Lithium-ion battery supply chain: enabling national electric vehicle and renewables targets

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Energy storage will play an important role in the Government of India's efforts to meet the ambitious targets with regards to electric mobility and renewable energy. Among the different types of storage technologies, lithium-ion battery (LIB) is considered to be the best suited for electric vehicles (EVs). LIBs can also address intermittency problems in renewable energy integration with the grid. It is estimated that 13.8 GWh of battery capacity is required by 2020 for the EV sector and 15 GWh battery capacity is needed for grid storage requirements. Indigenization of LIB manufacturing can help to meet this large-scale demand. Moreover, indigenization has the potential to bring down the cost of a battery. One of the key components in manufacturing LIBs is lithium (as raw material), which needs to be imported as India does not have sufficient reserves. Therefore it is important to estimate the total amount of lithium required for fulfilling the domestic demand. To set-up indigenous manufacturing facilities, it is important to identify the key players in the global supply chain of the LIB industry and formulate policies that enable the success of this industry in India. This study presents a review of a complete supply chain related to manufacturing LIBs, along with policy instruments to support the domestic battery demand and supply ecosystem.

Keywords: Electric vehicle, grid, lithium-ion battery, supply chain.

THE lithium-ion battery (LIB) rapidly outpaced the conventional Lead-acid battery in the electric vehicle (EV) and grid storage sectors due to technological advancement and reduced cost of LIBs. Currently, India fulfils its domestic demand by importing LIBs, primarily from the US, China, Japan, Taiwan and Denmark. Setting up indigenous manufacturing units will not only reduce costs, but also help in generating employment. To estimate the market potential for indigenous manufacturing, an assessment of LIB in the grid and EV sectors is required. This will also give manufacturers an idea about how much lithium (Li) raw material (lithium carbonate, LCO) needs to be imported in order to fulfil domestic demand of LIBs. Indigenous battery manufacturing will also enable higher penetration of EVs and renewables in the Indian transport and energy sectors.

As compared to the internal combustion vehicle, EVs have the potential to reduce greenhouse gas (GHG) emissions. According to a 2007 estimate, India's transport sector was responsible for 7.5% of the country's total GHG emissions[1]. With the success of the National Electric Mobility Mission Plan 2020 (NEMMP), India will be able to save 9500 million litres of fuel, as well as 2 million tonne of GHG emissions, by 2020 (ref. 2). Another advantage of adopting of EVs is related to improving the country's energy security. India imported 83% of the total crude oil consumed in 2015–16 and spent around INR 4160 billion[3]. As per the government's think tank, NITI Aayog, India can save upto INR 3.9 trillion by switching to green mobility by 2030 (ref. 4).

The Government of India (GoI) announced ambitious plans in 2013, to deploy 6–7 million EVs by 2020, under the NEMMP. The primary objectives of NEMMP were to achieve national fuel security and GHG emission reductions. However, the high cost of EVs and lack of charging infrastructure are the key barriers in achieving the objectives of NEMMP. For instance, in 2016, only 22,000 EVs were sold in India[5]. Our estimates show that a maximum battery storage requirement (Table 1) of 13.8 GWh will be required by 2020, for electric four-wheelers, buses and the light commercial vehicle (LCV) segments. Storage is also an enabler for high penetration of renewables, as mandated by the Ministry of New and Renewable Energy (MNRE), which has set a target of installing 175 GW of renewable energy (RE), by 2022. A grid, with proper storage, will not only help integrate renewables with other conventional sources of energy, but also play an important role in ensuring high quality of electricity supply. In grid-connected storage options, the battery would have a significant share, of about 5 GW, by 2022. This will further increase to 7.8 GW by 2032, as per NITI Aayog's 'India Energy Security Scenario 2047'. According to our analysis, if we consider 1–3 hours of storage backup, then the required grid storage capacity would reach 5–15 GWh by 2022.

LIBs are among the front runners for utility-scale applications and form the primary component in the EV

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Table 1. Required lithium carbonate by 2020 for EVs

	Four-wheelers			Buses			Light commercial vehicle	
Target 2020	HEV	PHEV	BEV	HEV	PHEV	BEV	HEV	BEV
No. of vehicles (thousand)	935	340	170–340	1.54	0.56	0.28–0.7	120	30–60
Battery capacity per vehicle (kWh)	1–2.5	2.5–10	10–20	10–20	50–70	100–324	0.5–3	07–10
Battery market size (GWh)	0.94–2.3	0.85–3.4	1.7–6.8	0.02–0.03	0.03–0.04	0.03–0.23	0.006–0.36	0.21–0.6
Lithium carbonate required for lithium-based cathode and graphite anode combination battery (tonne)			1020-8840			16.8–294.84		126–780
Lithium carbonate required for lithium-based cathode and LTO anode combination battery (tonne)	2057–5142.5	1870–7480		33.9–67.76	61.6–86.24		132–792	
Total LCO (thousand tonne)	5.32–23.48							

segment. Hence, estimations of the total amount of Li required, to align with the national renewable and EV targets, become crucial. This will help policy makers take informed decisions about LIB indigenization in India. To address this, we have conducted a detailed review of the complete manufacturing supply chain, along with existing bottlenecks in the Indian context.

Li requirement for EV and grid storage

It is important to estimate the total Li demand in India as the country mainly depends on imports due to limited reserves. However, there are sufficient resources of some of the other components of the LIB system such as graphite, aluminium and copper. LCO is the main precursor and the source of Li for most LIB cathodes. Before setting up LIB manufacturing units, a question to be considered is how much Li or LCO is required per kilowatt-hour (kWh) for synthesising lithium-based electrodes. According to the Argonne National Laboratory (ANL, USA), the required amount of LCO varies from around 600 g to 1.3 kg per kWh for various lithium-based cathode and graphite-based anode combinations[6]. This combination of electrodes is mainly used for high-energy density applications. On the other hand, the LIB, with a Li-based cathode and lithium titanate (LTO) anode requires a higher amount of LCO (i.e., approx. 2.2 kg per kWh) and this combination is useful for high power density applications[6]. The desirable features for the grid storage sector are high cycle life and high energy density. For hybrid electric vehicles (HEVs) and Plug-in hybrid vehicles (PHEVs), high power density batteries are desirable, whereas high energy and power density batteries are useful for pure EVs.

In Table 1, the total amount of Li required by 2020 has been calculated for different segments of EVs, assuming that all vehicles will be powered by LIB technology. According to the TechSci Research report[7], as of 2015, 95% of HEVs were powered by LIB. In the same year, around 350,000 electric cars that were sold globally, mainly used LIBs. As per NEMMP 2020, the targeted volumes of four-wheelers, buses and LCVs are 1.45–1.62 million units, 2380–2800 units and 150,000–180,000 units, respectively[8]. These vehicles operate at different battery capacity (kWh) ranges, as shown in Table 1. According to the present study, in order to meet the desired target of EVs by 2020, a significant amount of LCO, a maximum of 23.48 thousand tonnes, will be required to manufacturer Li-based electrodes (cathode and anode). In the case of grid storage, a maximum amount of 19.5 thousand tonnes would be required by 2022, assuming a scenario in which all the electrochemical storage in India will be through LIBs.

Based on the estimated demand for LIBs, there is a clear case for indigenization. In this context, an overview of the global players in the supply chain of LIBs is discussed in the following section.

Review of the global LIB supply chain

Many companies contribute to the LIB supply chain and provide a range of services, from Li extraction to battery pack assembly (Figure 1).

Major Li producers and suppliers

Globally, Li is mostly recovered from sea brine or hard rock. Among hard rocks, Pegmatite contains a significant amount of Li. Pegmatite is further processed to Li-bearing mineral like spodumene (3.7% Li)[9], followed by the preparation of LCO or lithium hydroxide. Extraction of Li from sea brine is less expensive, as compared to that from Pegmatite[10].

Currently, the top Li producers, Albemarle and Sociedad Química y Minera (SQM), process LCO from Chile's largest salt flat, named Salar de Atacama. Another Li producer, Food Machinery Corporation (FMC), produces lithium hydroxide and LCO from Argentina's Salar del Hombre Muerto lithium brine deposit.

Though the extraction of Li from hard rock is expensive, it requires lesser time, as compared to its extraction

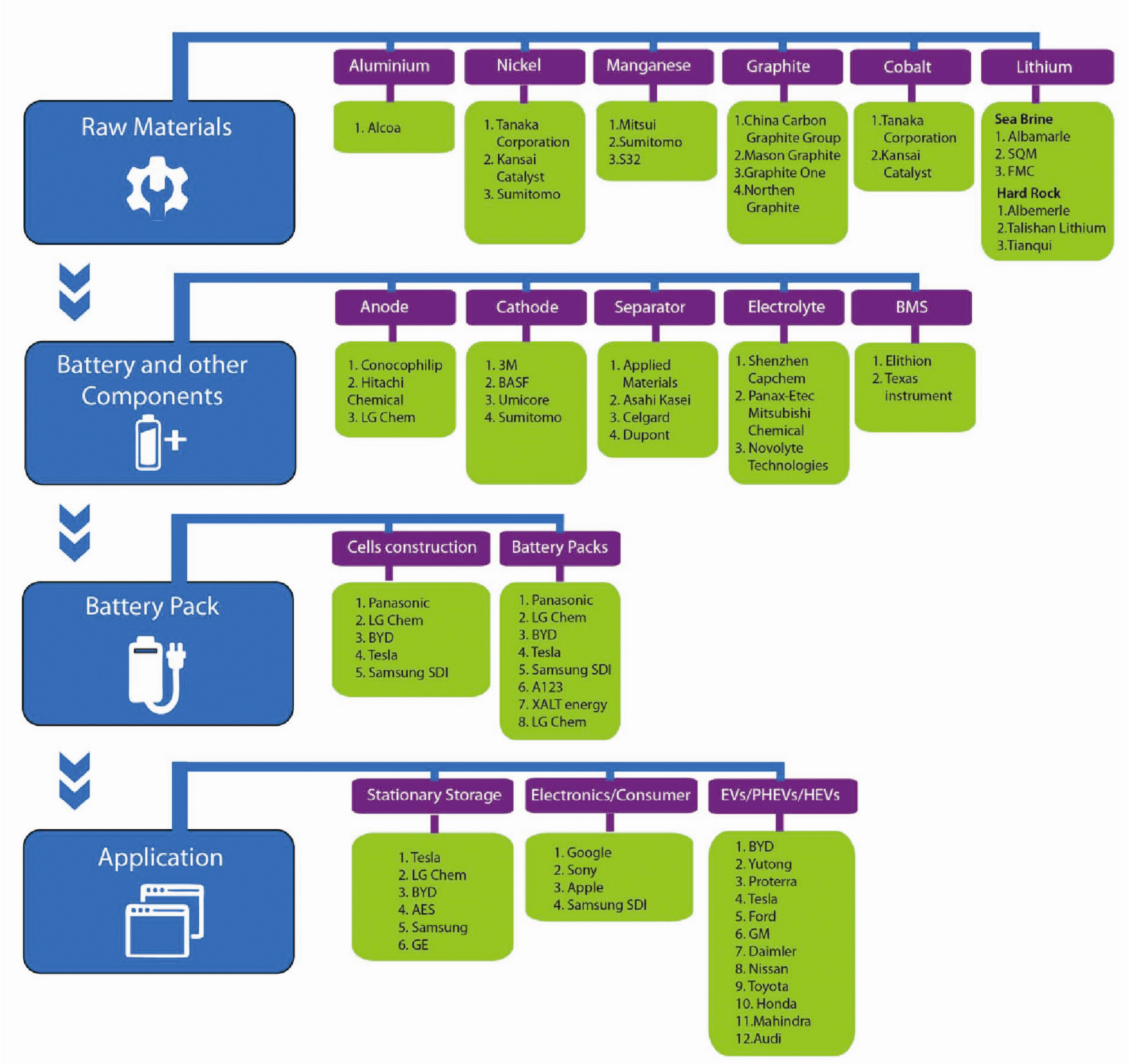

Figure 1. LIB supply chain and contributors.

from sea brine. Australia currently produces the highest amount of Li globally, mainly from hard rock. Australian company, Talison Lithium, extracts lithium-concentrate (spodumene) from the world's largest lithium ore deposit in Greenbushes, Western Australia. China based Sichuan Tianqi Lithium own 51% share of Talison Lithium and the US based Albemarle owns 49% share in it. Sichuan Tianqi Lithium further processes the spodumene in China to produce LCO. Albemarle supplies Li to Panasonic Corp., Syngenta AG, Umicore SA, Samsung SDI Co. Ltd and Royal DSM NV.

Globally, one of the top EV manufacturers, Build Your Dream (BYD) takes Li from Tibet's Lake Zabuye. The mining is operated by Tibet Shigatse Zhabuye Lithium High-Tech Co. Ltd. In 2016, BYD bought 18% stake in Tibet Shigatse Zhabuye Lithium High-Tech Co. Ltd. BYD also signed a deal in 2016 with the Qinghai Salt Lake Industry Group Co., where BYD owns 48% stake in the Li mining project.

India has a very small known Li reserve, as compared to other countries like Chile, Bolivia and Australia. Dar *et al.*[11] has reported about Li availability in India, based on a geological survey. According to the report, the Li ore-Lepidolite is present in the Bihar mica belt, while Pegmatite is present in Chitalnar, Mundwal and Govindpal areas of south Chhattisgarh. As per the Geological Survey of India[12], Maralagalla–Allapatna area in the eastern parts of Srirangapatna, Karnataka, contains spodumene, whereas Kabbur and Doddakadanur, Karnataka contain Li ore hiddenite.

Suppliers of other key materials

In addition to Li, other key materials such as manganese, nickel, cobalt, copper, graphite and aluminium are used in different forms in LIBs. It is anticipated that cobalt and nickel are prone to supply-chain risks as only a few countries control the global resource stock. For instance, more than one third of the world's cobalt is produced by the Democratic Republic of Congo. Similarly, some of the rare earth minerals used in producing EV components are mined primarily in China. South Africa is the world's largest producer of manganese (2015), followed by China and Australia. It is to be noted that India ranks sixth in the production of manganese.

Globally, China plays a significant role in LIB manufacturing. At present, China monopolises the spherical graphite supply, which is one of the key components in LIB. In addition, Shenzhen based Capchem held the world's top position as manufacturer of LIB electrolyte, with a market share of 9.2%.

Apart from electrodes and electrolytes, the separator is another key component. It prevents the battery from suffering a short circuit[13]. Polypropylene (PP) and polyethylene (PE) are commonly used as separators in LIBs. Asahi Kasei, Japan is the world's largest producer of battery separators. Other prominent separator manufacturers are Cangzhou Mingzhu Plastic, Celgard, Daramic, etc.[14].

There are several companies that are front-runners in the global LIB supply chain. Some of them, such as ConocoPhillips, Superior Graphite, 3M, XALT energy (previously named Dow Kokam), and South West Nano Technologies manufacture active materials and binders for electrodes. Texas Instruments, Elithion, Atmel, and Maxim play a major role in supplying battery management systems (BMS) to the LIB industries.

Battery manufacturers for EV and grid applications

Asian countries, mainly China, Japan and Korea play a key role in the LIB industry. Currently, Panasonic Sanyo, AESC, LG Chem and Samsung dominate the LIB market, which are based outside India. Figure 2 represents the global market share of LIB makers in 2015 (ref. 15). Samsung SDI had the largest market share of about 18%. In the following section, top battery manufacturers for EVs and grid application have been summarized.

BYD manufactures the highest number of electric buses in the world. Currently 10,000 BYD electric buses operate worldwide and each bus is fitted with a 324 kWh battery pack. Another prominent electric bus manufacturer is China based, Yutong. At present, 8000 of its electric buses are operating commercially. They procure batteries from ATL, Tianjin Lishen and Samsung SDI. Two other major battery manufacturers, Toshiba and LG Chem, who outsource their LTO and Nickel-Manganese-Cobalt (NMC) battery to Proterra (US based) for their XR35-foot catalyst model.

In the global LIB market, Chinese Li producers play a significant role as battery components suppliers. Currently, China is producing more LIB cathodes than Japan and Korea. BYD not only manufactures LIBs for their EVs, but also supplies battery for grid application. BYD supplies LIBs to the US-based energy storage solution industry Invenergy LLC, for its major installation Beech Ridge Energy Storage (31.5 MW, fully operational) and Grand Ridge Energy Storage (3 MW, operational as of March 2016).

LG Chem plays an important role in grid storage as well. It provides batteries to the leading grid-scale energy storage integrator AES of the US. It has installed 136 MW LIBs for energy storage projects. In the coming years, AES plans to install and commission two energy storage arrays, totalling 37.5 MW in San Diego County, California. Once completed, this will be the largest battery-based energy storage project in operation in the US. LG Chem also supplies lithium-ion storage modules to Europe's largest battery energy storage project (10 MW/10 MWh) in Feldheim, Germany. AES India and Mitsubishi Corporation have jointly announced a 10 MW grid battery project for Tata Power Delhi Distribution Limited, in January 2017, where Panasonic will supply LIBs. Panasonic also supplies LIBs to Tesla for stationary storage application. In Figure 3, a graphical representation shows the participation of different companies in the primary supply chain for Tesla's stationary and EV storage business.

Among the top battery manufacturers, Toshiba Corp. contributes significantly to the energy storage system. It has supplied battery energy storage system (BESS) to Tohoku Electric Power Company. The 40 MW/40 MWh lithium-ion BESS is one of the largest systems in the world[16].

The South Korean battery firm, Kokam, has deployed two Li NMC oxide energy storage systems (ESS) – rated at 24 MW/9 MWh and 16 MW/6 MWh – for frequency regulation in the national electricity grid. This is the world's largest capacity Li NMC ESS used for frequency regulation. Kokam will also supply battery to Powercor, which has installed Australia's largest battery storage system in its regional grid at Buninyong, south of Ballarat.

In India, lead-acid battery manufacturer, Exide Batteries, has planned to set up a LIB plant by 2018 (ref. 17). The company has tied-up with a Chinese group, Chaowei, to start battery production by 2019. Reliance Industry has recently unveiled their plans of setting up a 25 GWh capacity LIB plant in either Gujarat or Maharashtra[18]. Some major international players, namely Suzuki Motor Corp., Toshiba Corp. and Denso Corp. have jointly

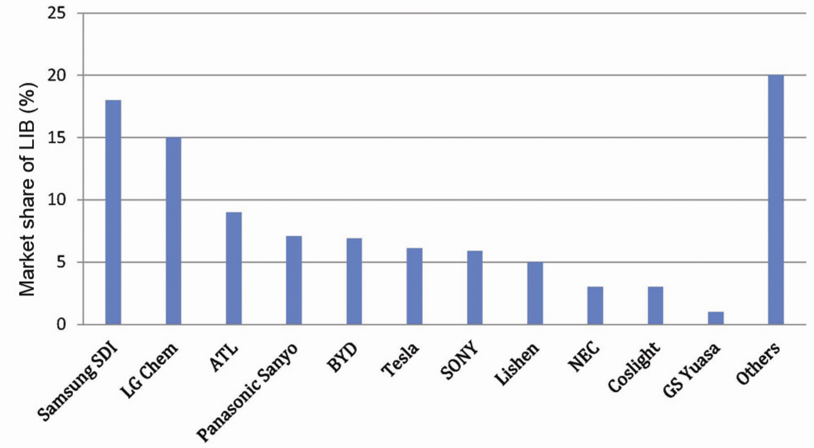

Figure 2. Market share of different LIB manufacturers[15].

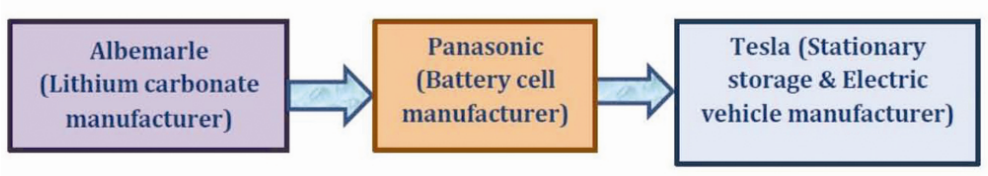

Figure 3. Primary supply chain for Tesla's stationary and EV storage businesses.

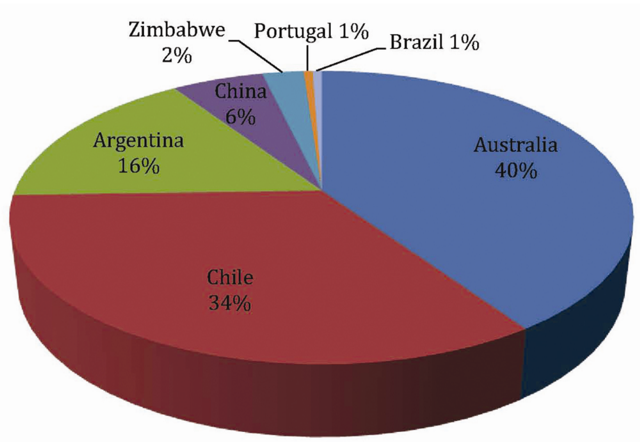

Figure 4. Country-wise distribution of extractable lithium from different sources[19].

announced an investment of Rs 1,150 crores for a LIB manufacturing plant in Gujarat.

Way forward

The study estimated the maximum potential of the Indian market for LIBs in EV and grid storage applications, which are 14 GWh by 2020 and 15 GWh by 2022, respectively. To manufacture this capacity LIBs indigenously, 24 and 20 thousand tonnes of LCO will be required for EV and grid storage, respectively. In view of this huge demand, this Note presented an overview of the different industries associated with the global LIB supply chain.

We propose the following recommendations for building a LIB ecosystem, which will have a huge impact on the national EV and renewables targets, considering the crucial role that LIB plays in these sectors:

1. The government's 'Make in India' programme can be leveraged; LCO can be imported from countries with rich Li reserves such as Chile, Argentina, etc.[19] (Figure 4) to manufacture batteries in India. India can also import Li-concentrate spodumene from Australia and process it domestically.
2. The government should support and incentivize local industries to synthesize battery-grade spherical graphite, which will reduce import dependency. At present, spherical graphite is manufactured only in China. However, indigenization will have to consider environmental concerns as fine carbon dust, which is a by-product from manufacturing graphite and hazardous.
3. For ensuring steady supply of cobalt, nickel and other key materials, Memorandum of Understandings (MoU) with mineral-rich countries like Congo, Australia, the Philippines and Indonesia will reduce India's supply chain vulnerability.
4. To support indigenous manufacturing, the government should reduce import duties on raw material and equipment. Moreover, providing initial capital subsidies to manufacturers will encourage greater penetration and development of a domestic LIB industry.

5. The government and private players can jointly develop a LIB manufacturing framework. This will open up the door for a huge work force and expertise advancement. It will give a boost not just to battery enterprises, but also to parallel industries.
6. India should identify emerging, high-performing LIB variants and take lead in manufacturing, with the help of R&D support. This includes enhancement of battery capacity as well as cycle life, which will bring down the cost of batteries. There is also a need to find a stable electrolyte (non-flammable) with high voltage tolerance to prevent thermal runaway, for safe operation.
7. India needs to develop expertise at large-scale battery pack assembly with BMS, under the 'Skill India' initiatives. This will enable players to set-up a long-term, sustainable LIB production ecosystem and facilitate employment generation.

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