Battery Materials Research (BMR) and Battery500 Overview

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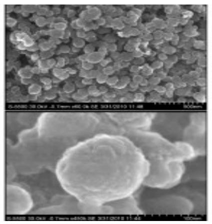
VTO Batteries R&D Program Structure

Advanced Battery Materials Research (BMR Program)

SEM of Li_2FeSiO_4/C Nanospheres



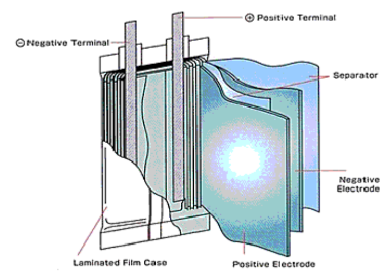
- ❑ High capacity cathodes
- ❑ Lithium metal anode
- ❑ High voltage electrolytes
- ❑ Solid state electrolytes

Cell Materials Targets

- ❑ Anode capacity > 1000 mAh/g
- ❑ Cathode capacity > 300 mAh/g
- ❑ Solid electrolytes with ionic conductivity >1 mS/cm

Battery500 Consortium

High Energy & High Power Cell R&D (ABR Program)



- ❑ Electrodes exhibiting high energy density and high rate capability
- ❑ Fabrication of high energy density cells
- ❑ Cell diagnostics
- ❑ Improved manufacturing processes

Cell Design Targets

- ❑ 350 Wh/kg, 750 Wh/l
- ❑ 1,000 cycles
- ❑ 10+ calendar year life

Full System Development & Testing (Developer Program)

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

- ❑ Cost reduction. Improved life and performance
- ❑ Robust battery cell and module development
- ❑ Testing and analysis
- ❑ Fast charge

Battery Pack Targets

- ❑ $100/kWh EV pack cost
- ❑ Fast charge (80% SOC in 15 minutes)
- ❑ $180, 12V start/stop pack cost

Advanced Battery Materials Research (BMR) Program

- **Previously known as:**
  - Exploratory Technology Research (ETR) (1980-2001)
    - Focused exclusively on batteries for automobile applications since 1992
  - Batteries for Advanced Transportation Technologies (BATT) (2002-2014)
- **Charter:**
  - Perform cutting edge research in new materials and electrochemical couples.
  - Employ comprehensive modeling and advanced diagnostic techniques to address chemical/mechanical instabilities of materials and poor cell performance.
- **7 Topic areas, 51 research projects:**
  - Modeling (11), Diagnostics (10), Polymer and Solid State Electrolytes (10), Metallic Lithium (7), Sulfur Electrodes (7), Air Electrode/Electrolyte (3), Sodium ion Batteries (3)
  - FY 2018: Research projects in high capacity, high voltage cathodes (NMC) and silicon composite anodes transferred to the Applied Battery Research program.
  - FY 2019: Initiate feasibility studies of sodium ion batteries for vehicle applications.

BMR – Current Participants

National Labs (7)

- Argonne National Laboratory
- Brookhaven National Laboratory
- Berkeley Lab
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- SLAC National Accelerator Laboratory
- Lawrence Livermore National Laboratory

Academia (23)

- BYU
- Brown University
- Carnegie Mellon University
- Michigan State University
- Michigan Technological University
- Massachusetts Institute of Technology
- NC State
- PennState
- Rutgers
- Stanford University
- Stony Brook University
- UK
- Michigan
- University of Pittsburgh
- University of Washington
- Texas A&M University
- University of Maryland
- University of Wisconsin UW Milwaukee
- Berkeley University of California
- UC San Diego
- The University of Texas at Austin
- West Virginia University

Industry (2)

- Daikin
- GM

BMR – Current Focus

- **Why?**
  - Research on new materials for beyond Li-ion batteries. Safe, abundant materials with higher capacity and lower cost, such as sulfur, solid electrolytes and lithium.
- **Issues**
  - Li metal: Reactivity and dendrite growth
  - Sulfur: Polysulfide shuttle
  - Solid Electrolytes: Low ionic conductivity and high interfacial resistance
- **Approaches**
  - Develop advanced modeling and characterization techniques to investigate and mitigate the reactivity at the interphases/interfaces.
  - Engineer a host for lithium and/or an artificial SEI layer to protect lithium surface.
  - Design novel structures to encapsulate polysulfides.

Battery Materials	Specific Capacity (mAh/g)	Cost ($/kg)
Graphite	372	18.5
Li metal	3,860	16.5
NMC	~ 200	27
Sulfur	1,673	~0

- **Participants** – National Labs (7), Industry (2), Academia (23)
- **Collaborative** research efforts (US–Germany) on Interphases/Interfaces (3 efforts just started)
- **Current FOA** on Solid State Electrolytes

Battery500 Consortium

❑ What is it?

– A multi-lab R&D program to develop battery cells providing 500 Wh/kg and 1,000 cycles by coupling Li-metal with high-capacity and high-voltage intercalation cathodes or sulfur

❑ Why it matters?

– The above goal is double that of today's best Li-ion cells. High specific energy (Wh/kg) technology means smaller battery to power an EV and thus lower cost.

❑ Issues

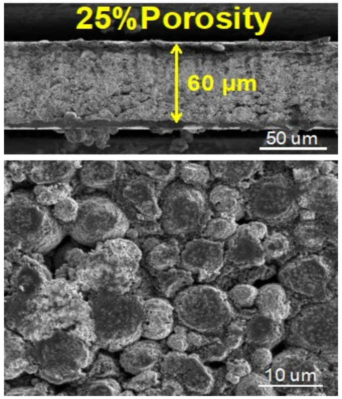
– High lithium reactivity resulting in poor cycle life

❑ Approach

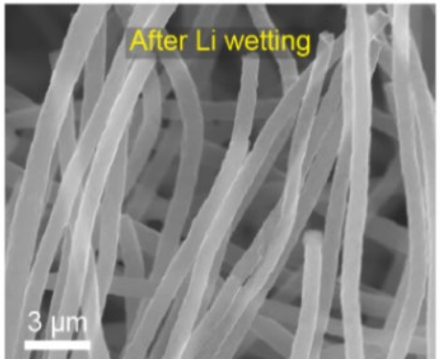
– Development of advanced electrolytes and additives to smooth out lithium deposition to improve coulombic efficiency

Developed new thick cathode architectures and carbon anode host materials to extend Li anode cycling to >200 cycles under realistic conditions.

Thick NMC811 Cathode



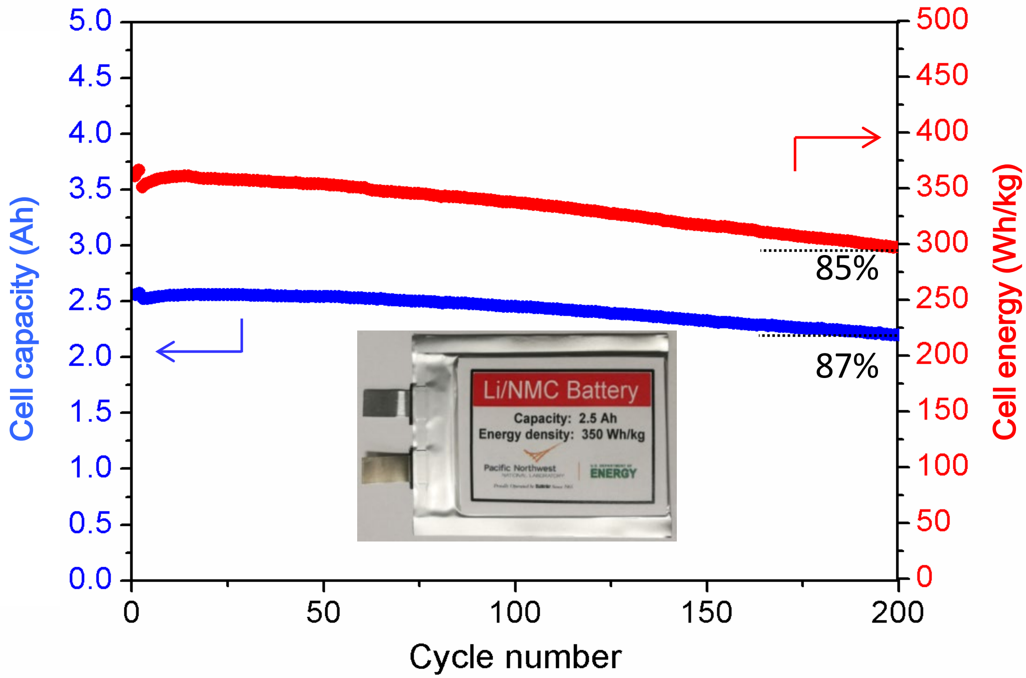
3D Carbon Host for Li



Phase II Battery500 Seedling Down-select Awards

Performer	Project Title
Cornell University	Highly Loaded Sulfur Cathode, Coated Separator and Gel Electrolyte for High Rate Li-Sulfur Batteries
Penn State University	Multifunctional Li-ion Conducting Interfacial Materials for Lithium Metal Batteries
University of Pittsburgh	Electrochemically Stable High Energy Density Lithium-Sulfur Batteries
University of Maryland, College Park	3D Printed, Low Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries
University of Maryland, College Park	Advanced Electrolyte Supporting 500 Wh/kg Li-C/NMC Batteries
Texas A&M	Controlled Interfacial Phenomena for Extended Battery Life
General Motors, LLC	Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries
Navitas Advanced Solutions Group, LLC	Solvent-free and Non-sintered 500 Wh/kg All Solid State Battery
University of Houston	High-Energy Solid-State Lithium Batteries with Organic Cathode Materials
Lawrence Berkeley National Laboratory	Composite Cathode Architectures Made by Freeze-Casting for All Solid State Lithium Batteries

Battery500 – Highlight (1)
350 Wh/kg Li/NMC811 Pouch Cell



Testing conditions

- ❑ Two formation cycles:
  C/10 for charge & discharge
- ❑ Subsequent cycling:
  C/10 for charge & C/3 for discharge

Key cell parameters

- ❑ Cathode areal loading: 4.2 mAh/cm^2
- ❑ Anode: 50 μm Li
- ❑ N/P ratio: 2.4
- ❑ Electrolyte: 1.2 M LiFSI-TEP/BTFE

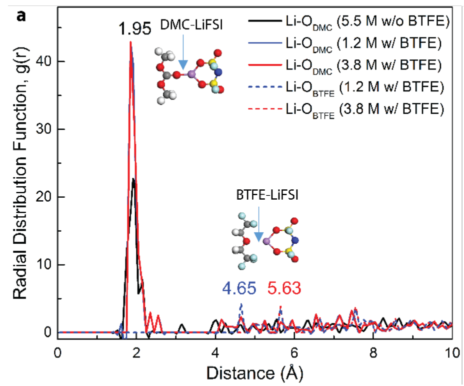
- ❑ High capacity/energy retention after 200 cycles without Li protection (still under testing)
- ❑ More challenges are expected as continuing to improve cycling stability of Li cells.

Battery500 – Highlight (2)
LHCE-Enabled Non-Flammable Li Metal Batteries

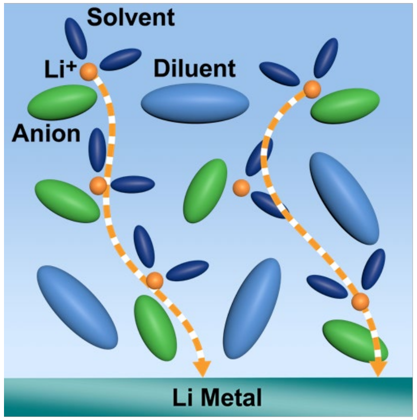
Rational Design of Localized High Concentration Electrolytes (LHCE)

- ❑ Retained all advantages of high concentration electrolyte (HCE)
- ❑ Low cost
- ❑ Low viscosity
- ❑ High conductivity

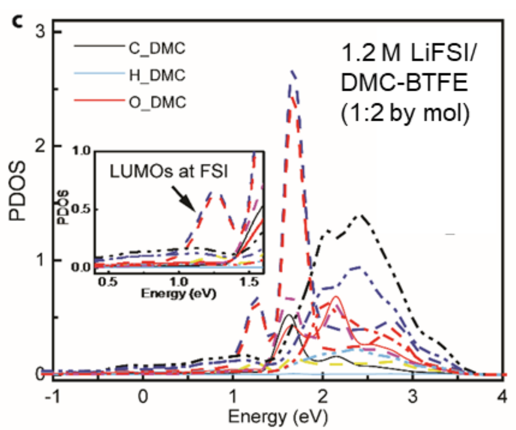
1. DMC-LiFSI binding is much stronger than BTFE-LiFSI binding



2. DMC-LiFSI forms high concentration clusters and guide Li^+ transport



3. FSI^- in HC clusters will decompose first to form stable SEI layer



4. Non-flammable LHCE (replace DMC by TEP)

a). *LiPF$_6$ in EC:EMC*

b).1.2 M LiFSI in TEP/BTFE

5. Non-flammable LHCE (1.2 M LiFSI in TEP/BTFE (1:3 by mol)) enabled long term cycling of high energy Li/NMC811 pouch cells (see the previous slide)

Source: PNNL

Milestones/Output

- Publish ***Standard Testing Protocols*** for coin and pouch cells for Li-NMC and Li-S
- ***Example*** of Li-S cell for 350 Wh/kg
  - Minimum areal capacity: 4.6 mAh/cm^2 @1,000 mAh/g
  - Lithium foil thickness: 50 microns
  - Electrolyte/capacity ratio: 4 mg/mAh
- Publish ***Recommended Practice for the Safe Handling of Lithium in the Laboratory***
- Publish a revised ***Handbook of Diagnostic Techniques***
- ***Quarterly Reports*** for BMR and Battery500 are available at http://lbl.bmr.gov

Collaboration within DOE

Close communication & coordination exists between Vehicle Technologies Office, Advanced Research Projects Agency-Energy, Basic Energy Sciences, and Office of Electricity to avoid duplication of effort, advance technologies and ensure timely transition to the consumer/market.

- ❑ VTO staff participate in an internal DOE tech team that meets periodically to coordinate R&D focus areas, information sharing, and future solicitations.
- ❑ Workshop sponsored by VTO and OE on sodium ion batteries is planned in August 2019

THANK YOU!

For more information, contact:

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