Vehicle Technologies Office

Overview and Progress of the Advanced Battery Materials Research (BMR) Program

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Introduction (1)

Energy Storage R&D Interactions at DOE

Fundamental Research	Transformational Research	Applied Research
Office of Science	**Advanced Research Projects Agency – Energy**	**Vehicle Technologies Office**
Fundamental research to understand, predict, and control matter and energy interactions at the electronic, atomic, and molecular levels • JCESR (Energy Storage Hub) • EFRC • Core Scientific Research	High-risk transformational research • BEEST (High Energy) • AMPED (Battery Sensors and Controls) • RANGE (Flow, Solid State, Multifunctional) • IONICS (Solid State)	• Electrification R&D – Battery R&D **Office of Electricity Delivery & Energy Reliability** • Grid Storage

Advanced Battery Materials Research (BMR) Program (2014 – present)

- Previously known as:
  - Exploratory Technology Research (ETR) (1980-2001)
    - Exclusively focused on batteries for automobile applications since 1992
  - Batteries for Advanced Transportation Technologies (BATT) (2002-2014)
- Charter: Perform cutting edge research in new materials and conduct comprehensive modeling and diagnostic of materials and electrochemical cell behavior to address chemical and mechanical instabilities
- 11 Topic areas, 63 research projects
  - Modeling (10), Diagnostics (9), Cell Analysis (4), Silicon Anodes (2), Intercalation Cathodes (8), Polymer/Liquid/Self-Healing Electrolytes (7), Solid State Electrolytes (4), Metallic Lithium (6), Sulfur Electrodes (9), Air Electrode/Electrolyte (3), and Sodium (1)

BMR: Current Participants

- BMR participants include 7 national labs, 20 universities, and 4 industry partners

National Labs

Argonne National Laboratory
Brookhaven National Laboratory
Berkeley Lab
Oak Ridge National Laboratory
NREL National Renewable Energy Laboratory
Pacific Northwest National Laboratory
SLAC National Accelerator Laboratory

Academia

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

Industry

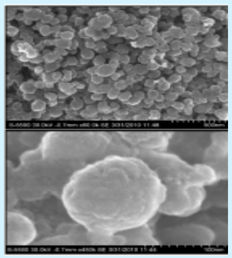
Daikin
GM
Hydro Québec
LIOX

Vehicle Technologies Office Energy Storage R&D Program Structure

- The BMR program is one of the three key energy storage R&D activities in VTO

Advanced Battery Materials Research (BMR activity)

SEM of Li_2FeSiO_4/C Nanospheres

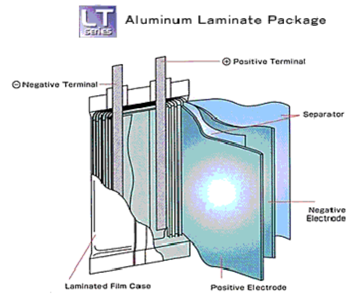


- High capacity cathodes
- Alloys, and lithium metal anodes
- High voltage electrolytes
- Solid State electrolytes

Cell Materials Targets

- Anode capacity > 1000mAh/g
- Cathode capacity > 300mAh/g
- High-voltage cathodes & 5V stable electrolytes
- Solid-polymer electrolytes with $>10^{-3}$ S/cm ionic conductivity

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



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

Cell Targets

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

Full System Development & Testing (Developer activity)

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

- Focus on cost reduction, life and performance improvement
- Robust battery cell and module development
- Testing and analysis
- Battery design tools

Battery Pack Targets

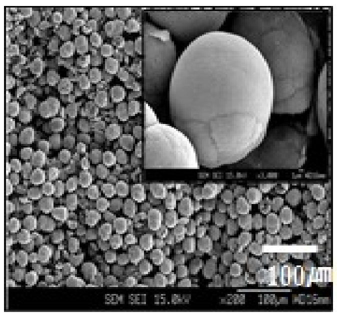
- $125/kWh EV pack cost
- Fast charge (80% SOC in 15 minutes)
- $180 12V start/stop pack cost

BMR Program in Context of VTO Battery R&D

Technology Progression Example: Advanced Cathode Materials

Argonne NATIONAL LABORATORY

Materials R&D
Lithium-rich NMC
1999–2015



BASF
TODA AMERICA
LG Chem
GM
envia SYSTEMS

Materials Scale Up and low Cost Processing
2007–2013

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM

LG Chem

Cells & Electrochemistry Development
Lithium-ion Polymer, Mixed Mn/NMC–Carbon, USABC
2005–2014

Commercialization

New BMR Project Starts in FY17

Diagnostics

- *In situ* Diagnostics of Coupled Electrochemical-Mechanical Properties of Solid Electrolyte Interphases on Lithium Metal for Rechargeable Batteries (**Xingcheng Xiao**, General Motors)
- Advanced Microscopy and Spectroscopy for Probing and Optimizing Electrode-Electrolyte Interphases in High-Energy Lithium Batteries (**Shirley Meng**, University of California–San Diego)

Liquid and Solid electrolytes

- Advanced Li-Ion Battery Technology: High-Voltage Electrolyte (**Joe Sunstrom**, Daikin America)
- Multi-Functional, Self-Healing Polyelectrolyte Gels for Long-Cycle-Life, High-Capacity Sulfur Cathodes in Li-S Batteries (**Jihui Yang**, University of Washington)
- Solid-State Inorganic Nanofiber Network-Polymer Composite Electrolytes for Lithium Batteries (**Nianqiang Wu**, West Virginia University)
- High Conductivity and Flexible Hybrid Solid-State Electrolyte (**Eric Wachsman**, University of Maryland)

New BMR Project Starts in FY17 (2)

Self-healing Electrolytes

- Self-Forming Thin Interphases and Electrodes Enabling 3D Structured High-Energy-Density Batteries (**Glenn Amatucci**, Rutgers University)
- Dual Function Solid-State Battery with Self-Forming, Self-Healing Electrolyte and Separator (**Esther Takeuchi**, Stony Brook University)
- Self-Assembling Rechargeable Lithium Batteries from Alkali and Alkaline-Earth Halides (**Yet-Ming Chiang**, Massachusetts Institute of Technology)

Modeling

- Engineering Approaches to Dendrite-Free Lithium Anodes (**Prashant Kumta**, University of Pittsburgh)
- Dendrite Growth Morphology Modeling in Liquid and Solid Electrolytes (**Yue Qi**, Michigan State University)
- Understanding and Strategies for Controlled Interfacial Phenomena in Li-Ion Batteries and Beyond (**Perla Balbuena**, Texas A&M University)
- First Principles Modeling and Design of Solid-State Interfaces for the Protection and Use of Li-Metal Anodes (**Gerbrand Ceder**, University of California–Berkeley)

Sulfur

- Electrochemically Responsive Self-Formed Li-ion Conductors for High-Performance Li-Metal Anodes (**Donghai Wang**, Pennsylvania State University)

Research Emphasis on Li-ion Batteries (1)

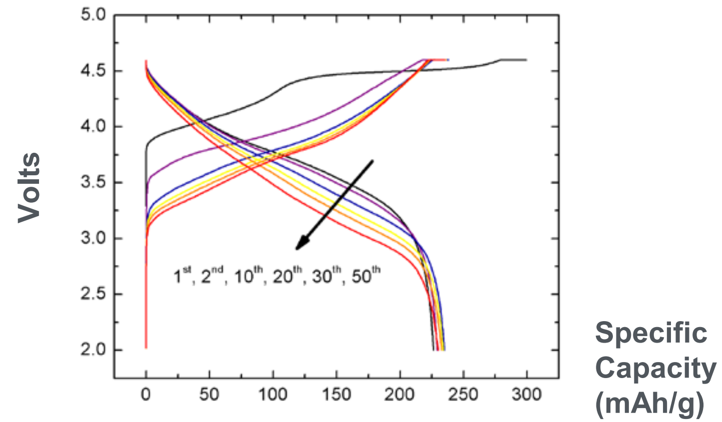
Cathodes

- Barrier: Electrode capacity – still a limiting factor

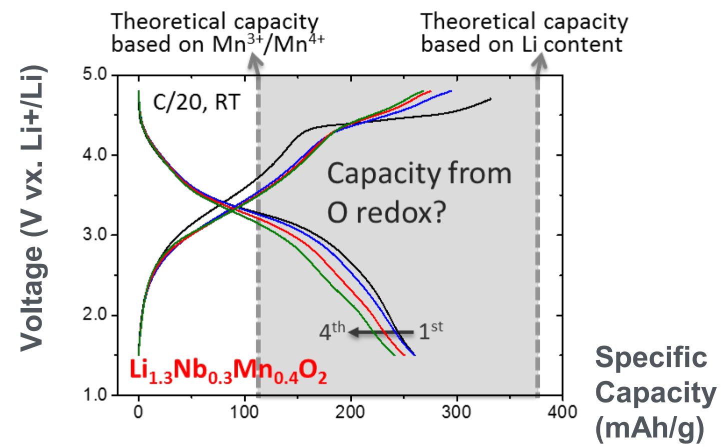
Approaches

- Develop Ni-rich cathodes that exhibit stable operation at high voltage with long cycle life
- Optimize the composition of structurally-integrated Li-rich ‘layered-layered’ and ‘layered-layered-spinel’ to mitigate voltage fade during cycling
- Discover new materials – gain fundamental understanding of the role of O_2 in Li-excess cathodes

Voltage Profiles for Li-rich, Layered Cathode



High-Capacity Li-Excess Oxides



Source: BATT projects

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Research Emphasis on Li-ion Batteries (2)

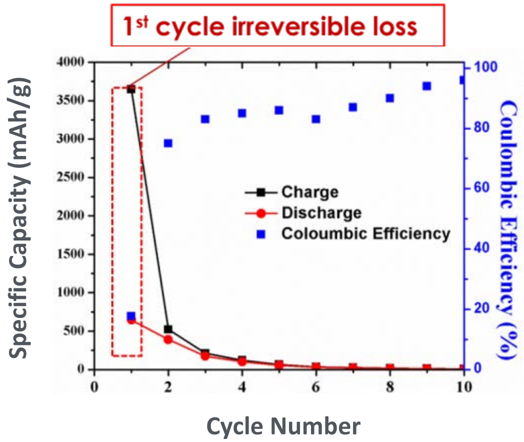
Silicon Anode

- Barrier: Continuing formation of the SEI during cycling consumes lithium and solvent

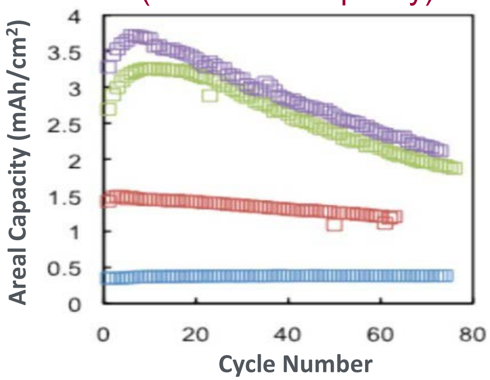
Approaches

- New architectures: Design of novel morphologies and configurations; e.g. nanotubes, nanowires, core-shell and nanocomposite structures
- Development of functional coatings: metals, Li^+ and e^- conducting ceramics and high strength and elastomeric polymer binders

Bulk Si Anode



Si Nanoparticle Anode
(Poor areal capacity)



(Note: most of the research projects in this area have been transferred to the ABR program.)

Research Emphasis on Li-ion Batteries (3)

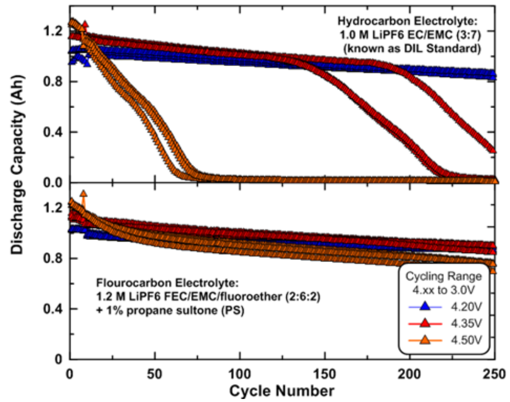
Electrolytes

- Current focus: Explore fluoro carbon electrolytes and fluorinated sulfones for high voltage operation and long cycle life.

Approaches

- Understand reactivity at voltages above 4.3V.
- Design new electrolytes and additives.
  - Daikin America – develop fluoro carbon electrolytes
  - Argonne National Lab – explore fluorinated sulfone as additives

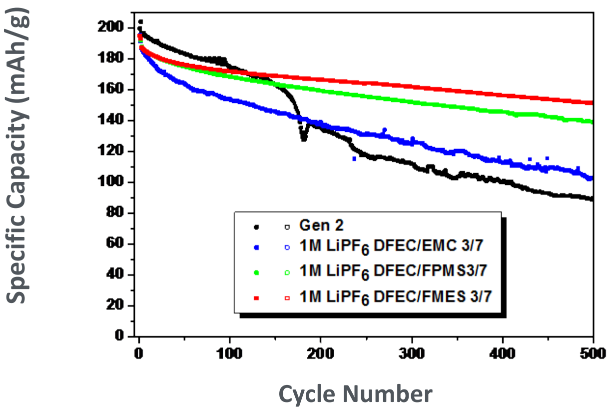
Fluoro Carbon Electrolytes for High Voltage Operation



Cycle life showing capacity of 1Ah NMC/graphite cells with both standard carbonate (top) and fluorinated (bottom) electrolytes at cycled at a Vmax of 4.2, 4.35, and 4.45V.

NMC532/Graphite Cells with ANL Fluorinated Sulfones as Additives

(C/3 for 500 cycles, cut-off voltage 3.0-4.6 V)



Li-metal Based Batteries: Enabling A New Class of Electrodes

Potential Benefits

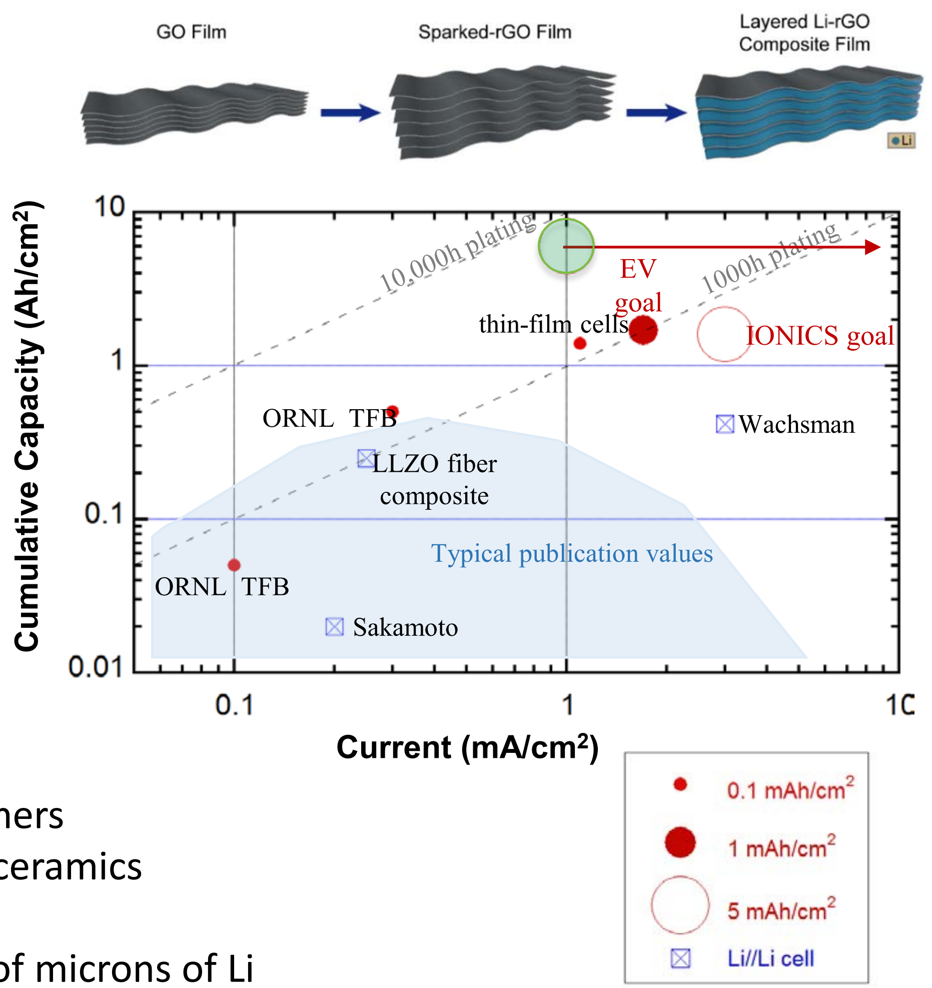
- Li metal anodes allow doubling of energy density. Enabling new class of high capacity cathodes, such as sulfur and other non-lithiated structures

Status

- Lithium reactivity and dendrite growth remain primary challenges

Approaches

- Additives/solvents to planarize deposition
- Polymers to compress protrusions
- Ceramics with high conductivity
- Novel framework structures for lithium storage and cycling



Future Issues

- Enable room temperature operation of polymers
- Interlayers protecting Li-metal reaction with ceramics
- Processing of thin, brittle ceramic layers
- Maintaining compression when moving 10's of microns of Li
- Need consistent testing protocols

Li-Sulfur Batteries: High Specific-Energy System

Potential Benefits

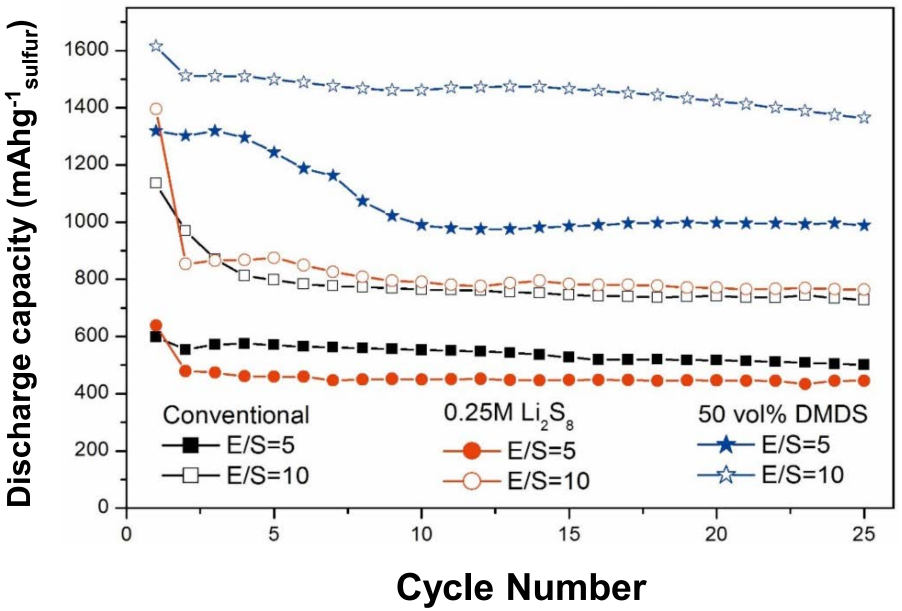
- Inexpensive, abundant material that promises high specific energy compared to Li-ion

Status

- Polysulfide "shuttle" and deposition of insoluble polysulfides remain challenges

Approaches

- Constraining the polysulfide within the cathode
- Development of separators with blocking ability
- Mechanistic understanding of speciation



Future Issues

- Operation of cathodes with high loading
- Understanding speciation in different electrolytes
- Operating under low electrolyte volumes
- Co-locating the oxidized and reduced products to ensure reversibility
- Ensuring isolation of Li metal from the polysulfide

Solid-State Batteries: A Path to Safe Li Metal-based Batteries

Potential Benefits

- Solid electrolytes provide a unique path to lithium metal anodes while enabling safer operation

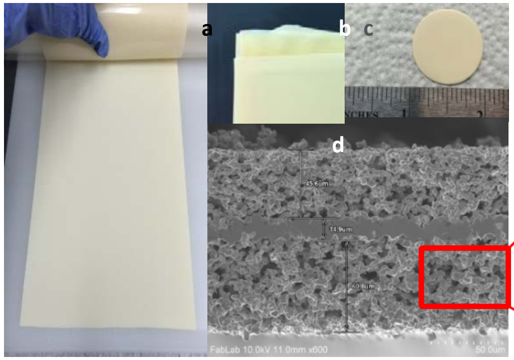
Status

- Current focus on Li conducting lanthanum zirconate ceramic structures (LLZO) and sulfide based glasses

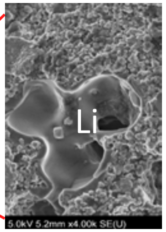
Approaches

- All-polymer systems e.g. PEO
- All inorganic systems with ceramic integrated into porous cathode

Scalable and reproducible process to fabricate multilayer garnet structures



With surface treatment, Li metal wets garnet surface continuously inside porous support



Future Issues

- Develop polymers with room temperature conductivity
- Ceramics with both high- and low-voltage stability
- Integrate ceramics into porous cathode structure with intimate contact
- Can we demonstrate an all solid-state Li-ion battery with same performance as liquid-based systems?
- Can Li-metal be controlled for abuse-tolerance?

THANK YOU!

For more information, contact:

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