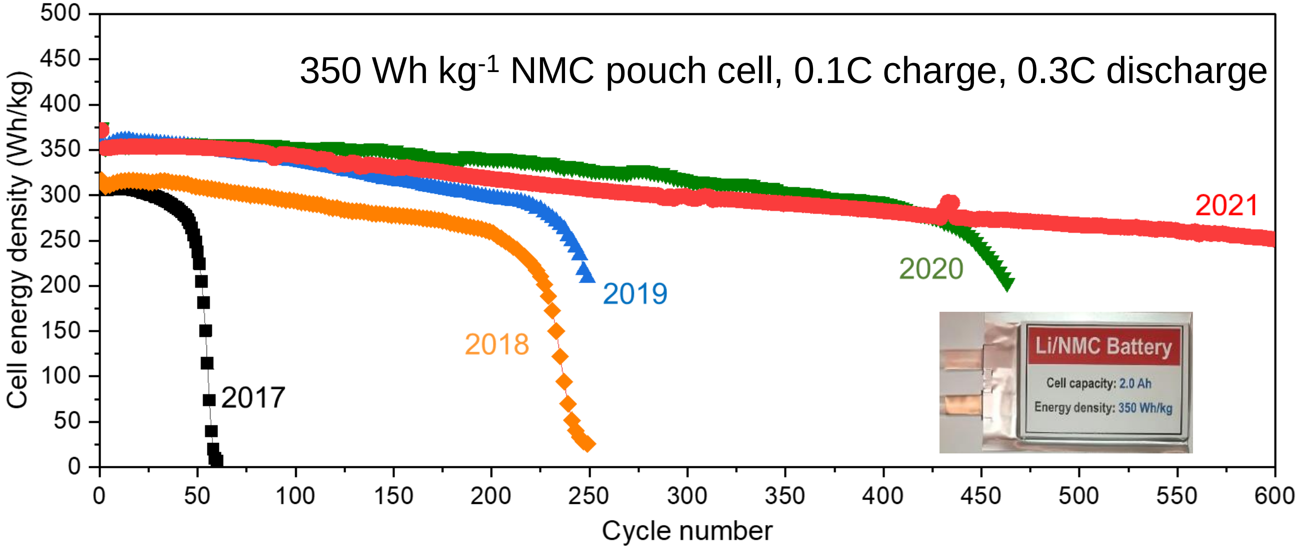
“Corrosion of lithium metal anodes during calendar ageing and its microscopic origins,” D.T. Boyle, W. Huang, H. Wang, Y. Li, H. Chen, Z. Yu, W. Zhang, Z. Bao, and Y Cui, Nature Energy, https://doi.org/10.1038/s41560-021-00787-9

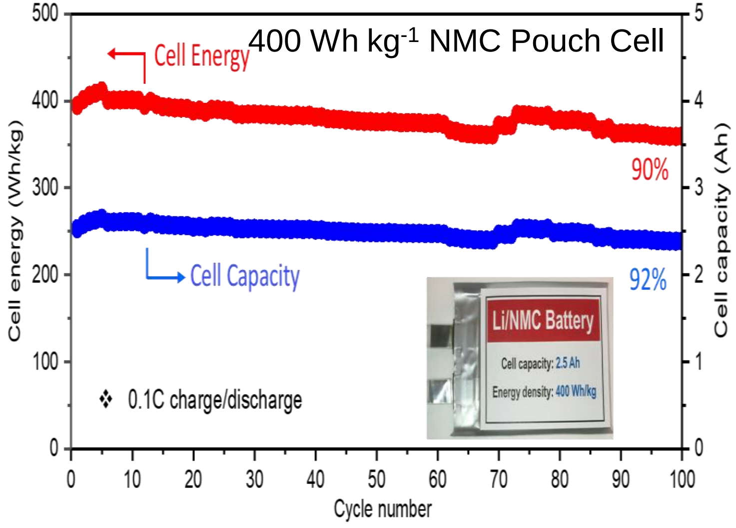
Stable electrolytes enables long term stability of the cell

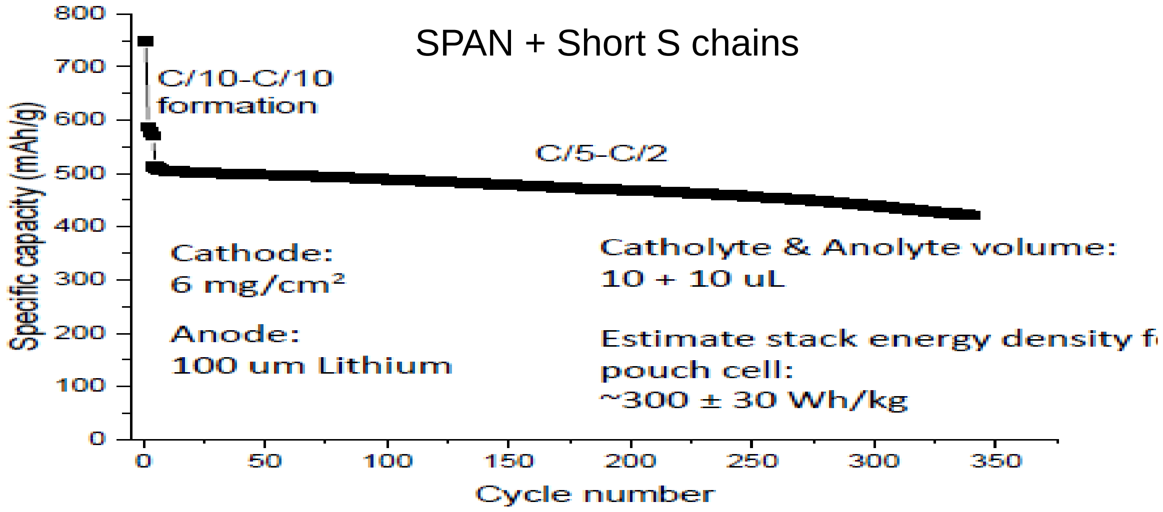


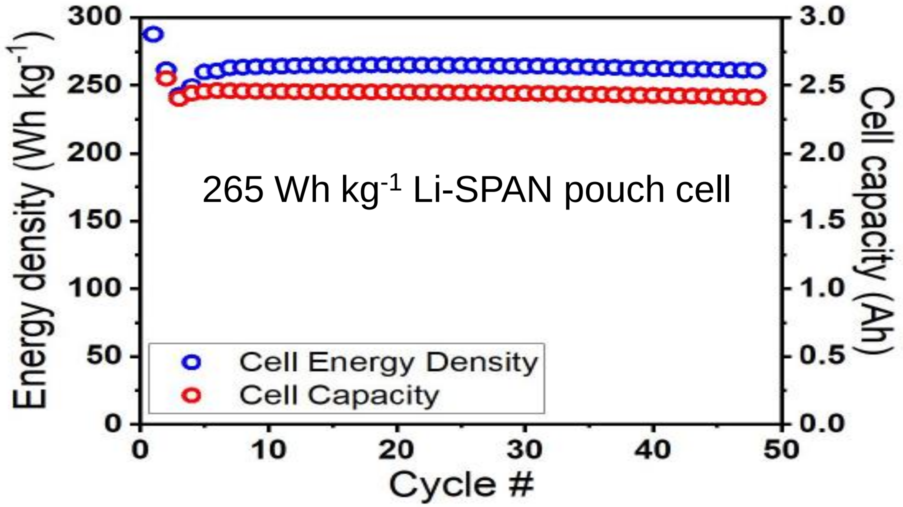
- Fully discharged cells are most stable during storage. ~80% capacity retention after 18-months.
- 50% SOC cells can still retain ~50% capacity after 9-months storage.

Accomplishment: high energy cells with stable, long cycling









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INL Idaho National Laboratory

UC San Diego

GM

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Proposed Future Work

- Push the limit of materials and materials utilization to achieve high energy density and low-cost cells.
- Control Li deposition and achieve near 100% Coulombic efficiency for long cycle life.
- Understand reactivities on every level for long life safe operation of cells.
- Control complex conversion cathodes for ultra-high energy or ultra low-cost cells.
- Scale up to large cell formats.
- Perform cell cost analysis and investigate performance under harsh conditions.

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 600 stable cycles for 350 Wh/kg pouch cells.
  - ✓ Achieved more than 100 cycles for 400 Wh/kg pouch cells.
  - ✓ Derived design principles for higher energy cells.

- Impact on science with numerous publications (Science, Nature, Nature Energy, etc.).

Responses to Previous Year Reviewers’ Comments

See comments and response from the specific projects