To

INNOLIA ENERGY
INTEGRATED SOLAR AND LITHIUM-BATTERY MANUFACTURER

Innolia Energy *Li-ion Guide to choose Cell chemistry*

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What is Battery?

A connected group of (one or more) electrochemical cells that store electric charges and generate direct current (DC) through the conversion of chemical energy into electrical energy. its positive terminal is the cathode and its negative terminal is the anode.

Who invented lithium-ion batteries?

Handy, helpful lithium-ion power packs were pioneered at Oxford University in the 1970s by chemist John Goodenough and his colleagues Phil Wiseman, Koichi Mizushima, and Phil Jones. Their research was published in 1980 and turned into a commercial technology by Sony, who produced the first lithium ion batteries in the early 1990s. Since then, they've become commonplace: around 5 billion are manufactured every year (according to a Bloomberg news report from 2013), most of them in China. Three pioneers of lithium-ion battery technology—John Goodenough, M. Stanley Whittingham, and Akira Yoshino—shared the 2019 Nobel Prize in Chemistry for their groundbreaking work.

What are the type of Battery

1. **Primary Battery** **-** Can not be charged, It's Single directional.
2. **Secondary Battery -** Can be charged and discharged, its Bi directional.

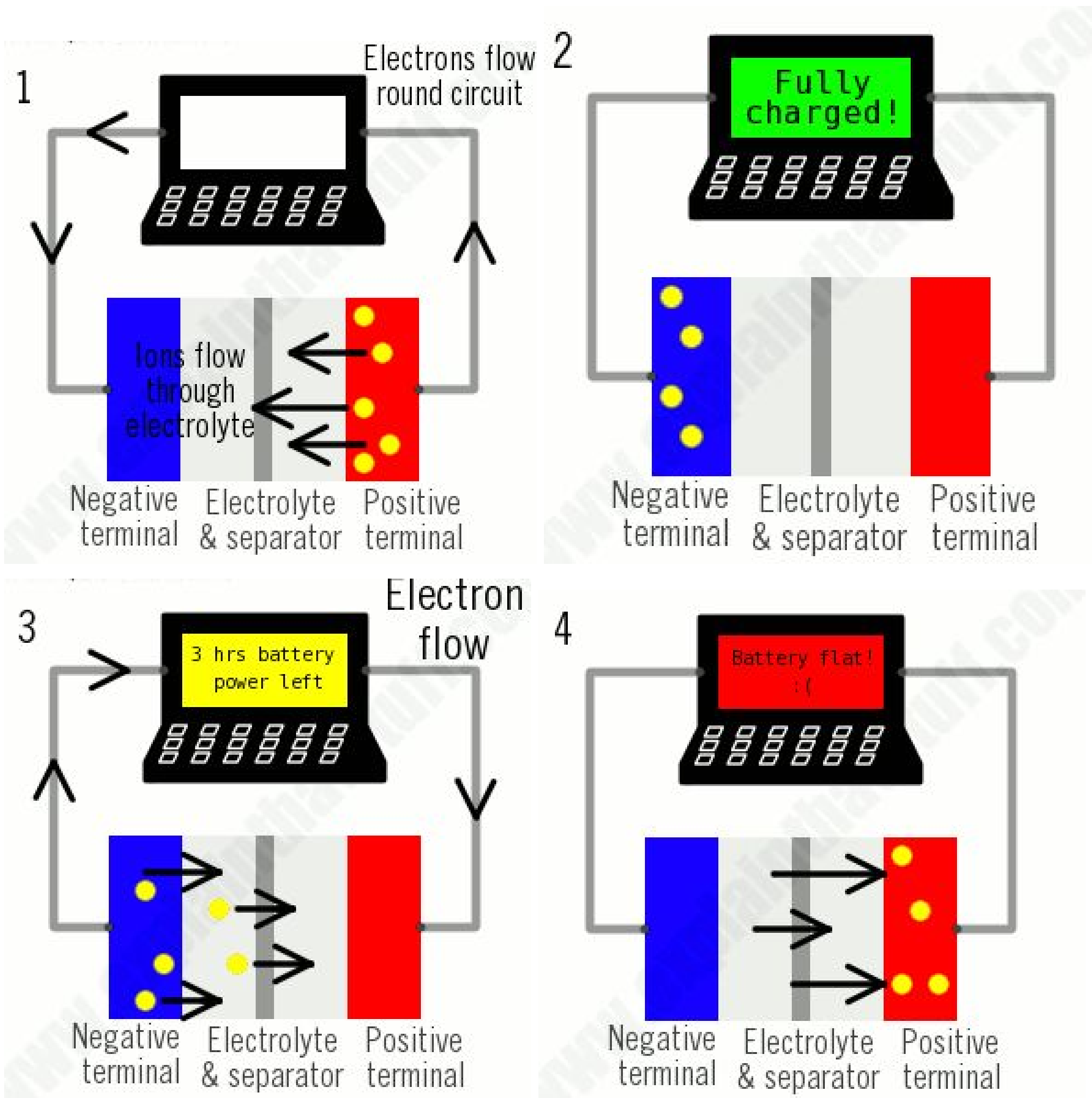
WHY Lithium battery?

Compared with traditional battery technology, lithium-ion batteries charge faster, last longer and have a higher power density for more battery life in a lighter package. When you know a little about how they work, they can work that much better for you.

How a lithium-ion battery charges and discharges

1. During charging, lithium ions (yellow circles) flow from the positive electrode (red) to the negative electrode (blue) through the electrolyte (gray). Electrons also flow from the positive electrode to the negative electrode, but take the longer path around the outer circuit. The electrons and ions combine at the negative electrode and deposit lithium there.
2. When no more ions will flow, the battery is fully charged and ready to use.

3. During discharging, the ions flow back through the electrolyte from the negative electrode to the positive electrode. Electrons flow from the negative electrode to the positive electrode through the outer circuit, powering your laptop. When the ions and electrons combine at the positive electrode, lithium is deposited there.
4. When all the ions have moved back, the battery is fully discharged and needs charging up again.

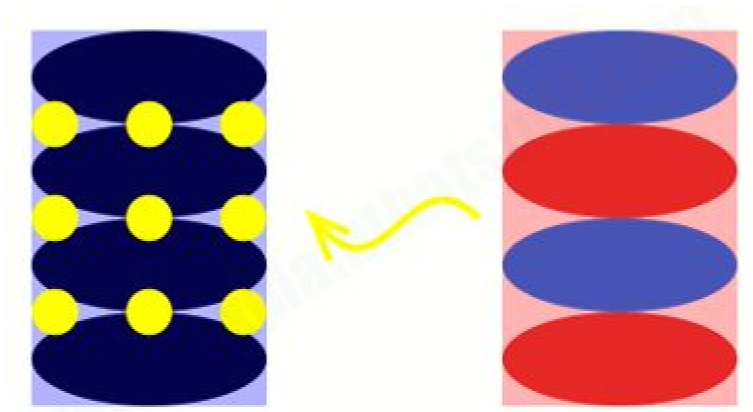


How are the lithium ions stored?

Charge:

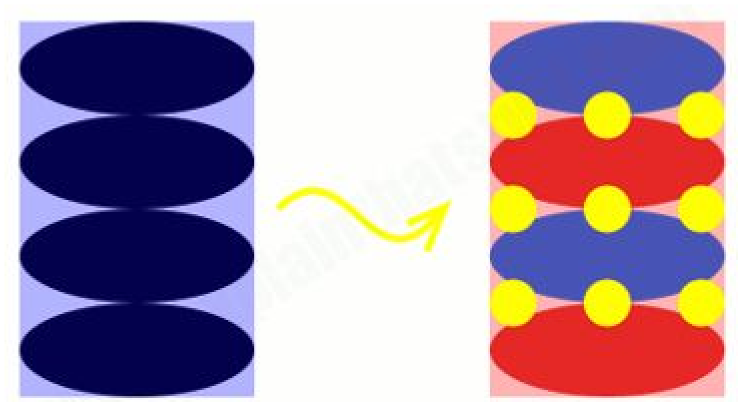
The below figure shows what's going on in the battery in a bit more detail. Again, the negative graphite electrode (blue) is shown on the left, the positive cobalt-oxide electrode (red) on the right, and the lithium ions are represented by yellow circles. When the battery is fully charged, all the lithium ions are stored between layers of graphene (sheets of carbon one atom thick) in the graphite electrode (they have all moved over to the left). In this charged-up state, the battery is effectively a multi-layer sandwich: graphene layers alternate with lithium ion layers.

Charge:



Discharge:

As the battery discharges, the ions migrate from the graphite electrode to the cobalt-oxide electrode (from left to right). When it's fully discharged, all the lithium ions have moved over to the cobalt-oxide electrode on the right. Once again, the lithium ions sit in layers, in between layers of cobalt ions (red) and oxide ions (blue). As the battery charges and discharges, the lithium ions shunt back and forth from one electrode to the other.



Merits of Li-ion Battery:

★ High Energy Density

★ Low Self Discharge

★ Low to Minimum Maintenance

★ Small in size

★ LIfe cycle is good

Lithium battery Application:

1. EV - Electric Vehicle
2. Telecom
3. Solar Application
4. ESS - Energy Storage Systems
5. Medical equipment
6. Power Backups / UPS
7. Mobile, Laptops, and other commonly used consumer electronic goods, etc…

Parameters to choose Cell

1. Energy Density of the Cells

Table 1. Comparison of energy densities for three types of lithium-ion cells.

Cell type	Energy density per weight [Wh/kg]	Energy density per volume [Wh/l]
LTO	90	200
LFP	130	247
NMC	150	300
NCA	240	670

This parameter is referred to as energy density and it informs how much energy can be stored in 1 kilogram or litre. Cell manufacturers specify this value, which is important information to evaluate suitability of a given technology for a solution to design. It is important to remember that the energy density is different for the cells alone, and different for the finished battery pack that includes the cells.

2. Temperature withstand capacity

All lithium-ion battery manufacturers define how performance depends on the temperature. The restrictions are safety related and affect charging and discharging current. Exceeding such limitations may damage the battery or cause much faster aging.

Table 2. Exemplary temperature ranges for battery operation at discharging and charging.

Cell type	Operating temperature range (discharging)	Operating temperature range (charging)
LTO	-30 to 55 ℃	-20 to 55 ℃
LFP	-30 to 55 ℃	-20 to 55 ℃
NMC	-20 to 55 ℃	-0 to 55 ℃
NCA	-20 to 60 ℃ [3]	-0 to 45 ℃ [3]

3. Battery working C - Ratings in electric vehicles

This parameter defines allowed currents for charging and discharging, specified for temperature ~20°C. The working current is specified as a multiplier of C number, for example 5C. C current (1C) is one hour current, which would allow it to charge the battery from 0 to 100% of its capacity in one hour, or discharge the battery from 100 to 0% of capacity in one hour. In the given example, 5C is the current that exceeds one-hour current five-fold, i.e. will discharge the battery completely in one fifth of an hour, which is 12 minutes.

Table 3. Exemplary working current ranges for discharging and charging batteries.

Cell type	operating current (discharging)	operating current (charging)
LTO	5 to 10 C	5 to 10 C
LFP	3 C	1 C
NMC	2 to 3 C	1 C
NCA	2 C	0.5 C

4. The required number of traction battery working cycles

Manufacturer's data do not always allow to compare the numbers of work cycles. This is because the number depends on many factors: charging and discharging currents and the process depth. Therefore, comparison requires data specific for exactly the same values of the mentioned parameters. Below is the collection of an exemplary number of cycles obtained from a battery packs manufacturer.

Relation between depth of discharge and loss of capacity caused by number of work cycles.

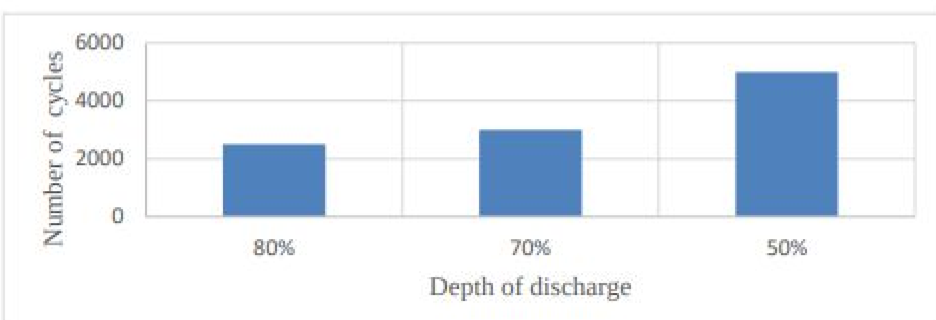
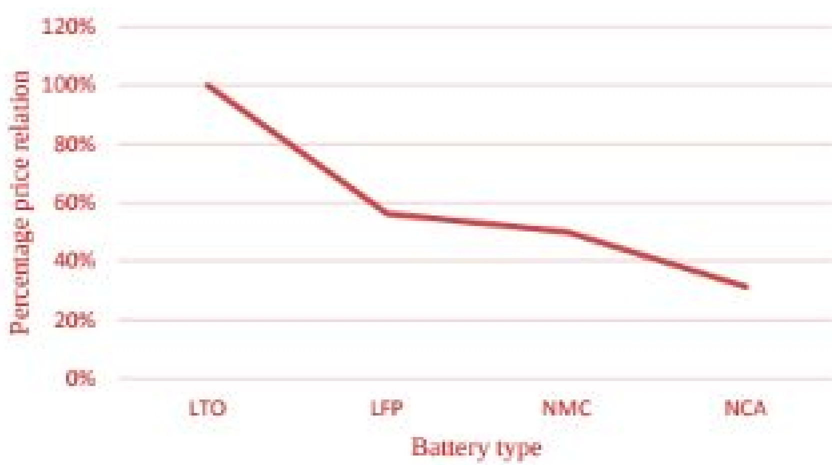


Table 4. Comparison of possible number of work cycles before capacity drops to 80% of rated capacity for LTO, LFP, NMC and NCA cells.

Cell type	Number of life cycles for 100% Depth of Discharge (DoD)
LTO	15000
LFP	3600
NMC	3000
NCA	500

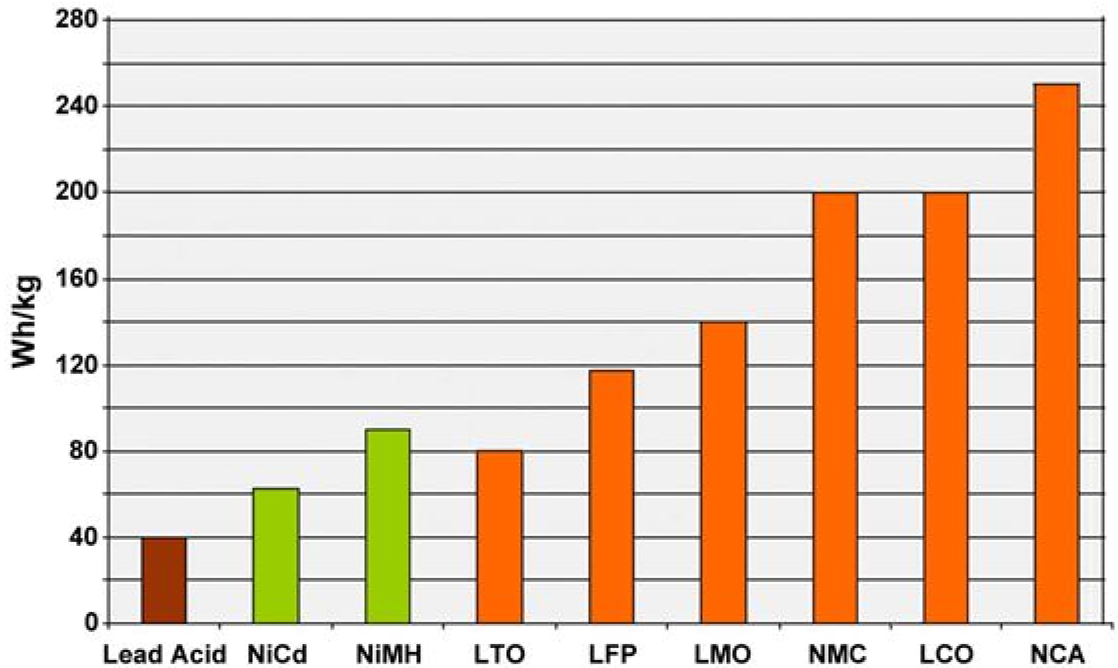
5. Economic aspect of EV Cell or Battery selection

The decision making process on the traction battery selection heavily depends on the economic aspect. Below Figure shows price relations for specific lithium technologies.



S No	Cell Chemistry	Specific Energy	Approx Cost per KWh. as per RWTH Aachen University.
1	LFP	90-120 Wh/Kg	USD 580
2	NMC	150–220Wh/kg	USD 420
3	NCA	200-260Wh/kg & 300Wh/kg	USD 350
4	LTO	50–80Wh/kg	USD 1005

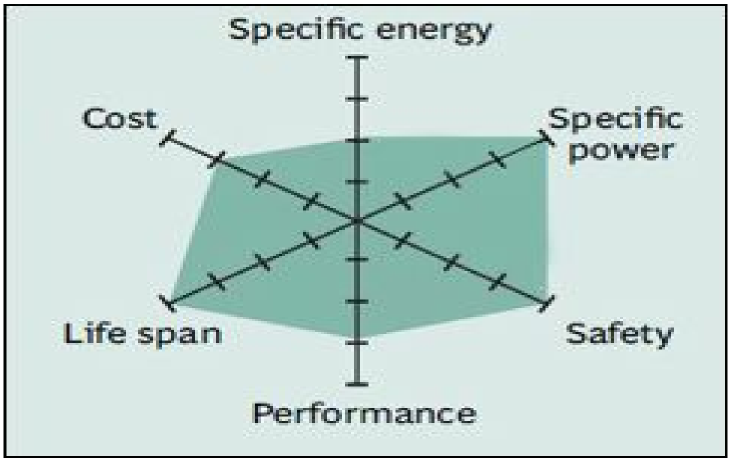
Types of Lithium ion battery performance graph



Types of Chemistry in market:

1) **Lithium Iron Phosphate(LiFePO4) — LFP**
2) **Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) — NMC**
3) **Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO2) — NCA**
4) **Lithium Cobalt Oxide(LiCoO2) — LCO**
5) **Lithium Manganese Oxide (LiMn2O4) — LMO**
6) **Lithium Titanate (Li2TiO3) — LTO**

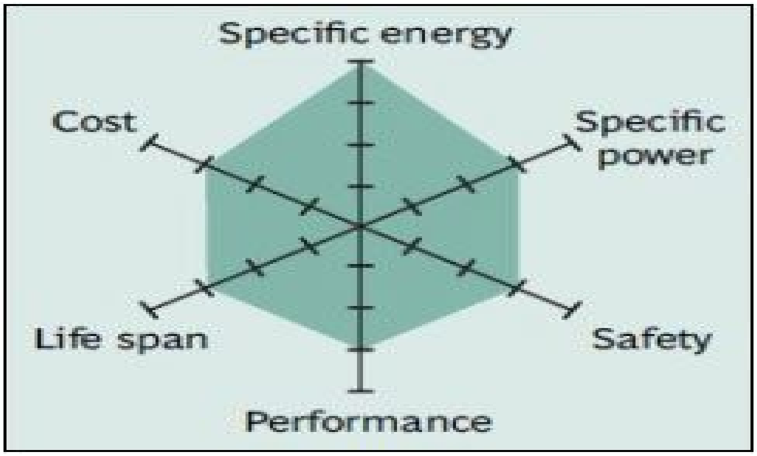
1. Lithium Iron Phosphate(LiFePO4) — LFP:



Summary Table:

Lithium Iron Phosphate: $LiFePO_4$ cathode, graphite anode Short form: LFP or Li-phosphate	Since 1996
Voltages	3.20, 3.30V nominal; typical operating range 2.5–3.65V/cell
Specific energy (capacity)	90–120Wh/kg
Charge (C-rate)	**1C typical, charges to 3.65V; 3h charge time typical**
Discharge (C-rate)	**1C, 25C on some cells; 40A pulse (2s); 2.50V cut-off (lower that 2V causes damage)**
Cycle life	**2000 and higher (related to depth of discharge, temperature)**
Thermal runaway	270°C (518°F) Very safe battery even if fully charged
Cost	~$580 per kWh (Source: RWTH, Aachen)
Applications	**Portable and stationary needing high load currents and endurance**
Comments	Very flat voltage discharge curve but low capacity. One of safest Li-ions. Used for special markets. Elevated self-discharge.
2019 update:	**Used primarily for energy storage, moderate growth.**

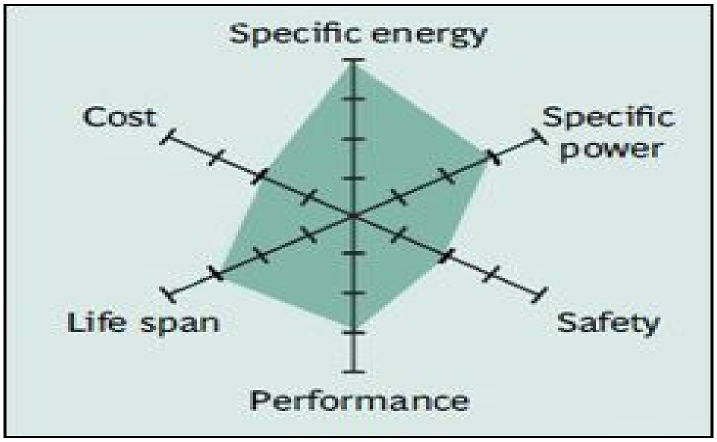
2. Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) — NMC:



Summary Table:

Lithium Nickel Manganese Cobalt Oxide: $LiNiMnCoO_2$. cathode, graphite anode Short form: NMC (NCM, CMN, CNM, MNC, MCN similar with different metal combinations) Since 2008	
Voltages	3.60V, 3.70V nominal; typical operating range 3.0–4.2V/cell, or higher
Specific energy (capacity)	150–220Wh/kg
Charge (C-rate)	**0.7–1C, charges to 4.20V, some go to 4.30V; 3h charge typical. Charge current above 1C shortens battery life.**
Discharge (C-rate)	**1C; 2C possible on some cells; 2.50V cut-off**
Cycle life	**1000–2000 (related to depth of discharge, temperature)**
Thermal runaway	210°C (410°F) typical. High charge promotes thermal runaway
Cost	~$420 per kWh (Source: RWTH, Aachen)
Applications	**E-bikes, medical devices, EVs, industrial**
Comments	Provides high capacity and high power. Serves as a Hybrid Cell. Favorite chemistry for many uses; market share is increasing.
2019 update:	**Leading system; dominant cathode chemistry.**

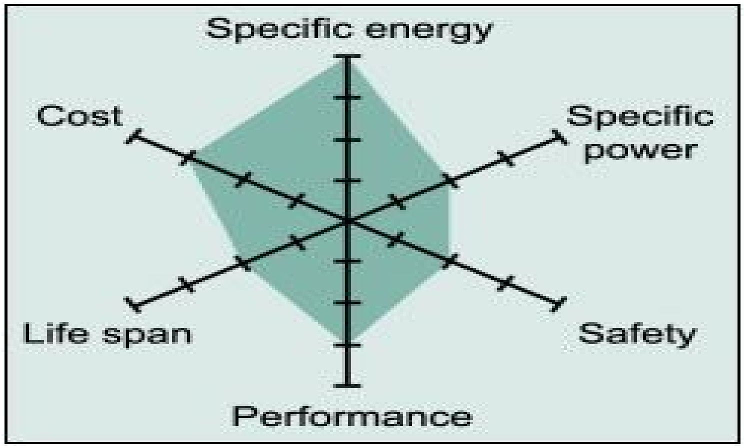
3. Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO2) — NCA:



Summary Table:

Lithium Nickel Cobalt Aluminum Oxide: $LiNiCoAlO_2$ cathode (~9% Co), graphite anode Short form: NCA or Li-aluminum. Since 1999	
Voltages	3.60V nominal; typical operating range 3.0–4.2V/cell
Specific energy (capacity)	200-260Wh/kg; 300Wh/kg predictable
Charge (C-rate)	**0.7C, charges to 4.20V (most cells), 3h charge typical, fast charge possible with some cells**
Discharge (C-rate)	**1C typical; 3.00V cut-off; high discharge rate shortens battery life**
Cycle life	**500 (related to depth of discharge, temperature)**
Thermal runaway	150°C (302°F) typical, High charge promotes thermal runaway
Cost	~$350 per kWh (Source: RWTH, Aachen)
Applications	**Medical devices, industrial, electric powertrain (Tesla)**
Comments	Shares similarities with Li-cobalt. Serves as an Energy Cell.
2019 update:	**Mainly used by Panasonic and Tesla; growth potential.**

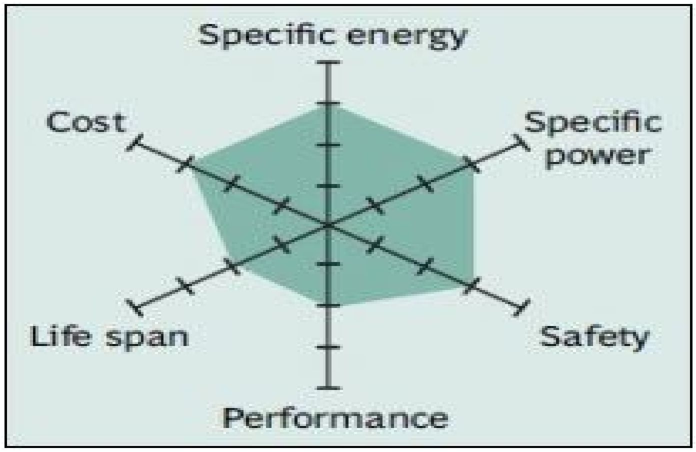
4. Lithium Cobalt Oxide(LiCoO2) — LCO:



Summary Table

Lithium Cobalt Oxide: $LiCoO_2$ cathode (~60% Co), graphite anode Short form: LCO or Li-cobalt.	Since 1991
Voltages	3.60V nominal; typical operating range 3.0–4.2V/cell
Specific energy (capacity)	150–200Wh/kg. Specialty cells provide up to 240Wh/kg.
Charge (C-rate)	**0.7–1C, charges to 4.20V (most cells); 3h charge typical. Charge current above 1C shortens battery life.**
Discharge (C-rate)	**1C; 2.50V cut off. Discharge current above 1C shortens battery life.**
Cycle life	**500–1000, related to depth of discharge, load, temperature**
Thermal runaway	150°C (302°F). Full charge promotes thermal runaway
Applications	**Mobile phones, tablets, laptops, cameras**
Comments	Very high specific energy, limited specific power. Cobalt is expensive. Serves as an Energy Cell. Market share has stabilized.
2019 update:	Early version; no longer relevant.

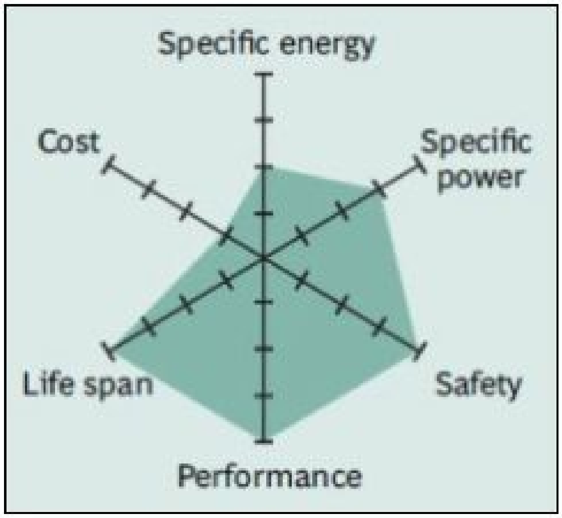
5. Lithium Manganese Oxide (LiMn2O4) — LMO:



Summary Table:

Lithium Manganese Oxide: $LiMn_2O_4$ cathode. graphite anode Short form: LMO or Li-manganese (spinel structure)	Since 1996
Voltages	3.70V (3.80V) nominal; typical operating range 3.0–4.2V/cell
Specific energy (capacity)	100–150Wh/kg
Charge (C-rate)	**0.7–1C typical, 3C maximum, charges to 4.20V (most cells)**
Discharge (C-rate)	**1C; 10C possible with some cells, 30C pulse (5s), 2.50V cut-off**
Cycle life	**300–700 (related to depth of discharge, temperature)**
Thermal runaway	250°C (482°F) typical. High charge promotes thermal runaway
Applications	**Power tools, medical devices, electric powertrains**
Comments	High power but less capacity; safer than Li-cobalt; commonly mixed with NMC to improve performance.
2019 update:	**Less relevant now; limited growth potential.**

6. Lithium Titanate (Li2TiO3) — LTO:



Summary Table:

Lithium Titanate: Cathode can be lithium manganese oxide or NMC; Li_2TiO_3 (titanate) anode Short form: LTO or Li-titanate	Commercially available since about 2008.
Voltages	2.40V nominal; typical operating range 1.8–2.85V/cell
Specific energy (capacity)	50–80Wh/kg
Charge (C-rate)	1C typical; 5C maximum, charges to 2.85V
Discharge (C-rate)	10C possible, 30C 5s pulse; 1.80V cut-off on LCO/LTO
Cycle life	3,000–7,000
Thermal runaway	One of safest Li-ion batteries
Cost	~$1,005 per kWh (Source: RWTH, Aachen)
Applications	UPS, electric powertrain (Mitsubishi i-MiEV, Honda Fit EV), solar-powered street lighting
Comments **2019 update:**	Long life, fast charge, wide temperature range but low specific energy and expensive. Among safest Li-ion batteries. Ability to ultra-fast charge; high cost limits to special application.

Conclusion:

This paper discusses the issues of battery selection for electric vehicles, taking into account many operation criteria. This problem is obviously a complex one. Selection of a battery for an electrically powered vehicle requires detailed analysis of many factors, such as: weight and volume, charging currents, route characteristics, depth of discharge, operating temperatures related to seasons of the year in the given area, potential integration of conditioning and heating. Selection method of the suitable technical solution is described, using comparison of the weighting sum of specific factors for each considered option. Correct selection of the battery and appropriate operation can extend the service life between replacements, thus reducing operating costs of the electrically powered vehicle.