**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. | | A Li-ion battery from a [Nokia 3310](https://en.wikipedia.org/wiki/Nokia_3310) [mobile phone](https://en.wikipedia.org/wiki/Mobile_phone) | | | --- | --- | | [**Specific energy**](https://en.wikipedia.org/wiki/Specific_energy) | 100–265 [W·h](https://en.wikipedia.org/wiki/Watt_hour)/[kg](https://en.wikipedia.org/wiki/Kg)[[1]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-PanaLI-1)[[2]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-greencarcongress-2)(0.36–0.875 MJ/kg) | | [**Energy density**](https://en.wikipedia.org/wiki/Energy_density) | 250–693 [W·h](https://en.wikipedia.org/wiki/Watt_hour)/[L](https://en.wikipedia.org/wiki/Liter)[[3]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-3)[[4]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-4) (0.90–2.43 MJ/L) | | [**Specific power**](https://en.wikipedia.org/wiki/Power_to_weight_ratio) | ~250 – ~340 W/kg[[1]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-PanaLI-1) | | **Charge/discharge efficiency** | 80–90%[[5]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-PHEV1-5) | | **Energy/consumer-price** | 6.4 [Wh](https://en.wikipedia.org/wiki/Watt_hour)/[US$](https://en.wikipedia.org/wiki/United_States_dollar)[[6]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-Bloomberg-6) US$156/kWh | | **Self-discharge rate** | 0.35% to 2.5% per month depending on state of charge[[7]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-Redondo-7) | | **Cycle durability** | 400–1,200 [cycles](https://en.wikipedia.org/wiki/Battery_cycle) [[8]](https://en.wikipedia.org/wiki/Lithium-ion_battery#cite_note-8) | | **Nominal cell voltage** | 3.6 / 3.7 / 3.8 / 3.85 [V](https://en.wikipedia.org/wiki/Volts), LiFePO4 3.2 [V](https://en.wikipedia.org/wiki/Volts) | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 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 |

|  | **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** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **LiNiO2** | Layered | 4.2 | 4.71 | 220/160 | 640 | 1 | 200 | Medium | Medium |
| **LiCoO2** | Layered | 3.9 | 5.10 | 272/145 | 520 | 1 | 700 | Medium | Medium |
| **LiMn2O4** | Spinel | 4.1 | 4.31 | 148/105 | 410 | 1-10 | 500 | Medium | Medium |
| **LiFePO4** | Olivine | 3.45 | 3.60 | 170/155 | 540 | 1-25 | 2000 | Medium | Highest |
| **Li (Ni1/3Mn1/3Co1/3) O2** | Layered | 3.8 | 4.7 | 272/200 | 760 | 1-2 | 1000 | Medium | Medium |
| **Li (Ni0.8Co0.15Al0.05) O2** | Layered | 3.8 | 4.7 | 300/200 | 680 | 1 | 700 | Low | Medium |
| **Li4Ti5O12** | 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. Li4Ti5O12 may be used as an anode or cathode. | | | | | | | | | |

References

Wikipedia: <https://en.wikipedia.org/wiki/Lithium-ion_battery>

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Chen, Hungru (2012) Simulations for new battery materials.

| **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 |  |

| **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. |
| **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 |