Battery Chemistry Update

200 Years of Success, Now With an Amazing Pace

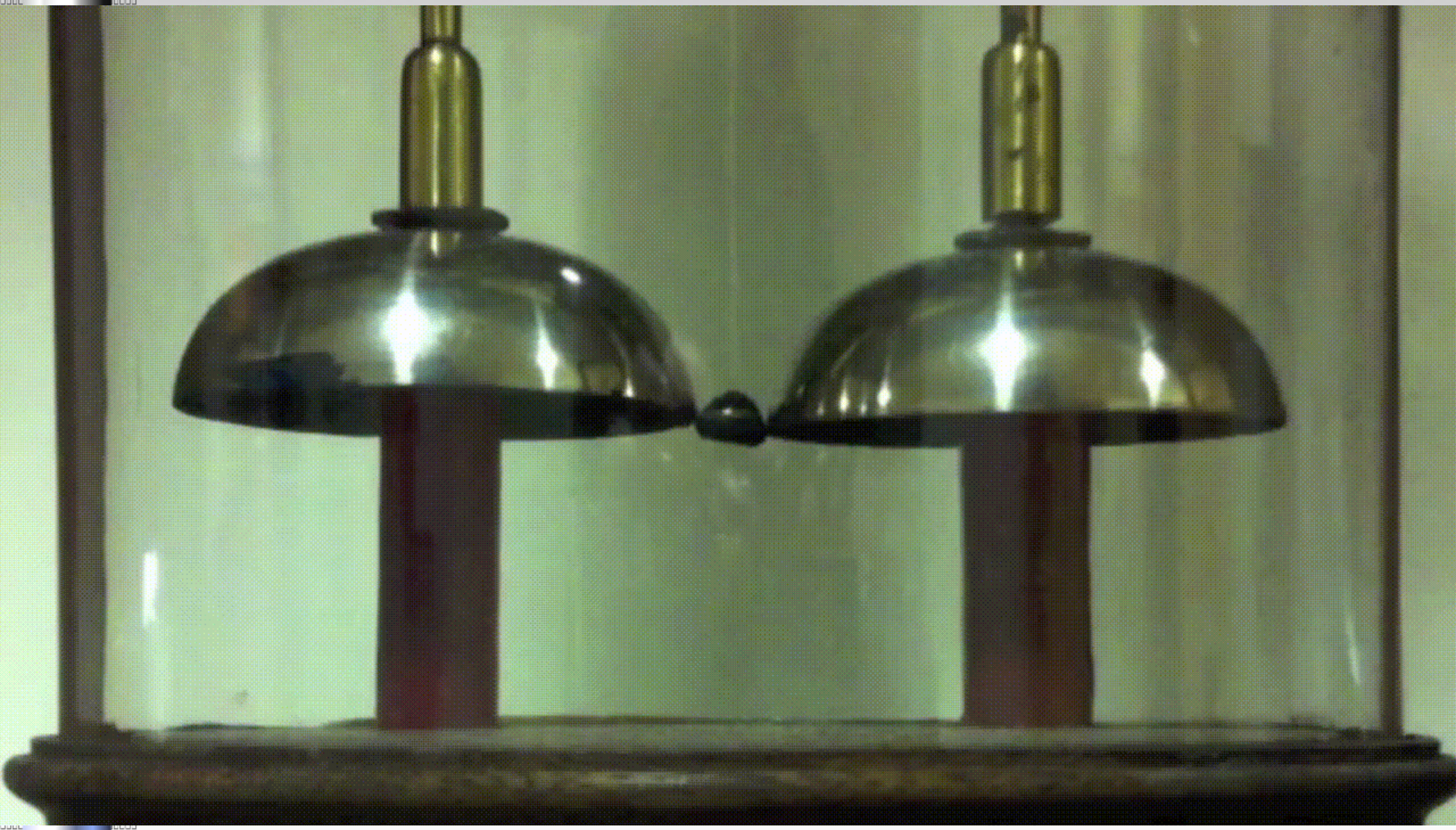
Overview

- Start with a brief look at history
- Examine current situation
- Discuss upcoming chemistries

What is a Battery's Maximum Age?

A bell in England has been operating for years. The clapper is making alternate strokes between bells, powered by a battery. The bells and clapper are in a bell jar (No relation) and behind a glass parition. The sound is barely audible, but heard in a quiet setting.

Watch Closely



A Brief History

- Oldest Working Manufactured Battery: 175 years old, still discharging
- Clarendon Laboratory at Oxford University
- Powered from a “dry pile,” an early name for

Oxford Electric Bell

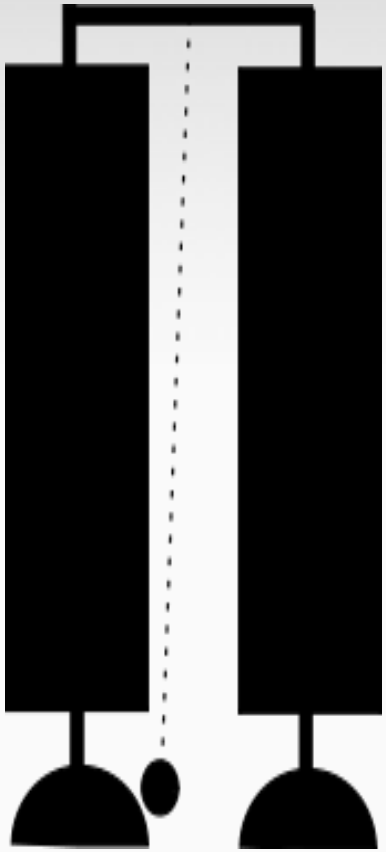
- Unknown composition
- No one wants to destroy while it still works. The charge in the battery has yet to run out.
- Clapper has likely rung 19 billion

Oxford Electric Bell

- Dry piles were first developed by Giuseppe Zamboni 200 years ago
- This bell was made in London by Watkin and Hill
- First displayed in 1840, may have been made circa. 1825

Oxford Electric Bell

- Clapper moves between 2 bells, with cycle of 2 hertz.
- Each bell is suspended below a dry pile
- Electrostatic force keeps clapper in motion.



Chemical Composition

- Likely has disks of silver, zinc, sulfur and other materials
- Sealed with a coating of molten sulfur (which used to be spelled 'sulphur' in England)
- Possibly 2,000 pairs of discs of tin foil glued to paper which is impregnated with a zinc sulfate coat on one side, and a manganese dioxide coat on the other side

100+ Years Ago

Jay Leno owns a **Baker Electric,** and still uses some of the original nickel-iron batteries from 1909

Forward to 1954

Automobiles begin to switch from 6 volt systems (3 PbAcid cells) to 12 volt sytems (6 PbAcid cells)

Why?

➔ More accessories dragging down cranking speeds

➔ Larger engines, higher compression

Little consideration of alternate chemistries

Forward to 2015

We now have almost 200 years of experimentation where various chemicals and salts were refined, and placed together to produce an electric charge.

Labor and time intensive, battery study has been interesting, but developments have been slow.

JCESR | Joint Center for Energy Storage Research

- Bring together all the resources of five national US laboratories, five major universities, and several large corporations.
- Start with computer modeling of various elements and compounds for their **atomic** characteristics and **predict battery chemistries** to pursue
- Create physical models where

JCESR | JOINT CENTER FOR ENERGY STORAGE RESEARCH

Partners - Labs

Argonne National Lab

Pacific Northwest National Lab

Lawrence Berkely National Lab

SLAC National Accelerator Lab

Sandia National Lab

Partners – Corporations

Dow Chemical

Applied Materials, Inc.

Johnson Controls

Clean Energy Trust

Partners – Universities

Northwestern University

University of Chicago

University of Illinois at Chicago

University of Illinois at Urbana-Champaign

University of Michigan

Plan announced in Dec. 2012 as

5 – 5 – 5

Using Lithium Ion batteries as base:

- 5 times cheaper
- 5 times more powerful
- In 5 years

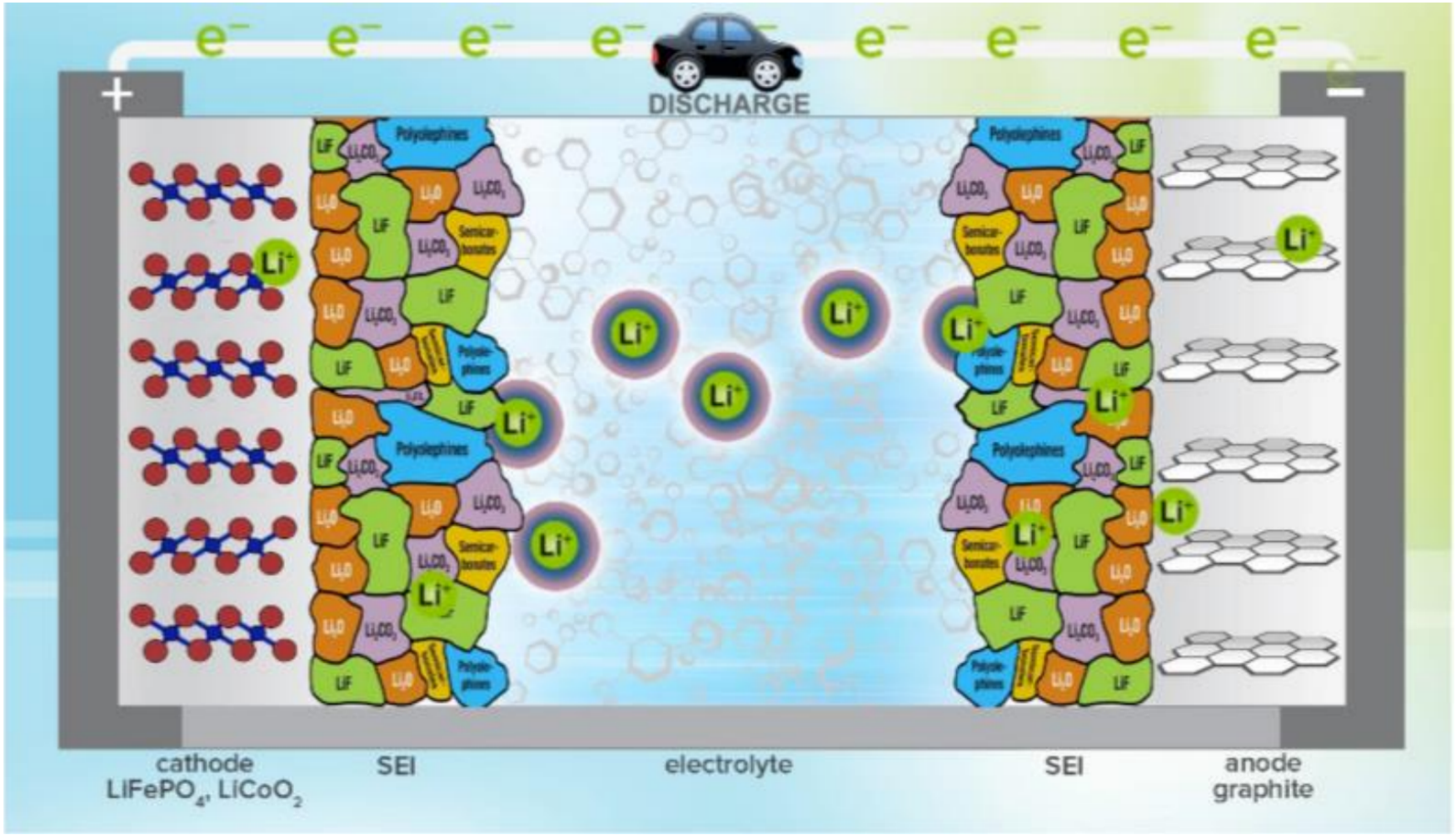
Lithium Ion Batteries

- Energy is stored by intercalation of single charged lithium ions in a graphite anode

(In chemistry, intercalation is the reversible inclusion or insertion of a molecule (or ion) into compounds with layered structures.)

- Release energy by transferring ions through an organic solvent
- Positively charged ions move to the cathode to lower energy intercalated state

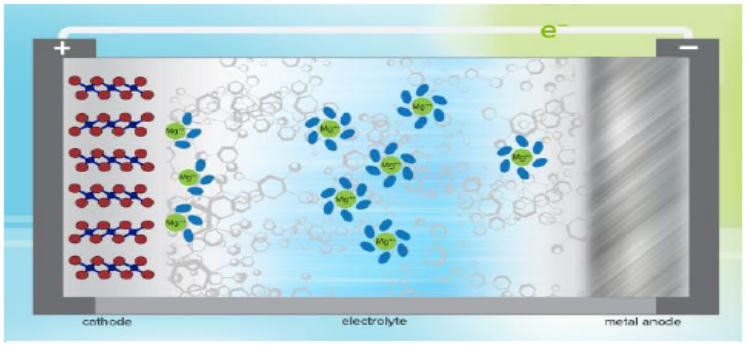
Lithium Ion Batteries

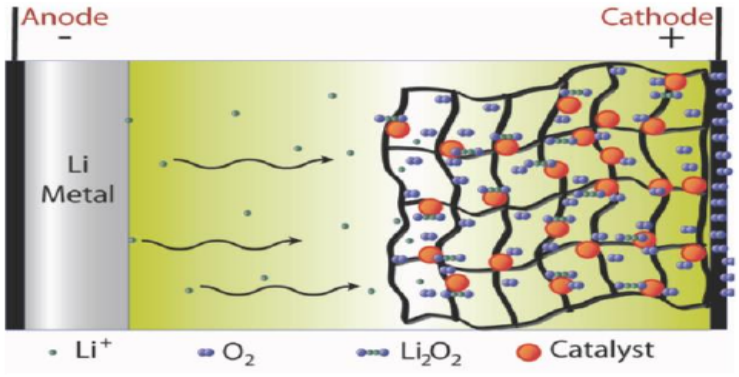


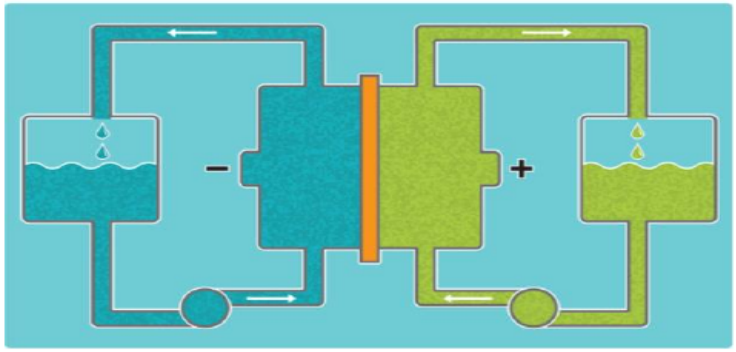
New Concepts

- Now, intercalation is with single valent ions, **Li^{+}**. Multiply charged ions give greater promise (e.g. **Mg^{++}**)
- High energy covalent chemical reactions at the anode and cathode in place of intercalation
- Fluid electrodes with large storage capacity and low cost

Improve Lithium Ion Batteries?

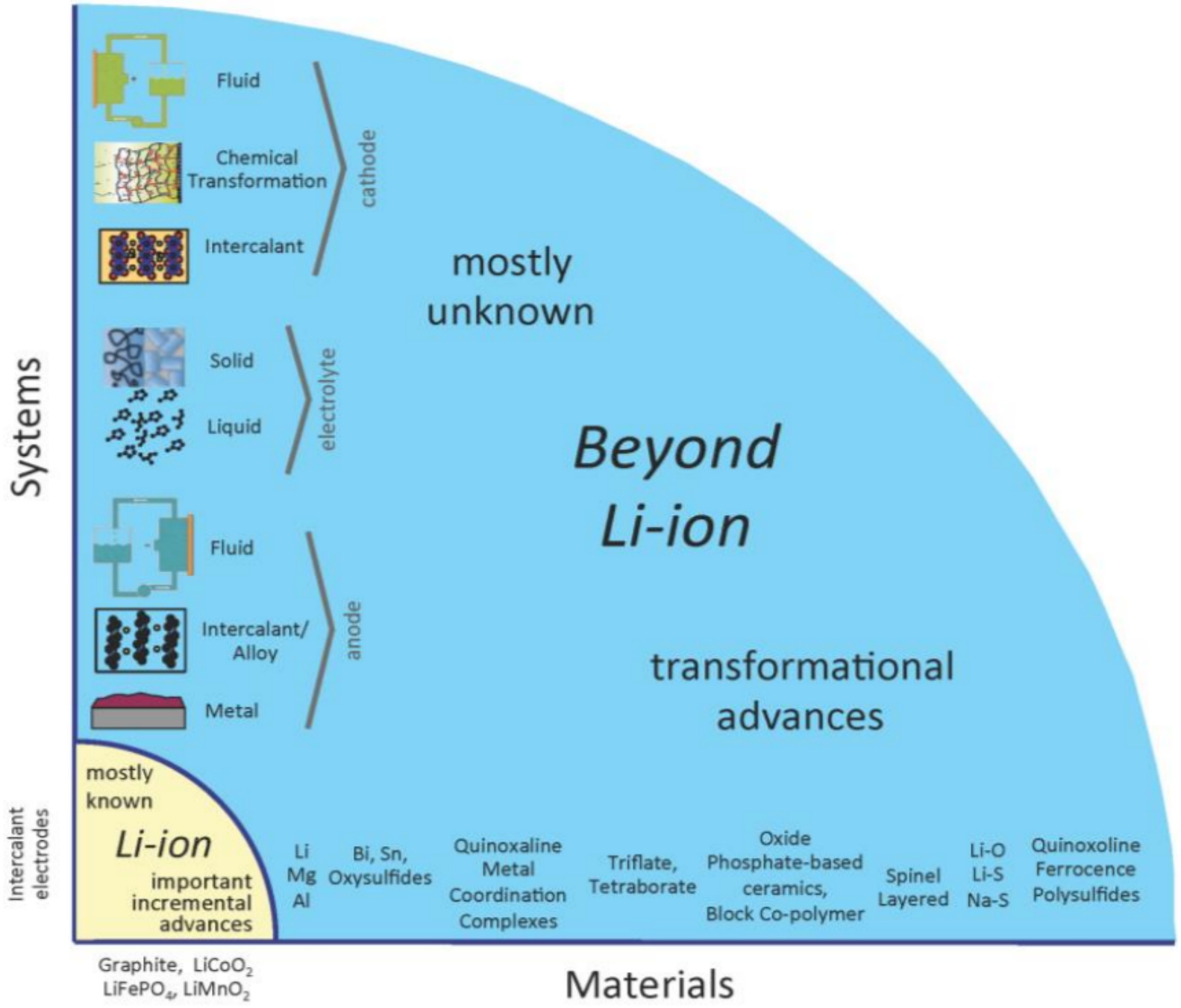






Doubly (like Magnesium) or triply charged ions (like Aluminum)

Replacement of intercalation with higher energy covalent chemical bonds


Systems
Fluid
Chemical Transformation
Intercalant
cathode
mostly unknown
Solid
Liquid
electrolyte
Beyond Li-ion
Fluid
Intercalant/ Alloy
Metal
anode
transformational advances
mostly known
Li-ion
important incremental advances
Intercalant electrodes
Graphite, $LiCoO_2$
$LiFePO_4$, $LiMnO_2$
...
Li
Mg
Al
Bi, Sn, Oxysulfides
Quinoxaline
Metal Coordination Complexes
Triflate, Tetraborate
Oxide
Phosphate-based ceramics, Block Co-polymer
Spinel
Layered
Li-O
Li-S
Na-S
Quinoxoline
Ferrocence
Polysulfides
Materials

We're ½ Way Into The 5 Years, What Research Have We Seen?

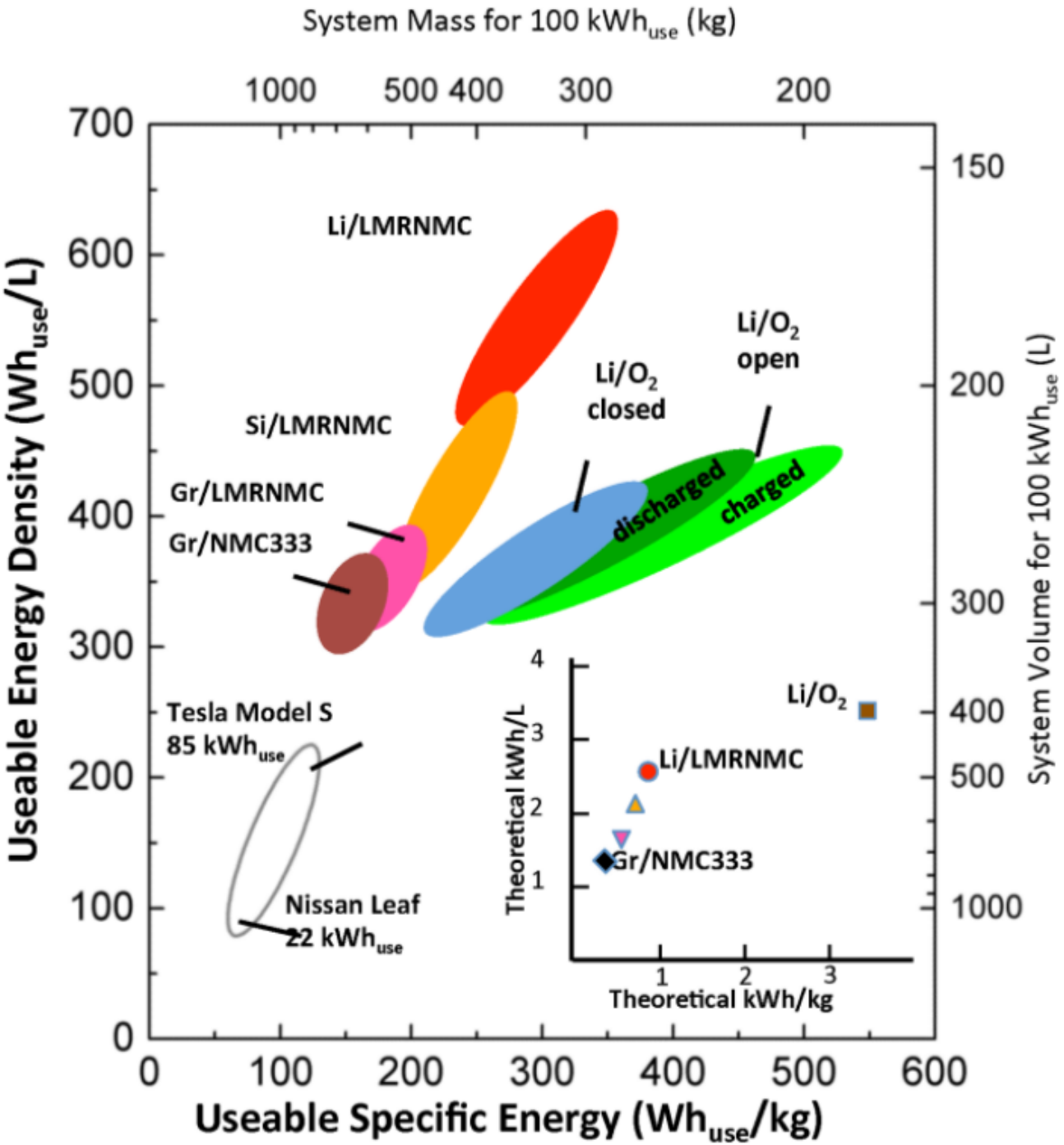
- Trace water in lithium-oxygen electrochemistry
- Solvation shell of Mg^{++}
- Multivalent intercalation
- New electrochemically active Lewis acid-base adducts

Developments in Battery Design

- Materials level performance targets
- System level performance simulation

Notes for Following Chart

- Lithium Oxygen is presented in an open environment (**Li/O_2 open**) and in a pressure vessel (**Li/O_2 closed**)
- **NMC333–Gr** is a specific 360V commercial battery, a prismatic pouch
- **LMR-NMC** = lithium-

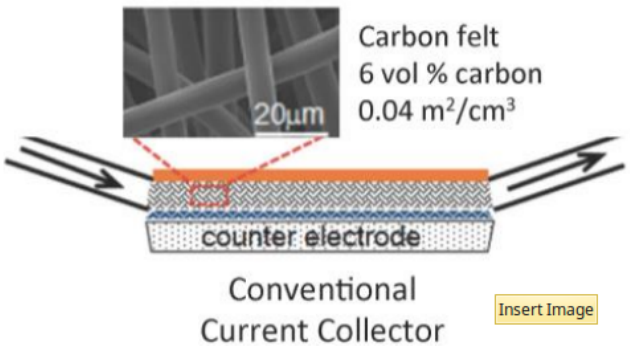


The useable volumetric energy density and gravimetric specific energy for various batteries.

This assumes science challenges are overcome, such as reversing the lithium-oxygen discharge reaction and protecting pure metal anodes under repeated stripping/plating.

Additional JCESR Research Prototyping

- Infinite Current Collectors which extends the electrochemical activity throughout the volume of the liquid compared to the small stationary area of conventional current collectors
- Gravity induced flow cells where the anode and cathode tanks are mounted on a tilt table straddling the reaction plate. Flow is controled by the tilt angle



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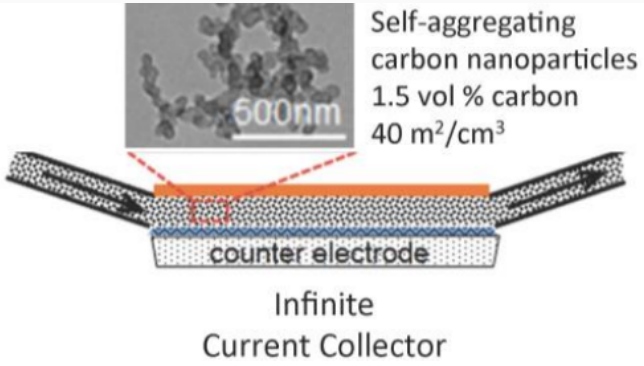
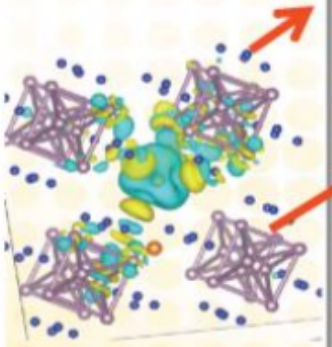


Battery Technology Readiness Level (BTRL)

BTRL - 1

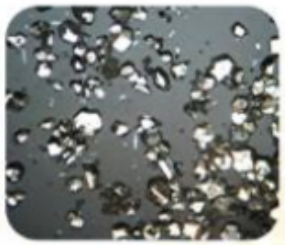
Scientific Breakthrough



BTRL - 2

1-2 YEARS

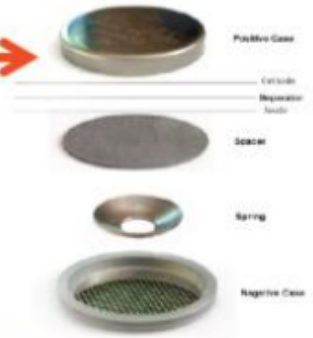
New class of materials synthesized



BTRL - 3

2-5 YEARS

Proven performance in half cells



BTRL - 4

2-5 YEARS

Proof-of-concept prototype

Research prototype

Proven performance in lab-scale full cells

BTRL – 5 - 6

5-10 YEARS

Material scale-up, cell testing and scale-up to pack

JCESR
"sweet spot"

“Why We Don’t Have Battery Breakthroughs?”

- Recent article in MIT Technology Review, which notes one promising advance that failed
- Envia, a startup company, followed a lead from ARPA-E and ANL for a new type of Lithium Ion cell
- Envia used two experimental electrode materials
- GM licensed the technology (for $7 million), but found that the voltage varied widely in cells.
- A composite coating for the electrode was used, but the results that were initially promising could not be reproduced.

Other Battery Types in News

- Nunzio La Vecchia is promoting his Quant F, which uses nanoFLOWCELL QUANT technology. At his display at the prestigious Geneva Auto Show, La Vecchia explained "Instead of using hydrogen and oxygen as in a conventional fuel cell, we work with two ionic fluids – one with a positive charge and one with a negative charge." Lots of hype and glitz seem to shroud the reality.
- University of Waterloo had announced a breakthrough in Li-S battery design using MnO_2 nanosheets as a co-cathode. Study is cofunded by BASF-SE (Germany)

UNIVERSITY OF WATERLOO

Other Battery Types in News

- If you are wondering where NiMH batteries have gone with the licensing difficulties noted 15 years ago, look to G4 Synergistics. After licensing the NiMH technology from Ovonic, which is now owned by BASF, they continued to improve performance in ultra high power situations. Remember NiMH batteries have very low resistance (less heating during charge) and better performance at very low temperatures.

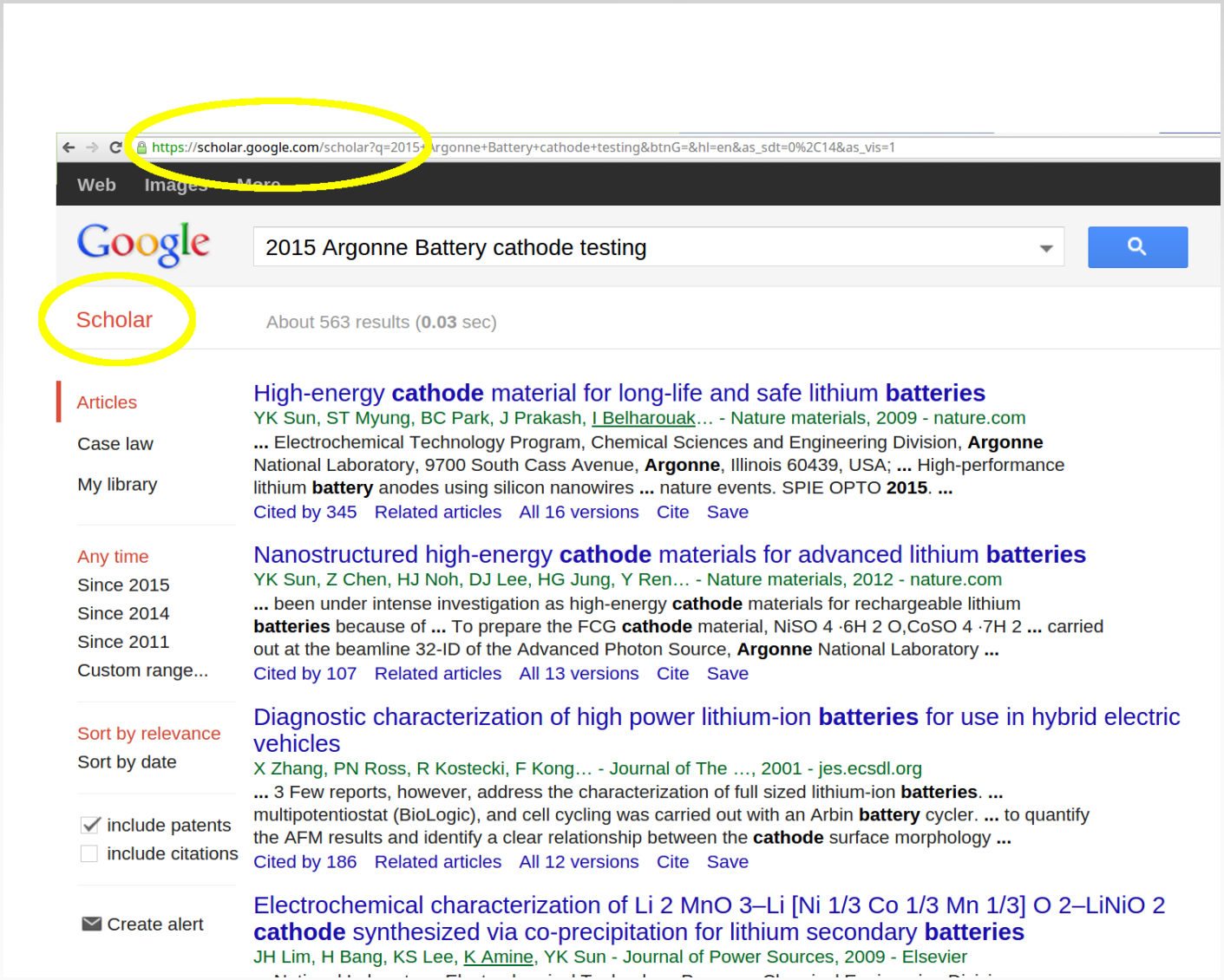
Other Battery Types in News

- Saft has been using lots of development time to allow their Li-ion batteries to give high performance and reliability over a much wider temperature range than previously. They have been testing from -40° (C or F, your choice) to 80°C (185°F). One version “xc” is even testing to -50°C.

Tesla Motors - incremental improvements

- Since 2008, the cost of Tesla battery packs has been cut to approximately in half.
- Since 2008, Tesla's storage capacity is up by 60%
- No radical changes by Tesla or Panasonic
- Incremental engineering and manufacturing improvements
- Tesla claims it can achieve a $35,000 electric car with a 200-mile range by 2017.

If You Want Detail



Resources

www.jcesr.org/about/

http://www.jcesr.org/press-room/press-room-archive/

www.abr.anl.gov/pdfs/2013_presentations/es177_gallagher_2013_o.pdf

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The Powerhouse: Inside the Invention of a Battery to Save the World, Steve Levine (published February 10, 2015)

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