JCESR | JOINT CENTER FOR ENERGY STORAGE RESEARCH

34th Annual International Battery Seminar and Exhibit

Storage at the Threshold: Li-Ion Batteries and Beyond

George Crabtree

Director, Joint Center for Energy Storage Research

Argonne National Laboratory
University of Illinois at Chicago

U.S. DEPARTMENT OF ENERGY

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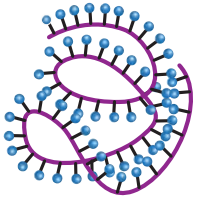
Further Reading

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

Diversity transportation fuels

Lower carbon emissions

Reduce energy use

Lower operating costs

28% of US energy
Transportation

Grid-scale electricity storage

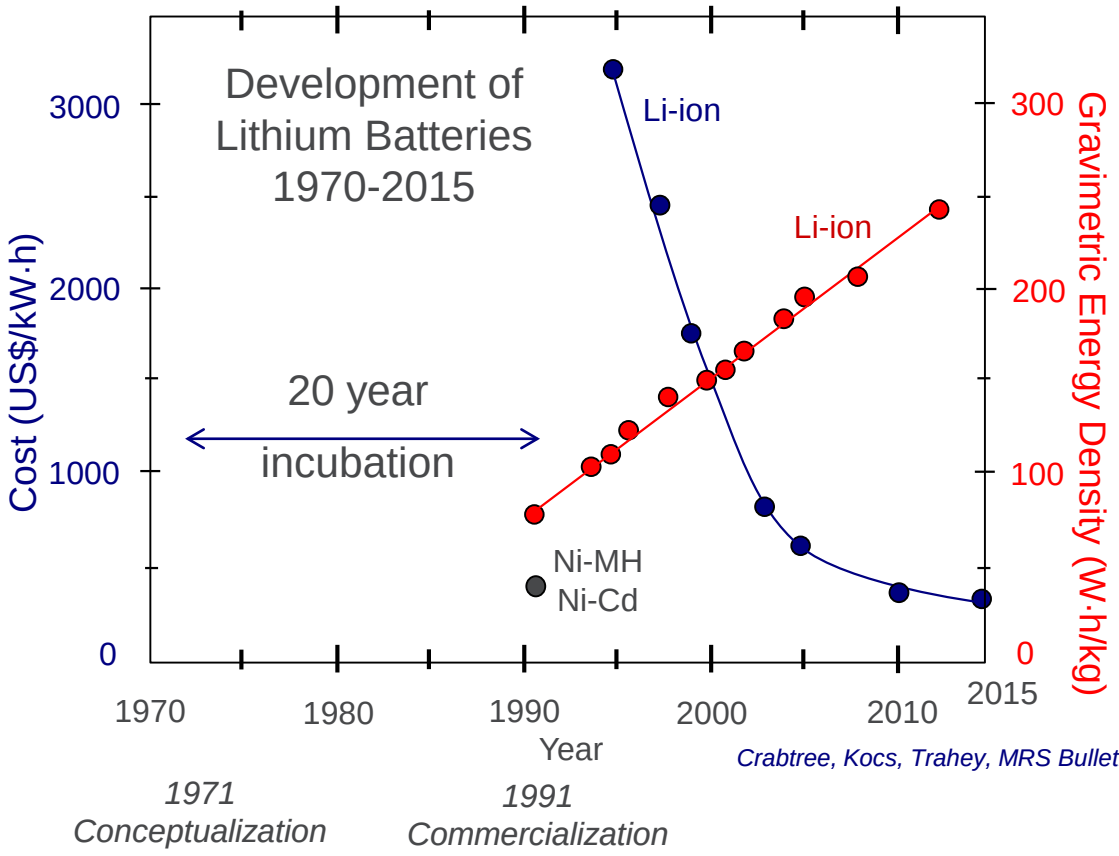
Widespread deployment of wind and solar

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 cost and performance targets than for personal electronics

Recycling Li-ion batteries is crucial at these scales

Discontinuous improvements in cost and performance may be needed

Electric Vehicle Challenges

- Driving range: hundreds of miles instead of tens of miles
- Fast charging: minutes instead of hours
- Inexpensive: $20K instead of $80K
- Cycle life: predictable and commensurate with car life
- Safe: routine and exceptional circumstances - car crash in the rain?

Reduced cost addresses some but not all challenges

Tesla Model 3 and GM Bolt: $35K/200 mile cars

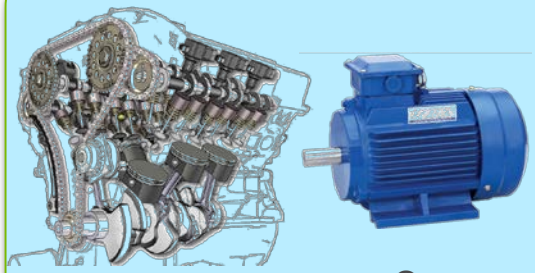
- Driving range: 200 miles - good
- Fast charging: unchanged
- Expensive: $35K, not $20K – few percent market penetration, like Prius
- Cycle life: unchanged
- Safety: unchanged

Lithium-ion batteries may be competitive, but not transformative

The Mobility Transformation

Electric Vehicles

Fewer Moving Parts



Hundreds One

Low Maintenance Cost

Electricity Is Cheaper than Gasoline

Gasoline: $0.08 - $0.12/mile
Electricity: $0.04 - $0.06/mile

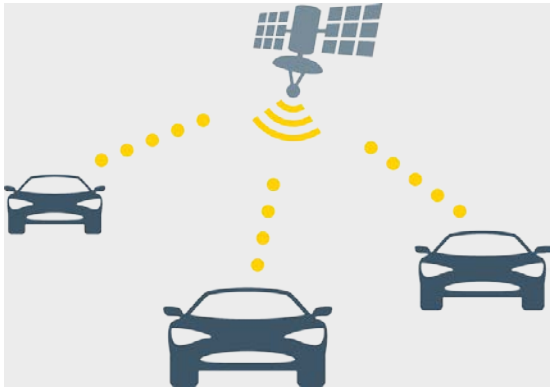
Low Fuel Cost

EVs are the economic choice for high mileage vehicles

Ride sharing services

Fewer, higher mileage vehicles

Autonomous connected vehicles

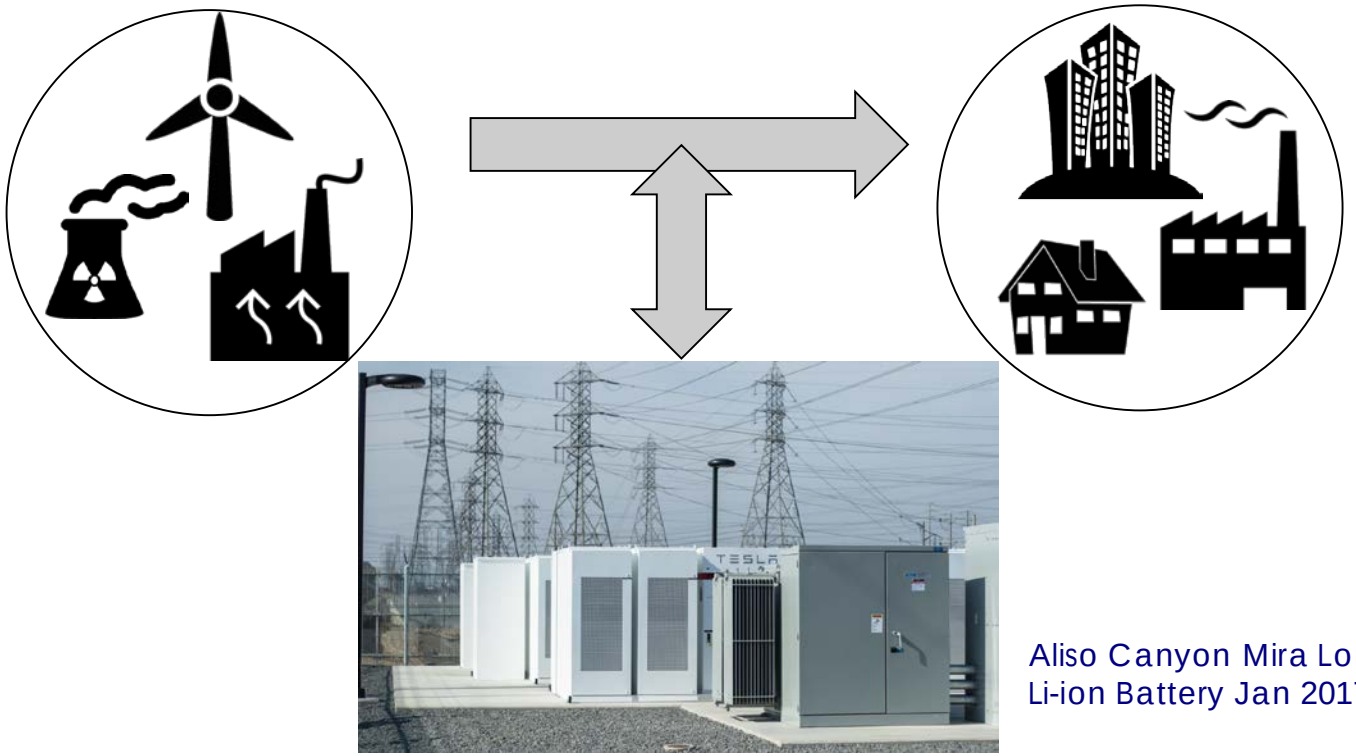


Driver optional
Smart traffic flow
Fewer accidents
Shorter travel times

Safe, low cost, fast charging, high cycle life batteries are the key to the mobility transformation

Storage: Game Changer for the Electricity Grid

Storage breaks the historic constraint of instantaneously balancing generation and demand

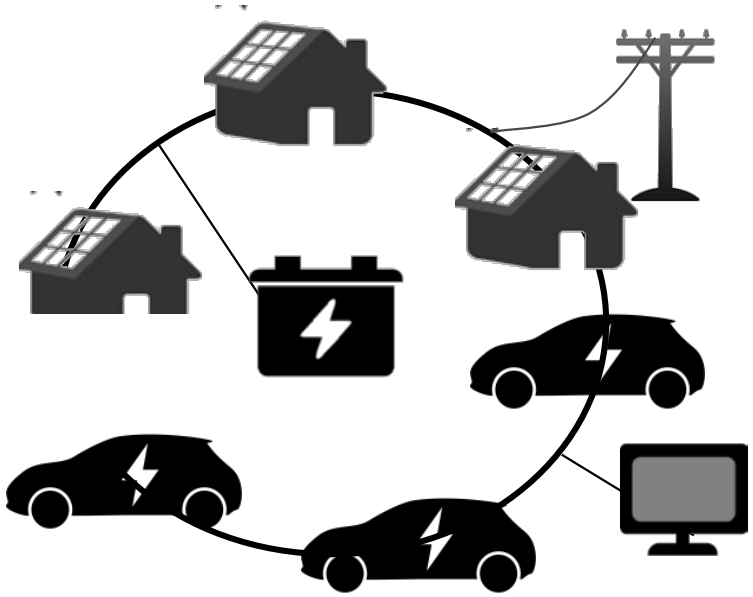


Aliso Canyon Mira Loma
Li-ion Battery Jan 2017

Storage time-shifts electricity generation and load

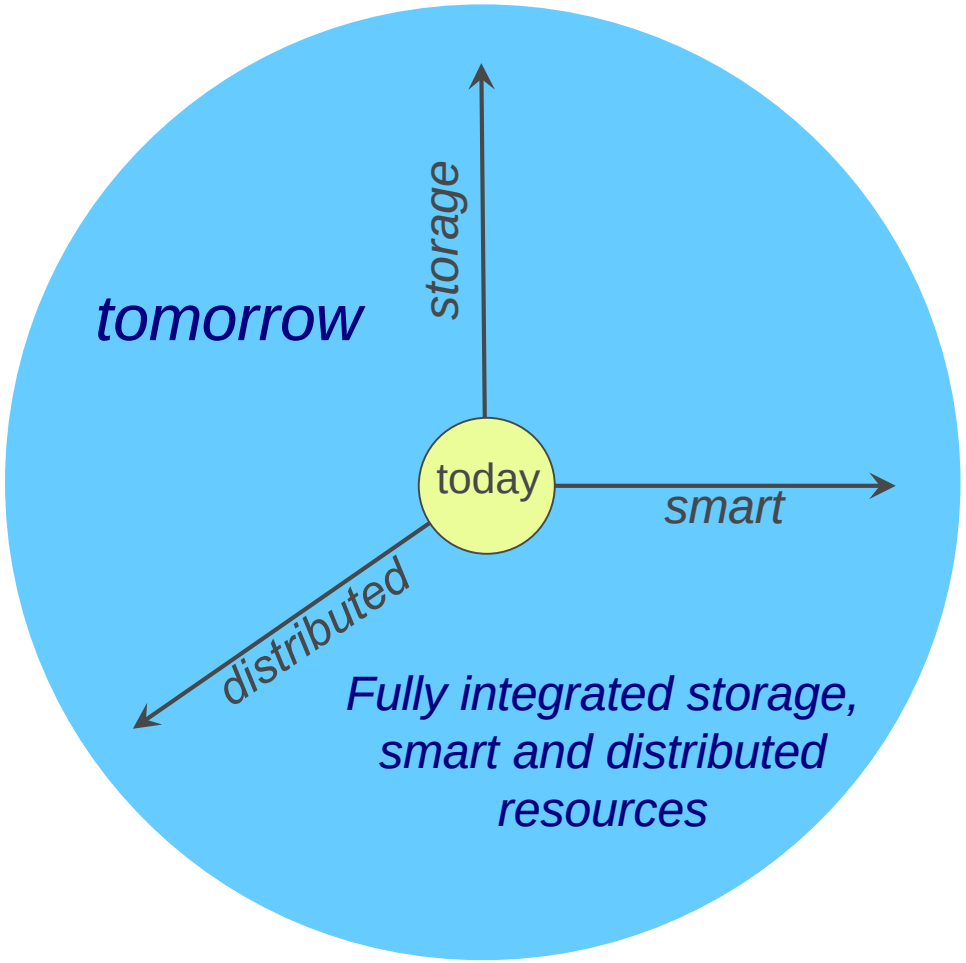
Enables new functionality, new operating paradigms, new business plans

Three Interacting Transitions: Storage + Smart + Distributed



Main grid +
smart distributed solar, storage,
electric vehicle and
neighborhood grid

Personalized electricity service



The grid of the future will not look like the grid of the past

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

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

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

Legacies

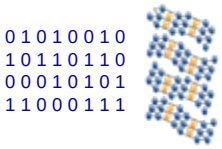
- **A library of the fundamental science** of the materials and phenomena of energy storage at atomic and molecular levels
- **Two prototypes, one for transportation and one for the electricity grid**, that, when scaled up to manufacturing, have the potential to meet JCESR's transformative goals
- **A 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

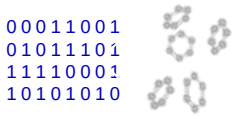
JCESR's Approach and Progress

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

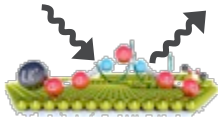
Materials Project



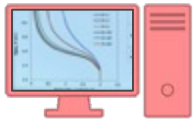
Electrolyte Genome



Electrochemical Discovery Lab



Techno-Economic Modeling



Organic Redox Flow

Air-Breathing Aqueous Sulfur *(from Dec 2015)*

Multivalent Mg++

(to May 2014) $Li-O_2$

Li-Sulfur

Manufacturing Collaboration

Materials Components Integration

Library of Fundamental Science

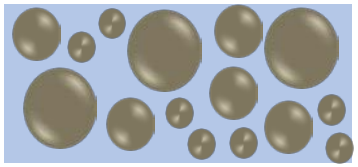
TWO PROOF-OF-CONCEPT PROTOTYPES

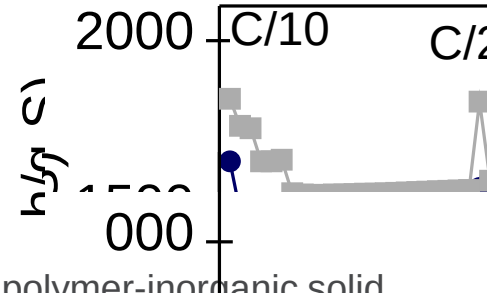
Prototypes on Track for Delivery in Dec 2017

JCESR Spins Out Two Startups

BLUE CURRENT

Nitash Balsara, Alex Teran and Joe DeSimone (UNC)





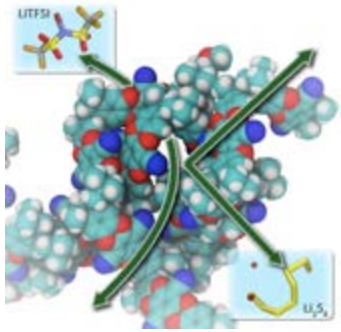
Li-S battery with novel polymer-inorganic solid state electrolyte developed in JCESR

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

SEPION TECHNOLOGIES

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

Polymers of intrinsic microporosity (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)

Moving JCESR Innovations to Commercialization

Perspective

Energy Storage at the Threshold

Driver for disruptive, transformational change
in transportation and the electricity grid

Cost and performance requirements are much higher
than for personal electronics

Safer, lower cost, faster charging,
longer lifetime, recyclable batteries are critical

Advanced Li-ion and beyond Li-ion batteries
are needed to move beyond the tipping point