

Storage at the Threshold: Li-ion Batteries and Beyond

Ryan Bayliss

*Senior Research Fellow, Department of Materials
University of Oxford*

On behalf of

George Crabtree

Director, Joint Center for Energy Storage Research

*Argonne National Laboratory
University of Illinois at Chicago*



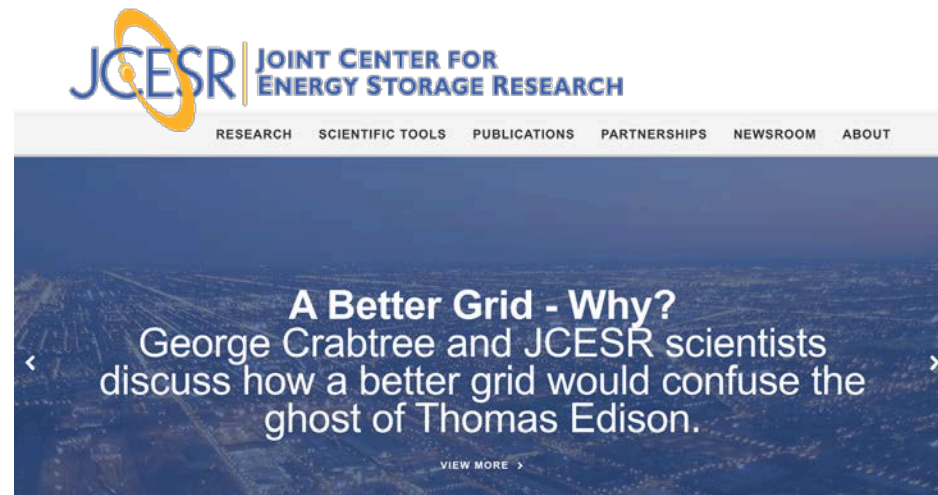
Outline

Li-ion Battery Trajectory

Transportation and Grid Challenges

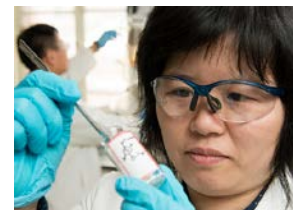
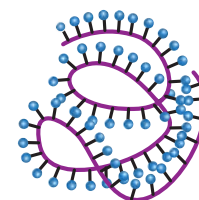
Beyond Li-ion Batteries

Further Reading



Polymer Intrinsic Microporous (PIM) membrane

Lithium-Sulfur electrolyte



Redox Active Polymer Flow

Review Article

George Crabtree, Elizabeth Kocs and Lynn Trahey
MRS Bulletin 40, 1067-1076 (Dec 2015)

http://journals.cambridge.org/download.php?file=%2FMRS%2FMRS40_12%2FS0883769415002596a.pdf&code=9324c4d620e316a0e051a6bcc1b17fc3

Webpage

<http://www.jcesr.org/>

The Energy Storage Trajectory

Personal Electronics

Lithium-ion batteries enabled
the personal electronics revolution

Forever changed the way we interact
with people and information



~ 2% of US energy
Personal electronics



Transportation: \$20K electric cars

Diversify transportation fuels

Reduce energy use

Lower operating costs

Lower carbon emissions

28% of US energy
Transportation

Grid-scale electricity storage

Widespread deployment of wind and solar

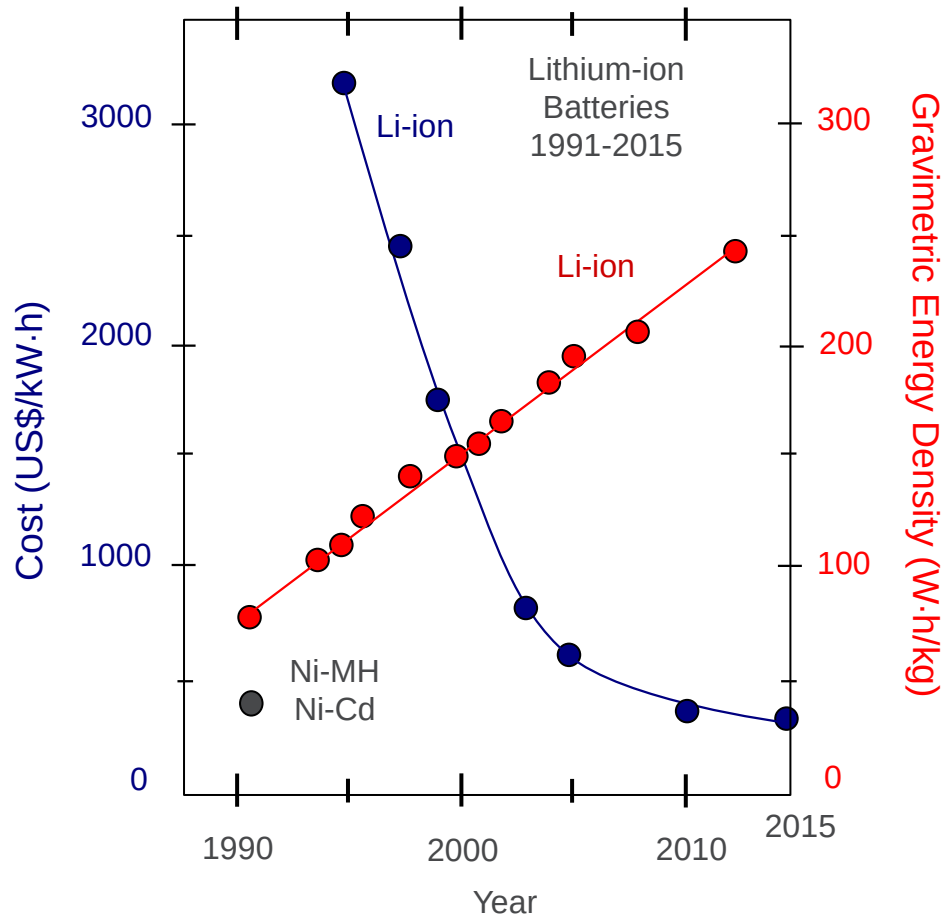
Enhance reliability, flexibility, resilience

*Uncouple instantaneous generation
from instantaneous demand*

39% of US energy
Electricity grid



Can Lithium-ion Batteries Conquer Transportation and the Grid?



Crabtree, Kocs, Trahey, MRS Bulletin 40, 1067 (2015)

Much higher safety, cost and performance targets than for personal electronics

Recycling Li-ion batteries is crucial

Discontinuous improvements in cost and performance may be needed

Can Li-ion Transform Transportation?

WHERE WE NEED TO BE

- Driving range: hundreds of miles instead of tens of miles
- Fast charging: minutes instead of hours
- Inexpensive: \$20K instead of \$80K
- Cycle life: 16 years instead of 8 years
- Safe: routine and exceptional circumstances – car crash in the rain?

GM Bolt and Tesla Model 3
\$35K / 200 miles

good

unchanged

\$35K but not \$20K, few % of market

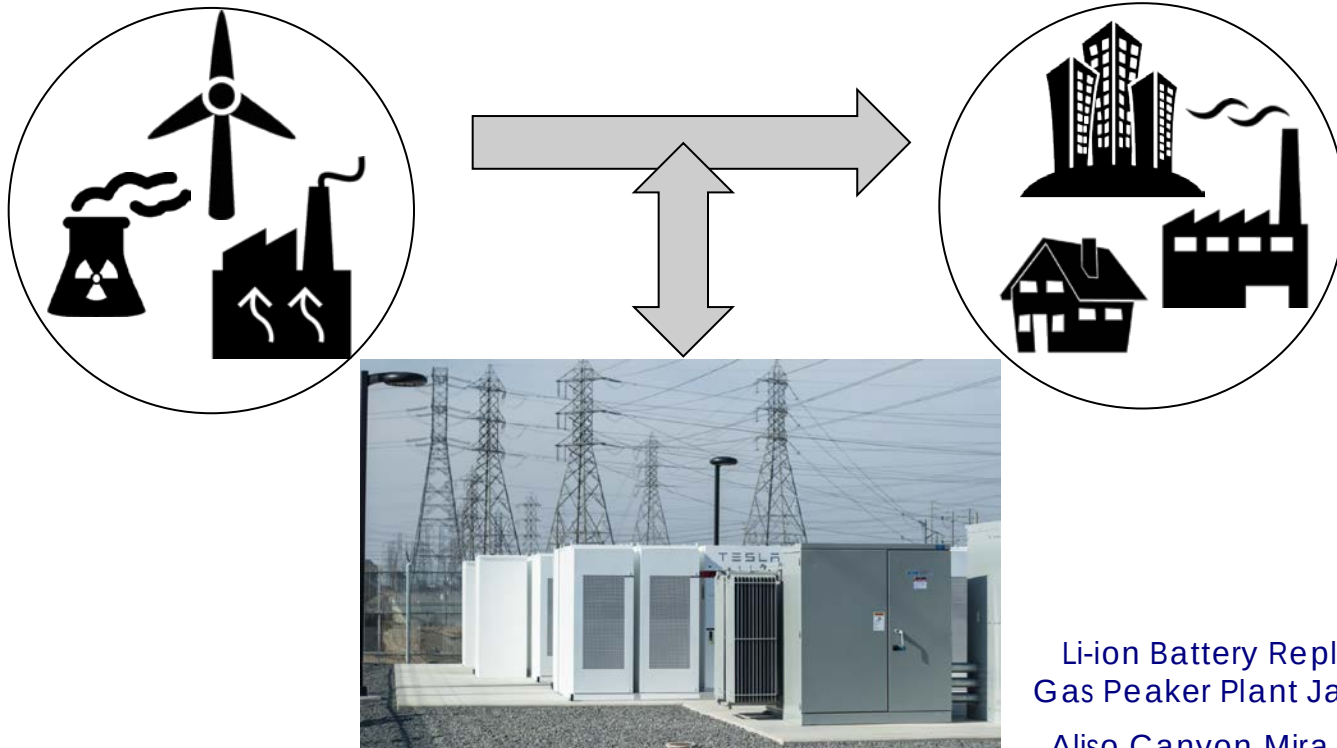
unchanged

unchanged

Lithium-ion batteries may be competitive, but not transformative

Storage: Game Changer for the Electricity Grid

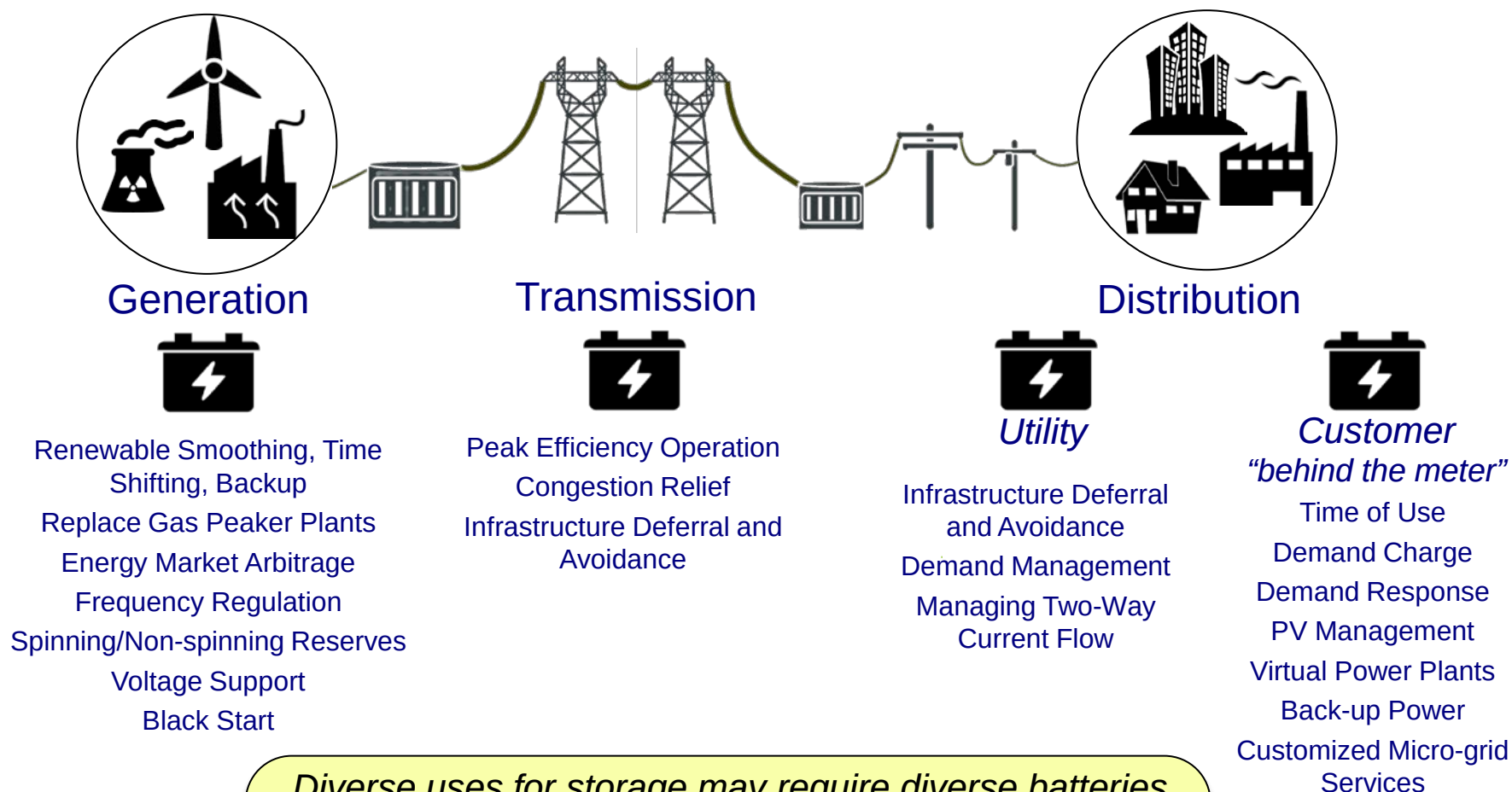
Storage breaks the historic constraint of instantaneously balancing generation and demand



Li-ion Battery Replaces
Gas Peaker Plant Jan 2017
Aliso Canyon Mira Loma

Storage time-shifts electricity generation and load
Enables new functionality, new operating paradigms, new business plans

The Grid Storage Horizon



*Diverse uses for storage may require diverse batteries
not just Li-ion*

High cost of storage – stack the benefits

Many stacking options – which are most compelling?

Need to analyze use cases

JCESR: Beyond Lithium-ion Batteries for Cars and the Grid

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

These are aggressive targets and
galvanizing forces

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

* 2011 Nissan Leaf



PRIME MINISTER THERESA MAY ANNOUNCES OUR PROPOSAL ON FARADAY INSTITUTION ON THE ANDREW MARR SHOW IN JANUARY 2017



**Further specifics from Greg Clark
MP**

**Secretary of State for Business,
Energy and Industrial Strategy**

The Faraday Challenge

An investment of £246 million over 4 years to help UK businesses seize the opportunities presented by the transition to a low carbon economy, to ensure the UK leads the world in the design, development and manufacture of batteries for the electrification of vehicles”

JCESR's Unique Approach

Materials Project

01010010
10110110
00010101
11000111

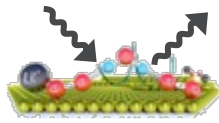


Electrolyte Genome

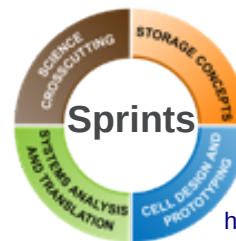
00011001
01011101
11110001
10101010



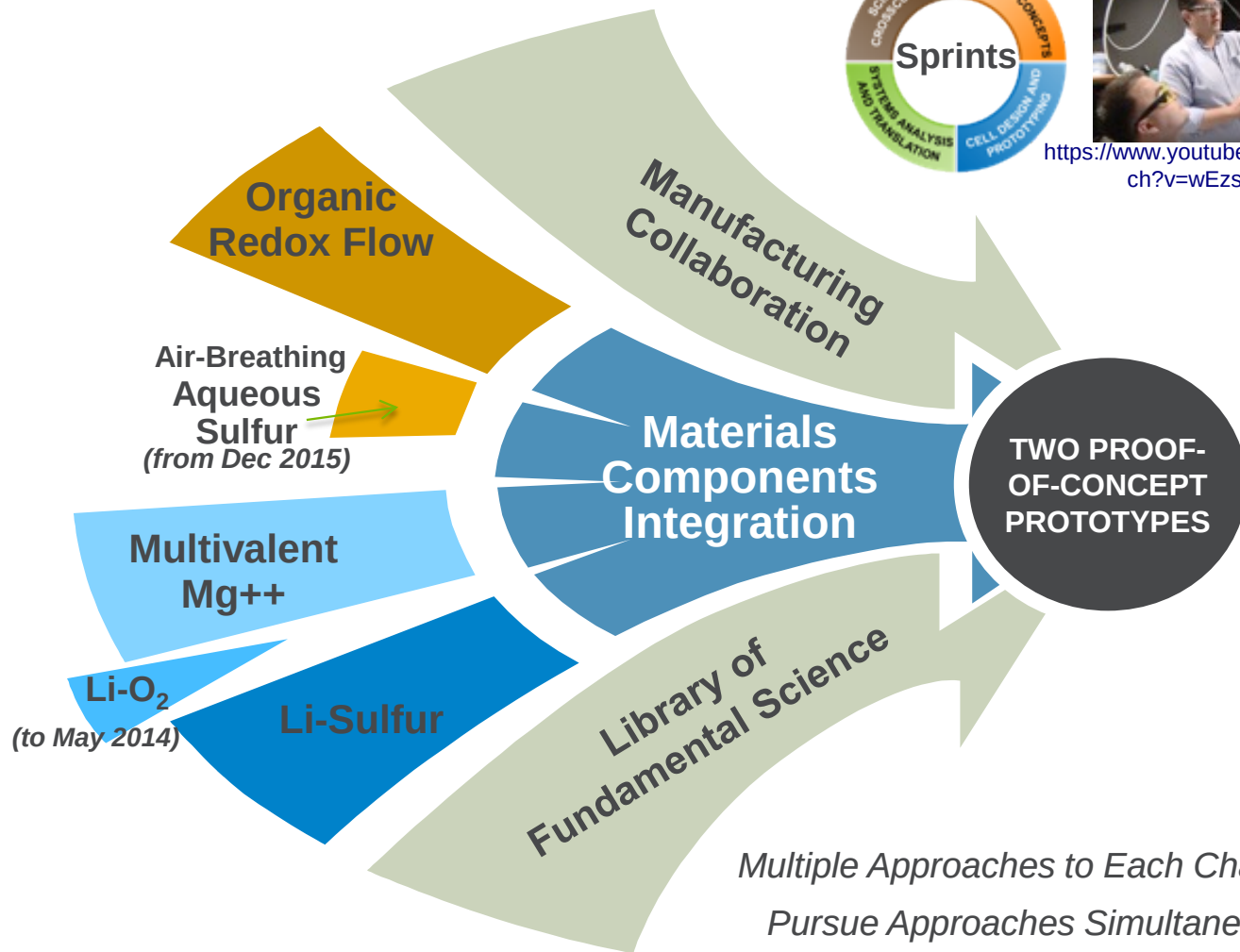
Electrochemical Discovery Lab



Techno-Economic Modeling



<https://www.youtube.com/watch?v=wEzsKJwYjDQ>



*Multiple Approaches to Each Challenge
Pursue Approaches Simultaneously*

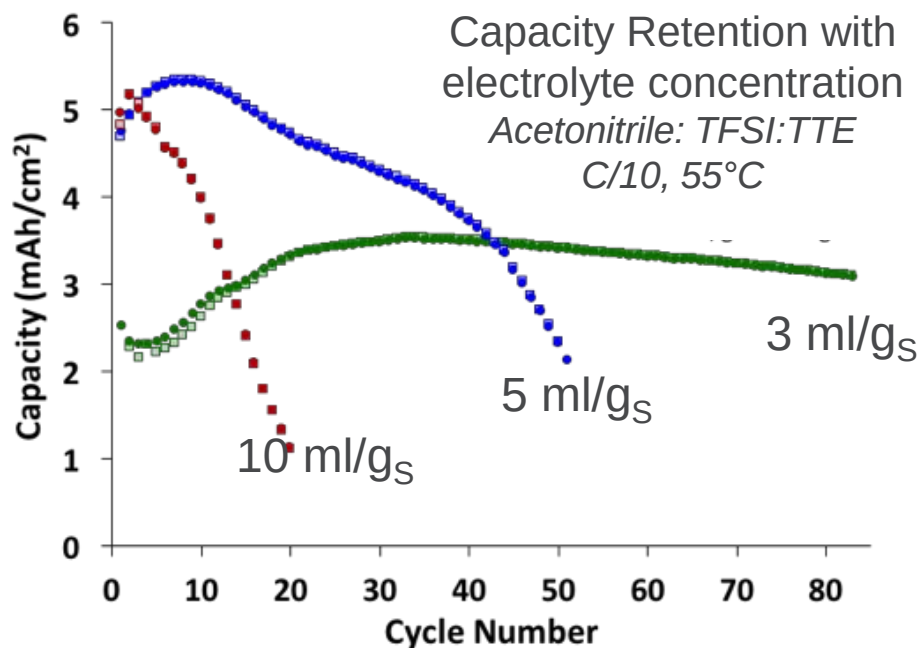
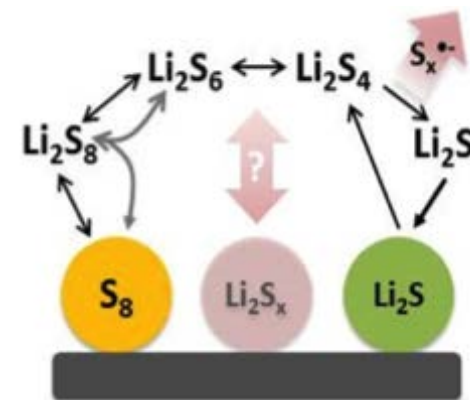
A Single Highly Interactive Organization

Focus Only on Beyond Li-ion

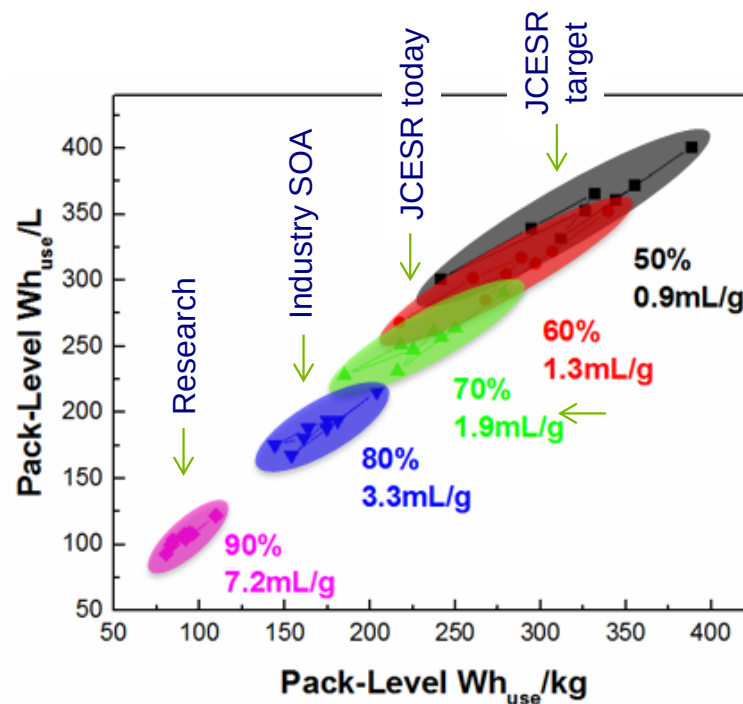
Li-Sulfur – Sparingly Solvating Electrolyte

JCESR Innovation

Solvation capability saturated with TFSI salt
No solvation of intermediate polysulfides



Conventional Electrolyte DOL:DME
Flooded Solvent
Solvation of intermediate polysulfides



For the Grid: Organic Flow Batteries

Scalable to any capacity

Power and energy separately controllable

Conventional

Vanadium Redox Flow Battery VRFB



expensive transition metal
few design options

JCESR

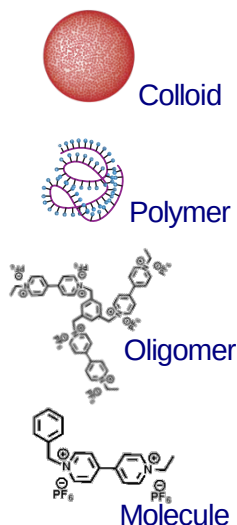
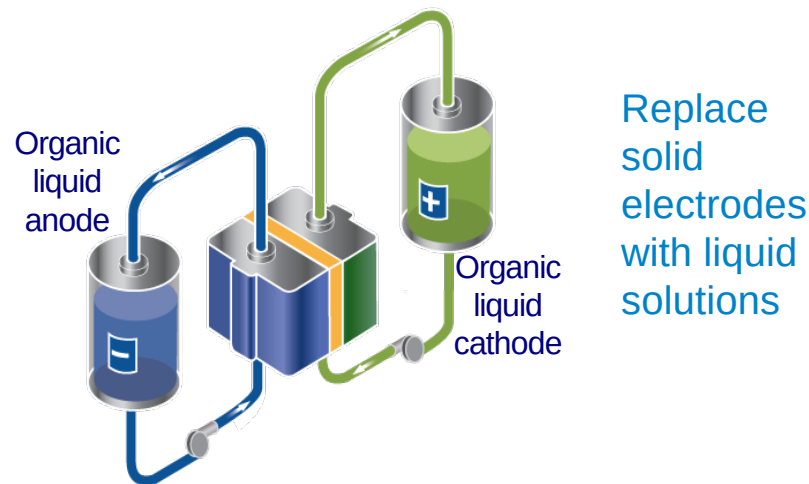
Non Aqueous Redox
Flow with Organics

inexpensive

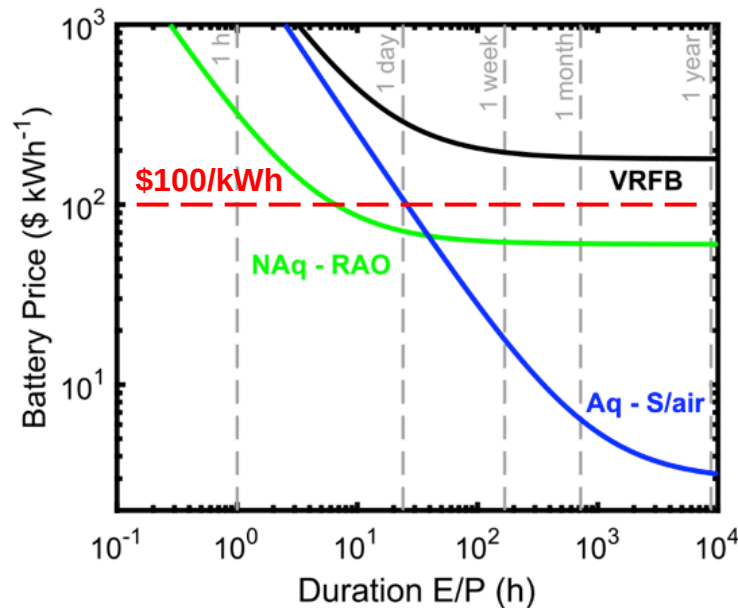
environmentally benign

recyclable

rich design space



NON-AQUEOUS REDOX FLOW

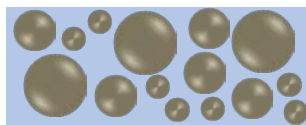
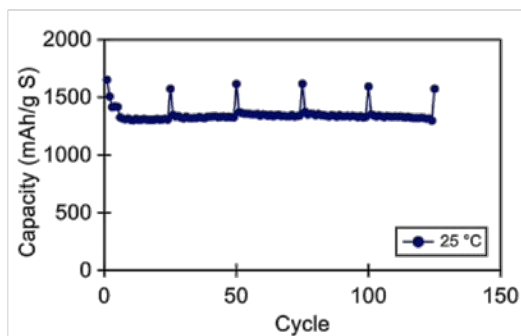


JCESR Spins Out Two Startups

BLUE  CURRENT



Nitash Balsara, Alex Teran and Joe DeSimone (UNC)



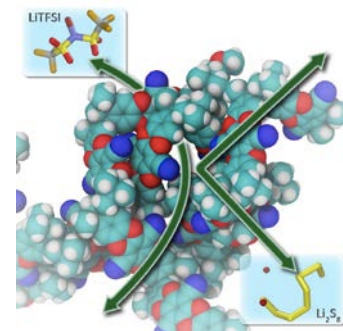
Li-S battery with novel polymer-inorganic solid state electrolyte developed in JCESR

Inorganic-polymer hybrid for Li anode batteries
Villaluenga et al, PNAS 113, 52, (2015)



Brett Helms, Kenneth Boblak, Peter Frischmann, and Jon-Michael Alessandro

Microporous polymer membrane (PIM) blocks Li polysulfides and redox active organic oligomers



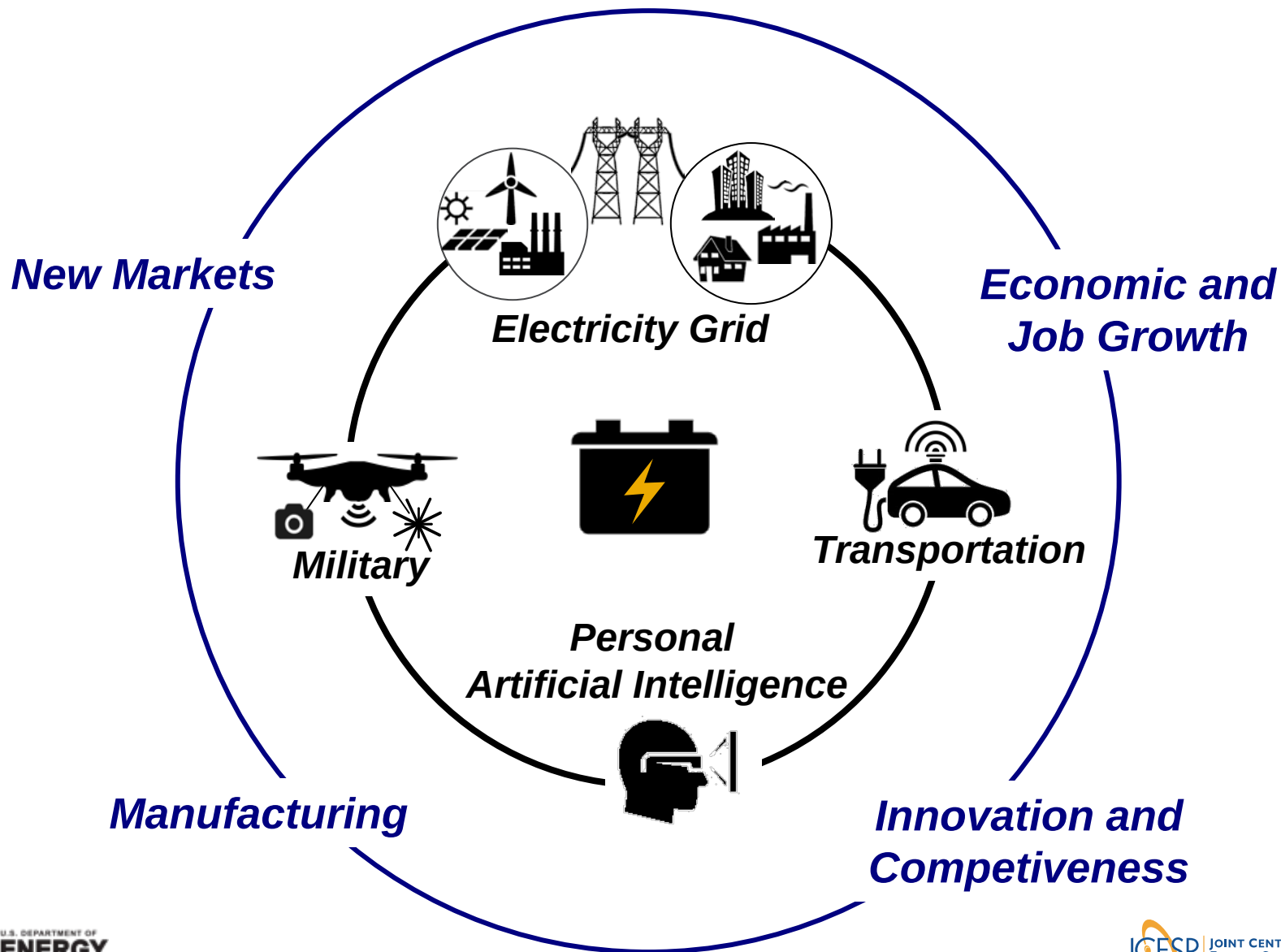
R&D100 Award 2016
Best All-around Team
Bay Area I-Corps competition 2016

Polysulfide-Blocking Microporous Polymer Membrane Tailored for Hybrid Li-Sulfur Flow Batteries, Li et al, Nano Lett. 15, 5724 (2015)

Commercializing JCESR Innovations
Training next generation entrepreneurs
Building JCESR relationships

The Energy Storage Ecosystem

Moving science and technology to society



Further Reading

Jonathan Walker and Charlie Johnson, *Peak Car Ownership: The Market Opportunity of Electric Automated Mobility Services*, Rocky Mountain Institute (2016)

http://www.rmi.org/peak_car_ownership.

Jeffery B. Greenblatt and Samveg Saxena, *Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles*, Nature Climate Change 5, 860 (2015).

Garrett Fitzgerald, James Mandel, Jesse Morris, Hervé Touati, *The Economics of Battery Energy Storage*, Rocky Mountain Institute (2016)

George Crabtree, Elizabeth Kocs and Lynn Trahey, *The Storage Frontier: Lithium-ion Batteries and Beyond*, MRS Bulletin 40, 1067 (2015).

Why Energy Storage May Be the Most Important Technology in the World Right Now

Forbes Apr 1, 2016



Why We Need A Revolution in Energy Storage

PBS Jan 5, 2016

Frontiers of Energy

Nature Energy Jan 11, 2016

Ten experts, including JCESR's George Crabtree, share their vision of coming energy challenges

Lithium Batteries: To the Limits of Lithium

Nature Oct 28, 2015



Search for Super Battery

NOVA Feb 1, 2017

<https://www.youtube.com/watch?v=JPcLWF4hask>

Perspective: The Energy Storage Revolution

Nature Oct 28, 2015

How next-generation storage can change the car and the grid