Introduction to Lithium Ion Batteries

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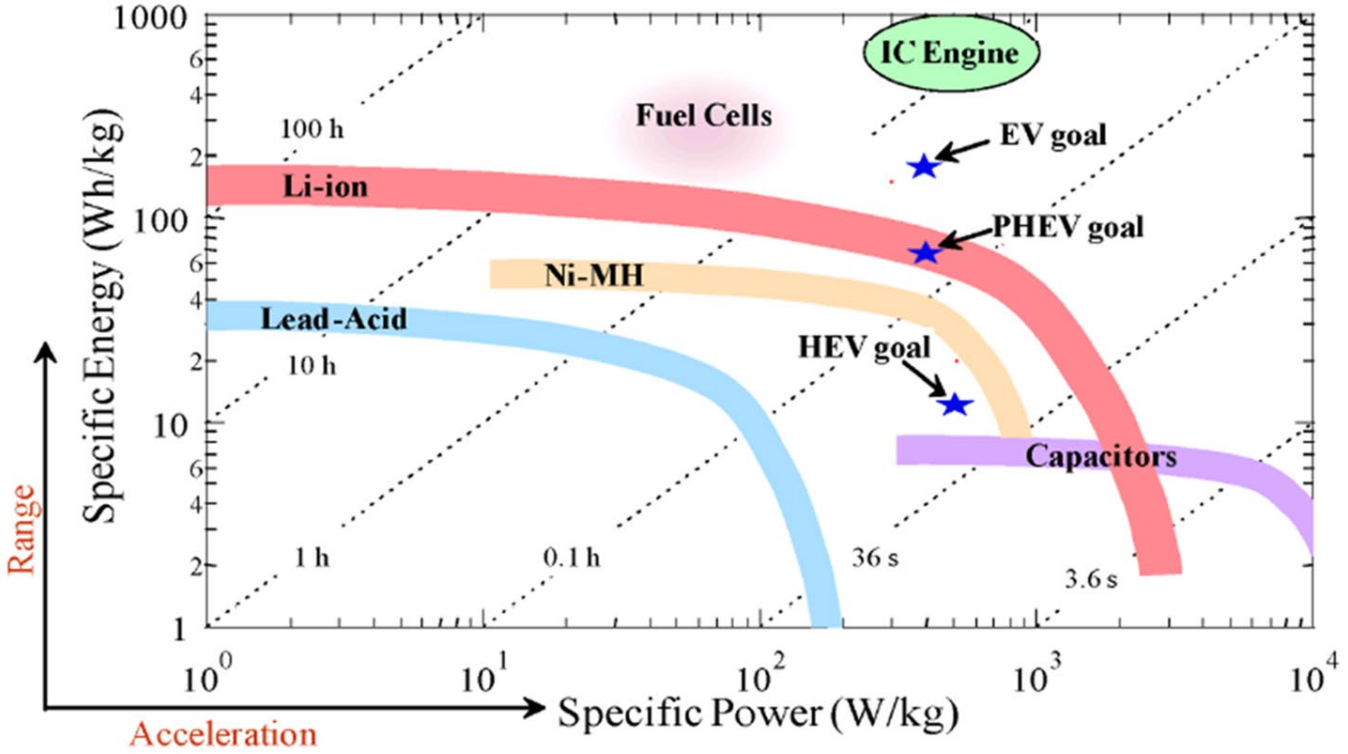
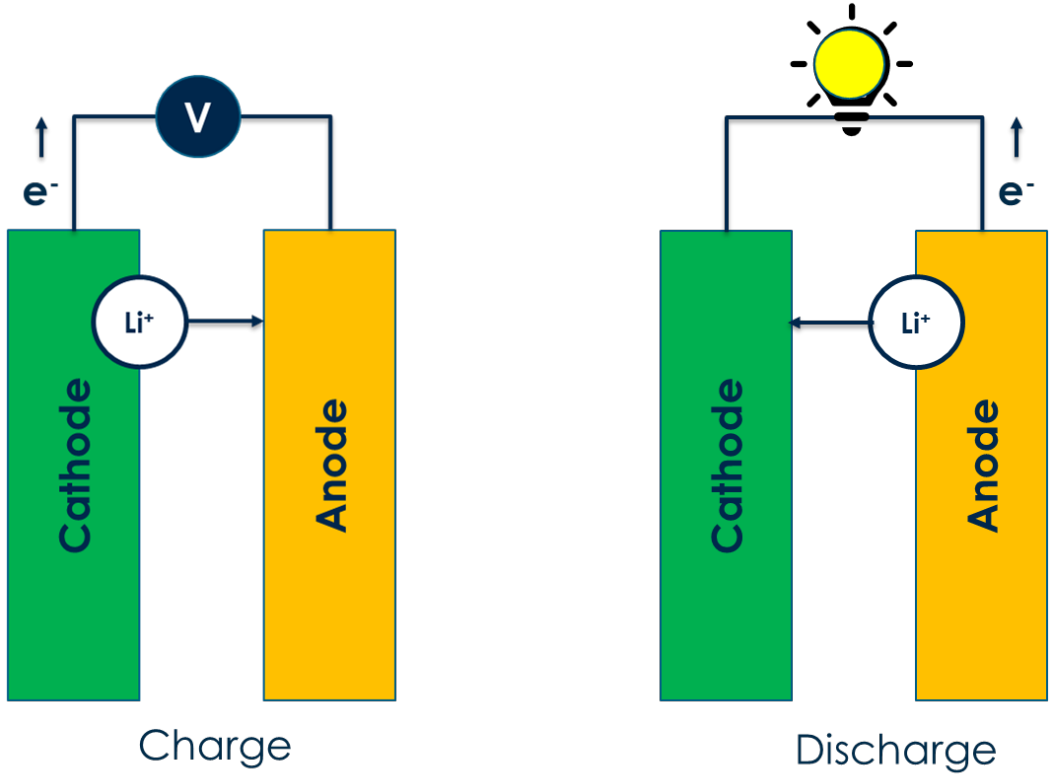
Why Lithium Ion?



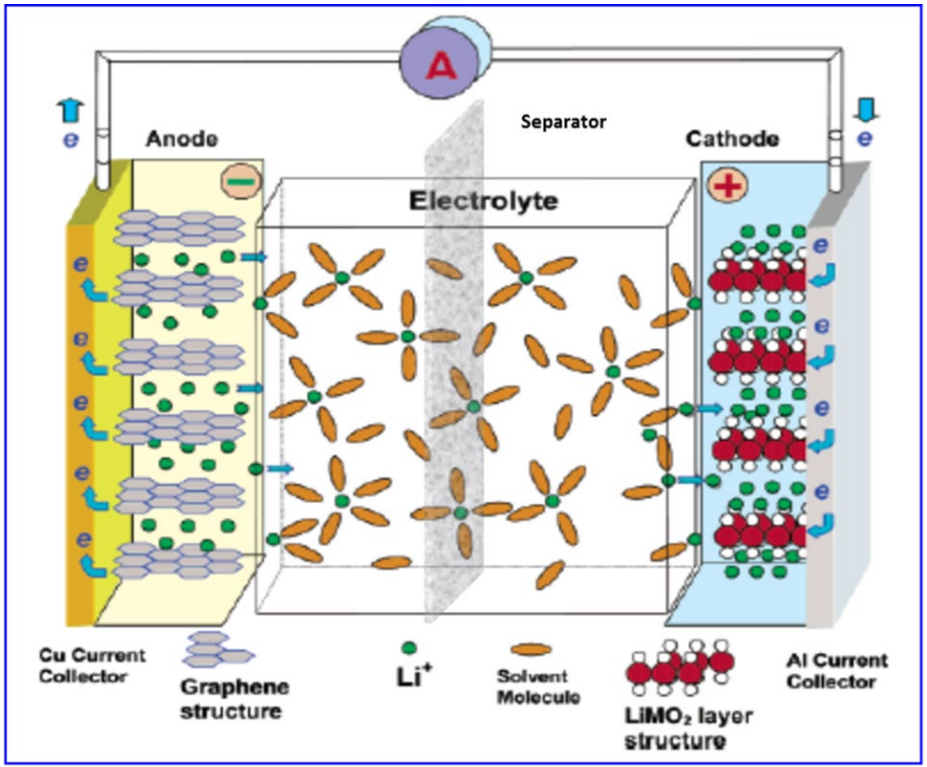
Lithium ion batteries have the best balance of energy and power for vehicle electrification

Lithium Ion Basics



Lithium ion batteries are a form of chemically stored energy

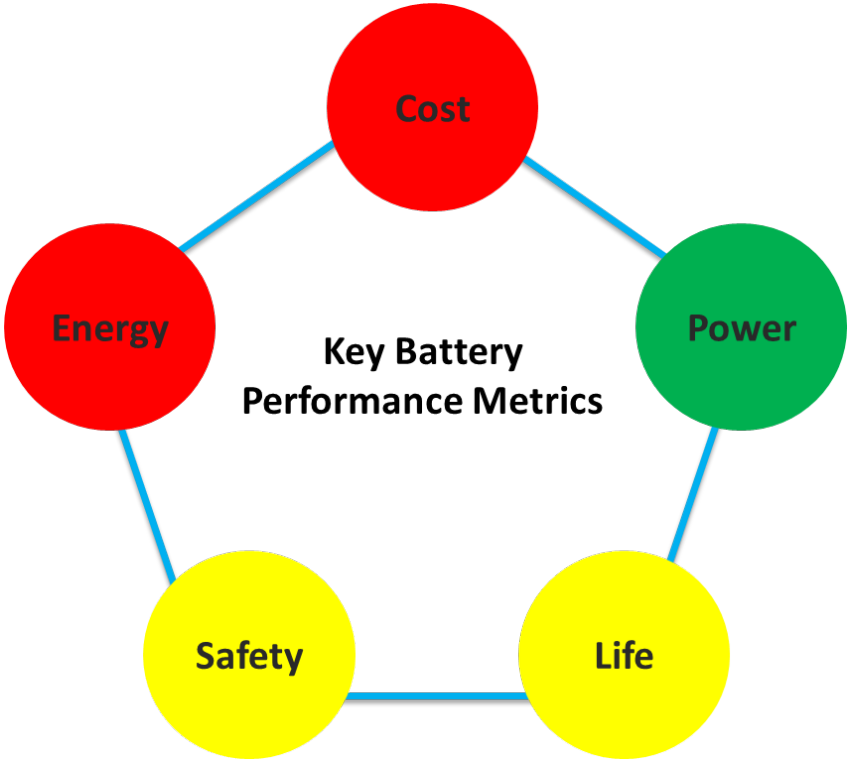
Lithium Ion Basics



Chem. Rev., **2004**, 104(10)

Amount of stored energy related to amount of lithium moving back and forth

Lithium Ion Basics

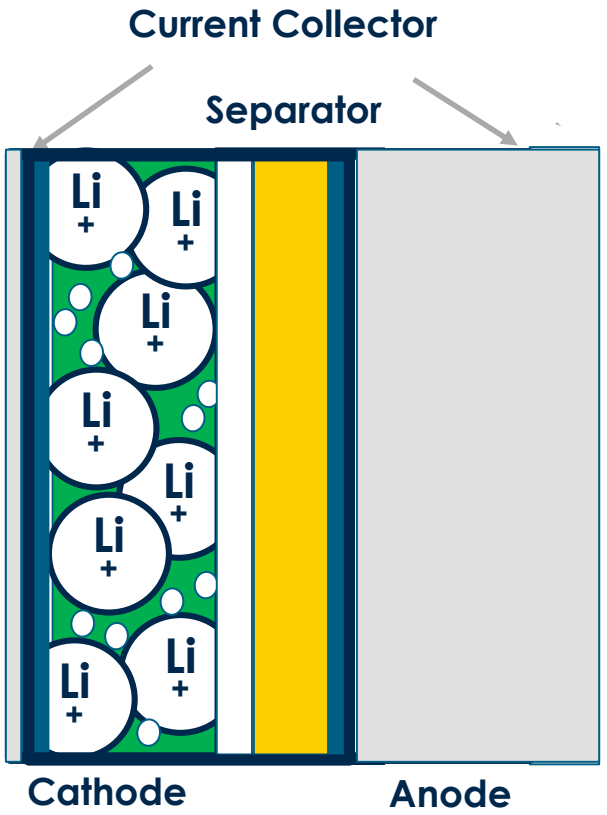


Automotive batteries have multiple important performance metrics

Energy Density

What affects energy density?

- Amount of lithium that can be removed from the cathode (capacity)
- Amount of cathode you can fit into the space you have in the cell
- Amount of anode required to hold all the lithium from the cathode
- All the other materials in the battery
- Operating voltage

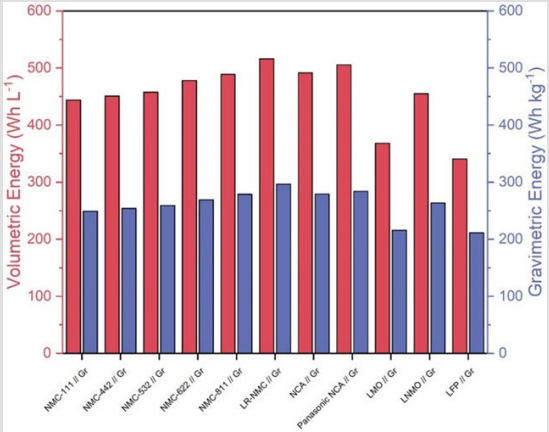


Improvement in energy density usually is detrimental to other performance parameters

Materials to Improve Energy Density

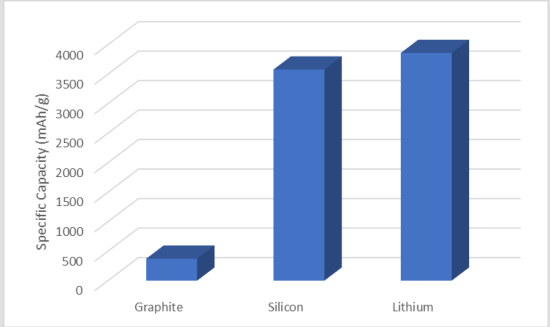
Cathode Evolution

- Automotive industry has trended towards cathodes that contain nickel (Ni), manganese (Mn), and cobalt (Co)
- Cobalt provides better stability, but is expensive and has supply chain risk
- Increasing nickel content translates to improved energy density but decreases cathode stability



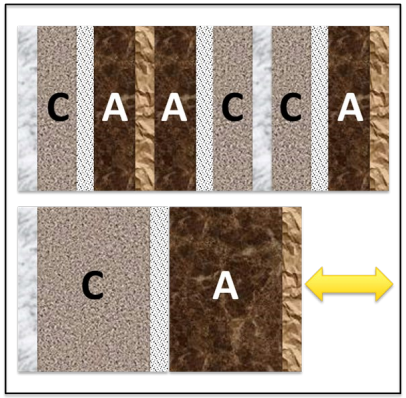
Anode Evolution

- Small amounts of silicon are added to many automotive LIBs
- Larger amounts (higher capacity) are challenging due to volumetric changes
- Lithium metal anodes are the “holy grail” for high energy density batteries, but to date have some technical barriers
  - Dendrite formation
  - High surface area after stripping/plating
- Solid electrolytes are beneficial in solving the problems with lithium metal anodes



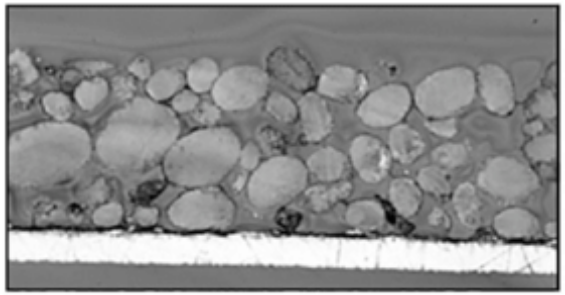
Battery “active” materials have performance trade-offs that must be managed

Power/Rate Performance



Electrode Loading & Density

- Thick dense electrodes translate to fewer layers with less separator and current collector
- Lithium ions and electrons now have to travel further through the electrodes
- Electrolyte must permeate through thick dense layers
- Power/rate performance can be diminished



Solid State Electrolytes

- Movement of lithium ions occurs through and between solid materials
- Solid state electrolytes can have conductivities similar to liquid electrolytes
- Movement of lithium ions at interfaces is still problematic

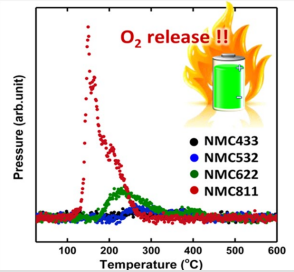
Cell engineering to improve energy is detrimental to power performance

Lifetime

Active Material Changes

Cathode Materials

- As lithium is removed, the layered structure can have irreversible change
- Safety/gas issues as oxygen comes out of the structure



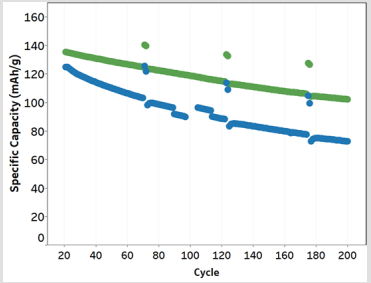
Anode Materials

- Silicon volumetric changes
- Lithium dendrites/high surface areas

Loss of Lithium

Electrolyte Stability

- Today's liquid electrolytes are not stable at the anode potential
- "Formation" cycle done after battery assembly results in reaction of the electrolyte with the anode to form a protective layer (SEI)

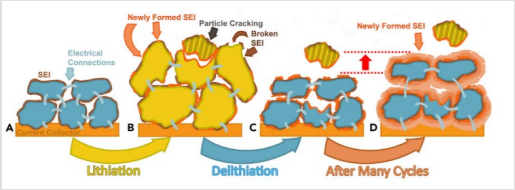


- High Ni cathodes or high voltage also result in electrolyte instability at the cathode

Cell Resistance Growth

Inter-related to other two problems

- SEI increases resistance, reduces power
- Material changes increase resistance
- If cathode materials change structure, resistance rises
- Silicon anode expansion/contraction result in adhesion failures in electrode, which increase resistance
- High surface area lithium makes lots of SEI which is bad for resistance

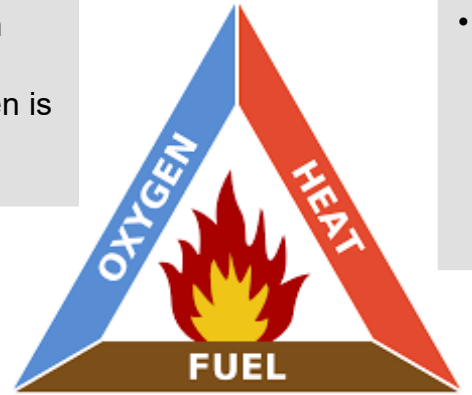


- If the cell resistance gets too high, you can't use all the energy that the battery can store

Batteries can fail for many reasons

Safety

Oxygen
- Cathodes such as NMC, NCA, LCO used in LIBs contain and can release oxygen
- If the cell packaging is compromised, oxygen is present in ambient air



Heat
- External sources such as a garage fire
- Internal sources
  - Exothermic chemical reactions such as SEI formation/degradation
  - Electrical short in battery resulting in large currents
    - Heat=i^2RT (Joule's Law)

Solid State Electrolyte

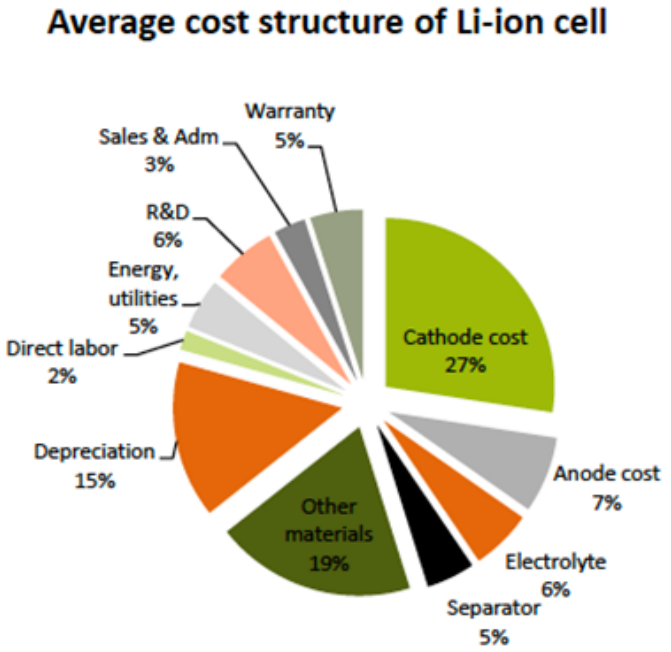
~~**Fuel**~~
- ~~Many components in the cell can burn, but the most flammable is the liquid organic electrolyte~~
- ~~If the cell is heated, the electrolyte is also volatile resulting in high pressure that can rupture the cell forming a flammable aerosol~~

Safety is always a concern when you store a lot of energy in a small volume

Cost

Cost Reduction Strategies

- Lower cost materials
  - Get rid of cobalt in cathode
  - Reduce energy requirements for synthesis
- Thicker, denser electrodes to reduce # layers
  - Reduce costs for separator, current collector
  - Reduce stacking time for pouch cells, which reduces capital
  - Reduce energy for electrode drying
- Increase energy/unit cost
- Less moisture sensitive materials
  - Reduces energy for HVAC in manufacturing
- Eliminate/minimize formation time



Materials represent a large fraction of the cell cost

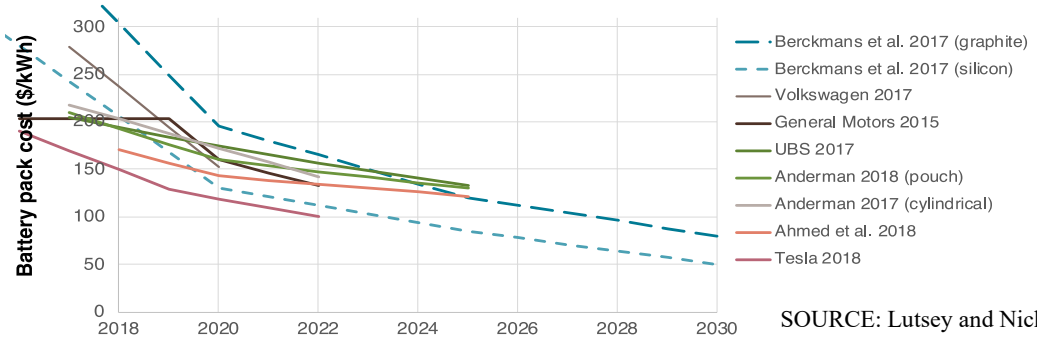
Key Findings/Summary

Battery Technology

- LIB's will be dominant
- Incremental improvements in performance and cost
- Opportunities for breakthroughs, but still large uncertainty in timing for technologies such as solid-state batteries
- Engineering improvements at module and pack level will contribute to improvements in performance and cost

BEV Costs

- Longer range BEVs may reach first-cost parity with comparable ICEs by 2030
- Shorter range BEVs could reach cost parity sooner



SOURCE: Lutsey and Nicholas, 2019