JOINT CENTER FOR ENERGY STORAGE RESEARCH

Public-Private Partnerships and Energy Storage for the Smart Grid

George Crabtree

Director, Joint Center for Energy Storage Research (JCESR)
Argonne National Laboratory
University of Illinois at Chicago

Outline

Introduction to JCESR

Challenges, Vision, Mission, Legacies

A New Paradigm

Energy Storage for the Smart Grid

Public Private Partnerships

Cross Sector Impact of the Smart Grid
Government University Industry Research Roundtable
National Academy of Sciences
Washington DC
February 10, 2015

Further Reading

In Press: *Physics of Sustainable Energy III: Using Energy Efficiently and Producing It Renewably*, edited by R. H. Knapp et al, AIP Conference Proceedings (Number ***), Melville, New York, 2014.

The Joint Center for Energy Storage Research: A New Paradigm for Battery Research and Development

George Crabtree

Joint Center for Energy Storage Research, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, and University of Illinois at Chicago, 845 W. Taylor Street, Chicago IL 60607

Abstract. The Joint Center for Energy Storage Research (JCESR) seeks transformational change in transportation and the electricity grid driven by next generation high performance, low cost electricity storage. To pursue this transformative vision JCESR introduces a new paradigm for battery research: integrating discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization. This new paradigm will accelerate the pace of discovery and innovation and reduce the time from conceptualization to commercialization. JCESR applies its new paradigm exclusively to beyond-lithium-ion batteries, a vast, rich and largely unexplored frontier. This review presents JCESR's motivation, vision, mission, intended outcomes or legacies and first year accomplishments.

Keywords: energy storage, batteries, materials science, electrochemistry, solvation
PACS: 61, 66, 68, 71, 72, 73, 81, 82, 88

OVERVIEW

Transportation and the electricity grid account for two-thirds of U.S. energy use [1]. Each of these sectors is poised for transformation driven by high performance, low cost electricity storage. The Joint Center for Energy Storage Research (JCESR) pursues discovery, design, prototyping and commercialization of next generation batteries that will realize these transformational changes. High performance, low cost electricity storage will transform transportation through widespread deployment of electric vehicles; it will transform the electricity grid through high penetration of renewable wind and solar electricity and a new era of grid operation free of the century-old constraint of matching instantaneous electricity generation to instantaneous demand. It is unusual to find transformational change in the two largest energy sectors driven by a single innovation: high performance, low cost energy storage.

These transformative outcomes for transportation and the electricity grid require electricity storage with five

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Webpage

http://www.jcesr.org/

Review Article

https://anl.app.box.com/s/wixxv7f3mg9ev3t926rc

http://arxiv.org/abs/1411.7042

Energy Storage Challenges

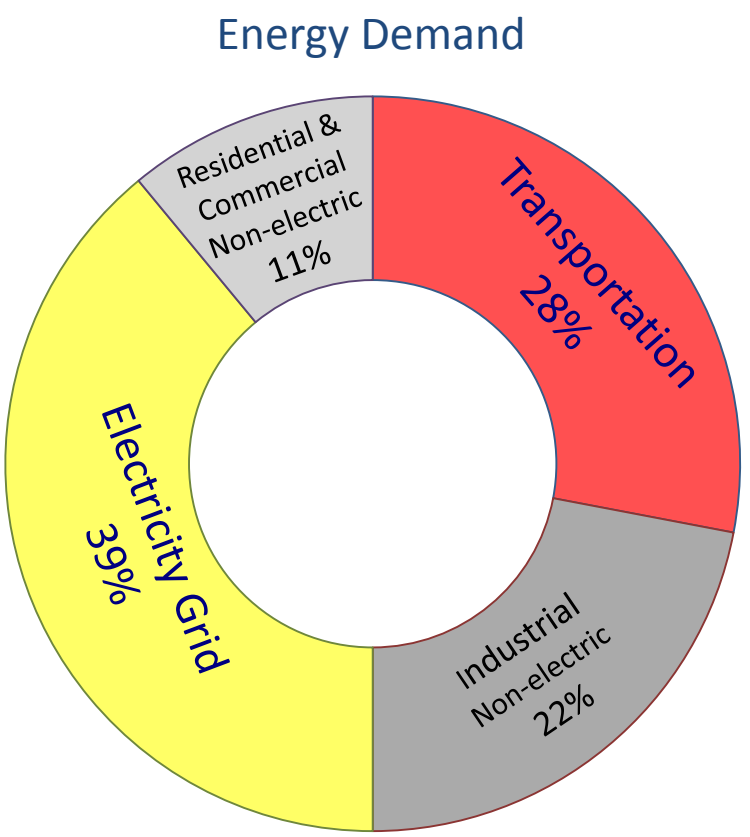
Two biggest energy uses poised for transformational change

Transportation 28%

- *Foreign oil → domestic electricity*
- *Reduce energy use*
- *Reduce carbon emissions*

Electricity 39%

- *Coal → Gas → Wind and Solar*
- *Greater reliability, resiliency, flexibility*
- *Replace "just in time" with inventory*



2013
EIA Monthly Energy Review Table 2.1
(May 2014)

The bottleneck for both transitions is inexpensive, high performance electrical energy storage

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JCESR Has Transformative Goals

TRANSPORTATION

$100/kWh

400 Wh/kg 400 Wh/L

800 W/kg 800 W/L

1000 cycles

80% DoD C/5

15 yr calendar life

EUCAR

GRID

$100/kWh

95% round-trip efficiency at C/5 rate

7000 cycles C/5

20 yr calendar life

Safety equivalent to a natural gas turbine

Vision

Transform transportation and the electricity grid with high performance, low cost energy storage

Mission

Deliver electrical energy storage with five times the energy density and one-fifth the cost of today's commercial batteries within five years

Legacies

- **A library of the fundamental science** of the materials and phenomena of energy storage at atomic and molecular levels
- **Two prototypes, one for transportation and one for the electricity grid**, that, when scaled up to manufacturing, have the potential to meet JCESR's transformative goals
- **A new paradigm for battery R&D** that integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization

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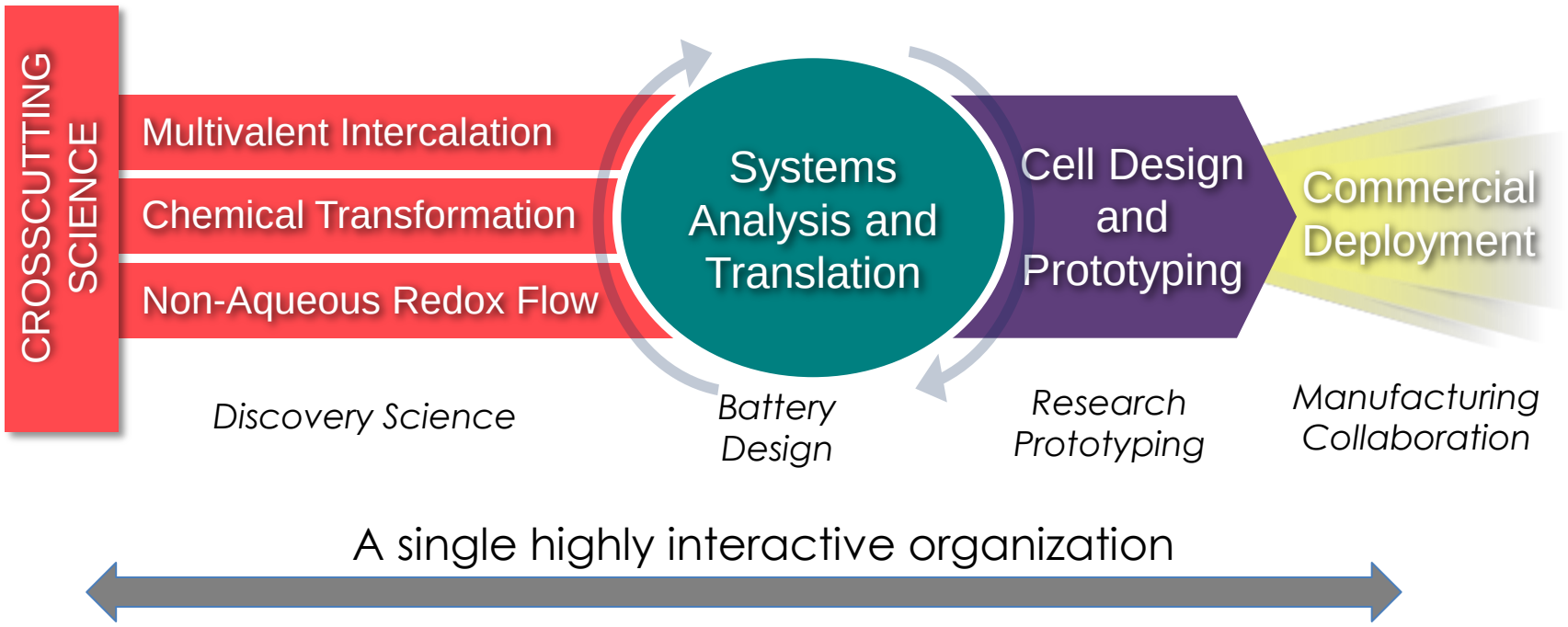
JCESR Creates a New Paradigm for Battery R&D



- Focus exclusively on transformative technologies beyond lithium ion
- 14 institutional partners + five funded collaborators embrace the challenge
- New tools to search the large, rich and unexplored beyond lithium ion space
- Pursue three storage concepts with 50-100 possible battery incarnations

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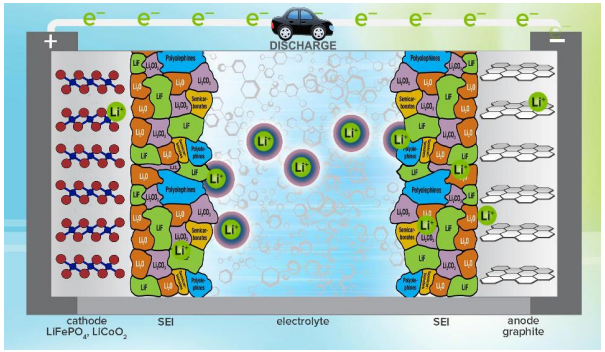
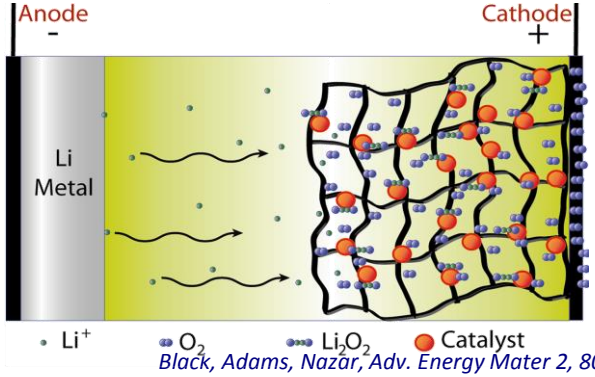
JCESR's Beyond Lithium-ion Concepts



Lithium-ion "Rocking Chair"

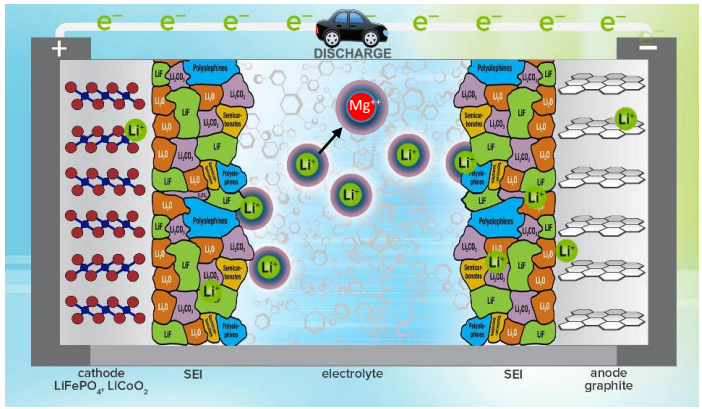
Li^+ cycles between anode and cathode, storing and releasing energy



Black, Adams, Nazar, Adv. Energy Mater 2, 801 (2012)

Chemical Transformation

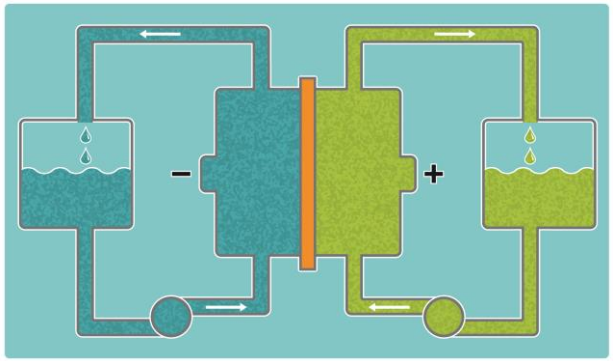
Replace intercalation with high energy chemical reaction: Li-S, Li-O, Na-S, . . .



Multivalent Intercalation

Replace monovalent Li^+ with di- or tri-valent ions: Mg^{++}, Al^{+++}, . . .

Double or triple capacity stored and released



Non-aqueous Redox

Replace solid electrodes with liquid solutions or suspensions:

lower cost, higher capacity, greater flexibility

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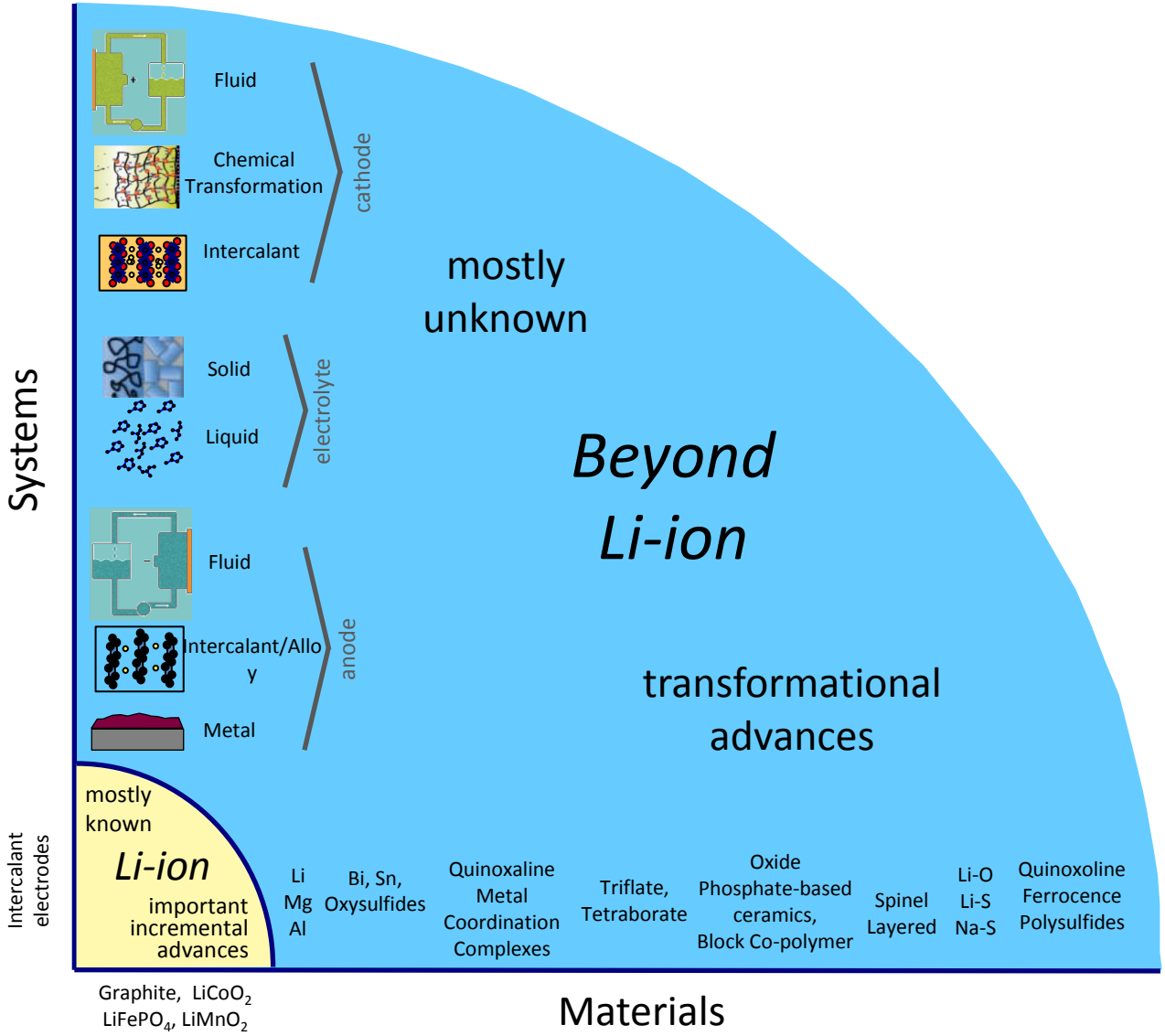
Beyond Lithium Ion Opportunity Space is Large, Unexplored and Rich



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JCESR Team and Affiliates

45 Affiliates *at launch*
80+ Affiliates *Nov 2014*

Affiliates Day
March 19, 2014

Regional Events
Urbana Oct 21, 2014
Buffalo Nov 5 2014

Affiliates Newsletter
July 2014

Toward a Multivalent Intercalation Battery

Challenges

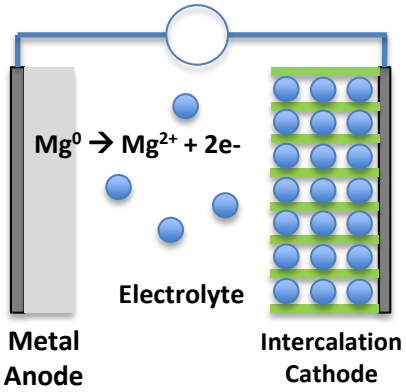
Mobility of ++ ions in cathode

Solvation – desolvation

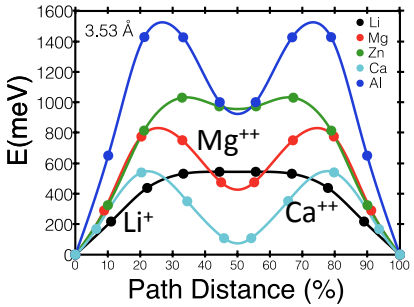
Stable electrolyte

Compatible anode, electrolyte, cathode

Only one demonstrated system Mg-chloroaluminate-Mo_6S_8 (Aurbach 2000)



Mobility in Mn_2O_4 Cathode



Energy barriers for MV ion diffusion in Mn_2O_4 spinel
Materials Project

High Li^+ diffusion ≠ high MV diffusion

Coordination environment controls diffusion barrier

Tetrahedral→ octahedral → tetrahedral

Ca^{++} has surprisingly low mobility barrier

Mg++ Solvation Shell

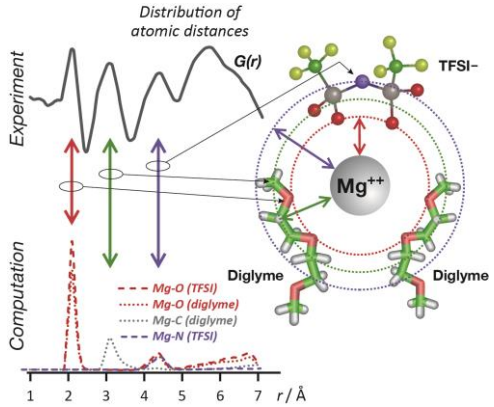
Controls

- Chemical reactions in electrolyte
- Interfacial ion exchange
- Mobility in electrolyte

Experiment: APS x-ray diffraction
Simulation: Electrolyte Genome

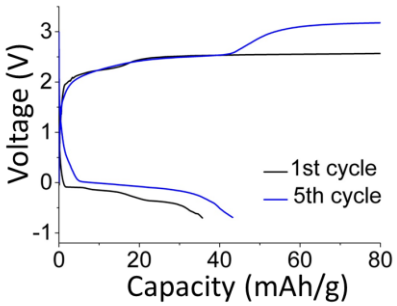
Pair Distribution Function

Quantifies anion presence in solvation shell



Lapidus, Rajput, Qu, Chapman, Persson and Chupas
Phys. Chem. Chem. Phys. 16, 21941 (2014)

First Fully Functional Mg^{++} Battery since 2000



Early stage prototype

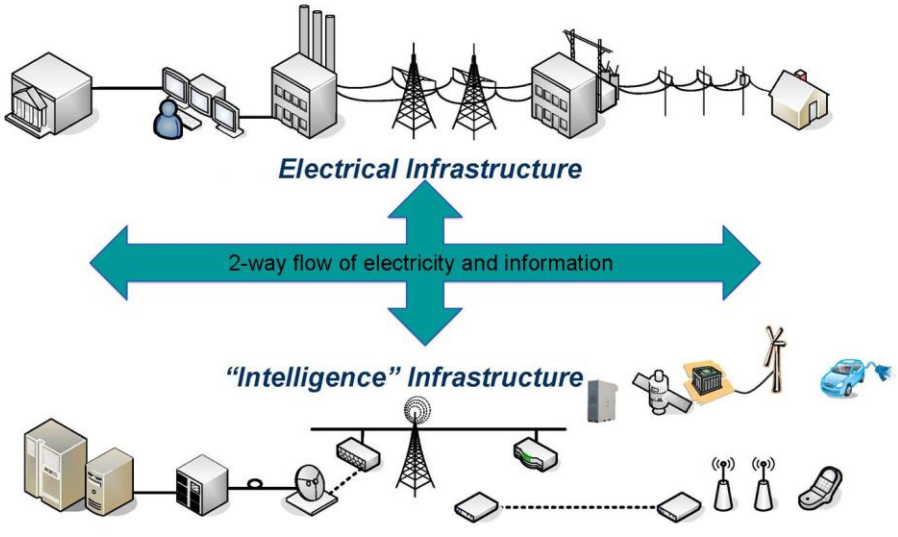
Compatible anode-electrolyte-cathode

Mg metal anode

Diglyme electrolyte

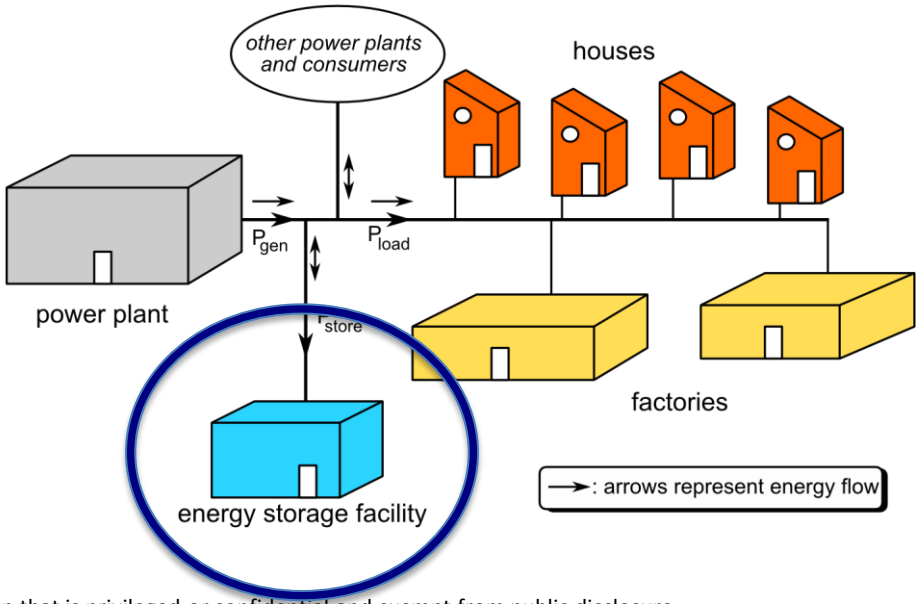
V_2O_5 cathode

First year summary + more highlights
www.jcesr.org



Smart Grid: Two Way Information and Power Flows

Energy Storage: Add a Third Dimension



Energy Storage for the Smart Grid

Breaks the centuries old constraint to match
instantaneous generation with instantaneous demand

→ Electricity management challenge and opportunity

At Macro-Grid Scale

Variability challenges for > 25% wind and solar

Compensate for large generation swings

Fast response in seconds due to clouds

Three way instead of two way power flows

opportunity: more efficient operation

challenge: management complexity

At Micro-Grid Scale

Generation - demand - storage managed locally

Tailor service to customer

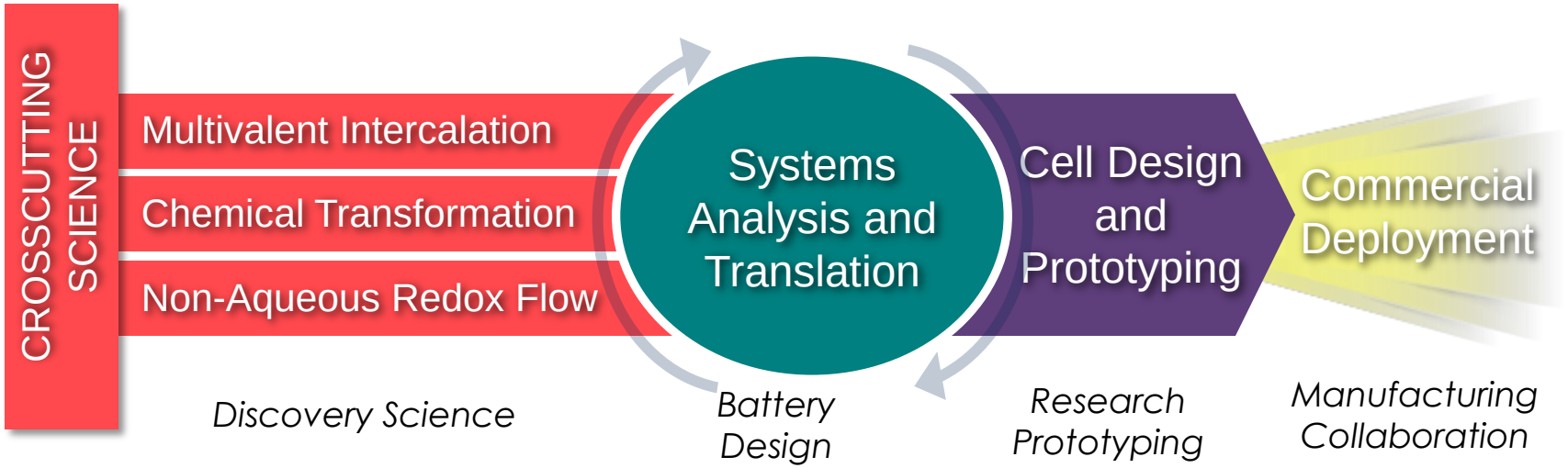
Single residence or neighborhood

Commercial buildings

Factories, university campuses, military bases

One size does not fit all

Public-Private Partnerships



A single highly interactive organization

Focus on a single challenge of national importance

Bring all capabilities needed to address the challenge

Address challenges beyond capacity of existing organizations

high risk or broad scope

Clear public good

Perspective

More on JCESR website
www.jcesr.org

Vision: Transform transportation and electricity grid with high performance, low cost energy storage

Mission: Deliver electrical energy storage with five times the energy density and one-fifth the cost

→ **Beyond lithium ion**

Legacies:

A library of the fundamental science of the materials and phenomena of energy storage at atomic and molecular levels

Two prototypes, one for transportation and one for the electricity grid, that, when scaled up to manufacturing, have the potential to meet JCESR's performance and cost goals

A new paradigm for battery R&D that integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization

- A bold new approach to battery R&D
- Accelerate the pace of discovery and innovation
- Bring the community to the beyond lithium-ion opportunity

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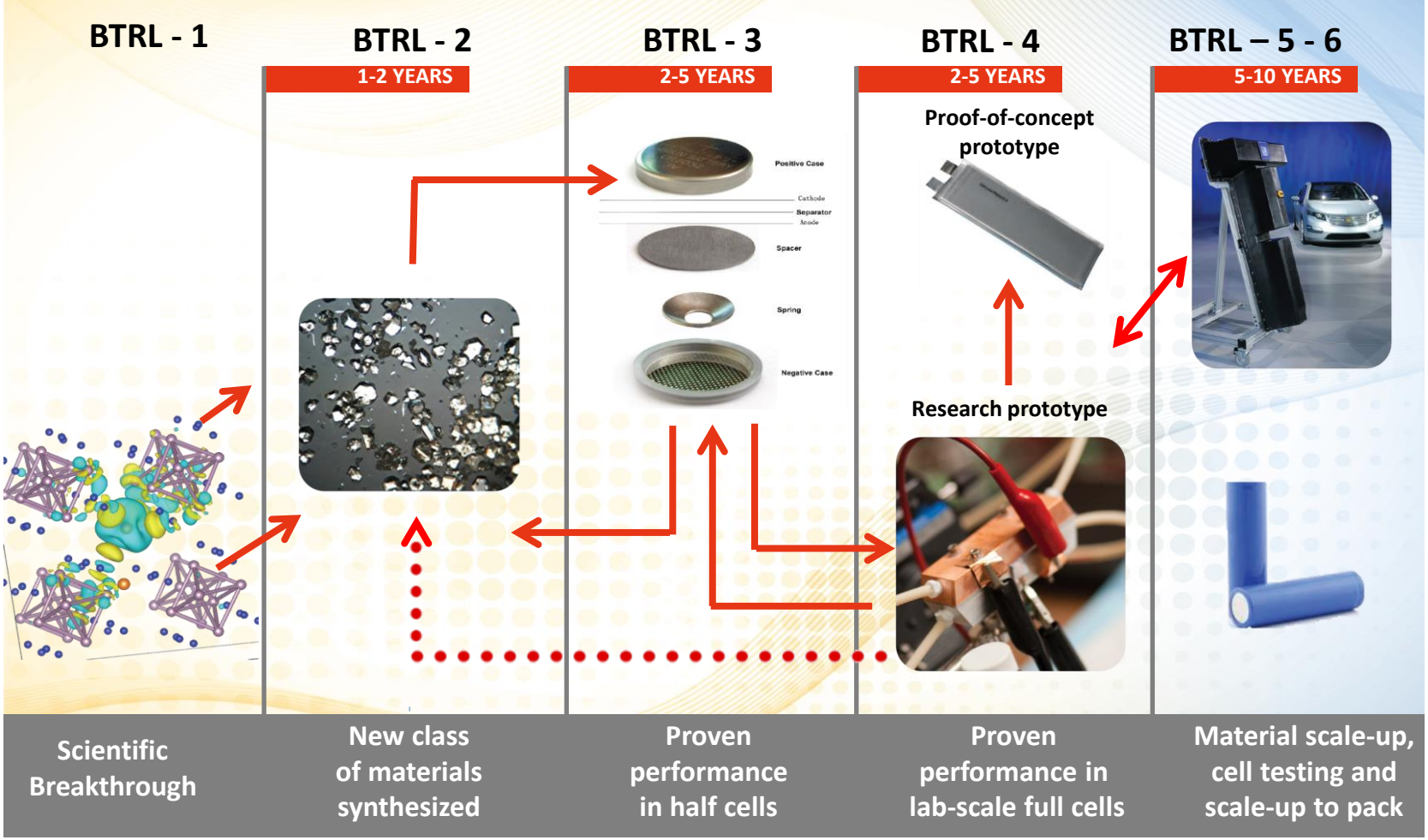
Battery Technology Readiness Level (BTRL)



Developed collaboratively with JCI, NASA-Glenn, TARDEC

JCESR "sweet spot"

JCESR Achieves Across the Science-Manufacturing Spectrum

CROSSCUTTING SCIENCE

- Multivalent Intercalation
- Chemical Transformation
- Non-Aqueous Redox Flow

Systems Analysis and Translation

Cell Design and Prototyping

Commercial Deployment

Link to Community

New IP

Infinite current collector

Industry-science collaboration

Six projects of interest to JCI

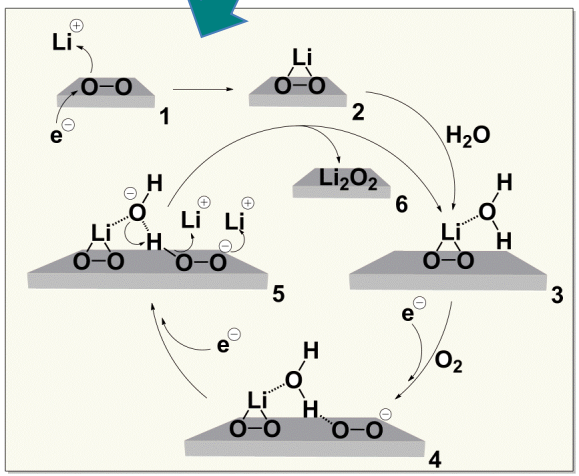
MOU with NASA-Glenn

Discovery Science

Battery Design

Research Prototyping

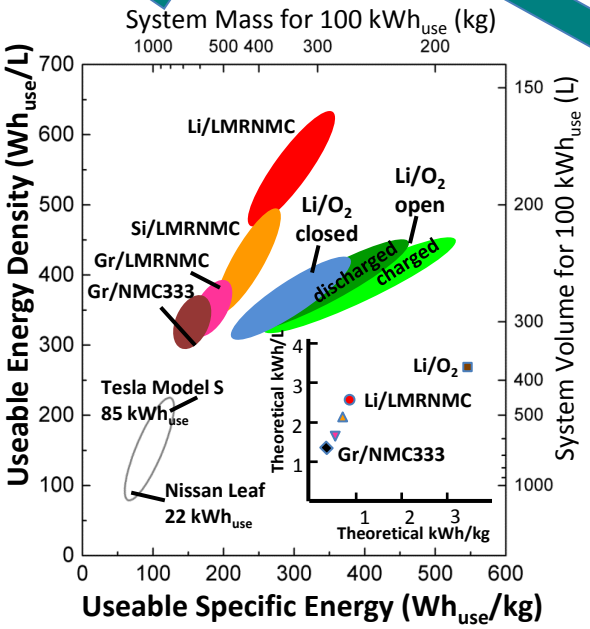
Manufacturing Collaboration



Trace water catalyzes lithium peroxide electrochemistry

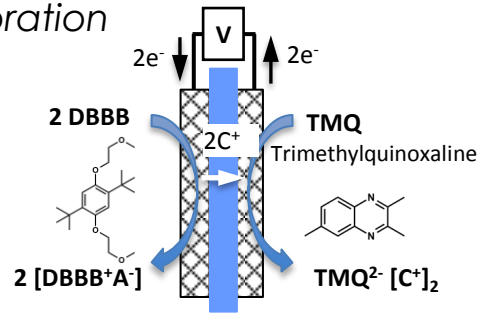
EDL+Electrolyte Genome

Jirkovský, Markovic et al, (submitted)



Quantifying the promise of Li-air batteries (with GM)

Gallagher et al, Energy and Environmental Science (2014)

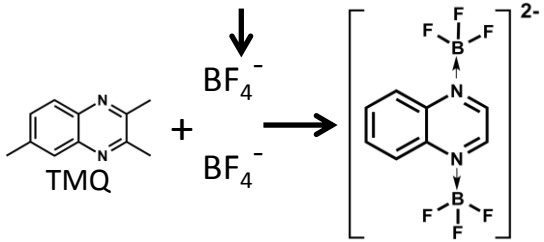


All Organic Redox Flow

Non-aqueous Redox Flow + Electrolyte Genome

Brushett, Zhang et al (MIT, ANL)

Su et al, JECS 161, A1905 ((2014)



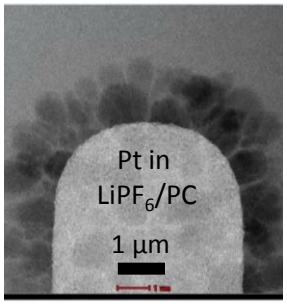
10x electrochemical activity

First year summary + more highlights
www.jcesr.org

Priority Research Areas

Metal Anodes

Robust surfaces over multiple dissolution/deposition

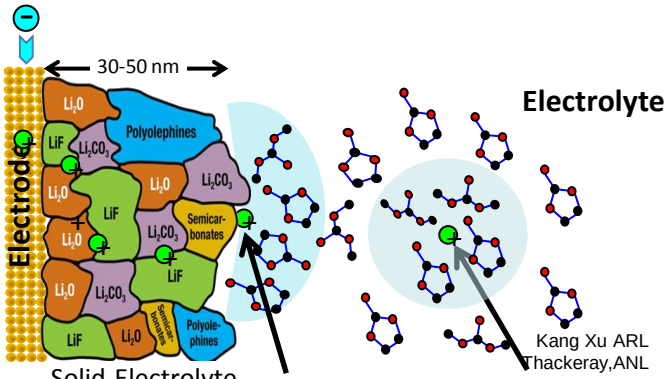


Mehdi, Browning et al (2014)

Solution/deposition dynamics, surface degradation, dendrite growth

Solvation/de-solvation

structure and transfer dynamics



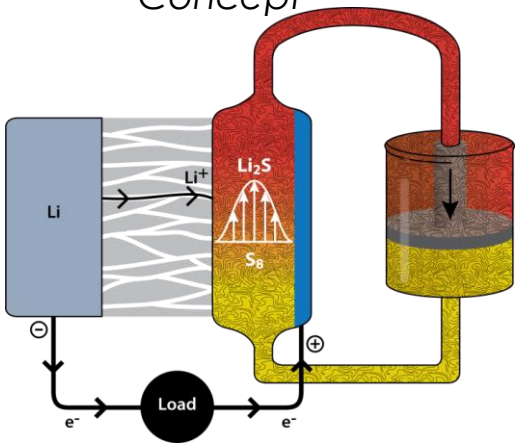
Solid-Electrolyte Interphase

partially solvated ion at interface

fully solvated ion In bulk electrolyte

Li-polysulfide Semi-Flow

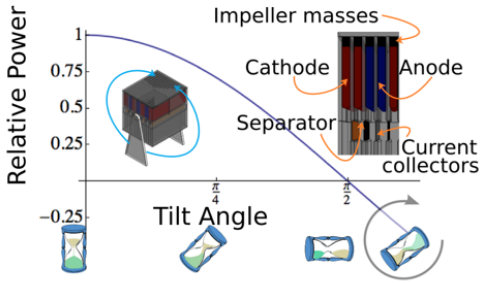
Concept



Y. Yang, G. Zheng, and Y. Cui, *Energy & Environmental Science*, 6, 1552 (2013)

Novel Prototyping Concepts

Gravity Induced Flow Cell



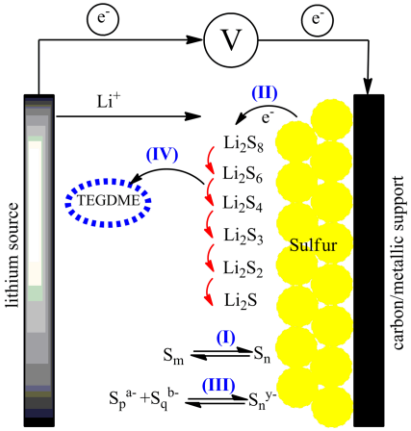
Molecular Understanding

of Reaction Pathways and Energetics

Lithium-Sulfur Batteries

Assary, Curtiss, Moore
J Phys Chem C 118, 11545 (2014)

Electrolyte Genome / EDL



Critical to battery science and technology strategies

Rich opportunities for in situ, time-resolved, multi-modal characterization, predictive theory and multiscale modeling

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