Battery500 Consortium Update

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BATTERY 500 CONSORTIUM

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Pacific Northwest NATIONAL LABORATORY

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Overview

Timeline

- Project start date: 10/01/2016
- Project end date: 9/30/2021
- Percent complete: 50 percent

Budget

- Total project funding
  - DOE share 50M
- Funding received: FY 2017,10M; FY2018,10M
- Funding for FY 2019: $11M

Core team

Advisors

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.

Partners

- Project lead: Pacific Northwest National Laboratory
- Battery500 Core Team: Binghamton Univ., BNL, INL, Stanford Univ./SLAC, Univ. of Texas Austin, UC San Diego, Univ. of Washington
- 15 Phase I seedling projects
- 10 Phase II seedling projects

Project Objectives

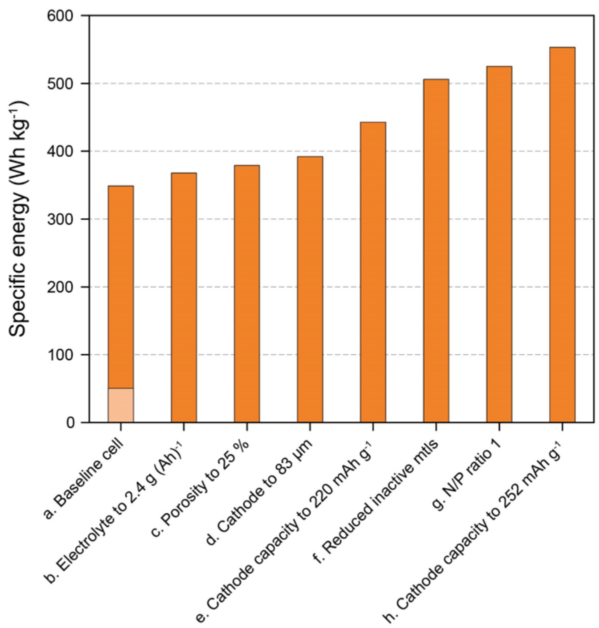
- The Battery500 Consortium aims to increase the specific energy (up to 500 Wh/kg) relative to today's battery technology and achieve 1,000 charge/discharge cycles.
- The Consortium aims to overcome the fundamental scientific barriers to extract the maximum capacity in electrode materials for next-generation Li batteries.
- The Consortium leverages advances in electrode materials and battery chemistries supported by DOE.

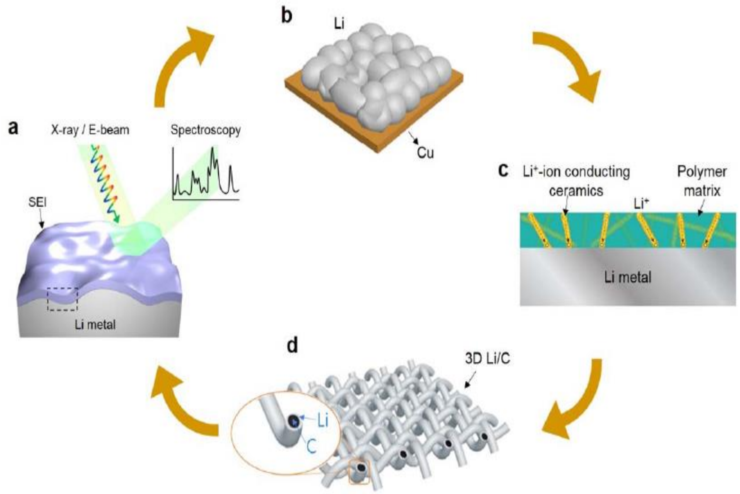
Keystone Projects	*Materials/ Interfaces*	*Electrode Architectures*	*Cell/Integration/ Fabrication/Diagnosis*

Milestones

Date	Milestones	Status
FY17 annual	Demonstrate 1 Ah pouch cell with 300 Wh/kg energy density, and over 50 cycles and continuing, and complete the preliminary testing protocols and demonstrate utilization of these protocols.	***Completed***
FY18 annual	Integrate materials and components into >1 Ah pouch cell and demonstrate 350 Wh/kg cell with over 50 charge/discharge cycles.	***Completed***
FY19 annual	Fabricate and test a pouch cell capable of 350 Wh/kg and 250 cycles.	***Completed***
FY19 annual	Fabricate and test a pouch cell capable of 400 Wh/kg and 30 cycles.	***On track***

Approaches: B500 strategy for high energy cells





- Pouch cell level design, integration and optimization of advanced electrode and electrolyte materials.
- A combination of new strategies to solve Li metal problems in Li||NMC and Li||S cells.
- State-of-the-art techniques for characterization, prognosis and diagnosis of the components and cells.

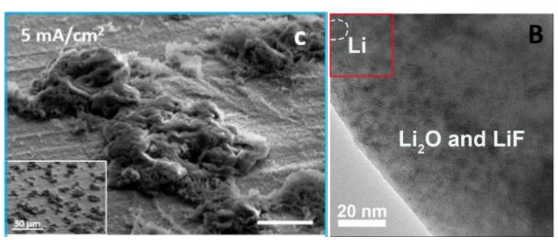
J. Liu, Z. Bao, Y. Cui, E. J. Dufek, J. B. Goodenough, P. Khalifah, Q. Li, B. Y. Liaw, P. Liu, A. Manthiram, Y. Meng, V. R. Subramanian, M. Toney, V. V. Viswanathan, M. S. Whittingham, J. Xiao, W. Xu, J. Yang, X.-Y. Yang, J-G. Zhang, "Pathways for Long-Cycling High-Energy-Density Practical Lithium Metal Batteries", *Nature Energy*, 2019, **4**, 180-186.

Accomplishments of Battery500 Keystones

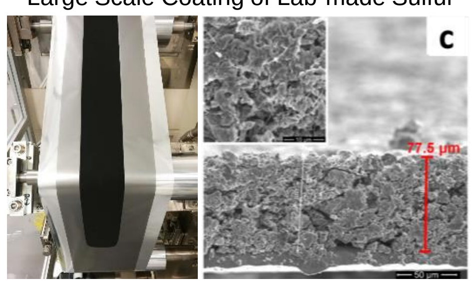
Developed and implemented strategies for design, fabricating, testing and safely handling high energy rechargeable Li metal batteries for >350 Wh kg^{-1} cells.

- Keystone Project 1: Completed synthesis, characterization and implementation of high Ni-rich NMC (NMC622 and NMC811) cathode materials and new electrolytes in high energy coin cells and pouch cells.
- Keystone Project 2: Developed new thick cathode architectures and carbon anode host materials to extend Li anode cycling to >200 cycles under realistic conditions.
- Keystone Project 3: Demonstrated and validated 350 Wh kg^{-1} pouch cells, extended the cycling life from less than 20 to over 250 cycles cycles, and developed new in-situ techniques for quantifying Li dendrites.

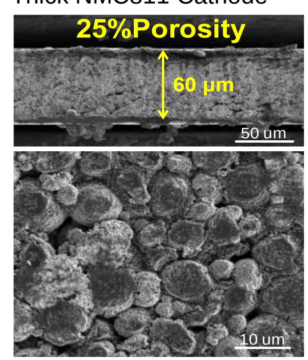
Inactive Li by Cryo-SEM/Cryo-TEM



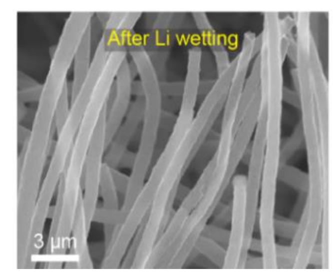
Large Scale Coating of Lab-made Sulfur



Thick NMC811 Cathode



3D Carbon Host for Li



Battery500 Progress on 350 Wh kg^{-1} Li||NMC Pouch Cells

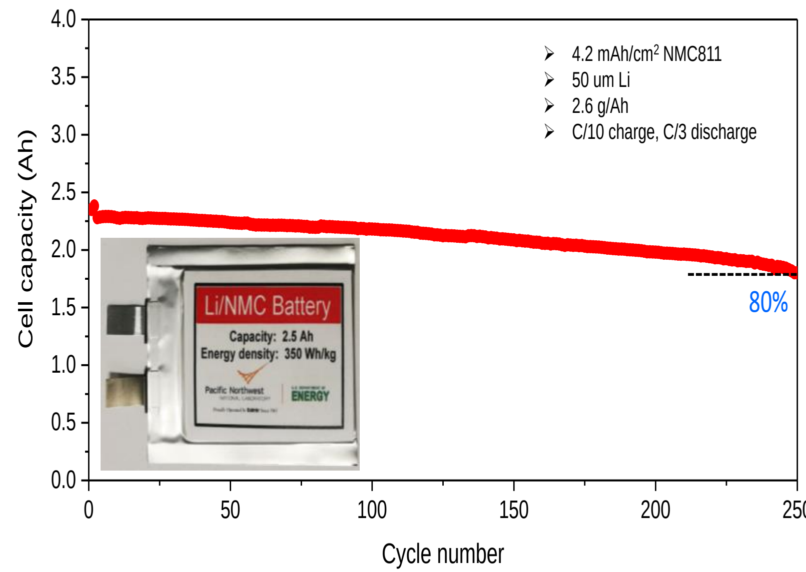
- ❑ **Annual Cell Deliverables containing**
  - High capacity Li-ion cathode
  - Li Metal anode
  - Liquid electrolyte
- ❑ With
  - only 100% excess electrolyte
  - only 166% excess Li
  - >4 mAh cm^{-2} loading
  - C/10 charge
  - C/3 discharge

2017 Baseline Deliverable

- ❑ 309 Wh kg^{-1}
- ❑ Achieved 275 cycles

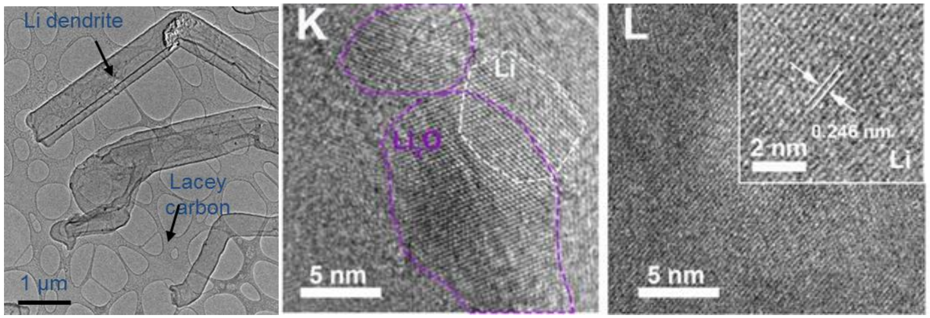
2018 and 2019 Deliverable

- ❑ 350 Wh kg^{-1}
- ❑ Achieved 250+ cycles so far



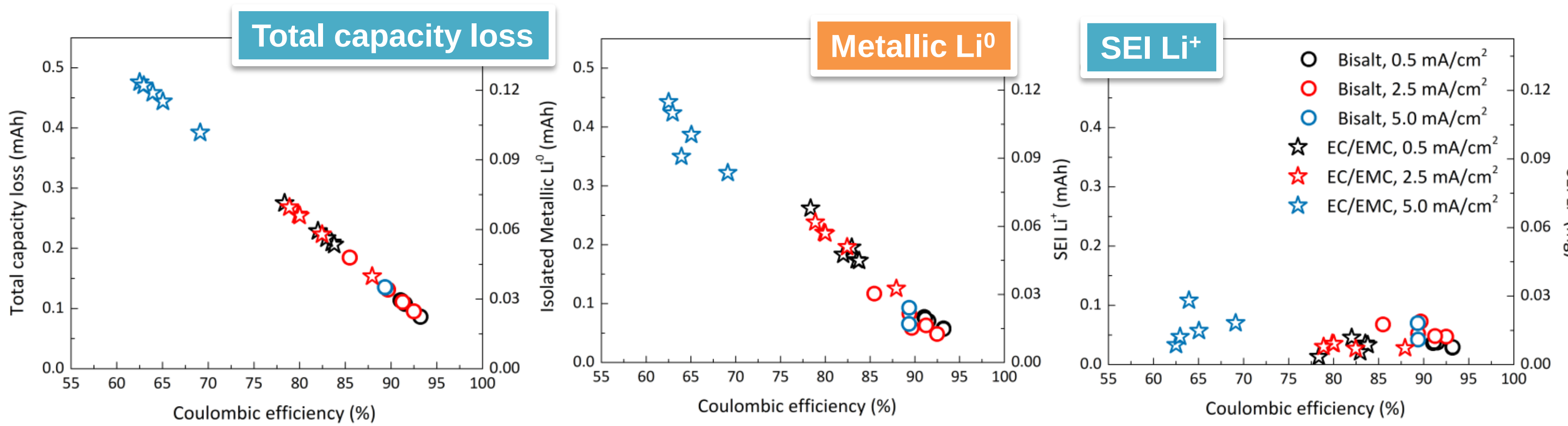
C. Niu, H. Lee, S. Chen, Q. Li, J. Du, W. Xu, J-G. Zhang, M. S. Whittingham, J. Xiao, J. Liu, "Lithium Metal Anode Structural Evolution in High-Energy Lithium Metal Pouch Cell with Stable Cycle Life, *Nature Energy*, 2019, in press.

Developing new methods to characterize and quantify Li dendrite, SEI and inactive or "dead" Li



Y. Li, A Pei, K. Yan, Y. Sun, CL, Wu, L.M. Joubert, R. Chin, AL. Koh, Y. Yu, J. Perrino, B. Butz, S. Chu, Y. Cui. "Atomic structure of sensitive battery materials and interfaces revealed by cryo-electron microscopy", *Science*, 2017, **358**, 506-510.

X. Wang† , M. Zhang, J. Alvarado, S. Wang, M. Sina, B. Lu, J. Bouwer, W. Xu, J. Xiao, JG. Zhang, J. Li, Y. S.Meng. "New Insights on the Structure of Electrochemically Deposited Lithium Metal and Its Solid Electrolyte Interphases via Cryogenic TEM", *Nano Letters,* 2017, **17**, 7606-7612.



C. Fang, J. Li, J. Z. Lee, Y. Zhang, F. Yang, N Williams, Y. Yang, J. Alvarado, M. A. Schroeder, L. Yang, M. Cai, J. Gu, K. Xu, X. Wang, Y. S. Meng, "Quantifying Inactive Lithium in Lithium Metal Batteries", 2018, arXiv:1811.01029.

- First atomic resolution image of Li dendrite and SEI layers on Li.
- Direct observation and 3D visualization of dendrite growth and mossy structures.
- Techniques to differentiate metallic and ionic Li in SEI.

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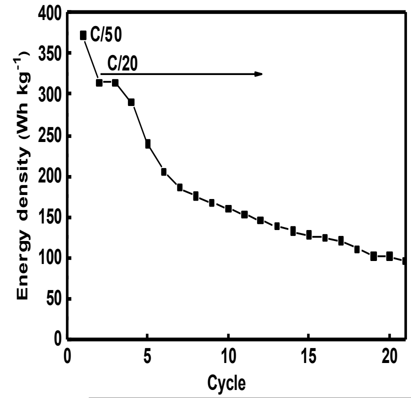
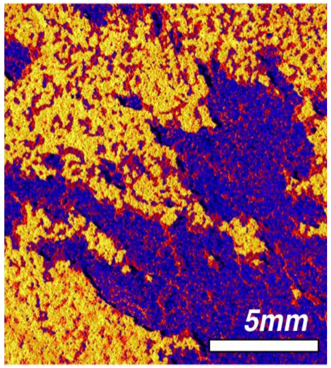
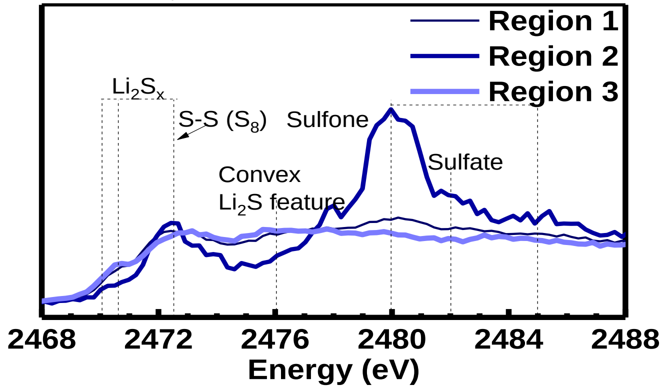
Redesigning Li-S Pouch Cells to Improve Cycling

	Parameters	Previous Li-S Cell Parameters (372 Wh kg^{-1})	FY19 Li-S Cell Design (350 Wh kg^{-1})
Cathode	Material	S (80%)/C (20%)	S (80%)/C (20%)
	1st discharge capacity (mAh g^{-1}, based on S/C composite wt.)	925 (C/50)	912 (C/10)
	Coating weight (mg cm^{-2} each side)	9.8 (S: 6.3 mg/cm^2)	6.25 (S: 4.0 mg/cm^2)
	Areal capacity (mAh cm^{-2} each side)	7.3	4.6
	Electrode press density (g cm^{-3})	0.7	0.67
	Electrode thickness (single side) (µm)	146	76
	Al foil thickness (µm)	15	12
Anode	Cell balance (N/P ratio)	1.4	2.2
	Li thickness (single side) (µm)	50	50
	Cu thickness (µm)	9 (Cu mesh)	2 (Cu foil)
Electrolyte	Electrolyte/capacity ratio (g Ah^{-1})	2.4	3
Packet foil	Thickness (µm)	86	86
Cell	Voltage (V)	2.1	2.1
	Capacity (mAh)	**2532**	**2300**
	Energy density (Wh kg^{-1})	**372**	**350**







In-situ investigation of the pouch cell failing mode due to uneven distribution of polysulfides

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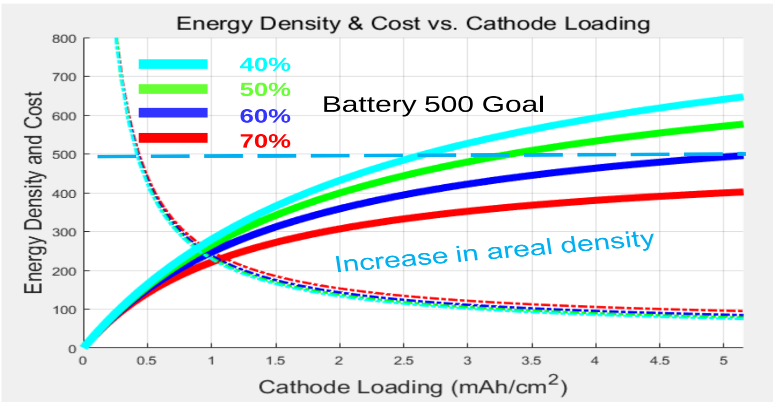
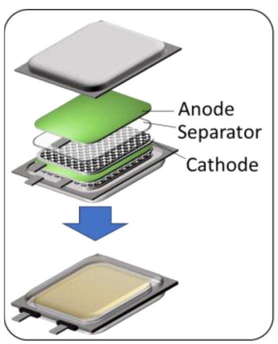
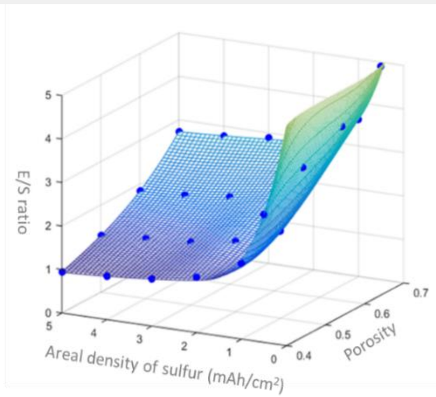
Progresses from Seedling Projects

Comprehensive cell designing tools for pouch cells (Li-S cell parameters are show here).



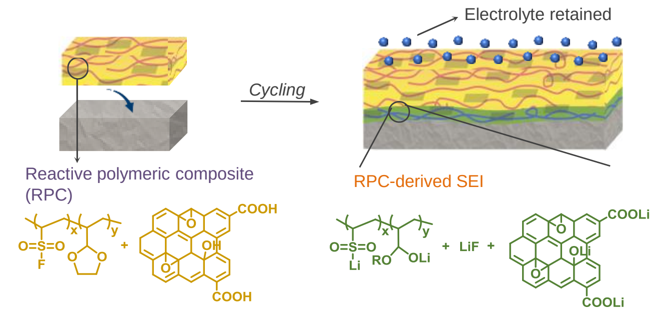


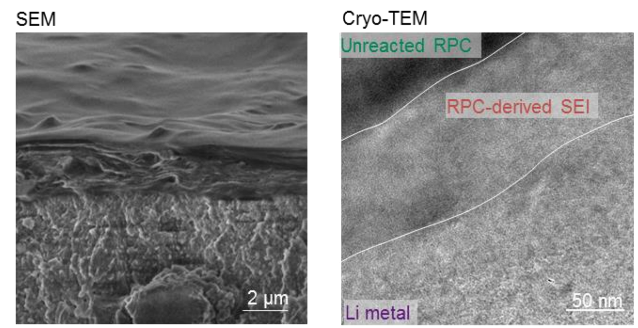


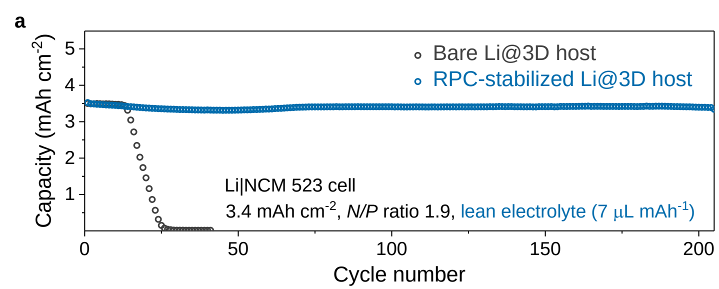
- The E/S ratio is correlated to both the sulfur loading and electrode porosity.
- The predicted energy density shows 640, 570, 500 and 400 Wh/kg for Li-S with 40%, 50%, 60% and 70% porosity.
- What is the influence of porosity on battery performance?

GM RESEARCH & DEVELOPMENT

Polymer-inorganic SEI layer for Li metal under lean electrolyte condition







Y. Gao, Z. Yan, J. L. Gray, X. He, Daiwei Wang, T. Chen, Q. Huang, Y. C. Li, H. Wang, S. H. Kim, T. E. Mallouk, D. Wang. “Polymer–inorganic solid–electrolyte interphase for stable lithium metal batteries under lean electrolyte conditions”, *Nature Materials*, 2019, **18**, 384–389.

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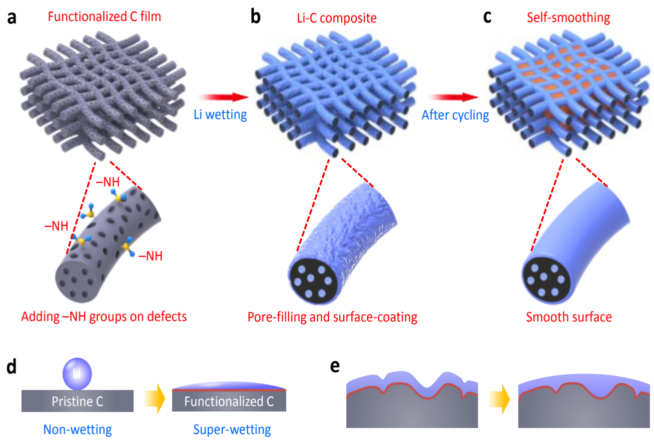
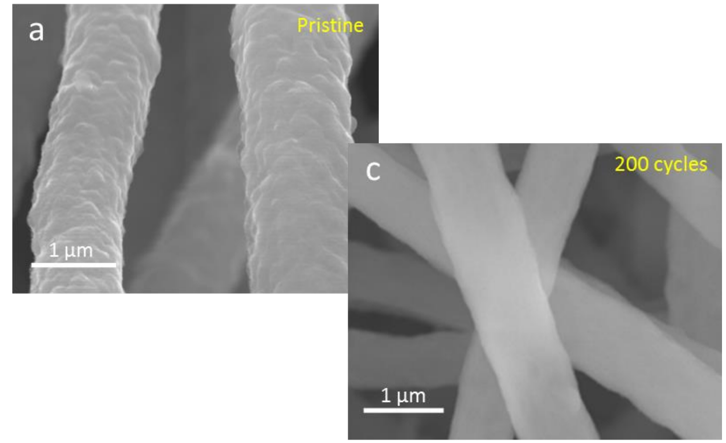
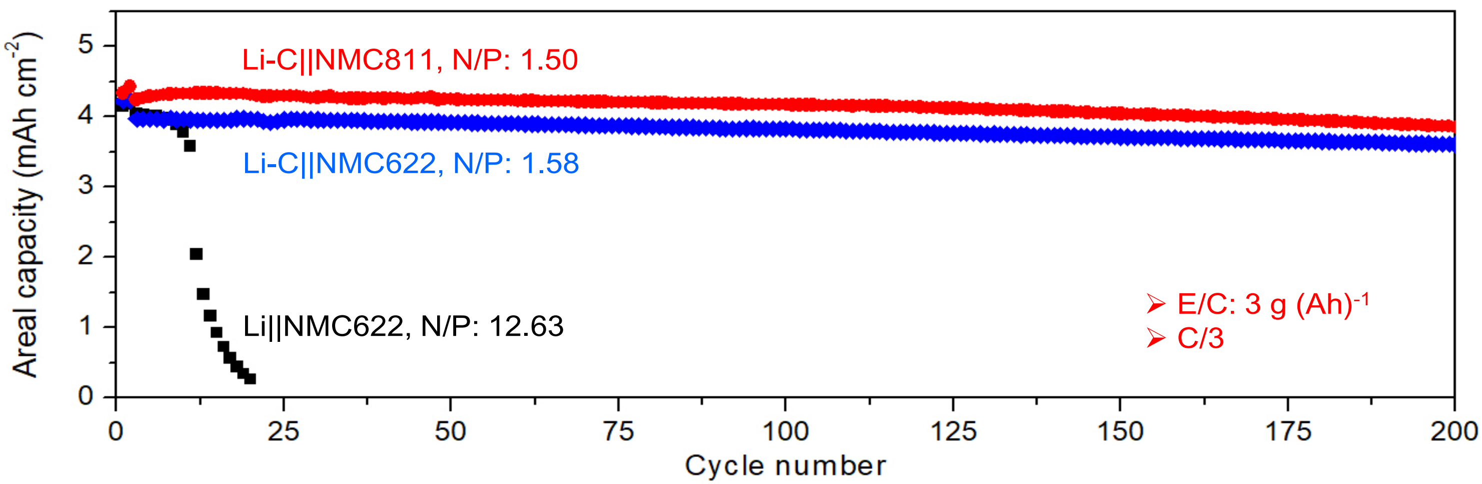
Remaining Challenges and Barriers

- A combination of new approaches to stabilize Li metal anode for long cycle life (>300 cycles)
  - Further improvement of electrolytes to reduce SEI reactions
  - New Li metal protection methods
  - Fully understand and quantify the Li metal cycle life during charge and discharge in real cells
- Fully utilization of active materials:
  - Reducing parasite weights (separators, conductors, additives, etc.)
  - Increasing the specific capacity and voltage stability
  - Increasing cathode material loading and reduce porosity
- Cell level configuration and optimization for >400 Wh/kg cells
- Long cycle life and safety of Li metal cells

Example for Future Directions: Stable Self-Healing Anodes, Coin Cell Results Under Realistic Conditions







C. Niu, H. Pan, W. Xu, J. Xiao, J-G. Zhang, L. Luo, C. Wang, D. Mei, J. Meng, X. Wang, Z. Liu, L. Mei, J. Liu. “Self-smoothing Anode for Achieving High-Energy Lithium Metal Batteries under Realistic Conditions”, *Nature Nanotechnology*, 2019, DOI:10.1038/s41565-019-0427-9.

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