Energy Storage Perspective

George Crabtree

Director, Joint Center for Energy Storage Research (JCESR)

Argonne National Laboratory
University of Illinois at Chicago

Outline

Storage: A Game Changer for the Grid

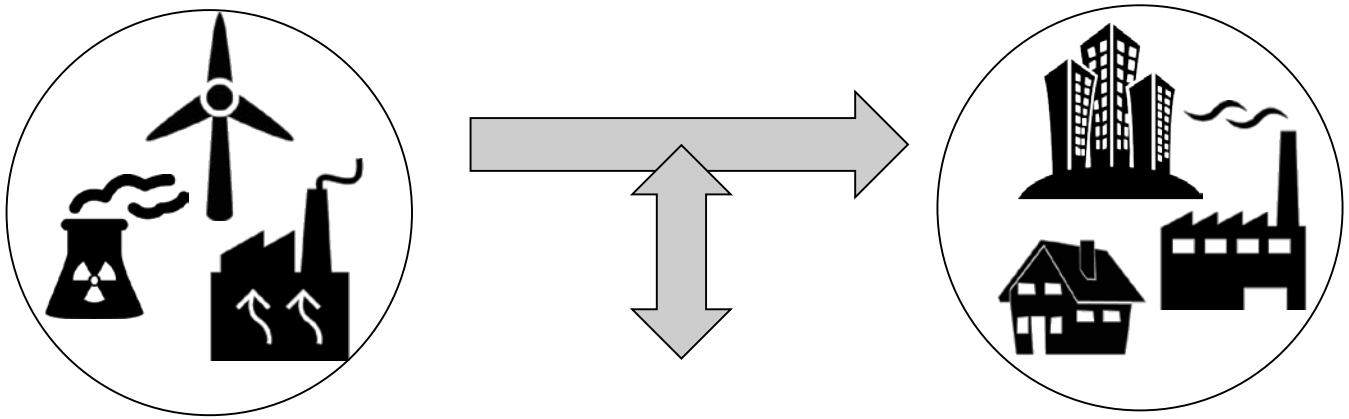
Thermal, Flywheel and Battery Energy Storage

Li-ion Battery Technology and Beyond

Illinois Commerce Commission
Policy Session on Energy Storage
Chicago, IL
June 27, 2018

Storage: Game Changer for the Electricity Grid

Storage breaks the historic constraint of instantaneously balancing generation and demand



Jan 2017

Aliso Canyon Mira Loma, Los Angeles, CA
Tesla, Greensmith, AES
70 MW

Dec 2017

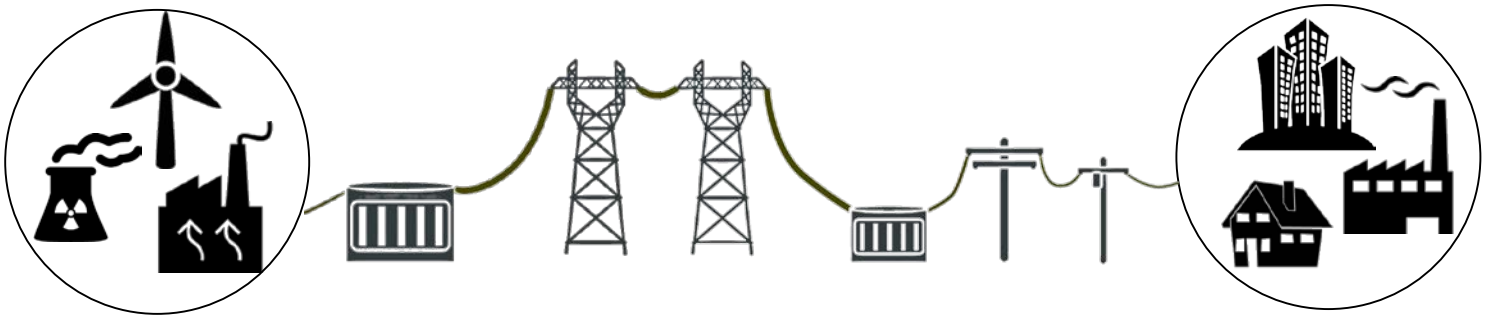
South Australia
Tesla 100 MW / 129 MWh

Li-ion Batteries Installed in Grid

Energy Storage can be a major player in the grid

Pervades generation, transmission and distribution

The Grid Storage Horizon



Generation

Renewable Smoothing, Time Shifting, Backup

Replace Gas Peaker Plants

Energy Market Arbitrage

Frequency Regulation

Spinning/Non-spinning Reserves

Voltage Support

Black Start

Transmission

Peak Efficiency Operation

Congestion Relief

Infrastructure Deferral and Avoidance

Distribution

Utility

Infrastructure Deferral and Avoidance

Demand Management

Managing Two-Way Current Flow

Customer

"behind the meter"

Time of Use

Demand Charge

Demand Response

PV Management

Virtual Power Plants

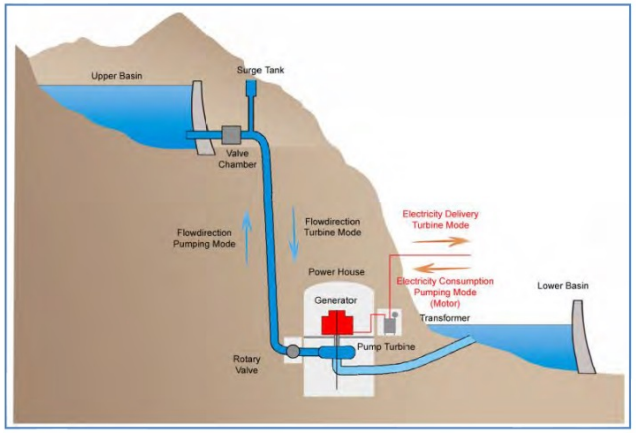
Back-up Power

Customized Micro-grid Services

Diverse uses for storage require diverse batteries beyond Li-ion

New applications require new technology, regulations and business plans

Pumped Hydro Energy Storage



Reversible turbines
70-90% round trip efficiency
Requires elevation difference
and water supply

Ludington MI
363 ft elevation 2.5 sq miles 1872 MW
Operational 1973. 5th largest in US

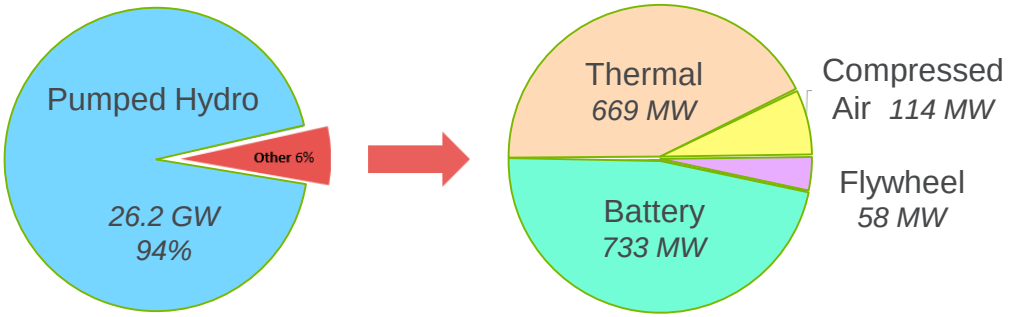
Converts baseload
nuclear to dispatchable

First use: Italy and Switzerland 1890s
First US use: Connecticut 1930

Appeal

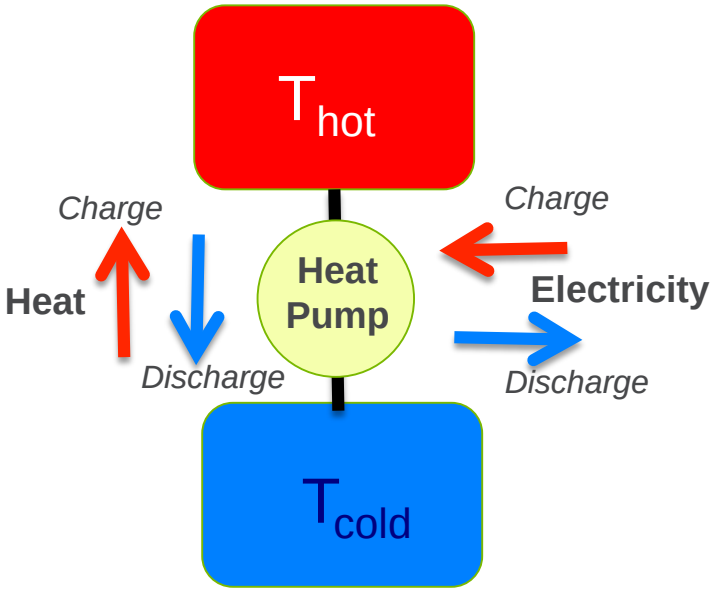
Simple, proven technology
Low cost, long life
Long duration storage

US Electricity Storage Mar 2018

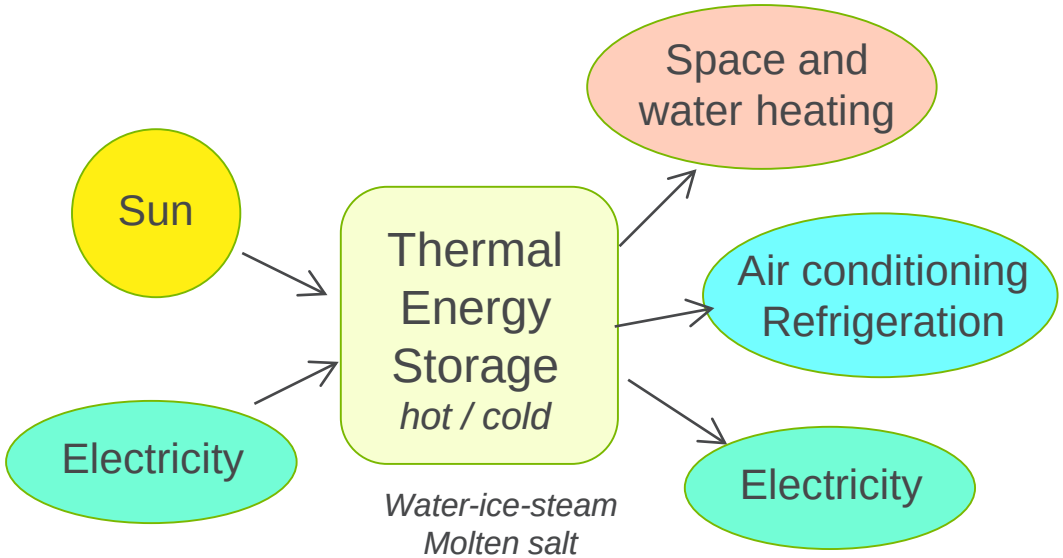


EPA Electricity Storage
https://www.epa.gov/energy/electricity-storage

Thermal Energy Storage

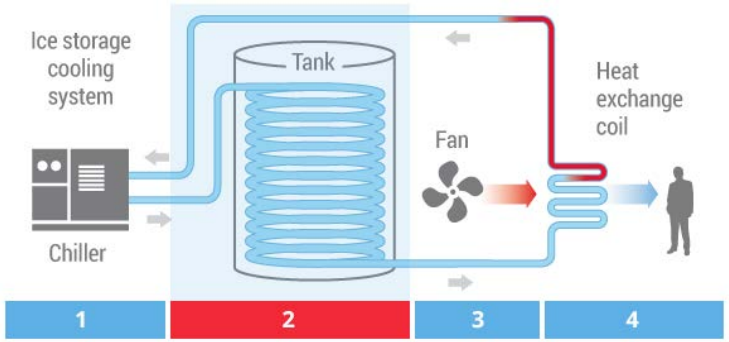


Electricity → Electricity
Pumped Heat Energy Storage (PHES)



Water-ice-steam
Molten salt
Paraffin wax
Concrete, rocks

Storage cost alone
~ $5 - $20/kWh



Excess electricity (night) | Thermal storage hot / cold | Space / water heating / cooling

Electricity → Heating / Cooling

Appeal

Simple, proven technology
Low basic cost
Long lifetime
Versatile

Status

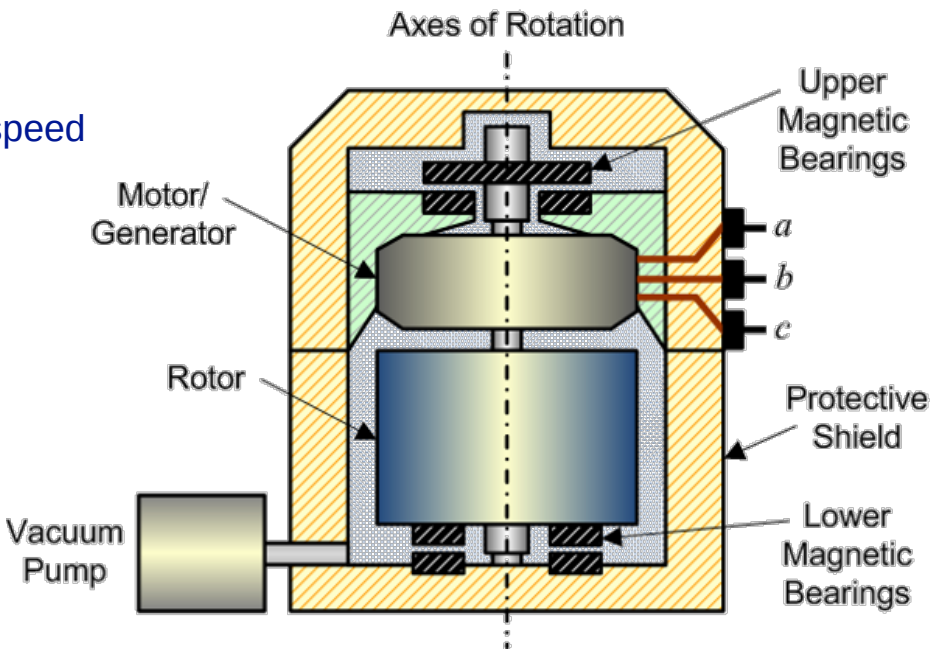
Electricity → Heating / Cooling widely deployed

Sun → Electricity: demonstration

Electricity → Electricity: R&D

Flywheel Energy Storage

Modular
Size limited by material strength and edge rotor speed
Carbon fiber flywheel
Frictionless magnetic bearings
Vacuum enclosed
15 000 – 50 000 rpm
10 – 100 Wh/kg specific energy
Up to 95% round trip efficiency
High self-discharge rate - 5%/day
Long life
Low maintenance



Beacon Power Flywheel Energy Storage Plant

Stephentown, NY (2011) Hazle Township, PA (2014)

200 modules – 20 MW / 5 MWh

Fast response - charge / discharge in 4 seconds

Used for frequency regulation

Battery Energy Storage

Take-away messages

10-20 applications for storage on the grid

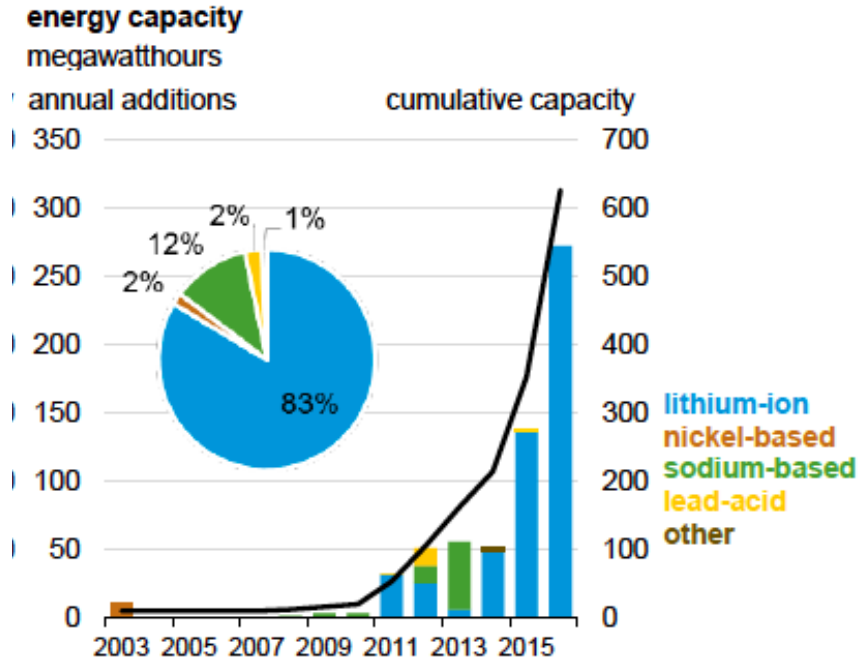
Frequency regulation most common now

Peaker plant replacement emerging

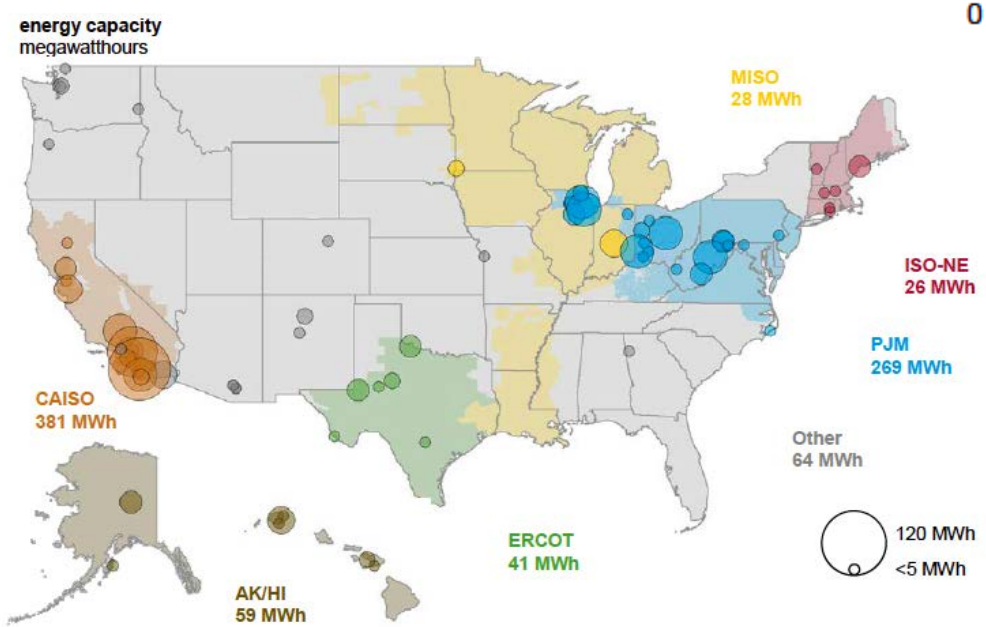
Renewable integration developing

Prices falling due to large EV demand

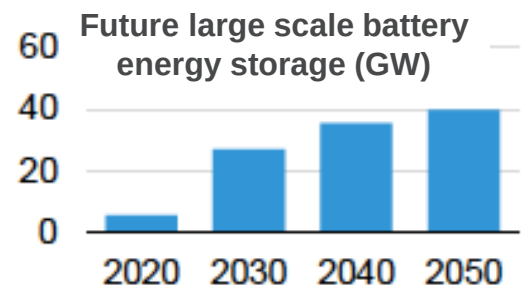
Li-ion dominant but other chemistries needed



Large scale battery capacity by chemistry



Large scale battery storage installations by region (2017)



Projected US large scale battery installations

U.S. Battery Storage Market Trends,
EIA, May 21, 2018.
https://www.eia.gov/analysis/studies/electricity/batterystorage/

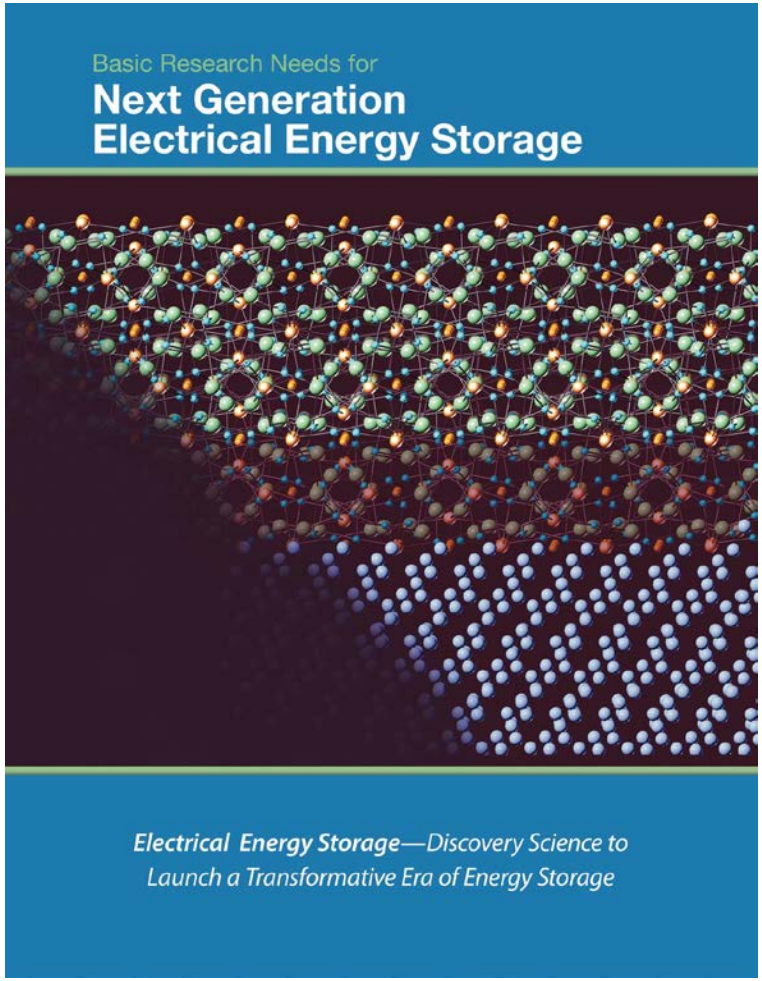
An Active Field of Research

BES Workshop March 27-29, 2017

175 leading battery researchers

Five Priority Research Directions

- *Tune functionality of materials and chemistries to enable holistic design for energy storage*
- *Link complex electronic, electrochemical, and physical phenomena across time and space*
- *Control and exploit the complex interphase region formed at dynamic interfaces*
- *Revolutionize energy storage performance through innovative assemblies of matter*
- *Promote self-healing and eliminate detrimental chemistries to extend lifetime and improve safety*



2017 DOE Workshop: G. Crabtree, chair,
E. Takeuchi and G. Rubloff, co-chairs

https://science.energy.gov/~/media/bes/pdf/reports/2017/BRN_NGEES_rpt.pdf

Further Reading

5 things utilities should consider for energy storage, *Utility Dive,* June 19, 2918
https://www.utilitydive.com/news/five-things-utilities-should-consider-for-energy-storage/525948/

Economics of Clean Energy Portfolios, *Rocky Mountain Institute, May 21, 2018*
https://www.rmi.org/news/report-release-the-economics-of-clean-energy-portfolios/

U.S. Battery Storage Market Trends
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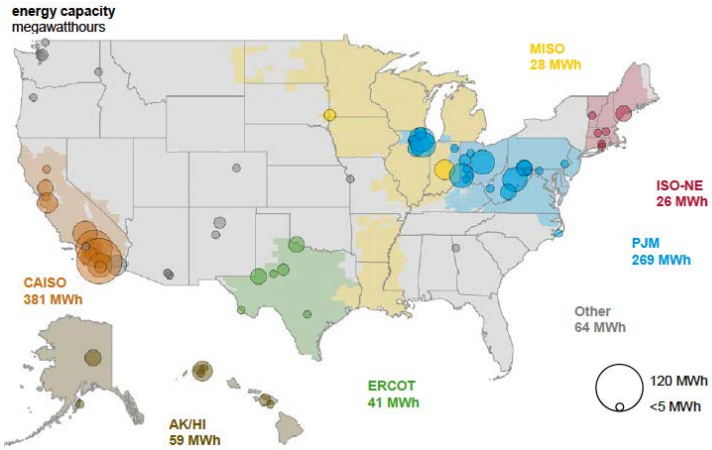
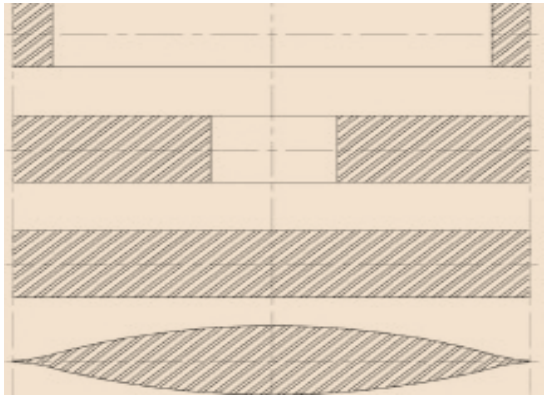


A Review of Flywheel Energy Storage System Technologies and Their Applications

Appl Sci 7, 286 (2017) Amiryar and Pullen,

http://openaccess.city.ac.uk/17719/1/AmiryarandPullenA%20Review%20of%20Flywheel%20Energy%20Storage%20System_applsci-07-00286.pdf



Thermal Energy Storage

UK_BEIS_Evidence Gathering (2016)

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545249/DELTA_EE_DECC_TES_Final__1_.pdf

Thermal Energy Storage

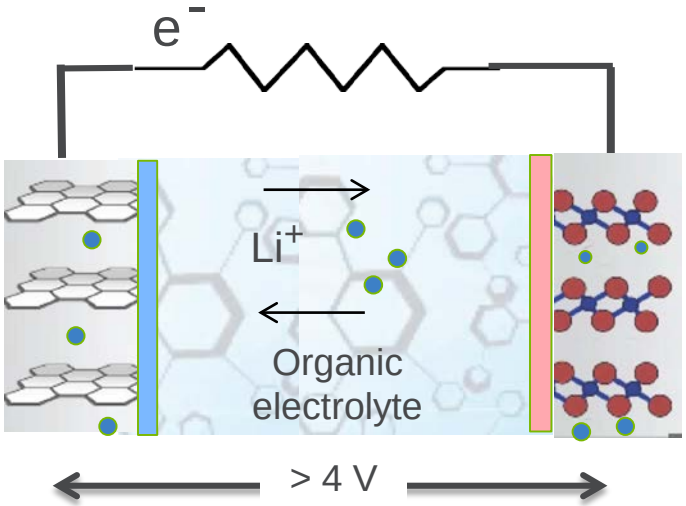
IEA-ETSAP-IRENA Technology Brief (2013)

https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf

Thank you for your attention

Questions?

Li-ion Battery Platform Improvements



Graphite intercalation anode Li_xC_6 $0 < x < 1$

$Li_x(NiCoMn)O_2$ Intercalation cathode $½ < x < 1$

Li_xFePO_4 Intercalation cathode

Anode

Add Si

Greater capacity, energy density

Volume expansion on intercalation

Incremental

Replace with pure Li metal

Much greater capacity, energy density

Dendrite growth across electrolyte

Compelling

Electrolyte

Replace with solid electrolyte

Block dendrites

Safer against thermal runaway

Low ionic conductivity

Brittle ceramics

Compelling

Cathode

Eliminate Co

Reduce cost,

Reliance on Congo

Stability, human rights

Significant

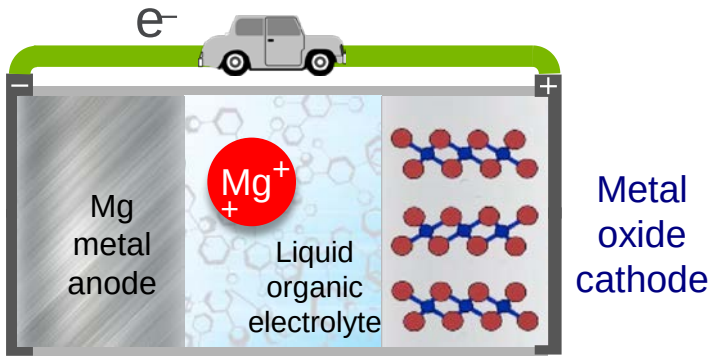
Tweak composition

Higher voltage

Greater capacity

Incremental

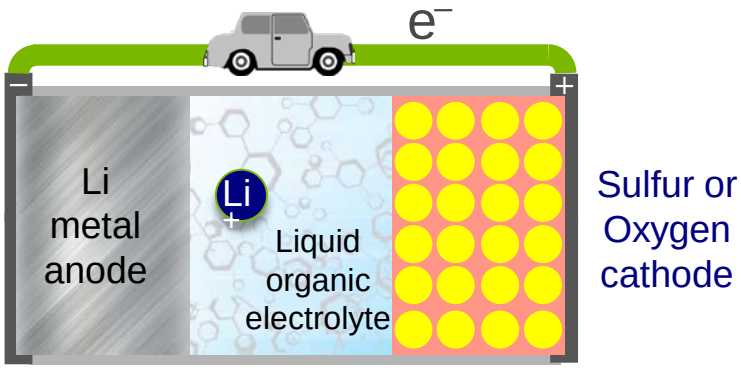
Beyond Li-ion Batteries



Mg ion battery

Mg^{++} carries twice energy of Li^{+}

Wide window electrolyte compatible with Mg and cathode



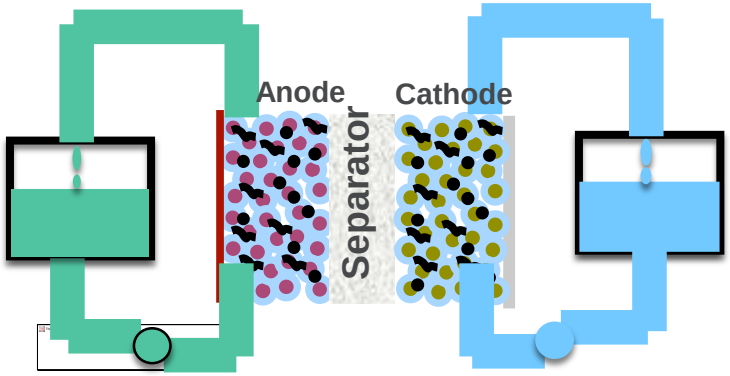
Li-S or Li-O battery

Less expensive

More energy in Li-S or Li-O bonds

Low cycle life

Reversibility of discharge reaction



Flow Batteries (Grid)

Liquid electrodes

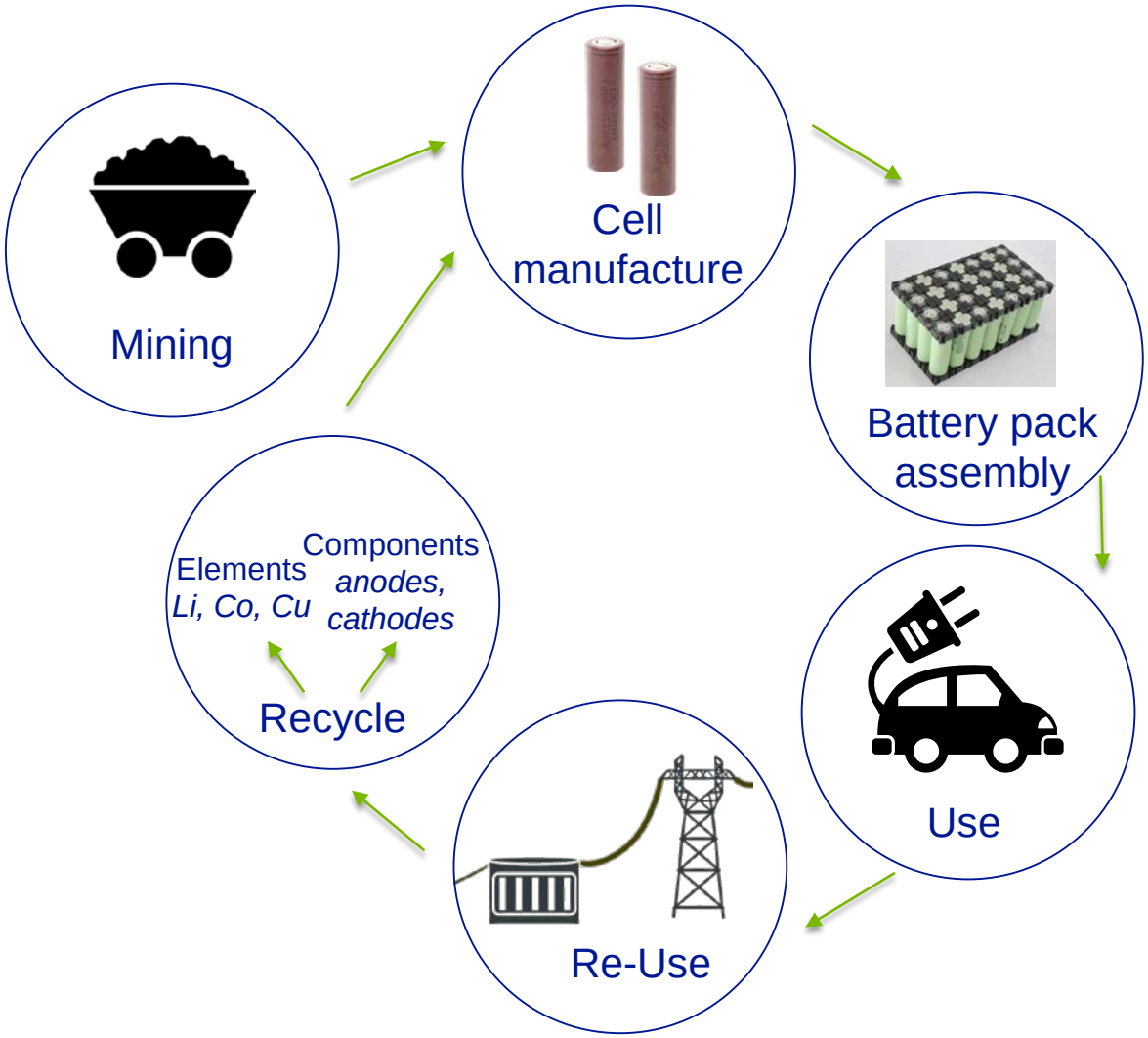
Reactions in solution

Capacity scales with tank size

Vanadium or organic reactants

expensive, unstable reactants

Li-ion Recycling – a Ripe Opportunity



> 99% of lead-acid batteries recycled

< 5% of Li-ion batteries recycled

Growing EV market → Li-ion recycling

Relieve supply chain challenges

- Expensive Co
- 40-60% from Congo
- Li resource