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Existing and Emerging Lithium-ion Battery Technologies for India

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This document should be cited as: CSTEP (2020). Existing and Emerging Lithium-ion Battery Technologies for India, (CSTEP-TB-2020-01)

September 2020

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Overview

This technical brief examines existing and emerging lithium-ion battery technologies. It also compares various lithium battery chemistries to identify the preferred options for both electric vehicles and renewable energy applications in the Indian landscape.

Context

Currently, lithium-ion batteries (LIB) are the front runners for electric vehicles (EVs) and renewable energy (RE) applications, as they offer high specific energy (energy per unit mass) and cycle life. It is estimated that by 2030, the storage demand in India for the EV sector will be in the range of 900-2300 GWh[1], considering 30% EV penetration. It is pertinent to note here that LIB is the best battery technology option available for this sector. In the second phase of the Faster Adoption and Manufacturing of Electric Vehicles (FAME-II) policy of the Government of India, the subsidy is based on vehicle battery capacity. Further, Central Electricity Authority (CEA) estimates grid-scale battery storage of 136 GWh[2] for RE applications to meet the 2030 Nationally Determined Contributions (NDC) target. Given this scenario, the objective of this article is to present the existing LIB technology options and identify emerging LIB variants for Make in India initiatives.

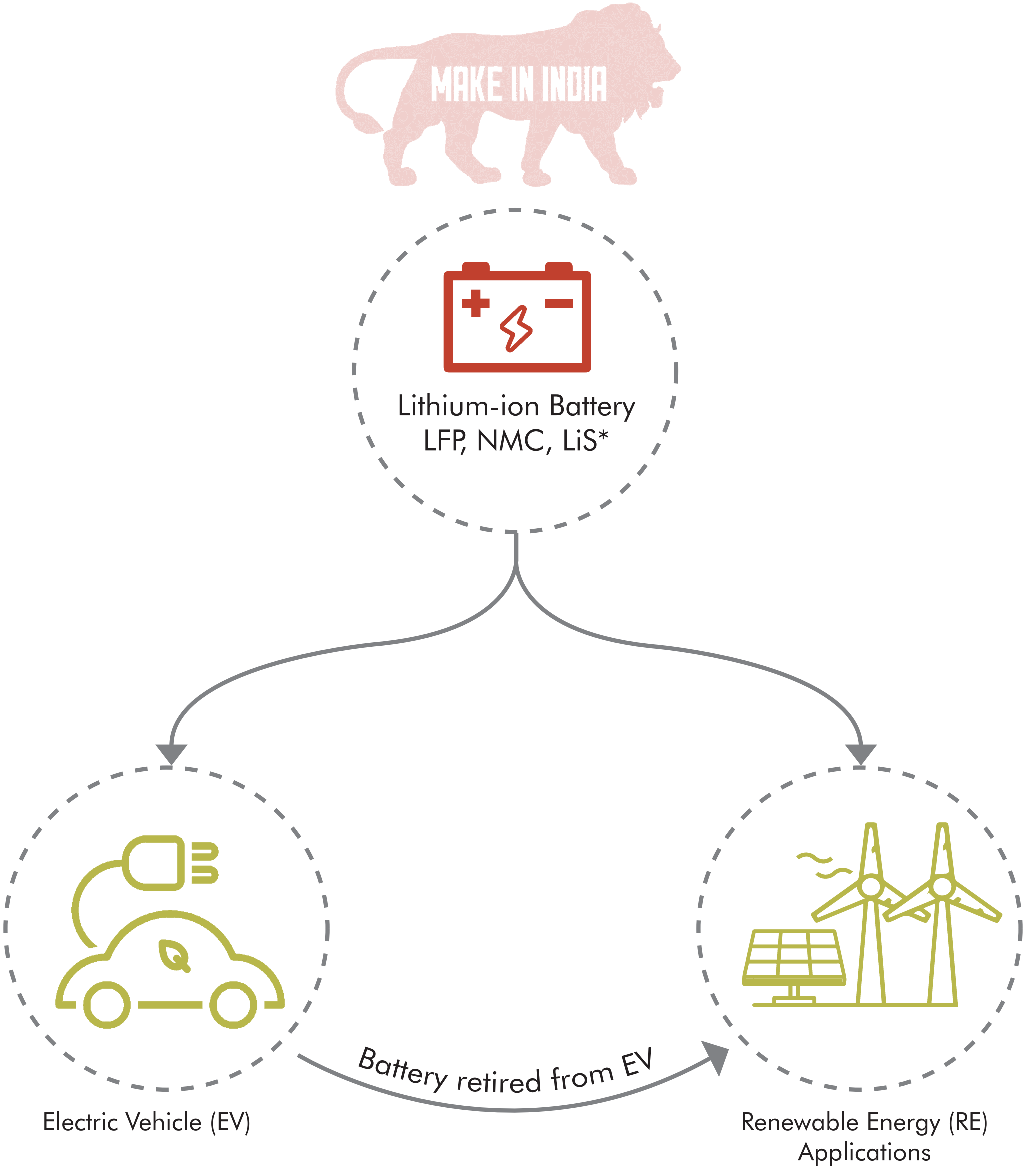


Figure 1: Thematic summary: Lithium-ion battery and its applications. Abbreviations: LFP (lithium iron phosphate), NMC (lithium nickel manganese cobalt oxide), LiS (Lithium Sulphur). *long-term plan

Highlights

- We recommend battery chemistries such as lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) to be given priority under the Make in India initiative of the Government of India.
- Both the batteries have high performance capabilities. While NMC battery systems are cheapest among LiB variants, LFP batteries are the safest.
- From the emerging technologies globally, GoI should incentivise the development and commercialisation of Lithium Sulphur (LiS) due to high cell voltage and energy density.

Existing Lithium Battery Variants

There are different types of commercially available lithium-ion batteries – lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), and lithium titanium oxide (LTO). The characteristics of these lithium-ion battery systems are shown in Table 1. These can be broadly divided into two categories based on their anode:

1. LIB with graphite anode[3]

a. LMO utilises manganese-based cathode. It is less costly and safer than other LIB variants. However, manganese dissolution reduces the battery life span at high temperature (~50°C).

b. LFP is the safest battery chemistry with long cycle life. It is cheaper than other LIB variants as it does not use nickel or cobalt. However, it has low specific energy.

c. NCA has high energy density and cycle life. It has the highest shelf-life (~15 years) but is more expensive than LMO due to the use of nickel and cobalt.

d. NMC is less costly due to economy of scale and safer compared to NCA[4]. It has a high cycle life. Due to its high performance, battery manufacturers prefer this battery though it has nickel and cobalt.

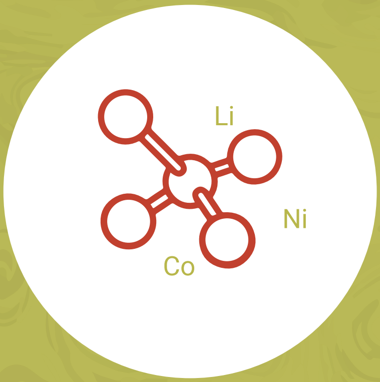
2. LIB with LTO anode

These variants have high rate capability (fast-charging-compatible), are safer, and have a high cycle life compared with conventional graphite anode-based systems. However, they have low cell voltage, low specific energy and are priced high due to the use of titanium and a higher concentration of lithium. The cathode of these batteries can be LMO, LFP, or NMC. Out of these, LFP/LTO is the safest cathode-anode combination, working even under extreme temperatures.

Table 1: Characteristics of existing Li-ion battery technologies [3], [5], [6]

Existing LIB Technology	Cell Voltage (V)	Specific Energy (Wh/kg)	Cycle Life (cycles)	Applications
LMO	3.7	100-150	300-700	EV
LFP	3.2	90-120	2000	RE & EV
NCA	3.6	200-250	1000-1500	RE & EV
NMC	3.7	140-200	1000-2000	RE & EV
LMO/LTO	2.5	50-80	6000	EV, UPS
NMC/LTO	2.3	50-80	27000	Hybrid EV
LFP/LTO	1.8	50-80	20000	Hybrid EV


Kg


Li
Ni
Co

Desired Battery Characteristics

For manufacturing battery modules in India, the important parameters to be considered are:

1. Cost

Battery cost is a major concern for RE and EV applications. Out of the seven variants of LIB in Table 1, currently LTO batteries are the most expensive, followed by LFP, NCA, LMO and NMC. The graphite-anode-based batteries cost around 200-840 USD/kWh, whereas for the LTO-anode -based batteries the cost ranges from 470-1260 USD/kWh[7]. With economy of scale, LIB prices are expected to drop 54%-61% by 2030[7]. During our earlier study, we found that NMC price reduces from 141 USD/kWh to 84 USD/kWh when the battery manufacturing capability is increased from 50 GWh to 200 GWh[1].

2. Safety

This is a key parameter while selecting different battery chemistries. When the battery is less prone to fire, it is considered to be safe. Absence of cobalt in LFP, LTO, and LMO batteries makes it safer compared to NMC and NCA variants.

3. Nominal cell voltage

This is an important battery characteristic as it decides the number of cells in a battery pack for a particular application, and has a direct impact on the cost of the battery. It is desirable for the battery to have a high cell voltage. Among the existing variants, LMO and NMC have the highest cell voltages.

4. Specific energy

It is the energy stored per unit mass of the battery. High specific energy reduces the weight of the battery pack, and hence, is an important parameter for electric transport applications. NCA system has the highest specific energy among the front runners, as shown in Table 1.

5. Cycle life

It represents the total operational life of the battery. It is desirable to have a high cycle life as it minimises battery replacements. NMC and LFP battery variants have the highest cycle life—up to 2000 full cycles—amongst the conventional graphite-anode-based systems.

6. Material availability

The raw material supply security is an important parameter in the context of a sustainable battery-manufacturing ecosystem. India does not have reserves of lithium. In addition, we depend heavily on imports for cobalt and nickel as well. These are critical raw materials for some front runner LIB systems. NMC and NCA have 10%-20% and 15% of cobalt, respectively. Graphite is the second largest component in lithium battery by weight. Even though India is the second largest producer of graphite, we lack technological knowhow to produce battery-grade-graphite[1], [7].

7. Recycling ecosystem

The exponential growth in LIB demand has triggered attention on the limited availability of raw materials and increasing industrial waste at the end-of-life of LIBs. This has generated interest among manufacturers and researchers to develop effective ways of recycling retired LIBs. LIBs retired from EV retain about 60%–70% of their original charge-storing capacity. It means that the retired batteries can be reused in solar and other power-grid-related applications. This can delay the need to recycle or dispose of LIBs phasing out from the EV sector. Burying the old batteries in landfills are neither environment-friendly, nor sustainable. At present, India does not have a LIB end-of-life policy. Globally, only 5% of LIBs are recycled, as a result of economic, technical, and other factors. Various labs around the world are exploring effective techniques such as (i) pyrometallurgy – involves melting metals to extract valuable materials like cobalt and nickel for reuse (ii) hydrometallurgy – involves leaching the target materials from the battery by immersing it in a solution and (iii) directly reusing certain 'still-good' components of a spent battery in new ones. The concern is that the current costs associated with these recovery processes often exceed the value of the materials if purchased from open market. The Government of India should consider technology partnership and bilateral trade agreements with countries like Finland, Belgium, Germany, USA, and Canada, which are front runners in LIB recycling business.

The relative ranking of the different existing cell chemistries based on the above desired characteristics is shown in Table 2. (The recycling capability is not included in the ranking exercise of Table 2 as all LIBs are eco-friendly and recyclable). Based on the ranking exercise, NMC and LFP are the best chemistries for manufacturing in India in the present LIB landscape.

Table 2: Ranking of battery chemistries with desired battery characteristics (1st means superior/top ranking)

LIB Technology	Low Cost	High Safety	High Specific Energy	High Nominal Cell Voltage	Long Cycle Life	Less Critical Materials
LMO	3rd	1st	3rd	1st	6th	1st
LFP	2nd	1st	4th	3rd	4th (1st among graphite anodes)	1st
NCA	4th	3rd	1st	2nd	5th	3rd
NMC	1st	2nd	2nd	1st	4th (1st among graphite anodes)	2nd
LMO/LTO	Prohibitive	1st	5th	4th	3rd	1st
NMC/LTO	Prohibitive	2nd	5th	5th	1st	2nd
LFP/LTO	Prohibitive	1st	5th	6th	2nd	1st

Emerging Lithium-ion Battery Systems

To enhance the performance of the state-of-the-art LIB variants, extensive research and development activities are being conducted globally. Some of the promising battery technologies (Table 3) are discussed below:

Table 3: Characteristics of emerging Li-battery technologies

Emerging Technology	Battery Characteristics	Cell Voltage (V)	Specific Energy (Wh/Kg)	Cycle Life
Lithium Sulphur	Anode: Li-metal protected by lithium nitrate (LiNO^{3}) Cathode: Sulfur-graphene composite Electrolyte: Ionic-liquid-based	4[8]	500[8]	1500[8]
Solid-state Li-ion Battery	Anode: Lithium metal Cathode: NMC Electrolyte: Solid polymer	3-4.3[9]	500[9]	23,000[10]
Li-Metal	Anode: Li metal with Li coating on asphalt-graphene substrate Cathode: Sulfurized carbon Electrolyte: Concentrated electrolyte	1.7-1.8[11]	900[11]	30-40[11]
Li-Air	Anode: Lithium metal Cathode: Pure oxygen infused into a porous carbon Electrolyte: Organic electrolyte same as conventional LIB	~ 2.4[12]	150-6000[13]	700[13]
Flexible thin-film Lithium	Anode: Silicon Cathode: Thin layer of Lithium oxides e.g. LFP, LMO, LCO Electrolyte: Polymer	~4.8-5[14]	300[15]	40,000[15]

1. Lithium Sulphur (LiS)

It has a high energy density, with no self-discharge issues. These batteries will cost less than other LIBs, since sulphur is abundantly available and cheaper than nickel and cobalt. However, a major drawback is the formation of polysulphide ions over time, reducing the efficiency and usable lifetime of the battery.

2. Solid-state LIB

In this system, liquid electrolyte is replaced by solid electrolyte. Besides safe operating features, the advantages of this variant include high specific energy and low cost. However, one of the major challenges is its premature failure after cycling at practical currents due to (a) dendrites (branching networks of lithium which grow through the solid, ceramic, electrolyte during charging of a battery, causing a short circuit) and (b) void formation (between the solid electrolyte and lithium anode during discharge of a battery, leading to a reduced area of contact between those two parts of the battery cell).

3. Li-Metal

Here, conventional graphite anode is replaced by Li-Metal, which helps the battery to store more energy per unit volume. However, metallic anodes suffer from dendrite growth issues, which can cause short circuit in batteries. Ongoing research suggests that dendrites can be suppressed through a special coating on the anode. The technology is still evolving at lab scale.

4. Li-Air

It has high theoretical energy density. However, lithium metal anodes have issues such as dendrite growth and large volume change during charging/discharge. Cathode is pure oxygen that requires auxiliary systems to purify, pump, and store air. Lithium and oxygen reaction creates a film of insulating lithium peroxide on the cathode. This film blocks the electron movement, which affects battery storage capacity and makes recharge difficult. This system, although promising, is still evolving at lab scale.

5. Thin film Li-batteries

These batteries offer high voltage, low price, high energy density, and a long cycle life with degradation. It can also work in a wider range of temperatures (~20 to 60^{0}C). The power consumption in this battery system will be faster because of thickness of the film (0.3 μm to 30 μm).

Key Recommendations

- The desirable battery characteristics for RE application are high specific energy, high cycle life, low cost, and safe operations.
- In addition to the features mentioned above, EV application requires the battery system to be lightweight.
- We suggest battery chemistries such as lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) to be given priority under the Make in India initiative of GoI.
- Manufacturing both the battery technologies will be ideal, as it will enable the GoI to effectively manage any shortage of critical materials, *e.g.*, cobalt, nickel, as LFP does not require these metals.
- Both the batteries have high performance capabilities. While NMC battery systems are cheapest among the lot, LFP batteries are the safest.
- From the emerging technologies, GoI should incentivise the development and commercialisation of Lithium Sulphur (LiS) due to high cell voltage and energy density.
- Industries should be encouraged to synthesise battery-grade-graphite in India. Manufacturing graphite locally will reduce import dependency as well as costs.
- India lacks high quality R&D infrastructure to design and develop next-generation LIB variants. GoI should also support R&D, to develop LIB recycling techniques to recover strategic materials such as lithium, cobalt, and nickel.

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