NREL Transforming ENERGY

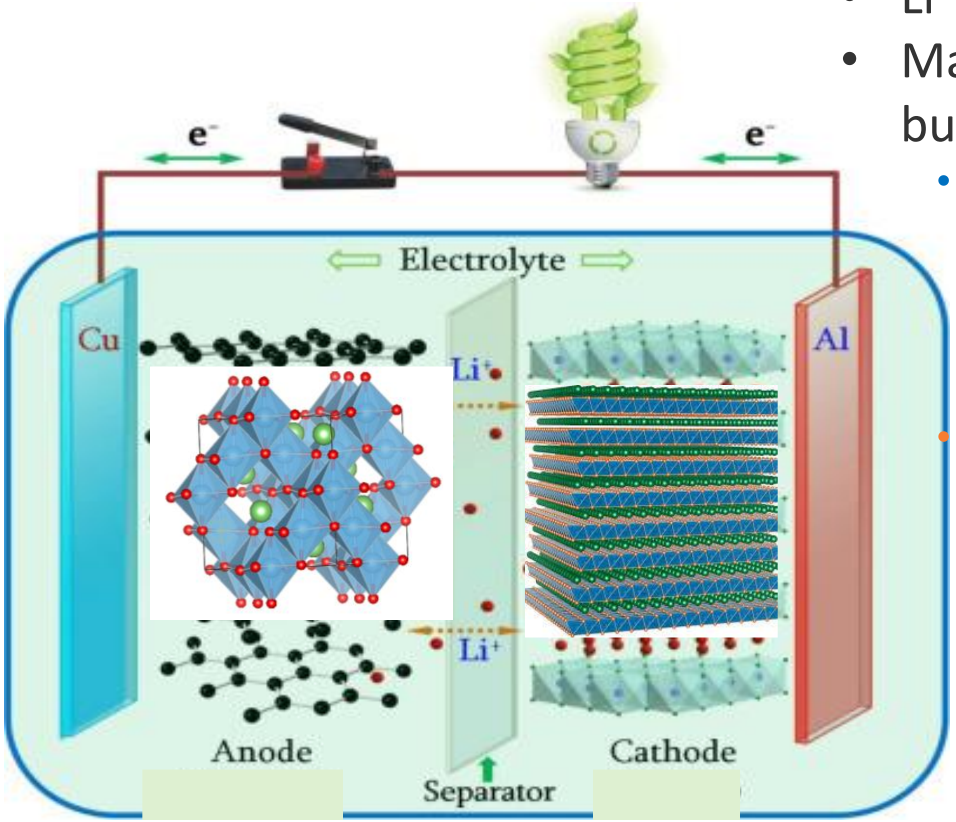
Advanced in Lithium Ion Batteries

Ahmad Pesaran,Ph.D
Chief Energy Storage Engineer
Center for Integrated Mobility Sciences
National Renewable Energy Laboratory

ACT VIRTUAL

August 27,2020

Evolution of Lithium-Ion with Changes in Chemistry



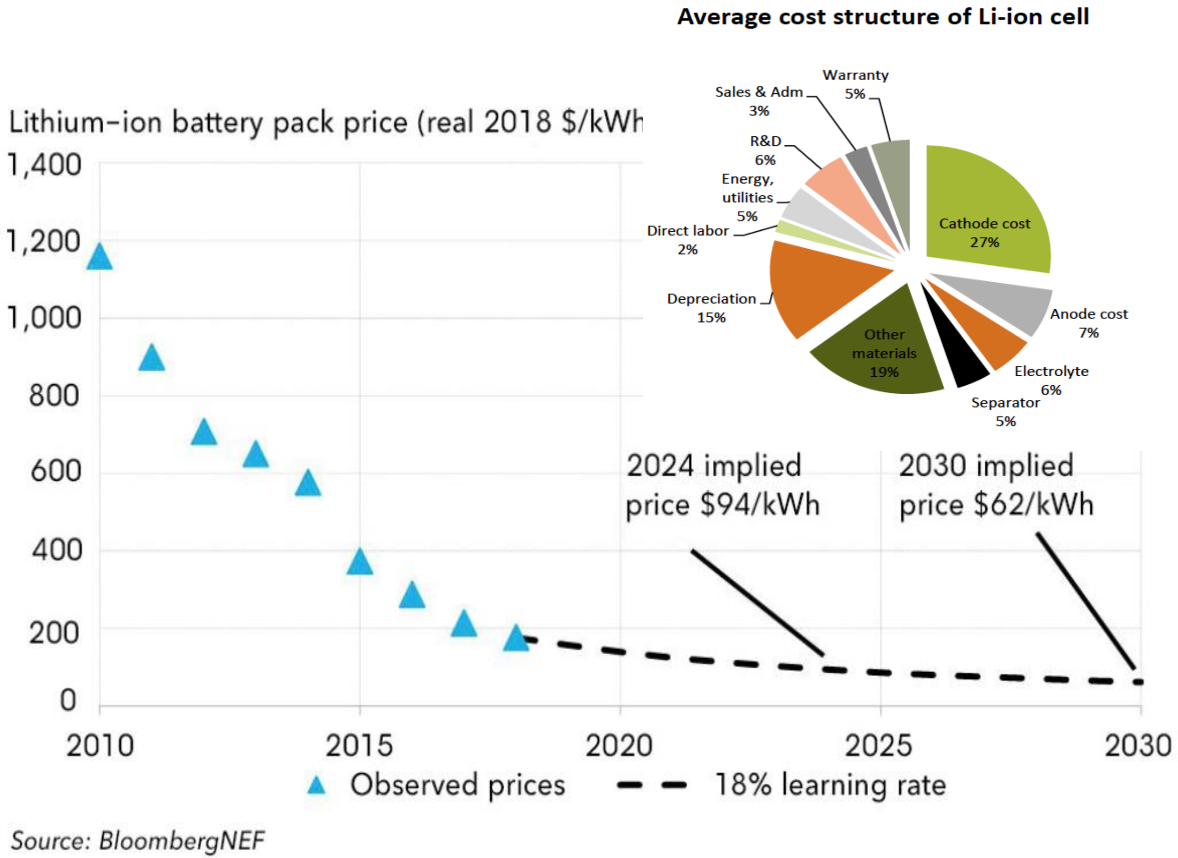
- Li^+ moves in an out of cathode and anode
- Many cathode or anode chemistries possible but with various tradeoffs
  - Anodes:
    - Graphite (Gr)
    - Titanate (Li_2TiO_3) - high power, low energy
    - Silicon (Si) or Si/Gr
    - Lithium metal (Li)
  - Cathodes:
    - Cobalt Oxide (LCO)
    - Iron Phosphate (LFP)
    - Nickel Cobalt Aluminum (NCA)
    - Manganese Oxide (LMO)
    - Nickel Manganese Oxide (LNMO)
    - Nickel Manganese Cobalt (NMC)
    - No Cobalt with Ni, Mn, Al, Ti,

Chemistry Choice Impacts Performance and Cost*

	Type of Chemistry (Cathode/Anode)	Specific Energy (Cells) Wh/kg	Specific Energy (Pack) Wh/kg	Battery Cost (Pack) $/kWh
Current	LCO/Gr	224.1	181.8	250
	NMC111/Gr	204.9	167.6	145
	NMC622/Gr	224.1	181.7	135
	NMC811/Gr	241.3	194.2	120
	NCA/Gr	230.4	186.4	130
Future	Hig Voltrage NMC622/Gr	231.4	186.5	125
	Hig Voltrage NMC622/ Si Anode	294.8	235.3	110
	High Volatge NMC811/Li Metal	350	259.3	100
	Lithium - Sulfur	380	257.3	95

*Based on a 100 kWh – 100 kW battery pack. Numbers are for relative comparison final values can change depending on the components used and volume production.

EV Li-Ion Batteries Cost Reduction and Outlook



Reduction in observed prices

- Higher demand (see next slide)
- Competition (Korea & China)
- Material supply – not specialty
- Higher volume manufacturing
- Innovation in cell & pack designs
- Automation

Outlook

- Chemistries with lower cost
- Chemistries with higher capacity
- Increased automation
- Increased yield (closed recycling)
- Improved packaging (solid state)

DOE VTO Battery R&D: Near, Next, and Long Term

Enhanced Li-ion
Graphite/NMC

Projected Cell Specific Energy, Cost
300Wh/kg, $100/kWh

Current cycle life	> 1000
Calendar life	> 10 years
Mature Manufacturing	Yes
Fast charge	No
Cost positive recycling	No

R&D Needs
- Fast charge
- Low temperature performance
- Low/no cobalt cathodes
- Cost positive recycling

Next Gen Li-ion
Silicon/NMC

Projected Cell Specific Energy, Cost
400Wh/kg, ~$75/kWh

Current cycle life	> 1000
Calendar life	~3 years
Mature Manufacturing	No
Fast charge	Yes, at BOL
Cost positive recycling	No

R&D Needs
- Enhanced calendar life
- Abuse tolerance improvement
- Low/no cobalt cathodes
- Cost effective and scalable pre-lithiation

Lithium Metal
Li metal/NMC or Sulphur

Projected Cell Specific Energy, Cost
500Wh/kg, ~$50/kWh

Current cycle life	> 300
Calendar life	???
Mature Manufacturing	No
Fast charge	???
Cost positive recycling	No

R&D Needs
- Enhanced cycle and calendar life
- Protected lithium
- Dendrite detection and mitigation
- Cost effective manufacturing
- High conductivity solid electrolyte

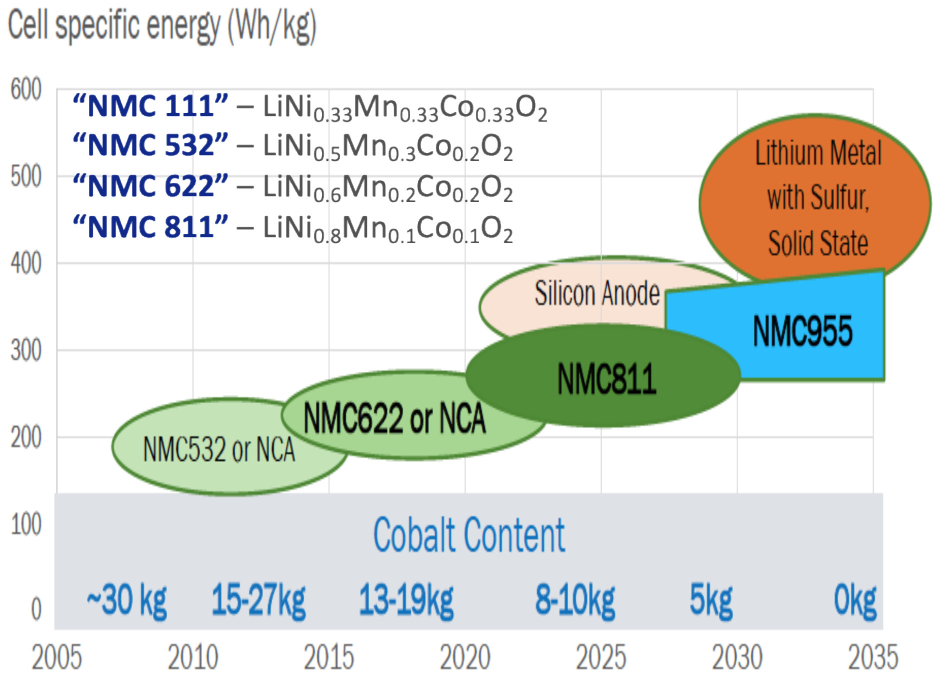
From DOE/VTO Annual Merit Review Plenary, Dave Howell, June 1, 2020

Current R&D for Future Li-Ion Batteries

- **Extreme Fast Charging (refuel as fast as an ICE Vehicle) :**
  - Overcoming lithium plating, extreme heat generation, and degradation of current EV cells with graphite anodes
  - Thicker electrodes to increase energy
- **Hi Capacity Cathodes with Non-Critical Materials (higher electric range)**:
  - Reducing or eliminating cobalt in lithium ion batteries is an opportunity to lower the cost of batteries.
  - For example Li Ni Mn Oxide with various doping and high voltage electrolyte
- **High Capacity Anode materials**:
  - Working to provide 350 Wh/kg with Si anode and high Ni cathodes with 10 years life
    - Silicon has 10 times capacity of graphite, but has large volume change & poor calendar life
  - Overcoming dendrite growth with Li metal anodes to provide 500 Wh/kg for 1000 cycles.
- **Solid State Batteries:**
  - Increase energy density, reduce cost, and improve safety developing solid state electrolytes that have ionic conductivities approaching today's liquid electrolyte systems

Toward higher Energy Density and Lower Cobalt Content

- Department of Energy has several R&D&D programs to increase energy and lower cost
  - Battery 500 (Li Metal)
  - Si deep dive
  - Low/No Cobalt
  - Solid Electrolyte
  - Battery Manufacturing
- 50-100 million vehicle in 2030 requires about 2 - 4.5 TWh battery.
- But significant supply chain and production issues
- End of life of batteries
  - Refurbish & Reuse
  - Recycle & Reproduce



Li-Ion Batteries – Final Thoughts

- Li-Ion Batteries have come a long way in performance and cost
- Incremental improvement are on-going and get commercialized every year. (Thicker electrodes and high Ni cathodes)
- Improvements in chemistry, cost, and performance still to come
- Breakthroughs with solid electrolyte and, lithium metal still several years away
- Supply chain is a big issue from USA perspective
  - More US material processing and cell manufacturing needed
  - Reuse and Recycling could help

Thank You! Questions?

Ahmad.Pesaran@nrel.gov

www.nrel.gov

www.nrel.gov/transportation/energy-storage.html

NREL
Transforming ENERGY