Progress and Status of Battery500 Consortium

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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: 30 percent

Budget

- Total project funding
  - DOE share $50M
- Funding received in FY 2017: $10M
- Funding for FY 2018: $10M

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: PNNL
- Battery500 Core Team: Binghamton Univ., BNL, INL, Stanford Univ./SLAC, UC San Diego, Univ. of Texas Austin, Univ. of Washington
- 15 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

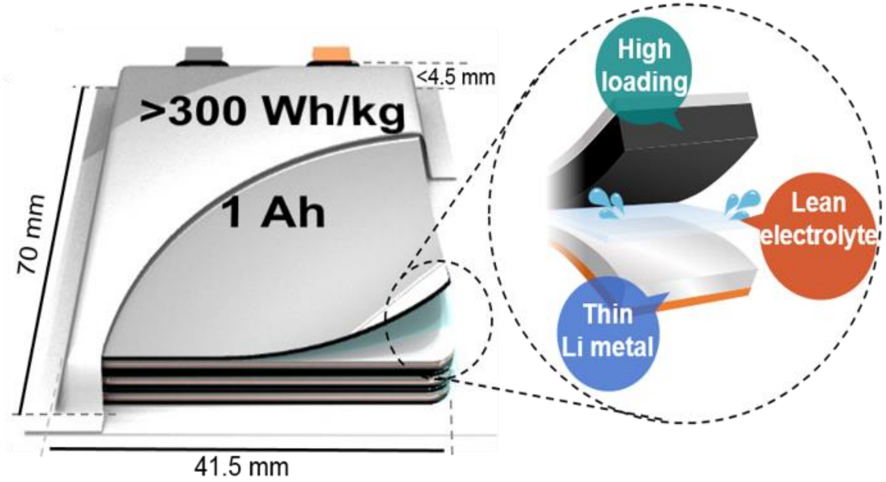
Date	Milestones	Status
FY17 annual	Demonstrate 1 Ah pouch cell with 300 Wh/kg energy density, and over 50 cycles and continuing, and complete the preliminary testing protocols and demonstrate utilization of these protocols.	***Completed***
Dec. 31, 2017	Scale up the synthesis capacity of high Ni content NMC to 500 g	***Completed*** (Manthiram, Whittingham)
March 31, 2018	Develop stage 1 pouch cell testing protocols and provide updated component parameters toward 350 Wh/kg; Establish baseline properties of Li-S coin cells using parameters required to reach 350 Wh/kg.	***Completed*** (Xiao, Dufek, Cui)
June 30, 2018	Provide feedback on characterization of the new materials and concepts by the characterization team; Develop procedures to identify Li anode failure in coin cells and pouch cells.	***On track***
Sept. 30, 2018	Establish the coin cell performance with 30% weight reduction in the anode current collector; Develop and implement methods to improve and understand cycle and calendar life of pouch cells.	***On track***
FY18 annual	Integrate materials and components into >1 Ah pouch cell and demonstrate 350 Wh/kg cell with over 50 charge/discharge cycles.	***On track***

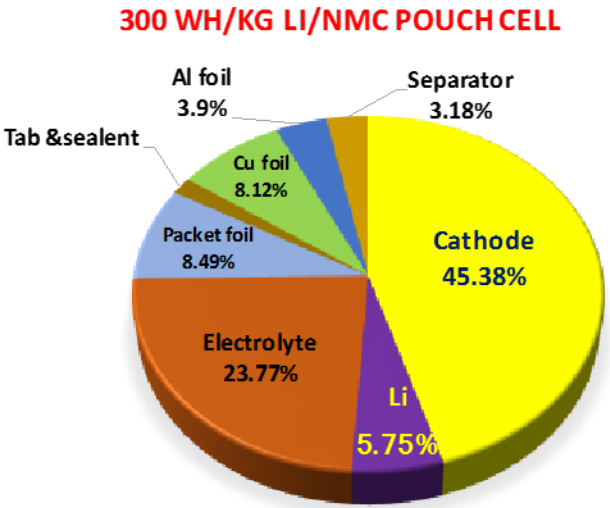
Approach

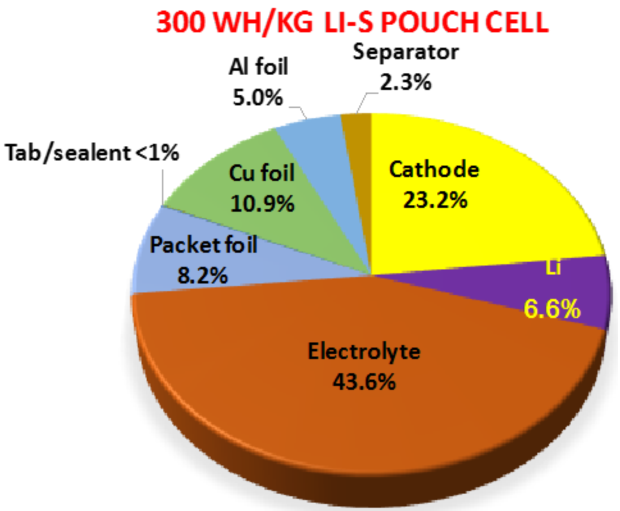
- Develop commercially viable Li battery technologies with a cell level specific energy of 500 Wh/kg through innovative electrode and cell designs that enable utilization of maximum capacity of advanced electrode materials.
- Utilize a Li anode combined with a compatible electrolyte system, and two cathodes — nickel-rich NMC ($LiNi_xM_{1-x}O_2$, M = Mn or Co and $x > 0.7$) and sulfur.
- Design novel electrodes and cell architectures that will allow 50% of the capacity to be attained at the cell level in order to meet the 500 Wh/kg goal.
- Integrate the multi-institute capabilities in battery materials and chemistry, electrode architecture, cell design and fabrication, and advanced diagnosis to optimize the materials performance in realistic cell architectures.

Approaches

Cell level design for >300 Wh/kg Li||NMC and Li||S Cells



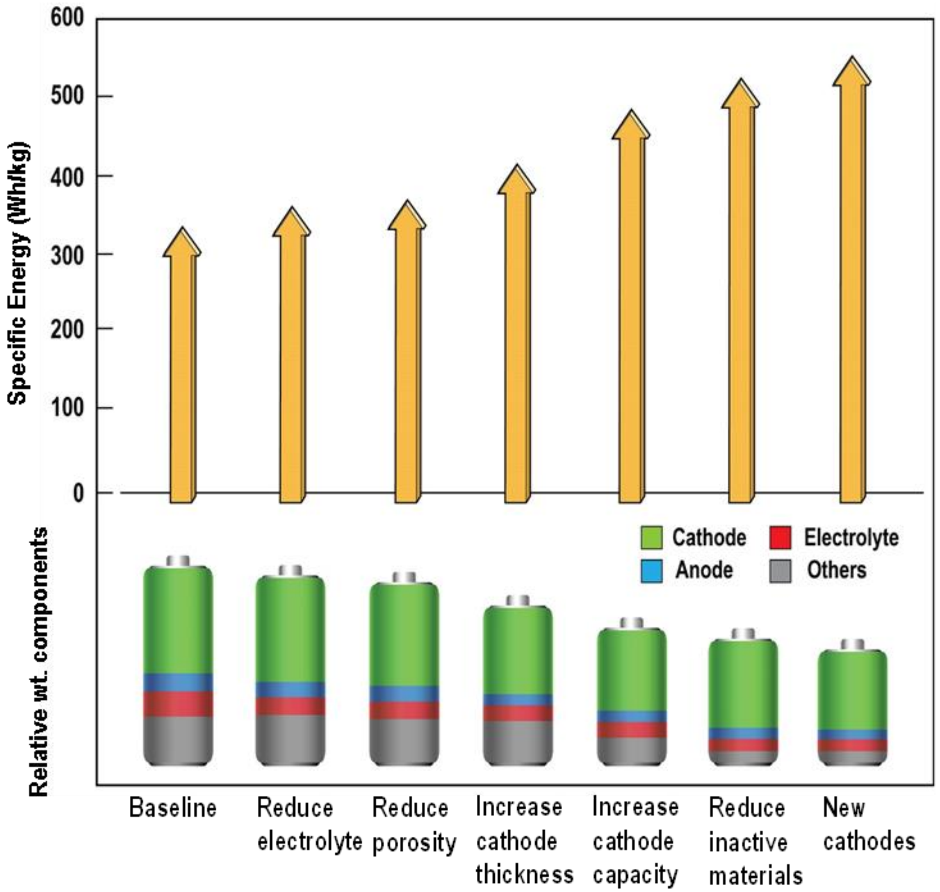




- ➢ Standard testing protocols have been developed.
- ➢ Lean electrolyte, thin Li metal and high cathode loading are needed.

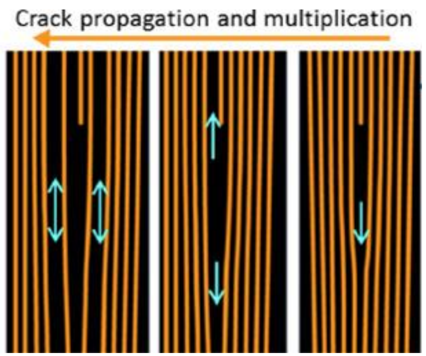
BATTERY 500 CONSORTIUM

Pushing the materials limits for advanced lithium batteries

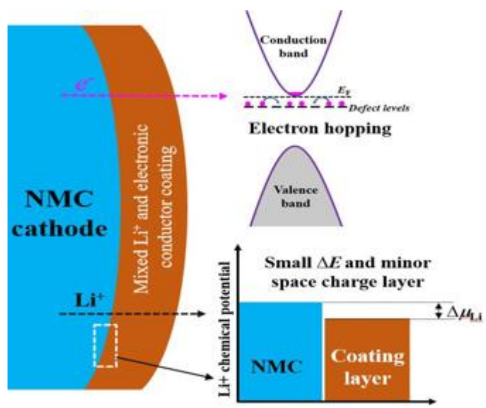


- Stable Li anode structure.
- Anode/cathode capacity N/P ratio < 2.
- Increasing cathode capacity to over 220 mAh/g and stability to over 4.4 V.
- Increasing stability window of electrolytes and interfacial stability on both cathodes and anodes.
- Developing thick (>120 μm) and dense (<23% porosity) electrode architectures.
- Reducing inactive materials (electrolyte, current collectors, separator, packaging).
- Optimizing materials properties on the cell level.

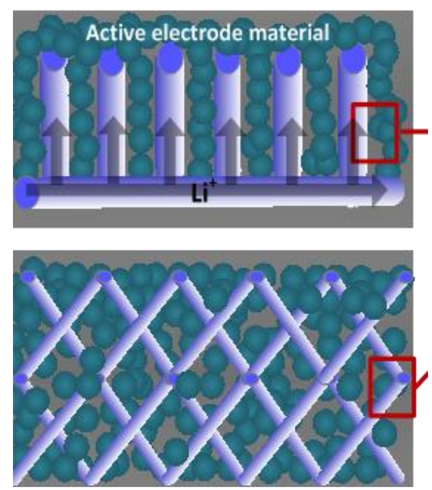
Multiscale approaches to develop thick cathode architectures



Understanding and controlling of degradation on atomic scale



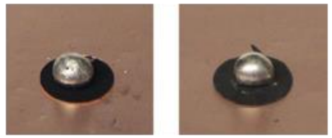
Controlling of synthesis, particle morphologies and interfacial chemistry



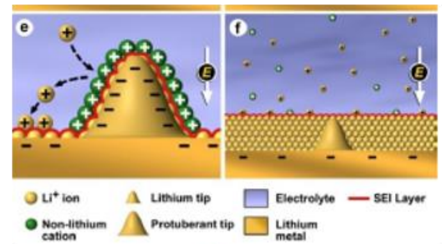
Thick electrode architecture to maximize cathode utilization

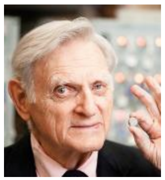
Multi-disciplinary approaches for lithium metal

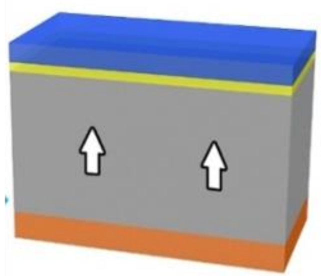
Interfacial wetting



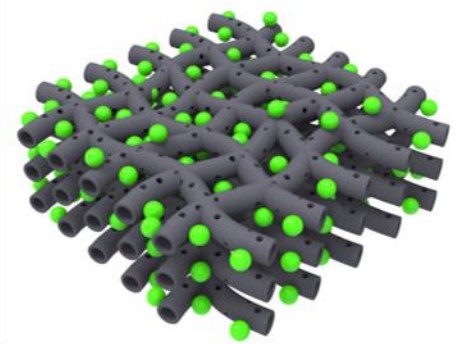
Electrolytes







Solid electrolyte



Lithium architecture

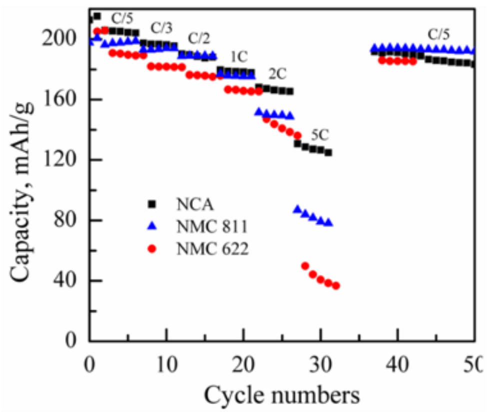
Technical Accomplishments

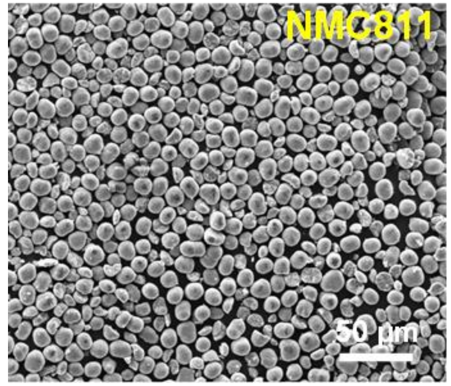
2017 Deliverable

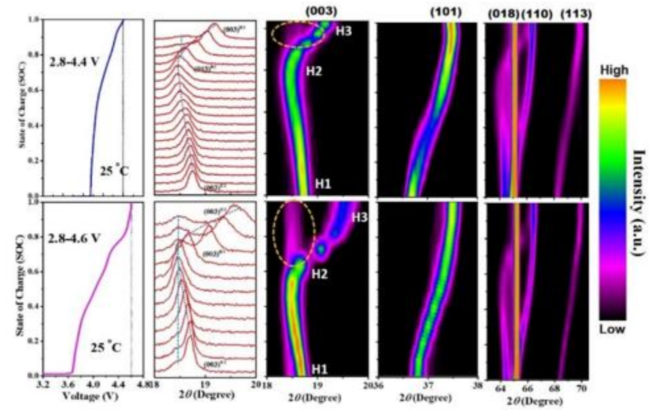
- ❑ Baseline cells containing
  - High capacity Li-ion cathode
  - Li metal anode
  - Liquid electrolyte
- ❑ 1 Ah, 309 Wh/kg
- ❑ Increased cycle life from <20 to over 188 cycles
  - C/10 charge
  - C/3 discharge
- ❑ With lean electrolyte and thin Li metal required for 300 Wh/kg cells
- ❑ 4 mAh/cm^2 loading

Technical Accomplishments

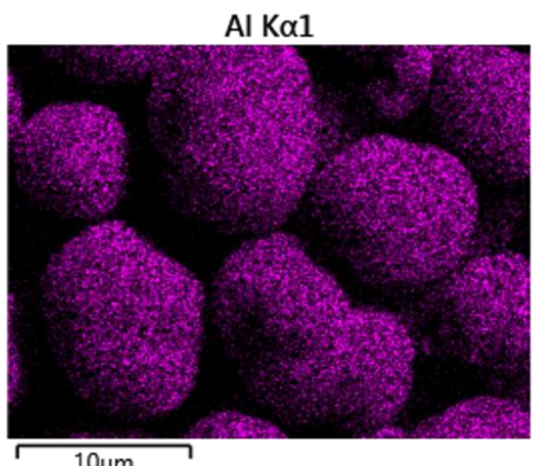
Synthesis and Improvement of High Ni NMC (NMC811)

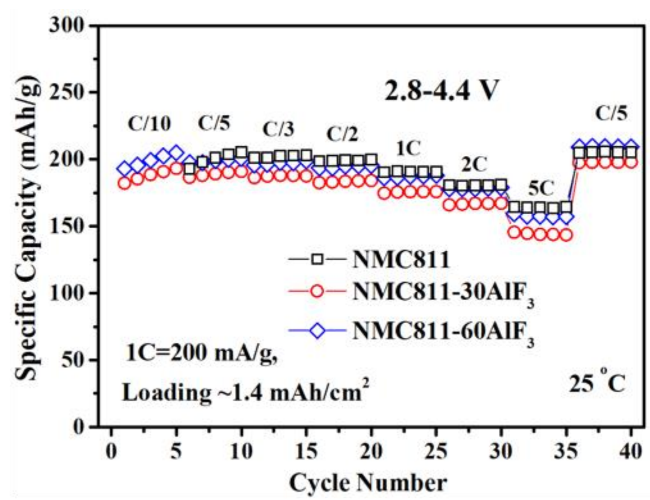






- Scalable synthesis of NMC 811.
- NMC811 (FY18 baseline material) has high specific capacity and good rate capability compared to NMC622 (FY17 baseline material).
- Surface initiated reactions could cause degradation of NMC811.
- ALD coating (AlF_3) improves the stability.

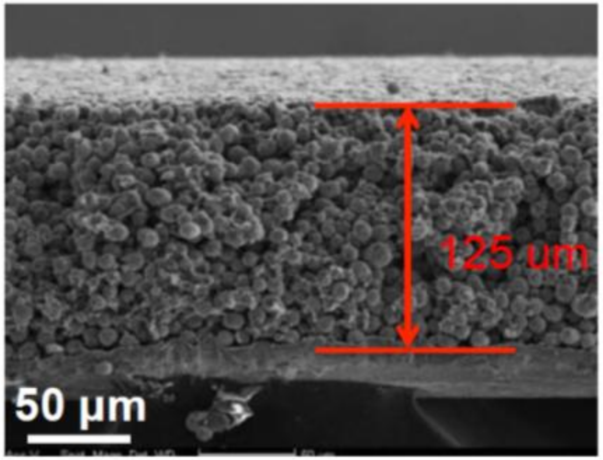


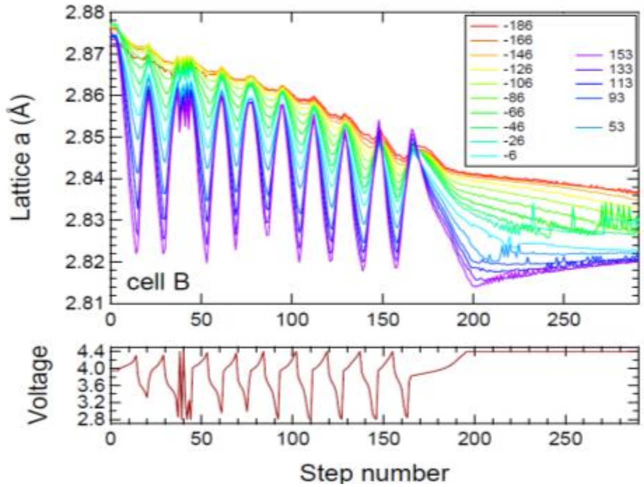


Technical Accomplishments

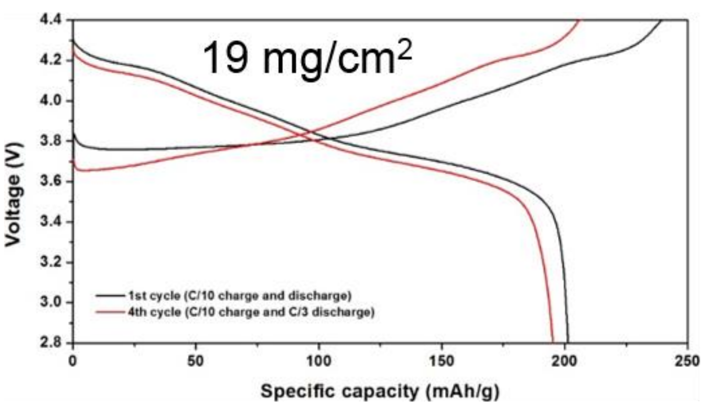
Increasing Cathode Loading

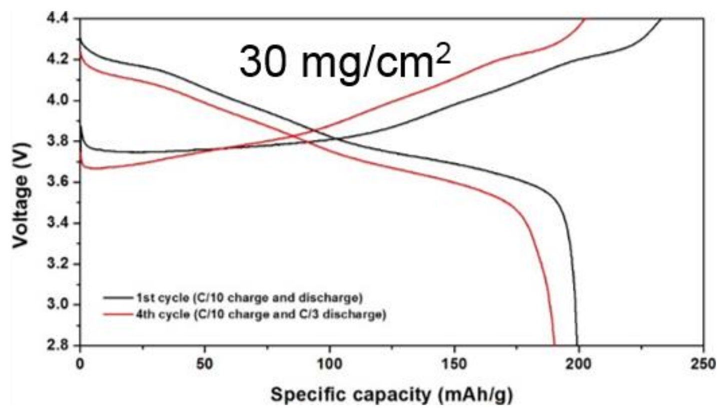
Under utilization of thick cathode





- At higher rate (C/3), thick film shows more inhomogeneity.
  - Variability even seen at top of cathode.
  - Bottom layer barely sees influence of cyclical applied voltage.

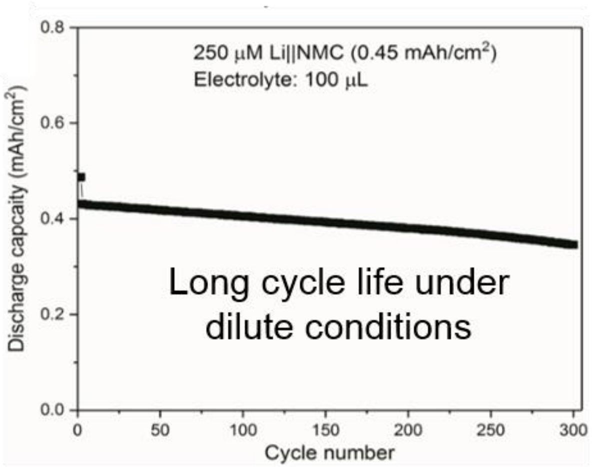




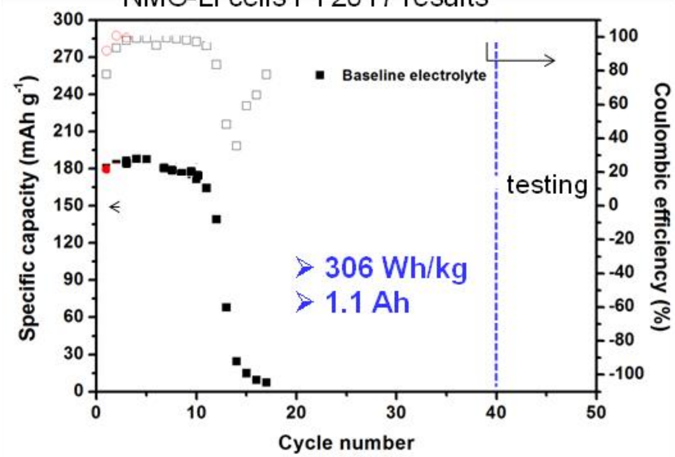
- High areal capacity (5.7 mAh/cm^2) at 30 mg/cm^2 loading is possible.

Technical Accomplishments

Understanding complex failure modes in real cells and developing new electrolytes to improve the properties

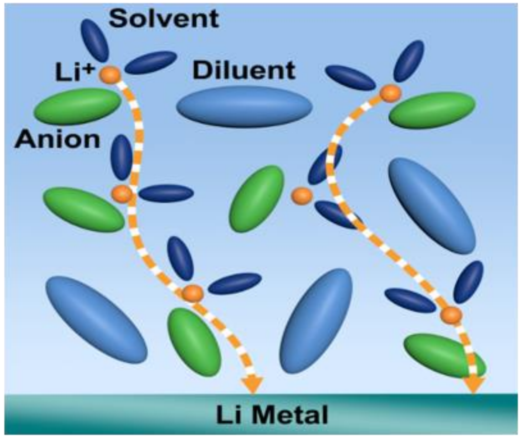


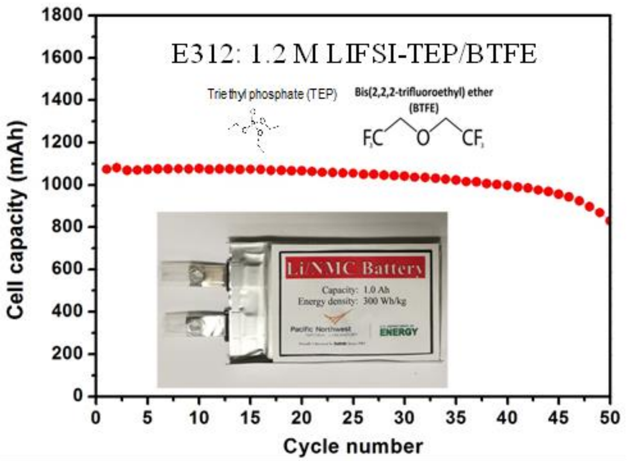
NMC-Li cells FY2017 results



- Formation: charge/discharge 2 cycles at C/10
- Charge: C/10
- Discharge: C/3

Limited cycle life due to mossy Li SEI to deplete the electrolyte and Li metal.



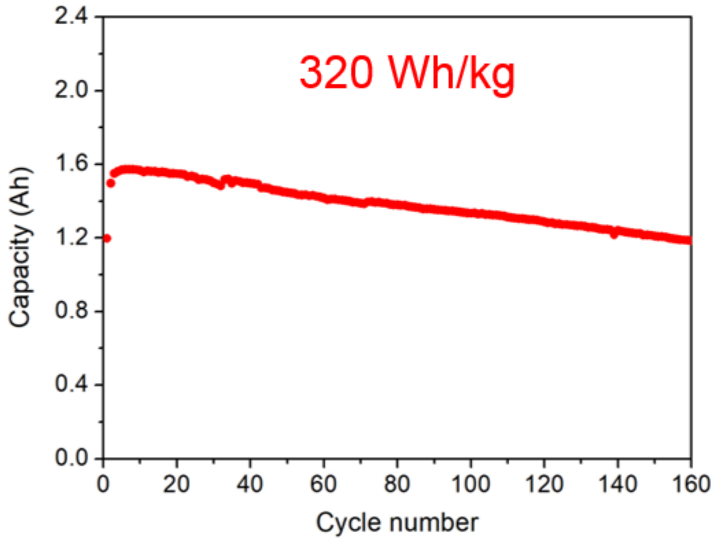


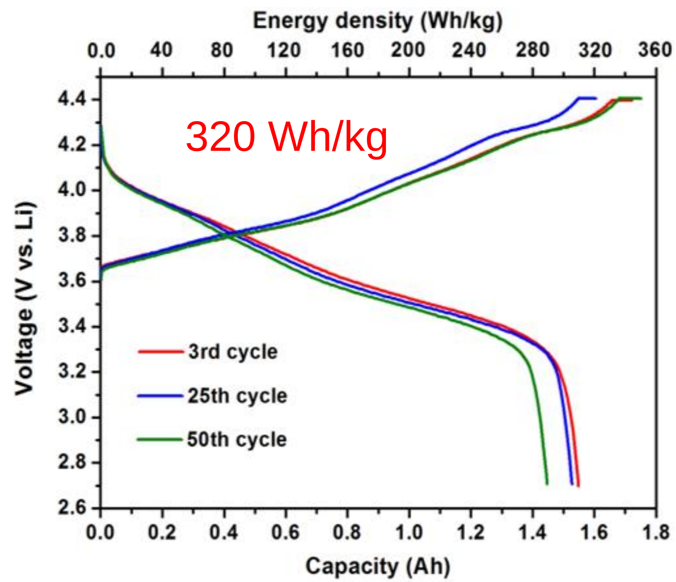
Improve cycle life using locally concentrated electrolytes

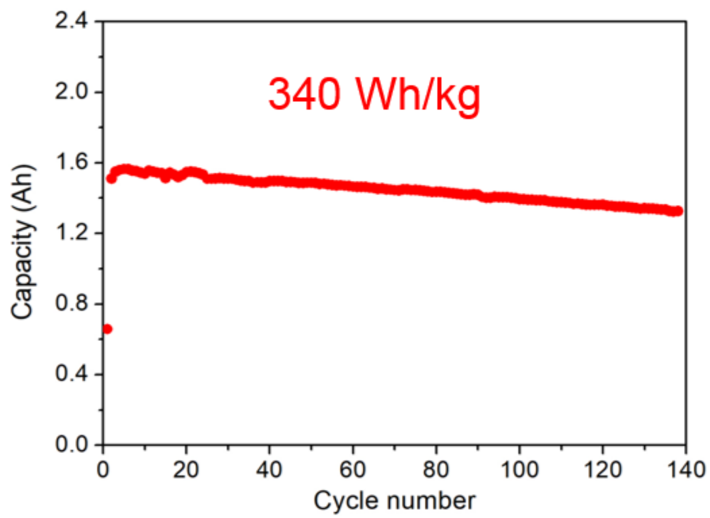


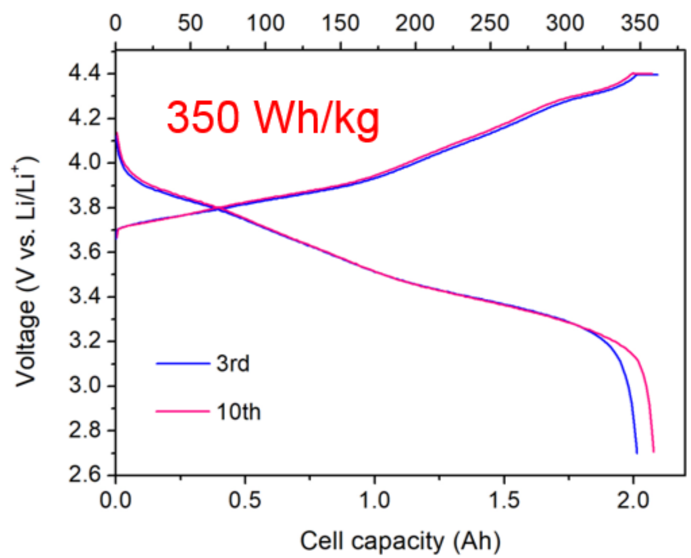

Technical Accomplishments

Achieved higher energy and longer cycle life by cell level optimization (NMC811 pouch cells, FY18 results)



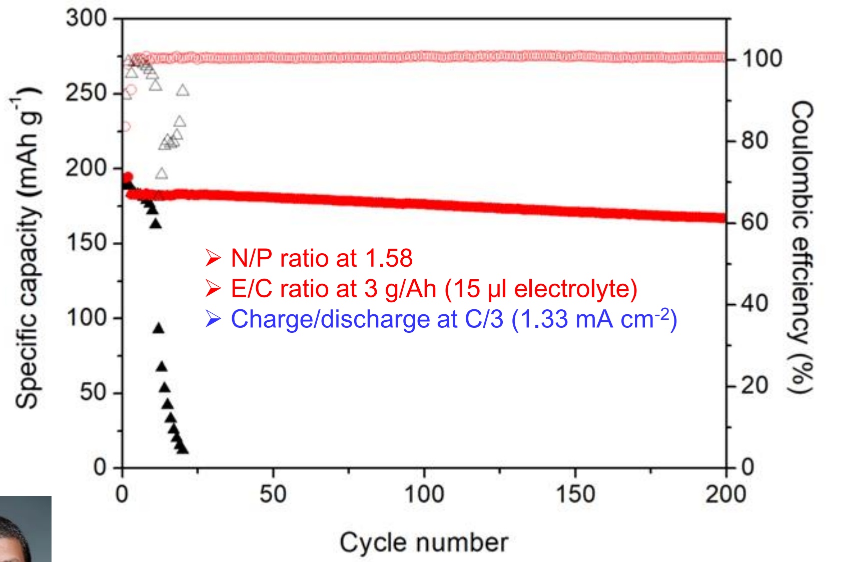


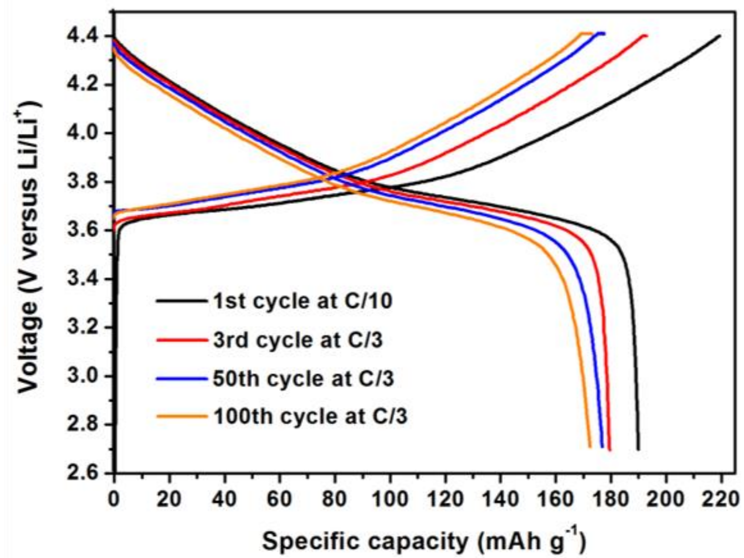


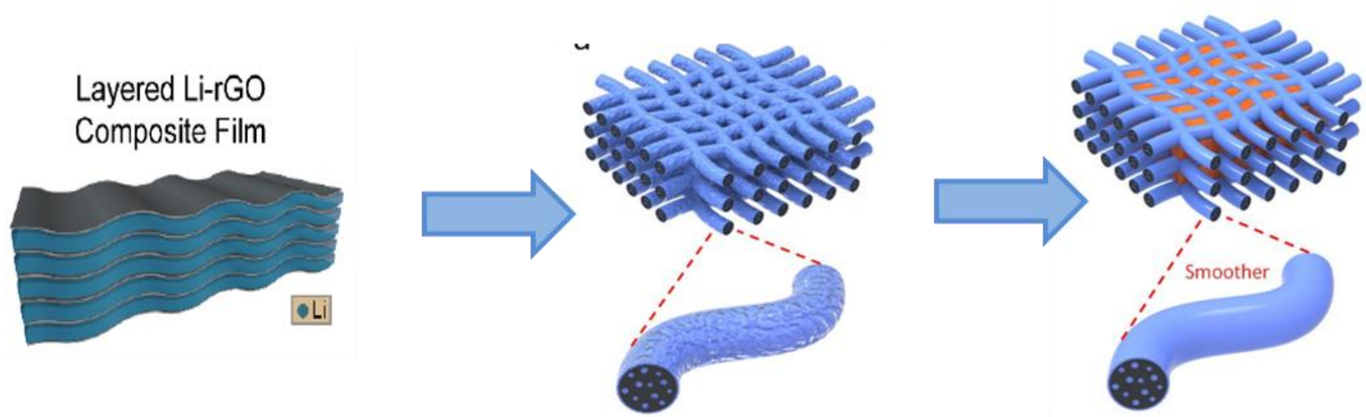


Technical Accomplishments

Self-Healing 3D Anodes for High Energy Cells and Long Cycle Life 350 Wh/kg cells counting all materials/components (Low N/P ratio, high cathode loading, lean electrolyte, packing materials)



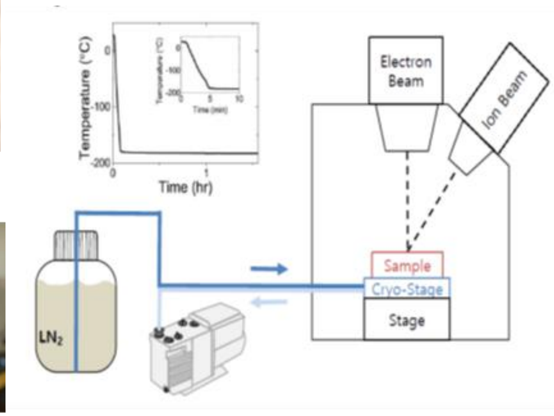


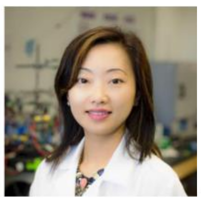


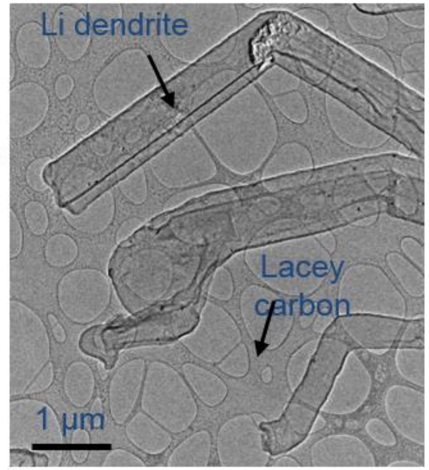
Technical Accomplishments

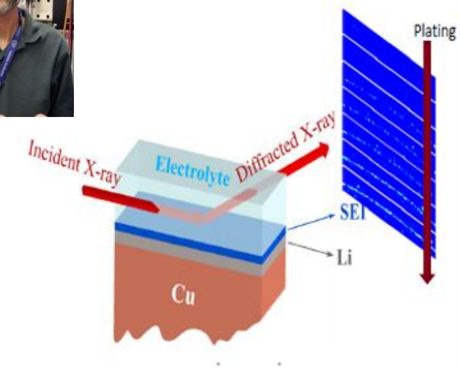
Developed and demonstrated multilevel characterization tools to characterize and quantify the Li metal anode degradation processes

Cryo-TEM



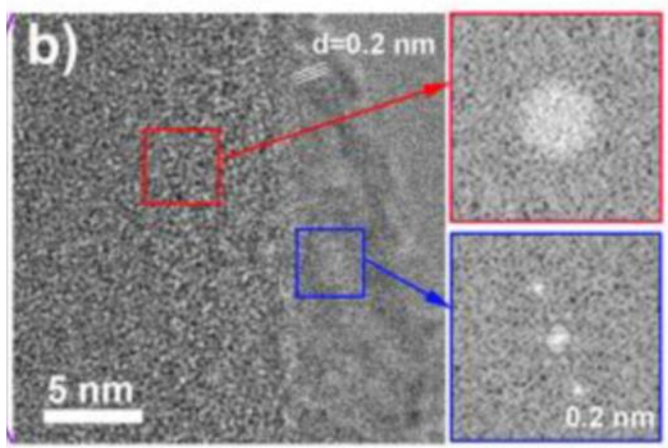


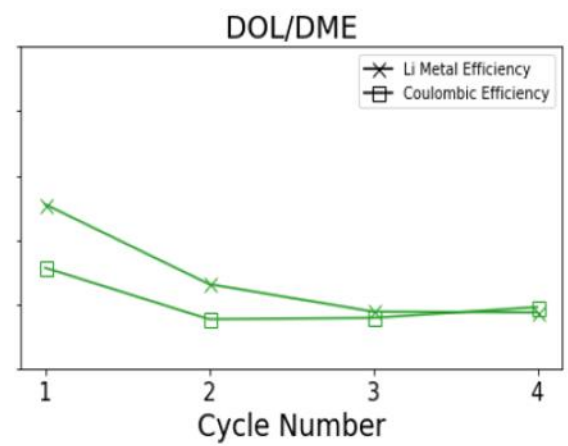




Electrolyte: 1 M $LiPF_6$ in 1:1 EC/DMC, 1.0 mA/cm^2

- Direct observation of the atomic structures in Li;
- Direct HRTEM observation of dendrite growth;
- Direct observation of SEI providing important new information.



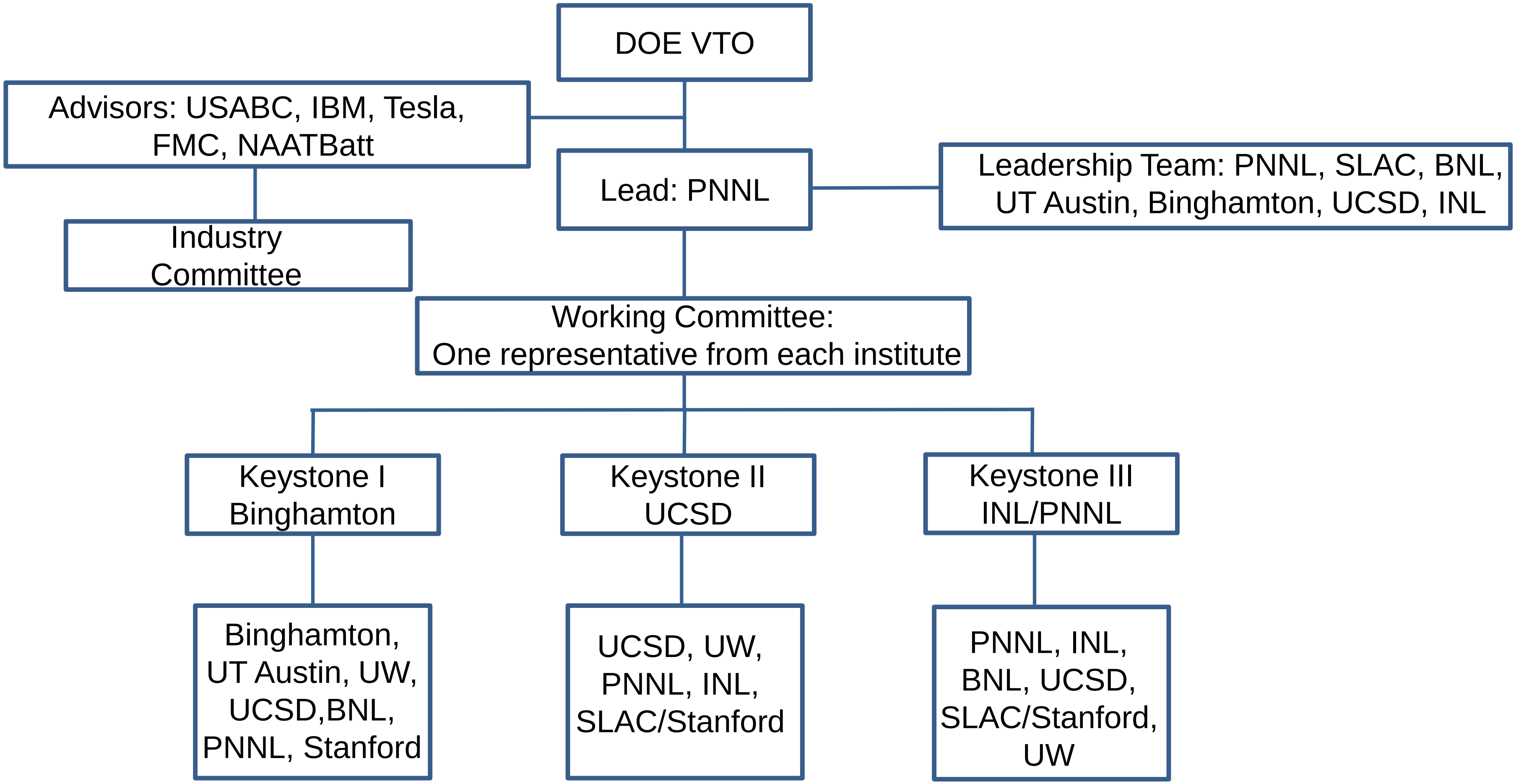


In-situ X-ray provide quantitative information of dead Li.

Responses to Previous Year Reviewers' Comments

No comments from previous years

Collaboration and Coordination with Other Institutions



Seedling Projects: U Pittsburgh, Cornell, OSU, SBU, UMD, UH, Penn State, Texas A&M U, LBNL, UMI, ORNL, WSU, GM

Remaining Challenges and Barriers

- A combination of new approaches to stabilize Li metal anode for long cycle life
  - Further improvement of electrolytes to reduce SEI reactions
  - New Li metal protection methods
    - Very thin protective coating (< 10mm)
    - Light weight and flexible
    - Stable to a higher voltage
  - Fully understand and quantify the Li metal life cycle during charge and discharge in real cells

- Fully utilization of active materials:
  - Reducing parasite weights (separators, conductors, additives, etc.)
  - Increase 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 cells

Proposed Future Work

- Integrate the multi-institute capabilities in battery materials and chemistry, electrode architecture, cell design and fabrication, and advanced diagnosis to maximize materials utilization and optimize the materials performance in realistic cell architectures.

- Focus on three keystone projects:

  I. Materials and Interfaces –High utilization of high-energy cathodes and high-capacity Li metal anode by developing interface doping/coating on cathode materials and novel electrolytes for stable operation of Li metal anode.

  II. Electrode Architecture – New electrode architectures to increase electrode thickness and maximize active materials utilization, and 3D Li architectures to stable the metal anode.

  III. Cell Design and Integration – Cell level optimization of the materials and architectures to achieve more than 400 Wh/kg specific energy and long cycle life.

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:
  - Keystone Project 1:
    - ✓ Systematically evaluated high Ni NMC and S cathode materials and developed and implemented strategies to optimize and improve their properties in high energy cells.
    - ✓ Developed new electrolytes to significantly extend the cycle life of Li metal anode.
    - ✓ Investigated a range of self-healing polymer coatings for Li metal anode.
  - Keystone Project 2:
    - ✓ Developed thick electrode architectures for high energy cells.
    - ✓ Developed new 3D anode architectures with potential for long cycle life.
  - Keystone Project 3:
    - ✓ Established cell level requirements and parameters for >300 Wh/kg cells.
    - ✓ Developed and implemented standard testing protocols for validation materials and cell performance.
    - ✓ Optimized cell configuration to improve the cell performance and cycle life.
    - ✓ Developed an utilized combination of state-of-the-art tools to investigate and quantify the complex failure processes in electrode materials under real operation conditions.
  - Program Level:
    - ✓ Achieved more than 100 cycles for 300 Wh/kg pouch cell in FY17.
    - ✓ On track to achieve more than 100 cycles for 350 Wh/kg pouch cells for FY18.

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