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High Performance Rechargeable Battery Technologies

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Rechargeable Battery Technologies

Current Market drivers

- Consumer electronics, mobile devices and EVs – primarily Li-ion batteries
- Grid energy storage – growing market, currently modest size. Range of technologies

Traditional Batteries
e.g. Lead-acid, Ni-Cd, Ni-MH, Zn-MnO_2

Lithium Batteries
e.g. Li-ion, Li-polymer, Li-metal, Li-S

High-temperature Batteries
e.g. Na-S, Na-$NiCl_2$

Flow Batteries
e.g. Vanadium redox, Zn-Br

	World Wide Production Capacity	Cost and Performance Improvements
Lead Acid Batteries	350 GWh	2%/year (30 year data). $80-150/kWh
Li-ion Batteries	220 GWh and growing rapidly	5%/year (20 year data). Cell level price reaching $150/kWh
NaS and NaNiCl	300 MWh	Mature, but no economies of scale
Flow Batteries	<200 MWh	Potential for lower cost. $400/kWh. Reach $270/kWh
Alkaline chemistries (Zn-MnO2, Zn-air)	<100 MWh	Not fully mature. Lowest cost BOM

High Performance Rechargeable Batteries

No near term alternatives to Li-ion batteries for energy dense batteries for high performance applications including EVs, Electric Aircraft.

- Solid state batteries – promising, need significant improvements
- Metal-air batteries – energy dense, need technical breakthroughs to fully realize

Application	Consumer Electronics, Hybrid EVs	Electric Grid Electric Vehicles	Electric Flight
Advance Technologies	Incremental Li-ion: Si anodes, low Co cathodes Adv. Pb-acid: Pb-carbon Adv. rechargeable alkaline	Significant Adv. Li: Li metal anode, Solid state electrolytes Zn metal: adv. MnO2 cathodes Adv. Flow	Breakthroughs Beyond Li-ion: Li-S, Li-Air Mg & Al Ion Zn-Air High voltage Zn Metal
Needed Technology Advances	Modest	Significant	Major

Adapted from G. Crabtree's presentation at Xlab, 2018

Li-ion Batteries

Family of electrochemical systems

Positive electrode
- Metal-oxides (e.g. LCO, NMC, NCA)
- Phosphates (e.g. LFP)

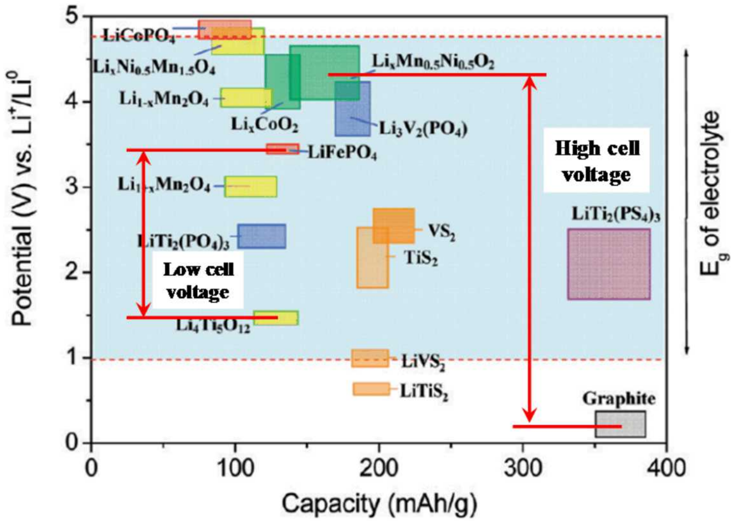
Negative electrode
- Graphite and other carbons
- Lithium titanate

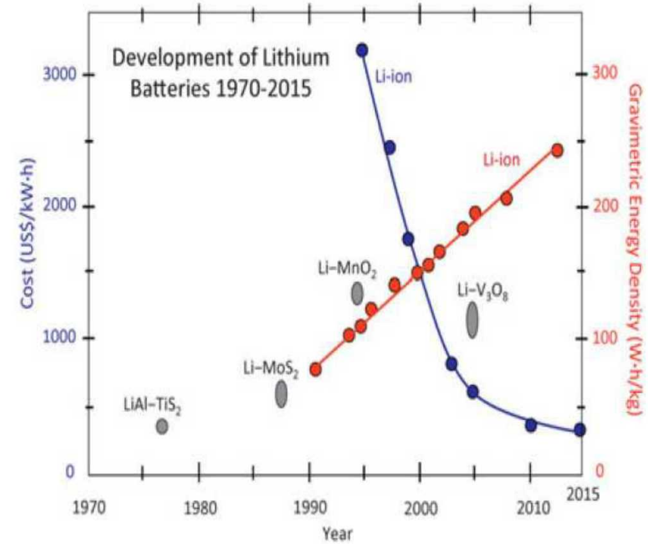
SOA EV batteries - Specific energies near 250 Wh/kg

330-350 Wh/kg possible near term with composite anodes (Si-based anodes)

500 Wh/kg as a longer term goal based on significant improvements in electrode design and composition (e.g., lithium anodes), electrolyte formulations, and separator innovations.

Safety continue to be a significant concern





Source: Crabtree, Kocs, Trahey, MRS Bulletin, Dec 2015

Li-ion Batteries – Challenges for Power and Energy Applications

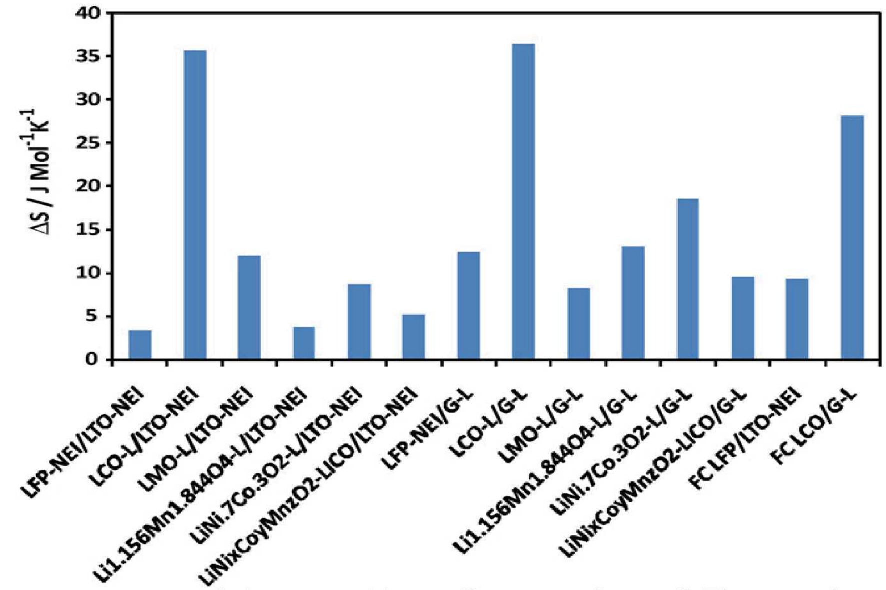
Battery safety is very important for applications where high power is required.

Heat generation during high power usage must be managed
- Dictates smaller form factor
- Higher production costs

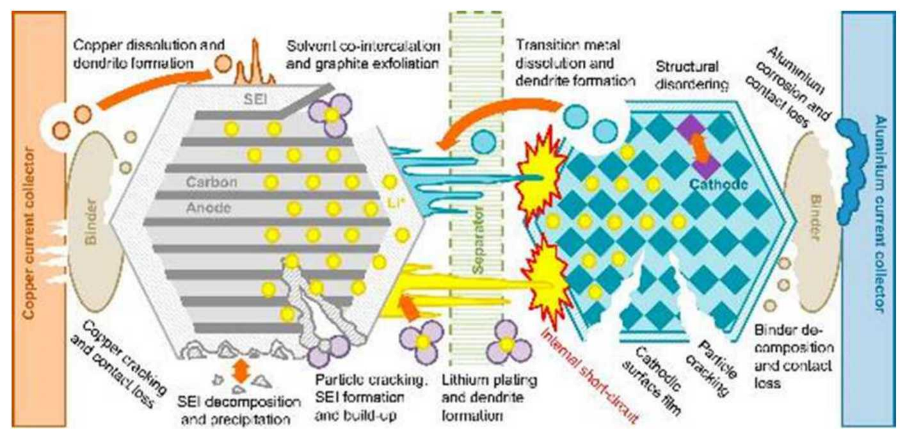
High Temperature
- Typical operating window 0-50°C
- Operation above this temperature can lead to organic electrolyte decomposition and flammable gas, rapid internal pressure build-up

Overcharging
- Overcharging can lead to Li metal plating on anode, potential for short

Need better understanding of the degradation pathways and engineering to control thermal runaway



Inherent Heat Generation of Electrodes



J. Power Sources, **2017**, 341, 373

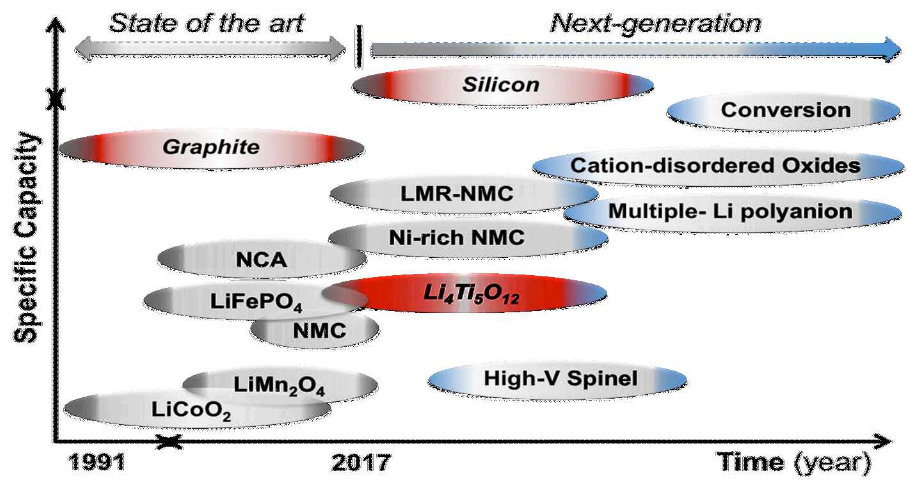
Future Developments in Li-based Batteries

Higher-voltage positive (cathode) materials
- Lithium manganese phosphate
- Lithium cobalt phosphate

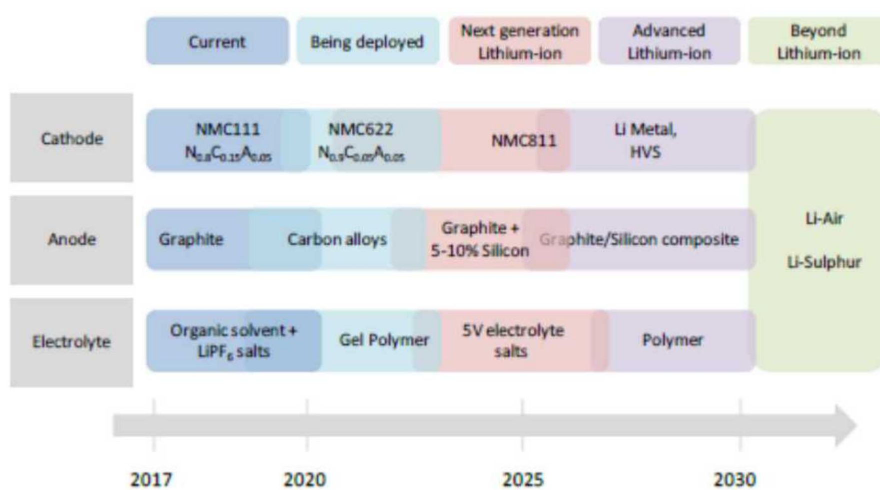
Higher-capacity negative (anode) materials
- Silicon-based

Safer electrolytes
- Inorganic
- Solid-state electrolytes

Other Li chemistries
- Lithium-sulfur



DOE Basic Research Needs Report on Energy Storage
DOE Office of Science, 2017



Global EV Outlook Report, IEA 2018
Based on DOE-VTO and NEDO Projections

High Energy Density Li-S and Metal Air Batteries

Li-S: high theoretical energy density (>2700 Wh/kg), prototype cells ~ 400Wh/kg

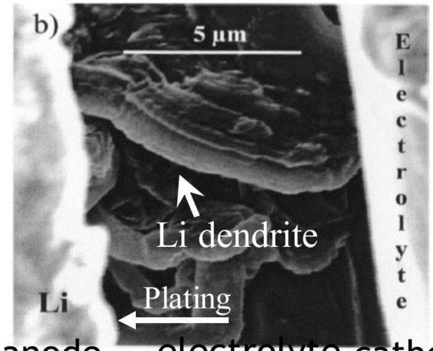
- Suffers from self discharge and poor life
- Breakthroughs needed with Li electrodes
- Managing the Sulphur shuttle reactions

Metal air batteries (Li-air, Zn-air)

- Potential to deliver high energy densities at low cost. Challenges with recharging have so far precluded commercialization of the technology.
- Not mature, many years away
- Potential fundamental problems

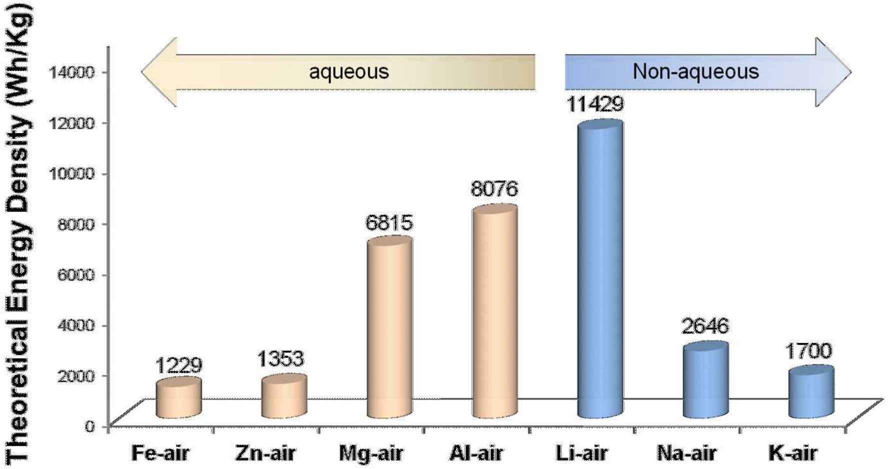
Li-Air combines difficulties of air and lithium electrodes

- Breakthroughs needed in cheap catalysts, more stable and conductive ceramic separators
- Developing a robust air electrode is a challenge, need major breakthroughs



anode electrolyte cathode
Li dendrite growth

H. Pan, et. al, Adv. Energy Mater., 2015



Y. Li and J. Lu, “Metal-Air Batteries: Future Electrochemical Energy Storage of Choice?,” PNNL, 2017

Future of High Performance Rechargeable Batteries

Battery technologies for electric vehicles and grid applications are advancing rapidly.

Engineering energy storage systems with higher energy and high power capacities while keeping safety and reliability remains a challenging task

Technical gaps exist for high power and energy applications

- How do we manage the universal tradeoff between energy and power due to a combination of electrical, ionic, structural and chemical effects?
- How to improve energy capacity without sacrificing safety and life?
- How do we optimize power and energy at multiple length scales, large format cells?
- How do we enable fast ion and electron transport without sacrificing energy density, while maintaining long life and safety?
- How do we design materials to realize high energy and power simultaneously?
- How to achieve high reversibility, with low capacity loss, and low over-potentials

Acknowledgements

DOE Office of Electricity Energy Storage Program

U.S. DEPARTMENT OF ENERGY