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HIGH PURITY METALS & COMPOUNDS

Lithium-ion Battery Chemicals

As the world moves increasingly toward electricity-based fuel, one important aspect is storage of that energy. Solar cells can only generate power during daylight hours and electric cars need to bring the electricity with them. The need for high performance batteries is higher than ever.

Lithium-ion batteries satisfy these needs and AEE can supply Lithium X-Y-Z Oxide cathode materials in coin cells as well as our typical targets, powders, and shapeless pieces.

When evaluating battery materials, the factors of importance are **Energy Density**: the amount of energy stored per unit weight or sometimes per volume. **Specific Power**: the speed you can deliver that energy. **Lifespan**: how many charge-discharge cycles can the battery sustain before chemical changes render it too weak to function. We should also consider **Safety** since lithium tends to cause fires without proper circuit controls, **Cost**, and **Durability** against high and low temperatures and idle time, and Recharge Rate.

Lithium-Ion batteries are rechargeable, have high energy densities, low memory-effect, and low passive charge loss.

They are heavily utilized in portable electronics such as flashlights, phones and laptops, power tools, electric vehicles including cars and aircraft and backup power sources.

The needs of the application will influence which material should be used. There are tradeoffs to be considered between Total Capacity, Power, and Longevity

A Li-ion battery from a Nokia 3310 mobile phone

Specific energy	100–265 W·h/kg[1][2](0.36–0.875 MJ/kg)
Energy density	250–693 W·h/L[3][4] (0.90–2.43 MJ/L)
Specific power	~250 – ~340 W/kg[1]
Charge/discharge efficiency	80–90%[5]
Energy/consumer-price	6.4 Wh/US$[6] US$156/kWh
Self-discharge rate	0.35% to 2.5% per month depending on state of charge[7]
Cycle durability	400–1,200 cycles [8]
Nominal cell voltage	3.6 / 3.7 / 3.8 / 3.85 V, LiFePO4 3.2 V

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	Structure	Potential [V] (Versus Li/Li^+)	Physical Density [g/cc]	Specific Capacity [Ah / kg] (theoretical / practical)	Specific Energy [Wh / kg]	Maximum Discharge Rate [C-rate]	Lifespan [cycles]	Cost	Safety & Durability
$LiNiO_2$	Layered	4.2	4.71	220/160	640	1	200	Medium	Medium
$LiCoO_2$	Layered	3.9	5.10	272/145	520	1	700	Medium	Medium
$LiMn_2O_4$	Spinel	4.1	4.31	148/105	410	1-10	500	Medium	Medium
$LiFePO_4$	Olivine	3.45	3.60	170/155	540	1-25	2000	Medium	Highest
Li $(Ni_{1/3}Mn_{1/3}Co_{1/3})$ O_2	Layered	3.8	4.7	272/200	760	1-2	1000	Medium	Medium
Li $(Ni_{0.8}Co_{0.15}Al_{0.05})$ O_2	Layered	3.8	4.7	300/200	680	1	700	Low	Medium
$Li_4Ti_5O_{12}$	Spinel	1.55	3.73	175/145	230	10	5000	Low	Highest
Notes: C-Rate is the allowable fraction of capacity discharged per hour. Carbon is the typical anode t the above cathode materials. $Li_4Ti_5O_{12}$ may be used as an anode or cathode.									

References
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Julien, Christian M., et.al. (2014) Comparative Issues of Cathode Materials for Li-Ion Batteries
Chen, Hungru (2012) Simulations for new battery materials.

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Item	Formula	Applications
Cathodes		
Lithium Cobalt Oxide	LiCoO2	Power Tools, Electric Vehicles, Few Medical Tools
Lithium Nickel(II) Phosphate	LiNiPO4	Rechargeable lithium batteries for electric vehicles, power tools, RC cars
Lithium Cobalt Phosphate	LiCoPO4	Energy storage systems, hybrid electric vehicles or electric vehicles
Lithium Manganese Phosphate	LiMnPO4	Pouch Cell, Rechargeable lithium batteries
Lithium Iron Phosphate	LiFePO4	Automobiles (Electric and hybrid vehicles) and renewable energy generation
Lithium Manganese Nickel Oxide	LiMnNiO (Mn1.5Ni0.5)	Electric vehicles (EVs) and plug-in hybrid electric vehicles (HEVs)
Lithium Manganese Oxide	LiMn2O4	Precursors to NMC batteries, Electric vehicles (Nissan Leaf had LMO-NMC in their older models. Nissan expected to switch to pure NMC cathode in second gen models)
Lithium Nickel Cobalt Aluminum Oxide	LiNiCoAlO2 (Al0.03Co0.09Ni0.88)	Electric vehicles, Grid storage (Energy density is increased from 150-200Wh/kg range to >280 Wh/kg Tesla is currently using NCA cell chemistry)
Lithium Nickel Cobalt Aluminum Oxide	LiNiCoAlO2 (Al0.01Co0.14Ni0.85)	
Lithium Nickel Cobalt Aluminum Oxide	LiNiCoAlO2 (Al0.05Co0.15Ni0.8)	
Lithium Nickel Manganese Cobalt Oxide NMC	LiNiMnCoO2	Power Banks, Flashlights, Electric Vehicles, Cordless Power Tools, Laptop Battery Packs (Recently battery manufacturers are moving toward higher nickel content in cathodes due to the high cost and toxic nature of cobalt Because of its increased energy density it is used more frequently in long range EVs)
Lithium Nickel Manganese Cobalt Oxide NMC	LiNi0.5Mn0.3Co0.2O2	
Lithium Nickel Manganese Cobalt Oxide NMC	LiNi0.6Mn0.2Co0.2O2	
Lithium Nickel Manganese Cobalt Oxide NMC	LiNi0.8Mn0.1Co0.1O2	
Lithium Nickel Manganese Cobalt Oxide NMC	LiNi0.4Mn0.4Co0.2O2	
Lithium Nickel Manganese Cobalt Oxide NMC	LiNi0.4Mn0.2Co0.4O2	
Lithium Nickel Oxide	LiNiO2	Rechargeable lithium batteries for electric vehicles

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Anodes		
Lithium	Li	Anode in Lithium-ion batteries and coin cells
Lithium Titanate (Lithium Titanium Oxide)	Li4Ti5O12	Batteries for Samsung's Bluetooth S-Pens, Seiko's wristwatches, Electric vehicles, energy storage systems
Lithium Titanate (Lithium Titanium Oxide)	Li2TiO3	
Lithium Tungsten Oxide	Li2WO4	Used for preparation of ceramics with ultra-low sintering temp. Catalyst for oxidative coupling reactions
Electrolyes		
Lithium Nitride	Li3N	Originally proposed for use as an electrolyte in all solid- state Li ion batteries given its exceptional ionic conductivity at RT. Used in the fabrication of lithium-ion batteries as cathode additive
Lithium Phosphorus Sulfide	Li3PS4	Solid state electrolyte material for all solid-state lithium-ion batteries.
Lithium Phosphorus Sulfide	Li7P3S11	
Lithium Silicate	Li2SiO3	Fuel cell Li-Ion batteries
Lithium Phosphorus Oxynitride	LiPON	Thin film LiPON - All solid-state batteries Layers of LiPON are deposited over the cathode material at ambient temperatures by RF magnetron sputtering, forms the solid electrolyte used for ion conduction between anode and cathode in a lithium-ion battery cell.
Lithium Phosphate	Li3PO4	Solid state electrolyte material for all solid-state lithium-ion batteries.
Germanium Sulfide	GeS2	Commonly used as a precursor material for sulfide based solid state electrolyte materials used in advanced lithium batteries (all-solid-state batteries, lithium-sulfur batteries, etc.) In addition, GeS2 is also used in electronic materials, catalysts, and optical materials.

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Lithium Sulfide	Li2S	All solid-state batteries Lithium sulfide is an important precursor material for synthesizing sulfide solid state electrolyte materials, such as LPS, LGPS, Argyrodite type Li6PS5Cl.
Lithium Germanium Phosphorus Sulfide	Li10GeP2S12	Have high ionic conductivity exceeding liquid electrolytes are not stable with Li metal exhibiting the lowest coloumbic efficiency when using high voltage cathode
Lithium Germanium Phosphorus Sulfide Chloride	Li10GeP2S12Cl	Used as a solid-state electrolyte material for advanced lithium batteries (all-solid-state batteries, lithium-sulfur batteries, etc
Lithium Phosphorus Sulfide Bromide	Li6PS5Br	Solid state electrolyte material for all solid-state lithium-ion batteries. Cathode electrolyte (catholyte).
Lithium Phosphorus Sulfide Chloride	Li6PS5Cl	
Lithium Aluminum Germanium Phosphate	LiAlGeP3O12	NASICON-type electrolyte, Lithium-sulfur battery system Superior to LATP because of the better electrochemical stability
Lithium Lanthanum Titanium Oxide	LiLaTiO3	Commercial solid electrolyte in thin film batteries
Lithium Aluminum Titanium Phosphate	Li1.3Al0.3Ti1.7(PO4)3	Lithium-Air, Lithium-sulfur, Lithium-bromine battery systems
Lithium Lanthanum Zirconium Oxide	Li7La3Zr2O12	Patented by QuantumScape as catholytes, electrolytes and/or anolytes for all solid-state lithium rechargeable batteries.
Aluminum doped Lithium Lanthanum Zirconium Oxide	Li6.75Al0.25La3Zr2O12	
Gallium doped Lithium Lanthanum Zirconium Oxide	Li6.4Ga0.2La3Zr2O12	Researched as solid electrolyte materials for lithium ion and lithium metal batteries
Niobium doped Lithium Lanthanum Zirconium Oxide	Li6.5La3Zr1.5Nb0.5O12	
Tantalum doped Lithium Lanthanum Zirconium Oxide	Li6.4La3Zr1.4Ta0.6O12	
Tungsten doped Lithium Lanthanum Zirconium Oxide	Li6.3La3Zr1.65W0.35O12	
Sodium Thioantimonate	Na3SbS4	Solid-state sodium ion batteries
Sodium Phosphorus Sulfide	Na3PS4	

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