Overview: Beyond Lithium-ion Research

Tien Q. Duong
Vehicle Technologies Program
U.S. Department of Energy

The 6th U.S.-China Electric Vehicles and Battery Technology Workshop

University of Massachusetts - Boston
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Organization

Energy Efficiency & Renewable Energy

U.S. DEPARTMENT OF ENERGY

- **Secretary** — Steven Chu
- **Deputy Secretary** — Daniel B. Poneman
- **Advanced Research Projects Agency – Energy (ARPA-E)** — Eric Toone (A)
- **Under Secretary for Nuclear Security/Administrator for National Nuclear Security Administration** — Thomas P. D'Agostino
  - Defense Nuclear Nonproliferation
  - Defense Programs
  - Naval Reactors
  - Counter-terrorism
  - Defense Nuclear Security
  - Emergency Operations
- **Under Secretary for Science** — Vacant
  - **Office of Science** — William Brinkman, Patricia Dehmer
    - Basic Energy Sciences — Harriet Kung
    - Advanced Scientific Computing Research — Dan Hitchcock
    - Biological & Environmental Research — Sharlene Weatherwax
    - SBIR/STTR — Manny Oliver
    - High Energy Physics — James Siegrist
    - Nuclear Physics — Tim Hallman
    - Fusion Energy Sciences — Ed Synakowski
    - Workforce Develop. for Teachers & Scientists — Patricia Dehmer (A)
- **Under Secretary of Energy** — David Sandalow (A)
  - Energy Efficiency & Renewable Energy — David Danielson
  - Fossil Energy — Charles McConnell
  - Nuclear Energy — Pete Lyons
  - Electricity Delivery & Energy Reliability — Pat Hoffman

Supporting R&D Activities in beyond Lithium-ion (shaded boxes: ARPA-E; Basic Energy Sciences; Energy Efficiency & Renewable Energy; Electricity Delivery & Energy Reliability)

Continuum of Research, Development, and Deployment

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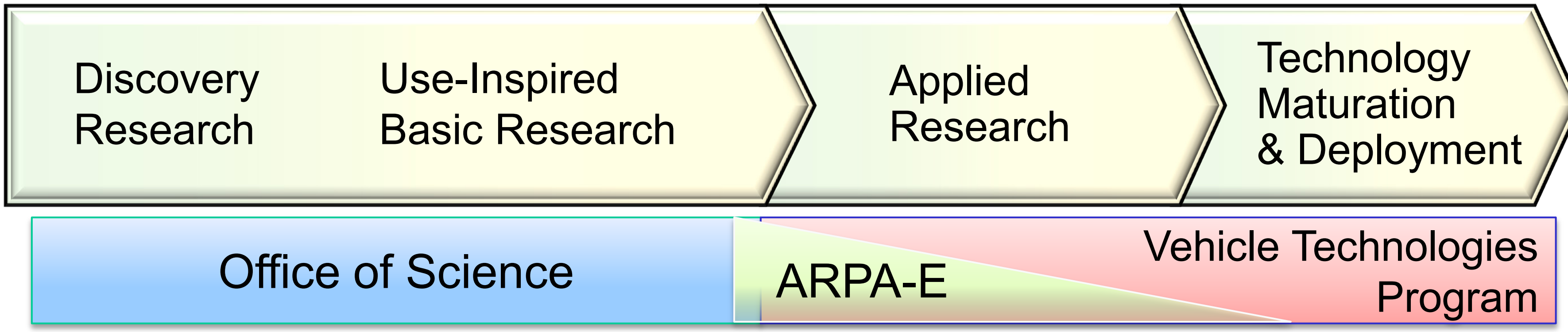

Goal:	new knowledge /understanding	**Goal:**	practical targets
Focus:	phenomena	**Focus:**	performance
Metric:	knowledge generation	**Metric:**	milestone achievement

Office of Science: Fundamental research to understand, predict, and control matter and energy at electronic, atomic, and molecular levels.

ARPA-E: High-risk transformational research with potential for significant commercial impact. Targets technology gaps, high-risk concepts, and aggressive delivery times.

Vehicle Technologies Program: Applied battery R&D to enable a large market penetration of electric vehicles, including scale-up research, demonstrations, deployment support, with industry cost-sharing.

USABC Long-term Goals for Advanced Batteries (EVs)

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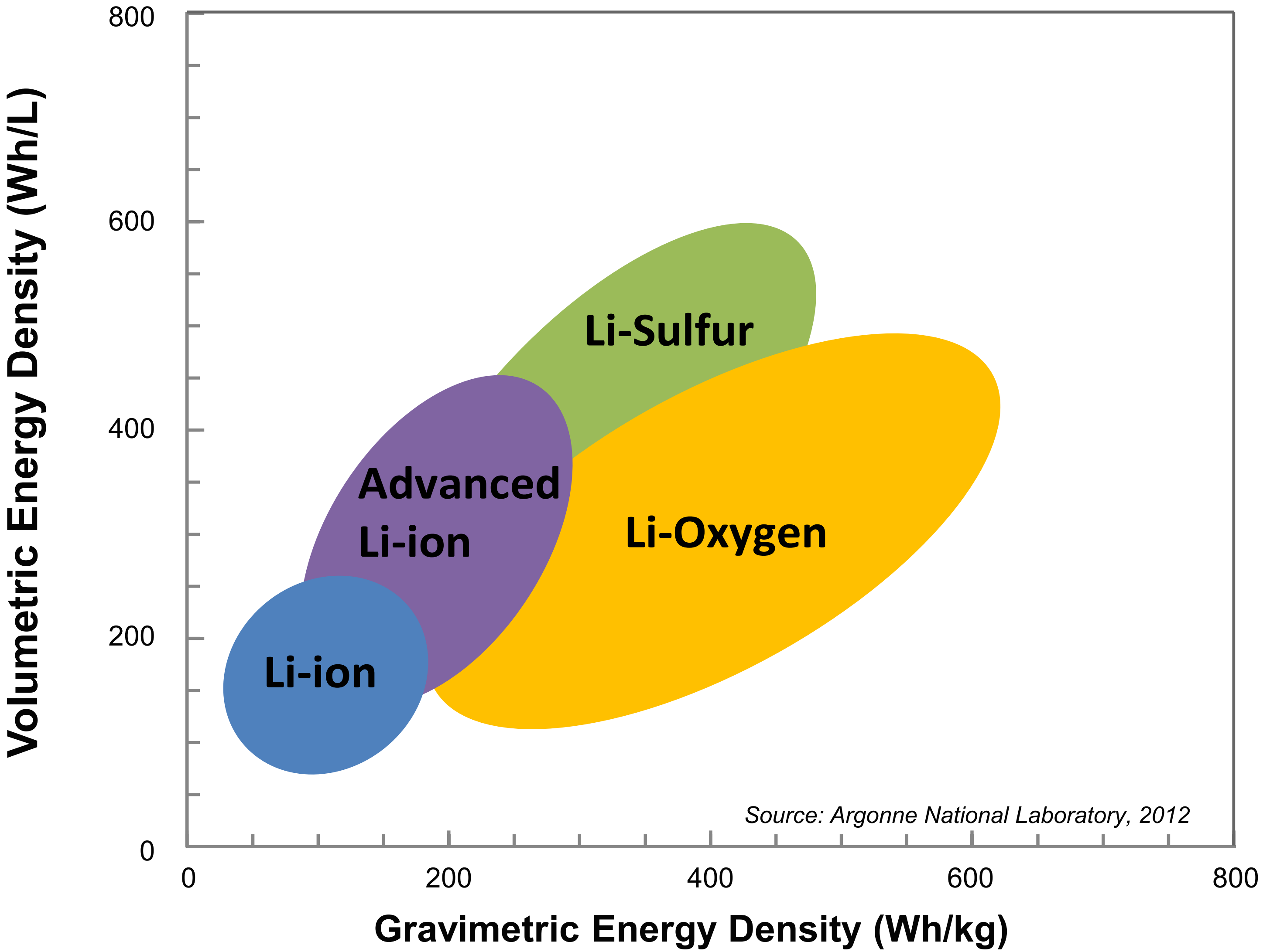
Parameters of Fully-burdened System	Long-term Goal
Power Density	600 W/L
Specific Power - Discharge (80% DOD/30 sec)	400 W/kg
Energy Density (C/3 Discharge Rate)	300 Wh/L
Specific Energy (C/3 Discharge Rate) State of the art: 100 Wh/kg	200 Wh/kg
Life	10 Years
Power & Capacity Degradation (% of rated spec)	20%
Selling Price (25,000 units @40 kWh)	$100/kWh

Energy Density for Lithium-based Batteries



Li Metal Anode

- Highest theoretical capacity of 3,862 mAh/g (compared to graphitic carbon capacity of 370 mAh/g)
  - Free from lithium intercalated cathode

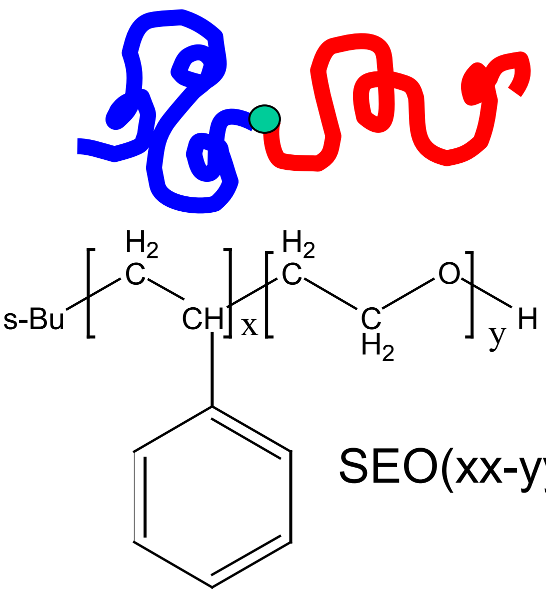
Issues

- Dendrite formation resulting in loss of lithium, possibly a safety hazard.
- Solvent reduction resulting in loss of lithium and electrolyte.

Approaches

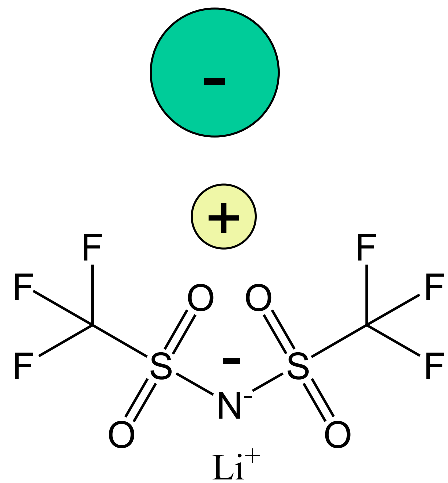
- Decouple lithium metal from cathode chemistry with an interphase layer stable with lithium, having good ionic conductivity and a low interfacial impedance.
  - Research projects supported through BATT's Integrated Laboratory and Industry Research Projects (ILIRP)
  - Block copolymers (Seeo)
  - Multiple polymer/ceramic layers (Sion Power)
  - Single Ion Conducting Ceramic (PolyPlus)

Block Copolymers (Seeo)



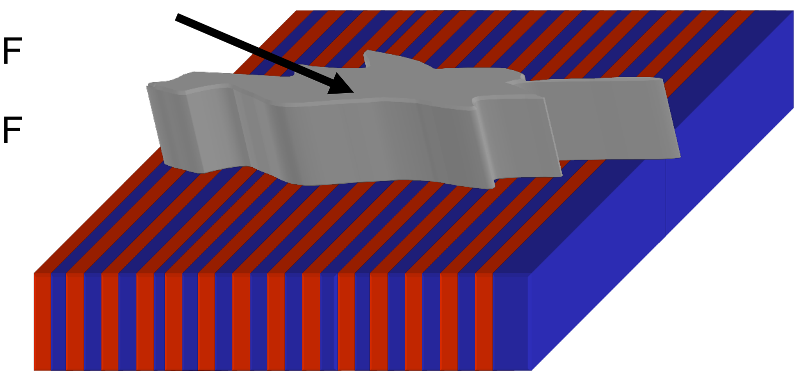
SEO(xx-yy)

+



LiTFSI salt
r = [Li+]/[EO]

Dendrites ~ mm



Nanostructured Conductor ~ 10 nm

Multiple Polymer/Ceramic Layers (Sion Power)

6	Applied Pressure	Stabilizes multi-layers and controls morphology.
1	~2 µm Release Substrate	Smoothes surface and increases specific energy.
2	<0.4 µm Current Collector	Improves morphology and increases rate at high DoD.
3	Vapor Deposited Lithium (VDLi)	VDLi allows thinner, denser, smoother Li with tailored chemical composition.
4	Anode Stabilization Laminate (ASL)	ASL protects Li from solvents and polysulfides.
3	Vapor Deposited Lithium (VDLi)	*Repeated VDLi/ASL stacks have been found to increase cycle life further than single VDLi/ASL.*
4	Anode Stabilization Laminate (ASL)	
5	Gel/Separator and Anode Compatible Solvent	Distributes force to stabilize ASL and is matrix for anode component of Dual Phase Solvent.
	New Solvent Cathode Compatible ~70%-95% S-Utilization	When anode is protected, more aggressive cathode solvents will increase sulfur utilization.
	Structurally Stable Cathode ~30 µm ~1.4 to 2 mg S/cm^2	Structurally stable cathode supports pressure. Higher carbon content increases sulfur utilization.
	In-House Primer	Adheres cathode to current collector.
	Al Foil Current Collector	Current collection and cathode coating substrate.
6	Applied Pressure	Stabilizes multi-layers and controls morphology.

Future Cell

Single Ion Conducting Ceramic (PolyPlus)

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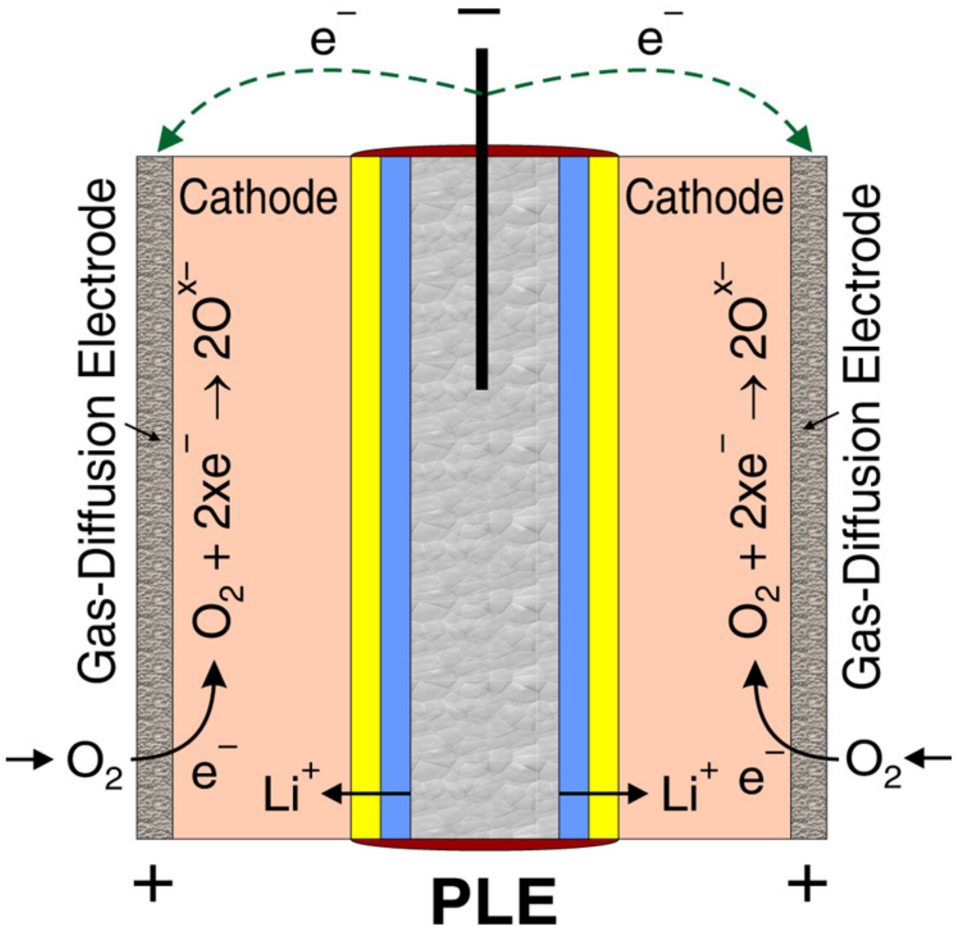

Protected Lithium Electrode (PLE) Structure

Sulfur Cathode

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- Abundant, low-cost and having a high capacity (1,675 mAh/g)
- *Over all Reaction:* $16Li + S_8 \leftrightarrow 8Li_2S$
  - Theoretical energy density: 2,550 Wh/kg
  - Practical energy density: 500 – 650 Wh/kg

Issues

- Dissolution of lithium polysulfides into the electrolyte → high self-discharge
- Insoluble sulfur species (such as Li_2S_2 and Li_2S) → electrode passivation

Approaches

- Confining the polysulfides in nano-channels can decrease their migration.
- Development of new solvents and additives that can change the solubility of polysulfides.

Polysulfide Shuttle

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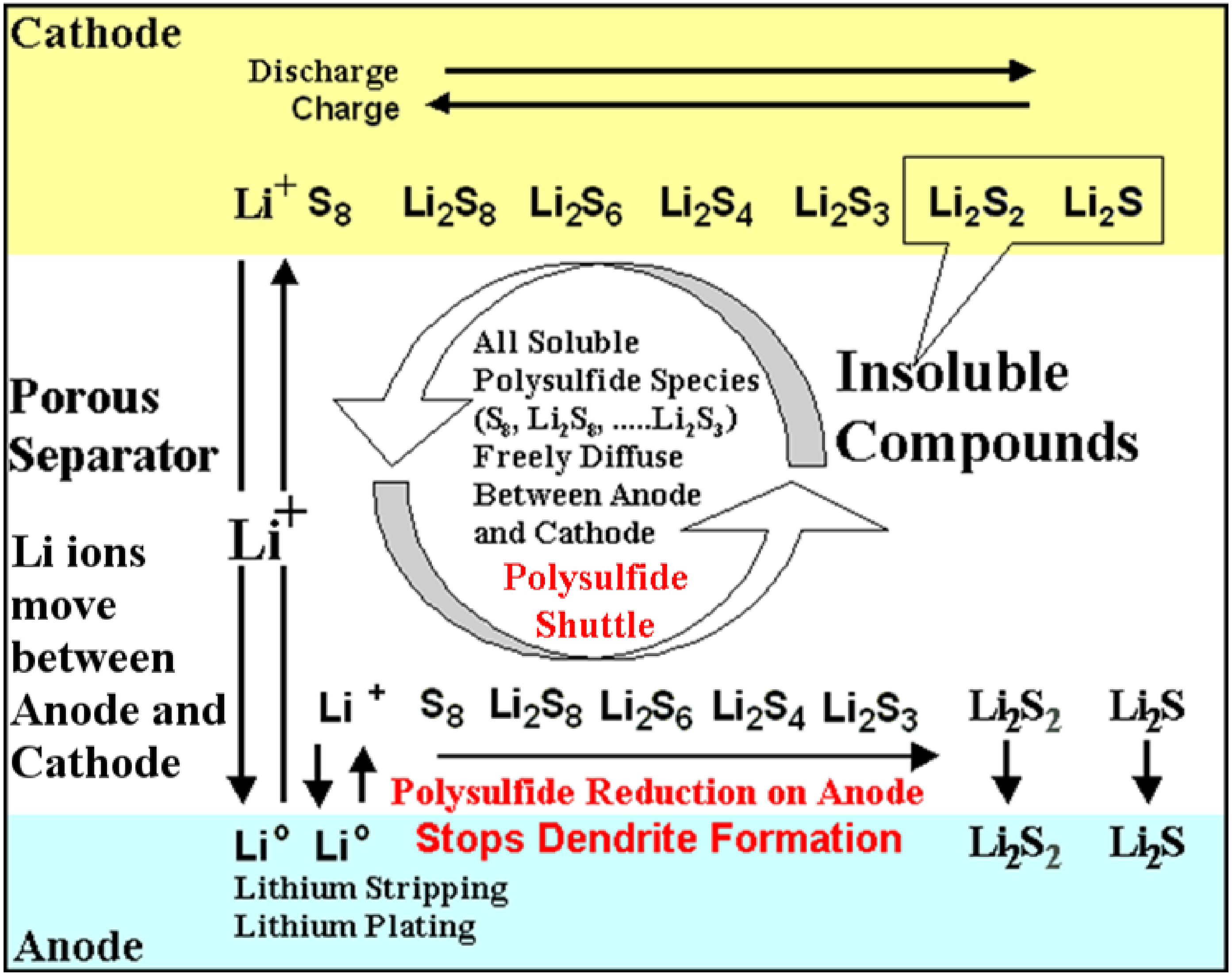

Oxygen Cathode

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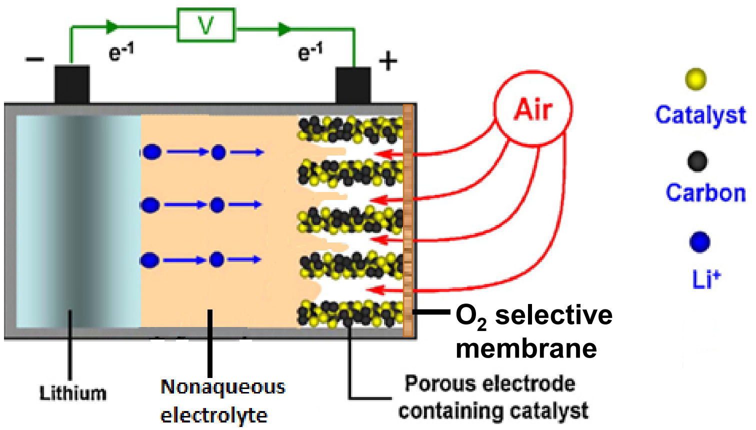
- Abundant and free
- Overall reaction: $2Li + O_2 \leftrightarrow Li_2O_2$
- Theoretical specific energy
  - Based on reactants excluding O_2: 11,972 Wh/kg
  - Based on reaction products: 3,622 Wh/kg

Issues

- Poor stability of non-aqueous electrolyte in O_2 rich environment
- Low solubility of reaction products
- Low power rate
- Poor energy efficiency
- Water sensitivity

Non-aqueous Li-air Batteries



$$2Li^{+} + 2e^{-} + O_2 \leftrightarrow Li_2O_2 \quad (2.96\ V)$$

Currently Awarded Projects

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Renewable Energy

Awardee	Amount ($ M)	Project Title	Performance Period
Solid State Batteries			
Planar Energy Devices (ARPA-E)	4	Solid-State, All Inorganic Rechargeable Lithium Batteries	7/10 – 3/12
Seeo (VTP)	4.8	Solid Polymer Batteries for Electric Drive Vehicles	10/11 – 9/14
Lithium-Sulfur Batteries			
Sion Power (VTP)	0.83	Protection of Lithium Anode with Dual Phase Electrolytes	10/09 – 9/12
Sion Power (ARPA-E)	5	Development of High Energy Li-S Cells for Electric Vehicles	10/10 – 9/13
Pennsylvania State University (VTP)	5	Development of High Energy Lithium Sulfur Cells	9/11 – 1/13
Lithium-Air Batteries			
Missouri University of Science & Technology (ARPA-E)	1.2	High Performance Cathodes for Li-Air Battery	8/10 – 7/13
PolyPlus (ARPA-E)	5	Development of Ultra-High Specific Energy Rechargeable Lithium/Air Batteries Based on Protected Lithium-Metal Electrodes	10/10 – 3/13
PolyPlus /Corning Glass (AMO)	9	Innovative Manufacturing of Protected Lithium Electrodes	8/12 – 8/15
Magnesium-Ion Batteries			
Pellion (ARPA-E)	3.2	Low-Cost, Rechargeable Magnesium-Ion Batteries with High Energy Density	9/10 – 8/12

Relevant Funding Opportunity Announcement

- Batteries and Energy Storage Hub (BES)
  - Develop energy storage systems that safely approach theoretical energy and power density limits with a very high cycle-life.
  - Single award: +$20M/year for 5 years (to be announced in late summer)

Partial List of Funded Research Projects (to be Presented at the Workshop)

- Advanced Lithium-air Batteries
  - Prof. Yang Shao-Horn, MIT
- Overcome the Obstacles for the Rechargeable Li-air Batteries
  - Prof. Deyang Qu, University of Massachusetts, Boston
- All-solid Li-Sulfur Batteries
  - Dr. Chengdu Liang, ORNL
- Development of Rechargeable Lithium Metal Batteries
  - Dr. Jason Zhang, PNNL

THANK YOU!

For more information, contact:

Tien Q. Duong

Senior Advisor / BATT Program Manager
Energy Storage R&D

Vehicle Technologies Program

Office of Energy Efficiency & Renewable Energy

Tien.Duong@ee.doe.gov