JOINT CENTER FOR ENERGY STORAGE RESEARCH

Energy Storage and Distributed Energy

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Outline

Centralized vs Distributed

Beyond Lithium-ion Batteries

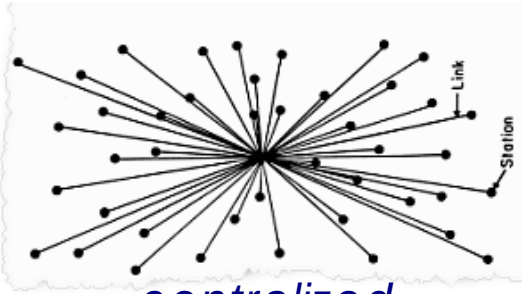
A New Paradigm

Perspective

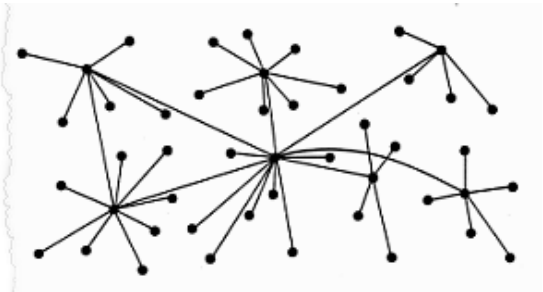
American Physical Society Energy Workshop
San Antonio, TX
March 1, 2015

Centralized, Decentralized or Distributed?

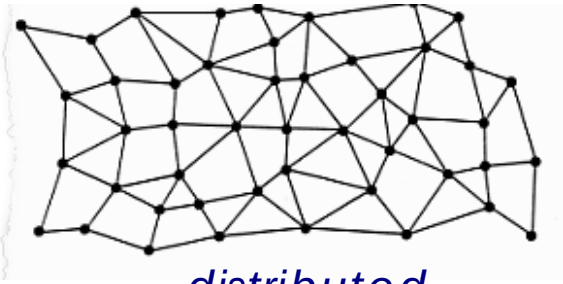
Electricity grid Internet Highways



centralized



decentralized



distributed

Until late 1960s

Central power plants

- expensive
- economies of scale
- unique
- unreliable

Electricity grid

- inexpensive
- reliable: most outages due central plants

1970s - 2000s

Central power plants

- inexpensive
- reliable
- fossil, nuclear, hydro
- environmental stigma

Electricity grid

- expensive
- regulatory challenge
- unreliable: most outages due to grid

2000s – 2015

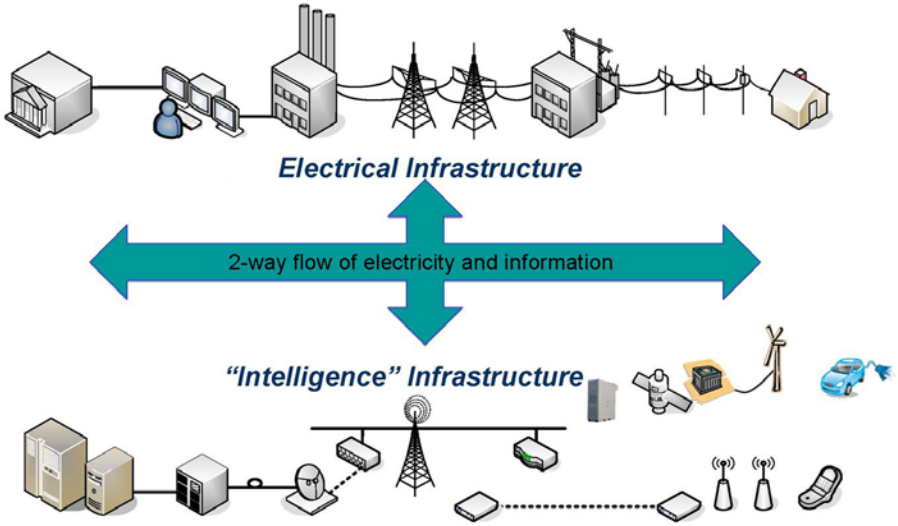
Distributed wind and solar

- *inexpensive*
- *robust*
- *mass produced*

Electricity grid

- aging
- outmoded
- security target
- smart

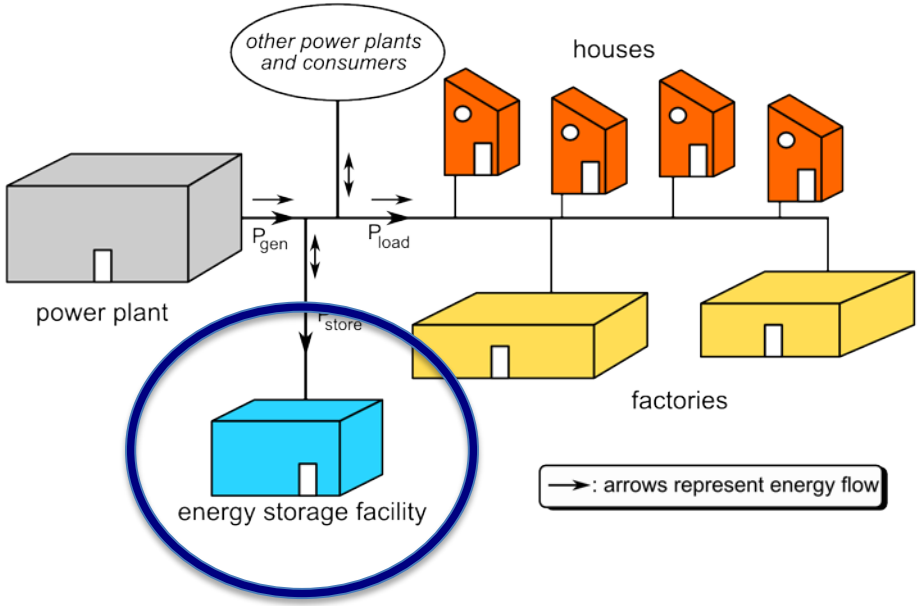
Economic, environmental, technological evolution favors distributed energy



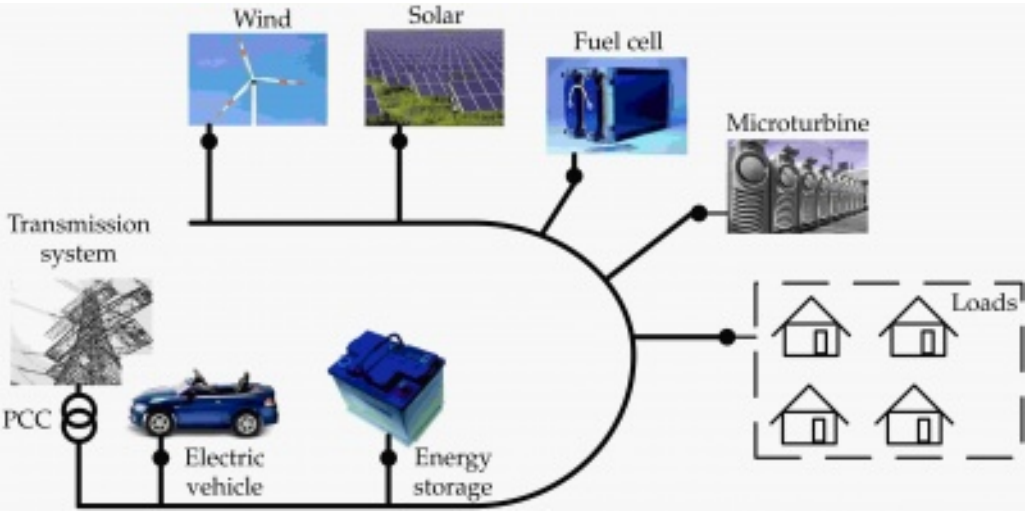
Smart Grid: Two Way Information and Power Flows

Energy Storage: Add a Third Dimension

Breaks the century old constraint to match instantaneous generation to instantaneous demand



Distributed Energy + Smart Grid + Energy Storage → Microgrid



Microgrid

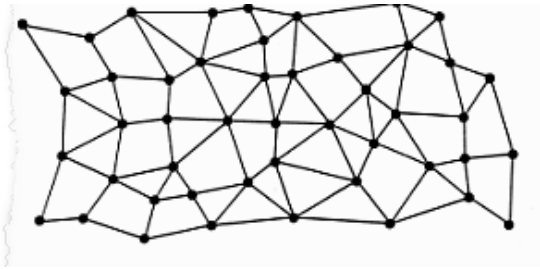
Generation – Demand – Storage

- *Local energy management*
- *Renewable generation*
- *Close to customer*
- *Reduced dependence on grid*
- *Service profile tailored to customer*
- *"Personalized" energy*

Tailor service for customer

- *Neighborhood*
- *Office buildings*
- *Shopping center*
- *Factory*
- *Campus*
- *Military base*

One size does not fit all



A network of interacting microgrids

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Energy Storage Challenges

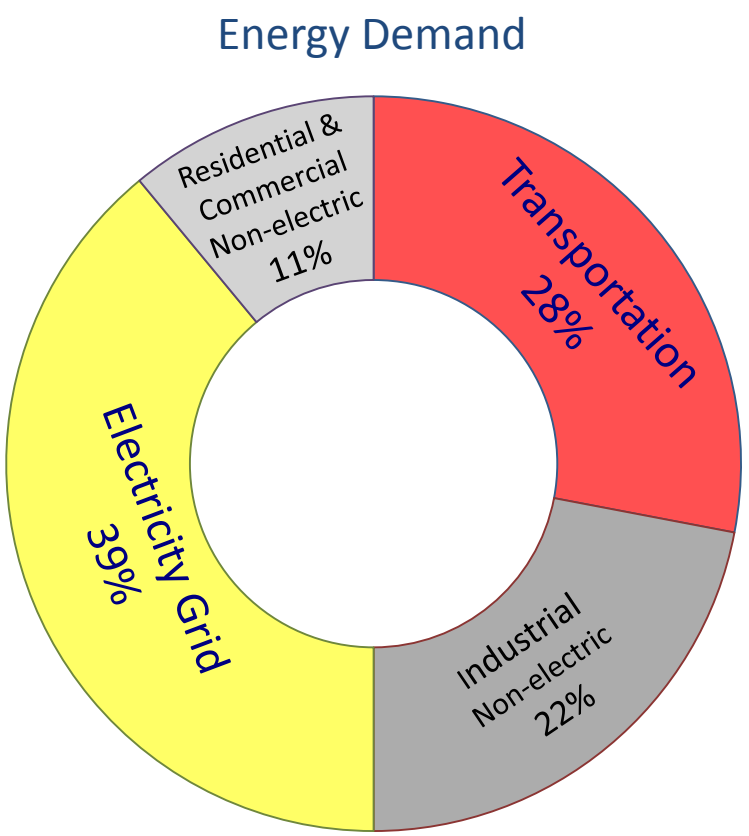
Two biggest energy uses poised for transformational change

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: Focus exclusively on beyond lithium-ion batteries

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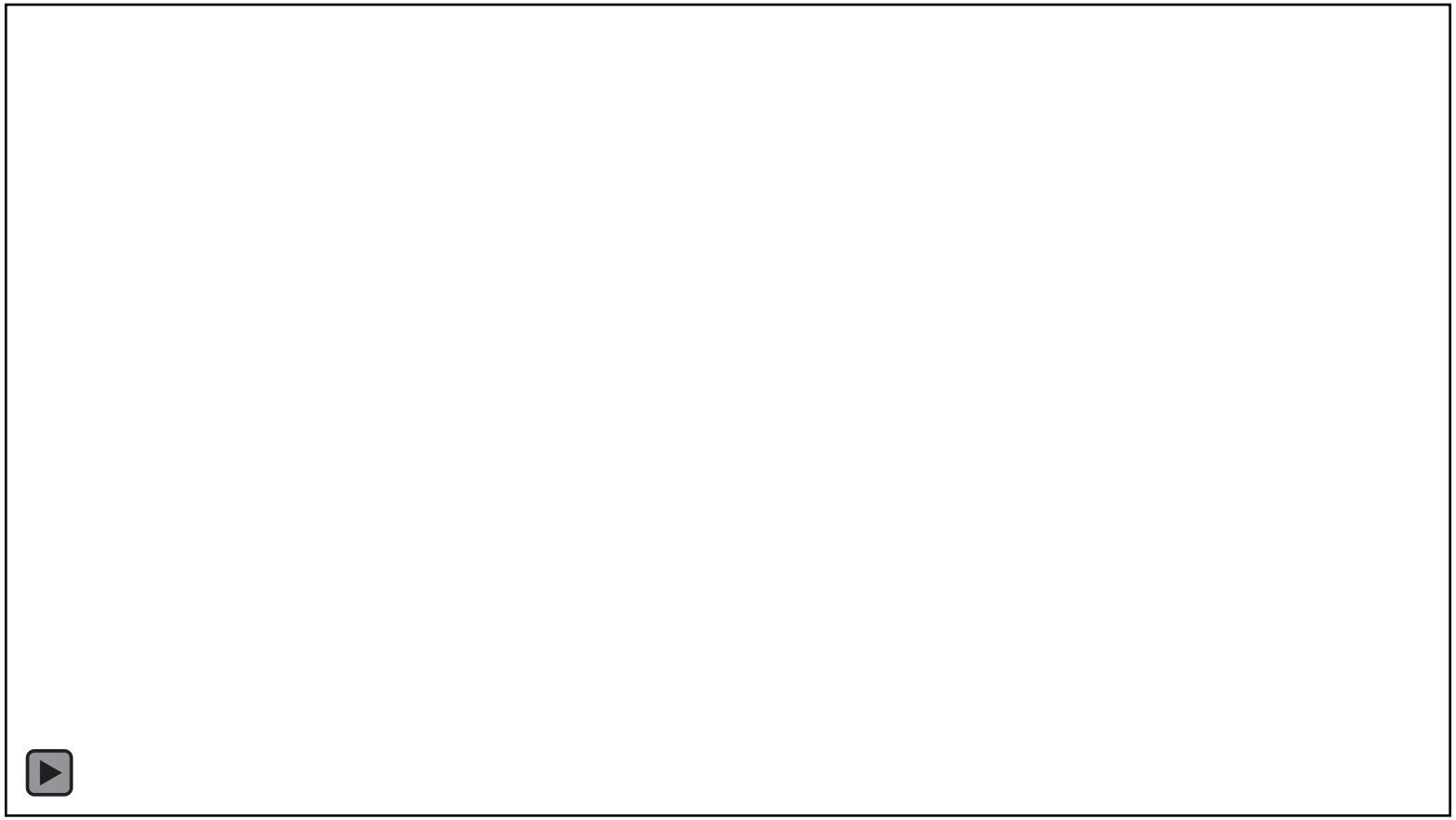
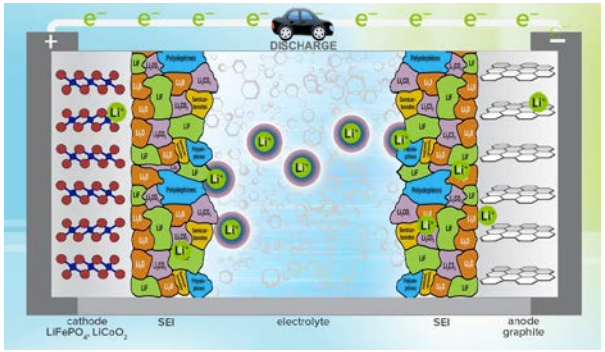
Lithium Ion Battery Technology

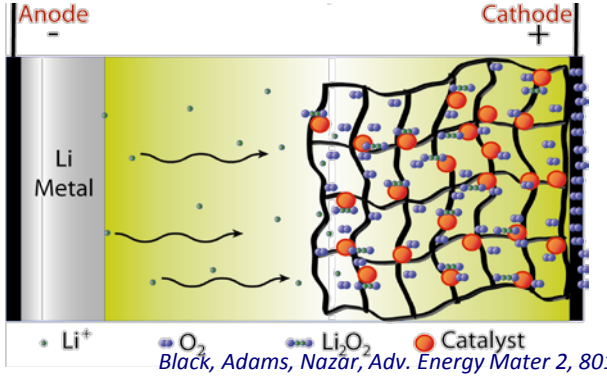


JCESR's Beyond Lithium-ion Concepts



Lithium-ion "Rocking Chair"

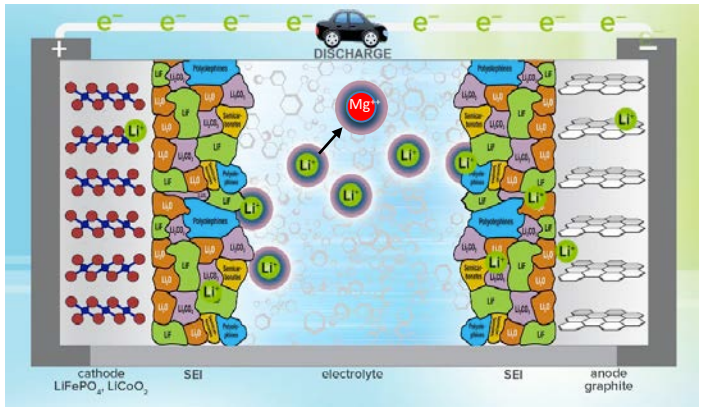
Li^+ cycles between anode and cathode, storing and releasing energy



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

Chemical Transformation

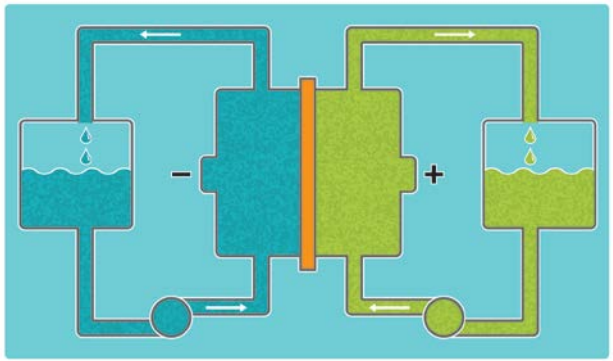
Replace intercalation with high energy chemical reaction: Li-S, Li-O, Na-S, . . .



Multivalent Intercalation

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

Double or triple capacity stored and released

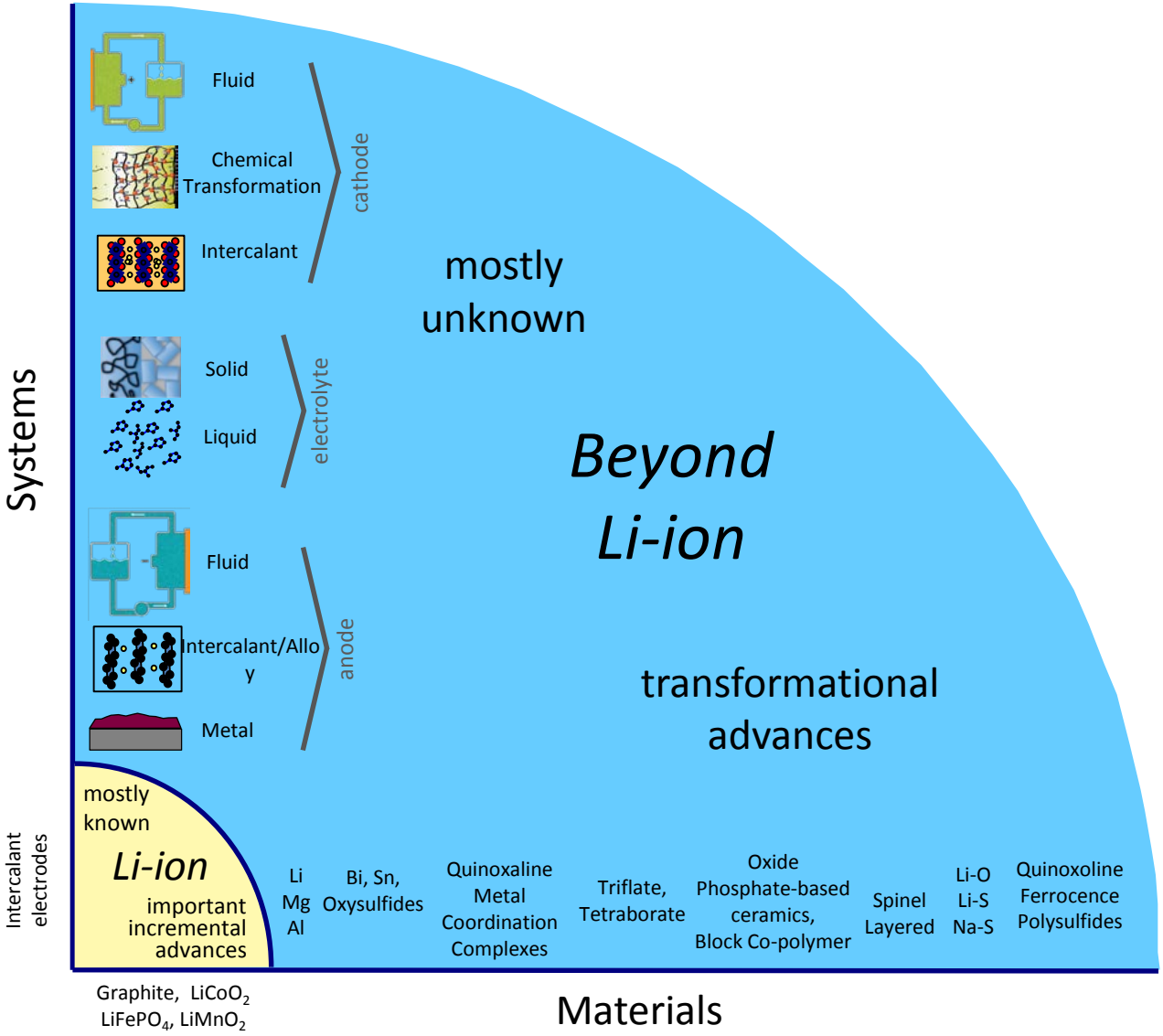


Non-aqueous Redox

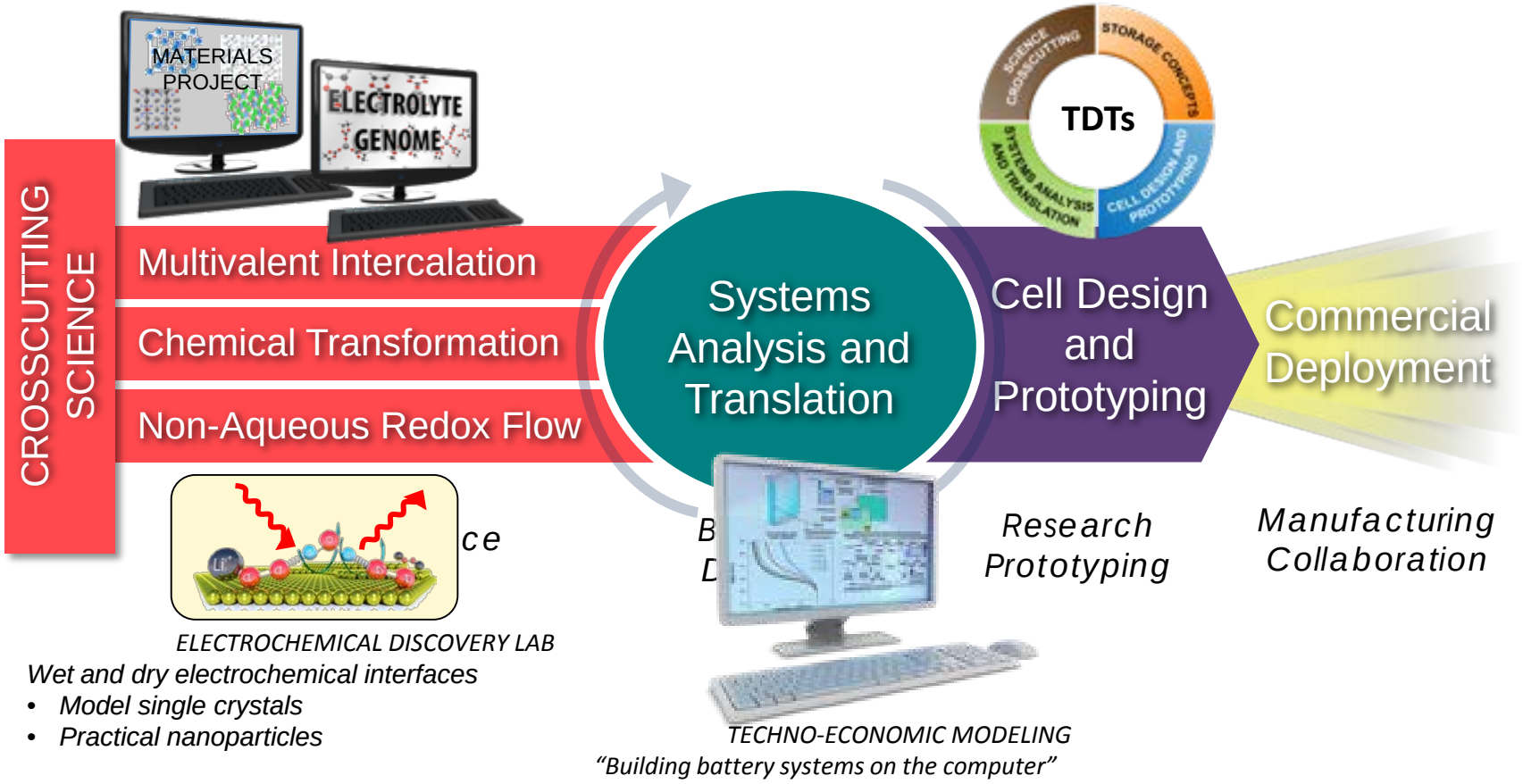
Replace solid electrodes with liquid solutions or suspensions:

lower cost, higher capacity, greater flexibility

Beyond Lithium Ion Opportunity Space is Large, Unexplored and Rich



JCESR Creates a New Paradigm for Battery R&D



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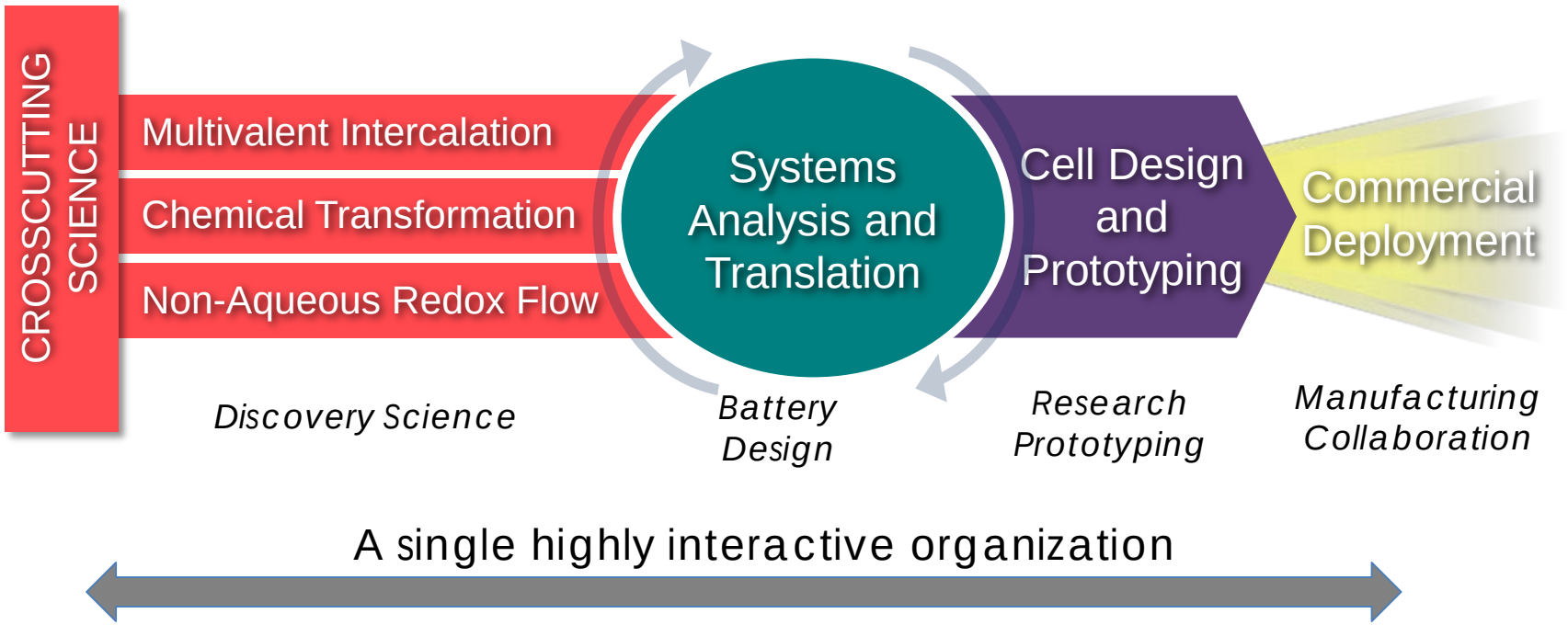

- Focus exclusively on transformative technologies beyond lithium ion
- 14 institutional partners + five funded collaborators embrace the challenge
- New tools to search the large, rich and unexplored beyond lithium ion space
- Pursue three storage concepts with 50-100 possible battery incarnations

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Toward a Multivalent Intercalation Battery

Challenges

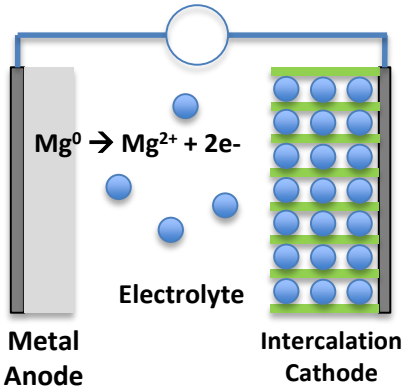
Mobility of ++ ions in cathode

Solvation – desolvation

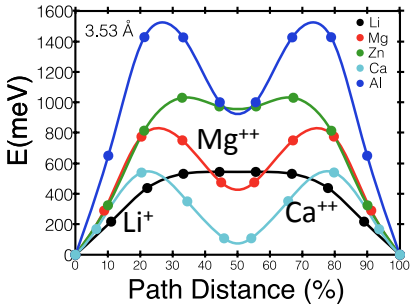
Stable electrolyte

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

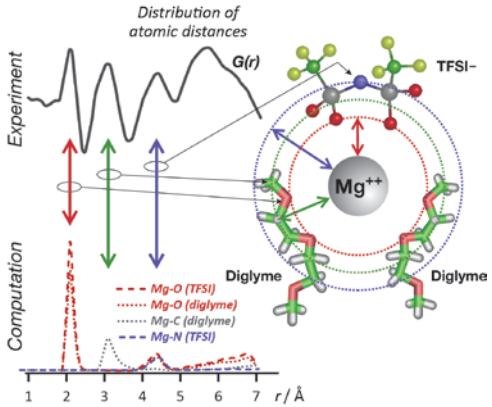
Controls

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

Experiment: APS x-ray diffraction
Simulation: Electrolyte Genome

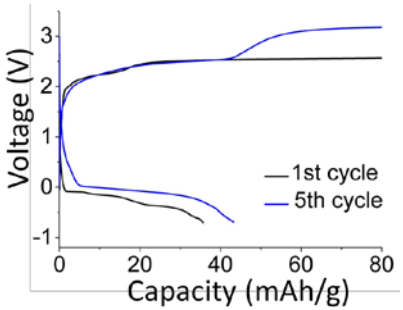
Pair Distribution Function

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

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

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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

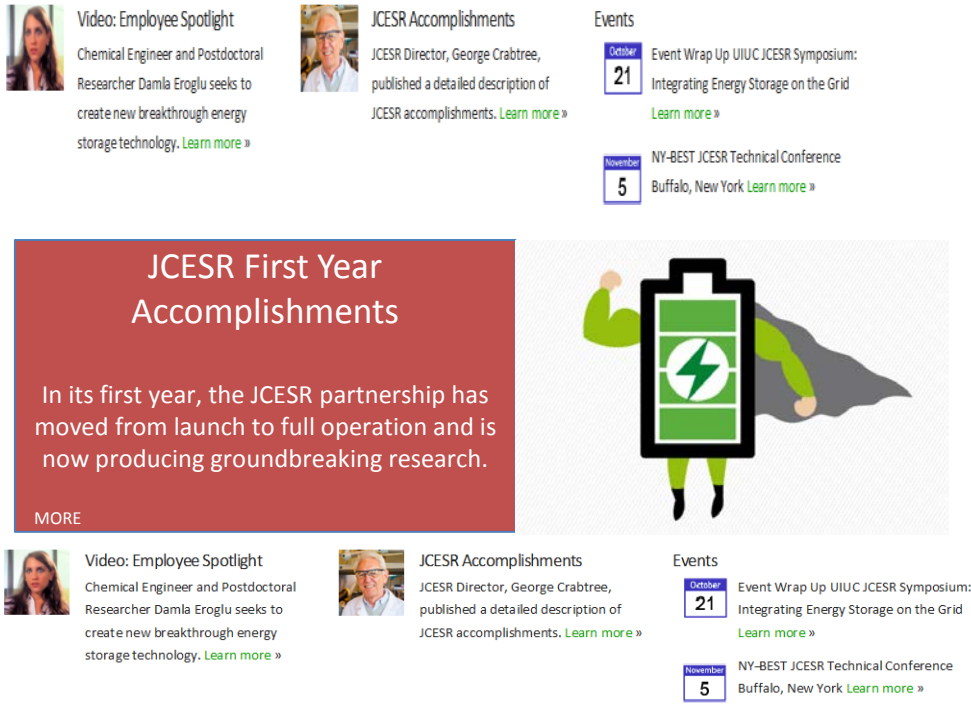
Transportation and the electricity grid account for two-thirds of U.S. energy use [1]. Each of these sectors is poised for transformation driven by high performance, low cost electricity storage. The Joint Center for Energy Storage Research (JCESR) pursues discovery, design, prototyping and commercialization 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

Review Article

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

http://arxiv.org/abs/1411.7042



Webpage

http://www.jcesr.org/

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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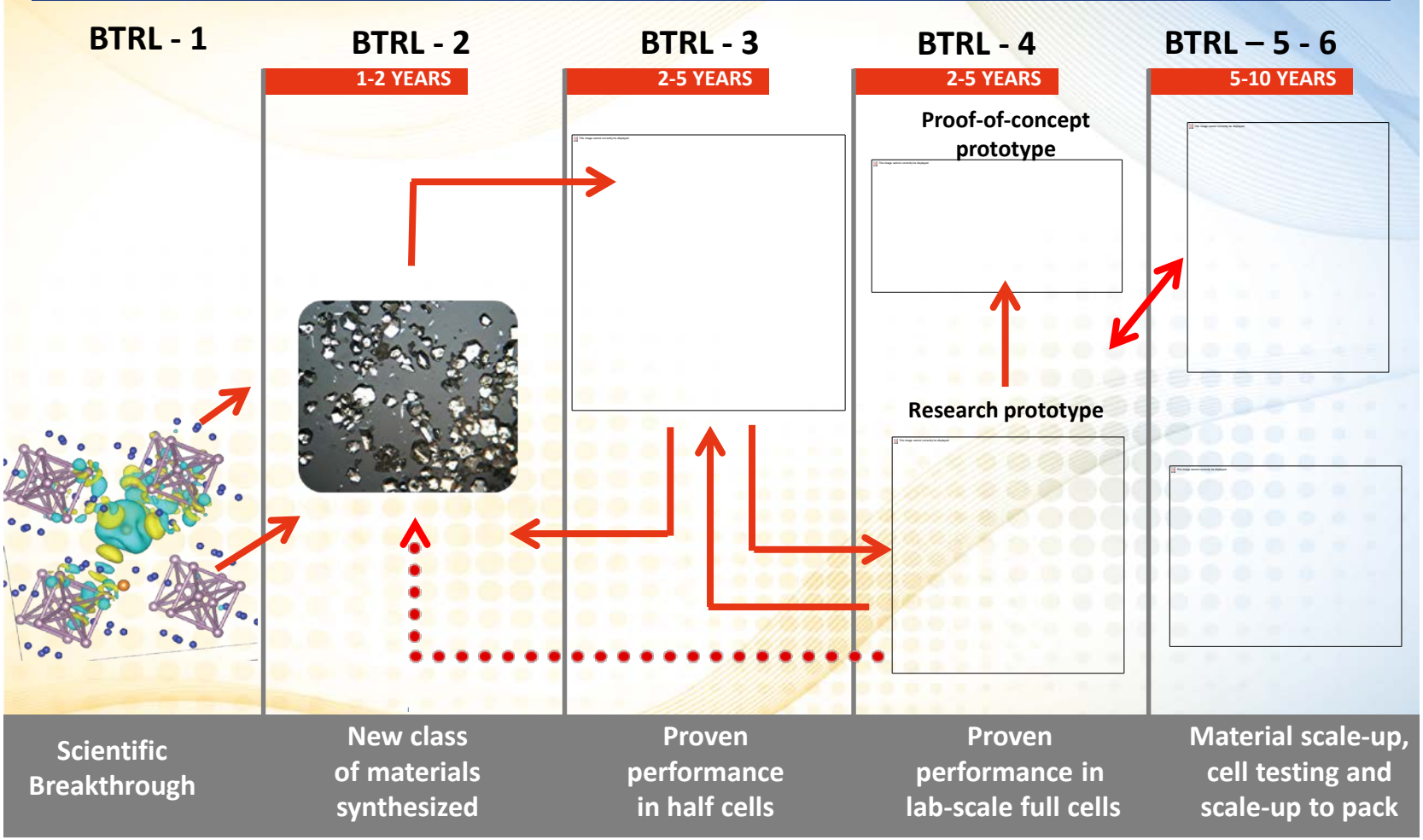
Battery Technology Readiness Level (BTRL)



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

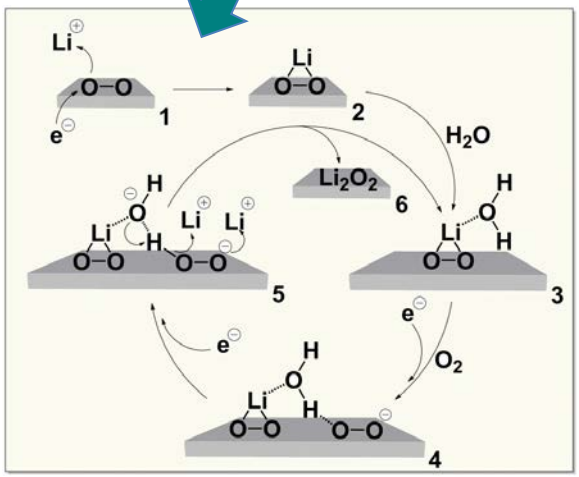
MOU with NASA-Glenn

Discovery Science

Battery Design

Research Prototyping

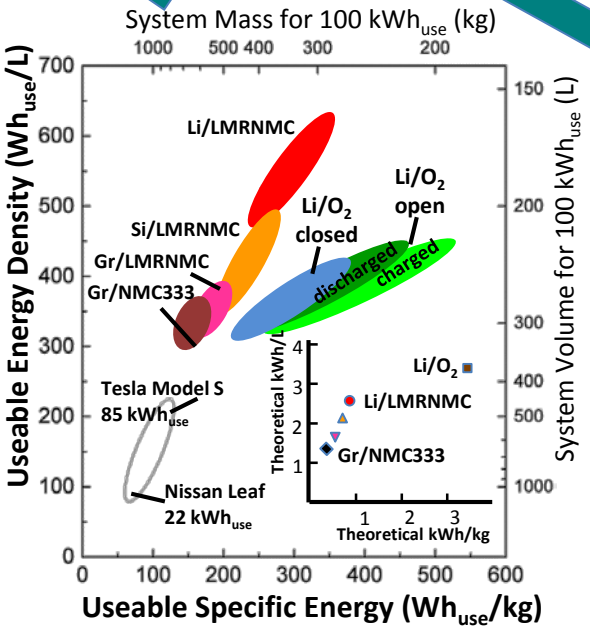
Manufacturing Collaboration



Trace water catalyzes lithium peroxide electrochemistry

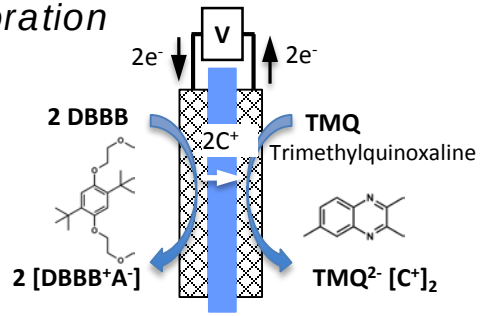
EDL+Electrolyte Genome

Jirkovský, Markovic et al, (submitted)



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

Gallagher et al, Energy and Environmental Science (2014)

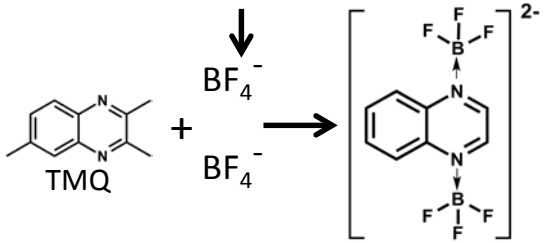


All Organic Redox Flow

Non-aqueous Redox Flow + Electrolyte Genome

Brushett, Zhang et al (MIT, ANL)

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



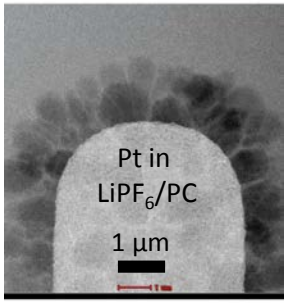
10x electrochemical activity

First year summary + more highlights
www.jcesr.org

Priority Research Areas

Metal Anodes

Robust surfaces over multiple dissolution/deposition

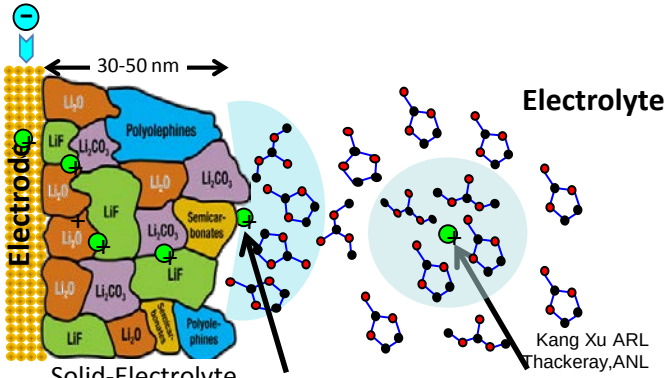


Mehdi, Browning et al (2014)

Solution/deposition dynamics, surface degradation, dendrite growth

Solvation/de-solvation

structure and transfer dynamics



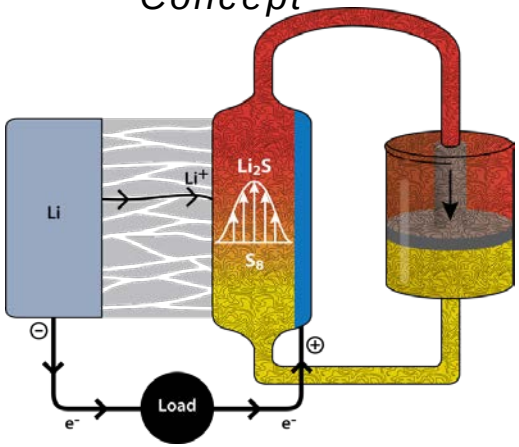
Solid-Electrolyte Interphase

partially solvated ion at interface

fully solvated ion In bulk electrolyte

Li-polysulfide Semi-Flow

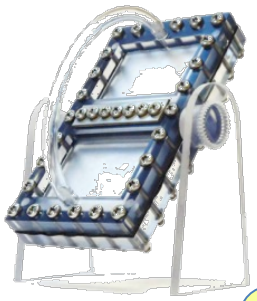
Concept

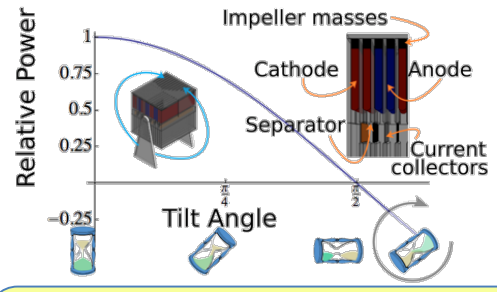


Y. Yang, G. Zheng, and Y. Cui, *Energy & Environmental Science*, 6, 1552 (2013)

Novel Prototyping Concepts

Gravity Induced Flow Cell





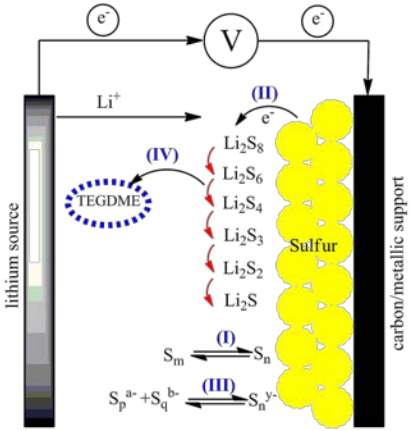
Molecular Understanding

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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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