CSTEP
CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

Indigenisation of Lithium-ion Battery Manufacturing: A Techno-economic Feasibility Assessment

Indigenisation of Lithium-ion Battery Manufacturing: A Techno-economic Feasibility Assessment

Tanmay Sarkar

Bhupesh Verma

Epica Mandal Sarkar

Mridula Dixit Bharadwaj

Center for Study of Science Technology and Policy (CSTEP)

June , 2018

Center for Study of Science, Technology and Policy (CSTEP) is a private, not-for-profit (Section 25) Research Corporation registered in 2005.

Designing and Editing by CSTEP

This report should be cited as: Sarkar, T., Verma, B., Sarkar, E.M., Bharadwaj, M.D. (2018). *Indigenisation of Lithium-ion Battery Manufacturing: A Techno-economic Feasibility Assessment*, (CSTEP-Report-2018-10).

June, 2018

Center for Study of Science, Technology and Policy
#18, 10th Cross, Mayura Street,
Papanna Layout, Nagashettyhalli, RMV II Stage,
Bangalore-560094 Karnataka, INDIA
Tel.: +91 (80) 6690-2500
Fax: +91 (80) 2351-4269
Email: cpe@cstep.in
Website: www.cstep.in

Executive Summary

The Government of India (GoI) recently announced plans for India's transition to all electric public transportation by 2030. GoI also introduced the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) policy in 2015, to increase the adoption of Electric Vehicles (EV) on the road. However, EV deployment in India has been modest, so far. This is because of the high cost of vehicles, lack of EV-related infrastructure and awareness among users. Lithium-ion Batteries (LIBs) and related components account for about 40–50% of an EV's total cost. The government's ambitious targets for EVs and Renewable Energy (RE) are expected to create a huge demand for LIB systems in the coming years. However, at present, India lacks domestic manufacturing capacity at commercial scales and imports LIBs, mainly from China and the US.

This report presents an evaluation of the economics of indigenously manufacturing LIBs. We have considered a manufacturing plant of 50 GWh capacity. Our analysis suggests that if a 50 GWh plant were to be established in India, the cost of a battery is expected to be competitive with global costs. As per our estimates, such a facility would have a capital cost of around INR 30,000 crore (USD 4.6 billion). It would take about 3 years to build a plant of this scale. We have also presented a financial model to estimate the cost of manufacturing LIBs in India. An indigenously manufactured LIB is expected to cost INR 9614/kWh (USD 148/kWh). Furthermore, a sensitivity analysis was performed to see the impact of various parameters on the LIB's costs.

This report also includes an analysis of the impact of different technologies, subsidies and economies of scale on the cost of manufacturing LIBs. The cost of a LIB can reduce significantly if new battery chemistries and government subsidies are taken into account.

Finally, we also identified the challenges of domestic manufacturing, in the Indian context. We provided suggestions on key policy instruments to address these challenges, which will help facilitate indigenous LIB manufacturing.

Acknowledgement

CSTEP is grateful for the core support provided by the International Development Research Corporation (IDRC) and Oak Foundation, which made this report possible.

We deeply appreciate the inputs provided by Dr Anshu Bharadwaj (Executive Director, CSTEP) during the course of this project. We extend our special thanks to Dr Bellarmine K.C. (Chief Financing Officer, CSTEP) for his support in the financial analyses. We would like to thank Dr Gangadhara Rao (Technical advisor), Dr S.S. Krishnan (Advisor) and Harshid Sridhar (Senior Research Engineer) for their valuable feedback and insights. We gratefully acknowledge Arushi Sen, Merlin Francis and Aswathy Shivaji for the editorial review and communication activities. We are also thankful to Dr Jai Asundi (Research Coordinator, CSTEP) for overseeing the quality control process for this report.

Table of Contents

List of Figures

List of Tables

1. Introduction

The Government of India's (GoI) ambitious target of achieving 100% Electric Vehicle (EV) sales by 2030 could be a big boost for the EV industry[1], particularly in the battery sector, as a battery accounts for 40–50% of the total cost of a vehicle. A report by the Rocky Mountain Institute and NITI Aayog has predicted the creation of a market worth USD 300 billion for batteries in EV applications, between 2017 and 2030 (NITI Aayog and Rocky Mountain Institute, 2017). In addition to EVs, batteries play an important role in Renewable Energy (RE) penetration. Therefore, it becomes an important sector for India, to meet the storage requirements for GoI's ambitious target of 175 GW of RE by 2022.

Among the various existing battery technologies, such as Lithium-ion battery (LIB), Lead-acid battery, Nickel cadmium battery, LIBs have been widely tested for their performance in EVs (Deng, 2015). Globally, LIBs are also being used for grid frequency regulation (Greenwood, Lim, Patsios, Lyons, Lim, & Taylor, 2017). In the current scenario, the high cost of LIBs is one of the main reasons for limited adoption of EVs and slow growth in RE applications.

India presently imports LIBs, primarily from China and the US, to fulfil its domestic demand. The demand for LIBs is low in the country, but it is anticipated to increase in the future owing to the government's initiatives in the EV and RE sectors. Some of these initiatives are the National Electric Mobility Mission Plan (NEMMP), Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME), and RE initiatives like the National Solar Mission by the Ministry of New and Renewable Energy (MNRE). Given the huge market potential and evolving policies, indigenous manufacturing of battery technology could be a potential solution to bring down its costs. However, choosing the right capacity of a manufacturing plant is a big challenge.

As per the *Charging the future: Asia leads drive to next-generation EV battery market* report (Goldman Sachs, 2016), BYD has the largest LIB manufacturing facility, with an annual capacity of 6 GWh, followed by Nissan AESC (5 GWh), Loitech (1.5 GWh) and A123 (1.4 GWh). The capital expenditure (CAPEX) per capacity varies according to the capacities of these plants. As seen in Figure 1, the CAPEX per capacity decreases with an increase in production capacity. Tesla's gigafactory aims to ramp up their production to 50 GWh by 2020. The total investment required for Tesla's gigafactory is about USD 5 billion[2]. The capital cost for a plant of this scale is about USD 100 million/GWh. Moreover, Tesla has estimated that manufacturing at such a large scale will significantly impact the cost of the product. The price of a battery from Tesla's gigafactory will be around USD 150/KWh (Mckinsey&Company, 2017). If India builds such a giant facility (50 GWh), it will have additional advantages like low cost of raw material procurement, cheaper labour and land costs, etc. These factors will effectively help to further reduce the cost of a battery beyond USD 150/KWh.

[1] Source: http://www.thehindu.com/news/national/karnataka/india-to-sell-only-electric-vehicles-by-2030-piyush-goyal/article19516175.ece
[2] Source: www.tesla.com

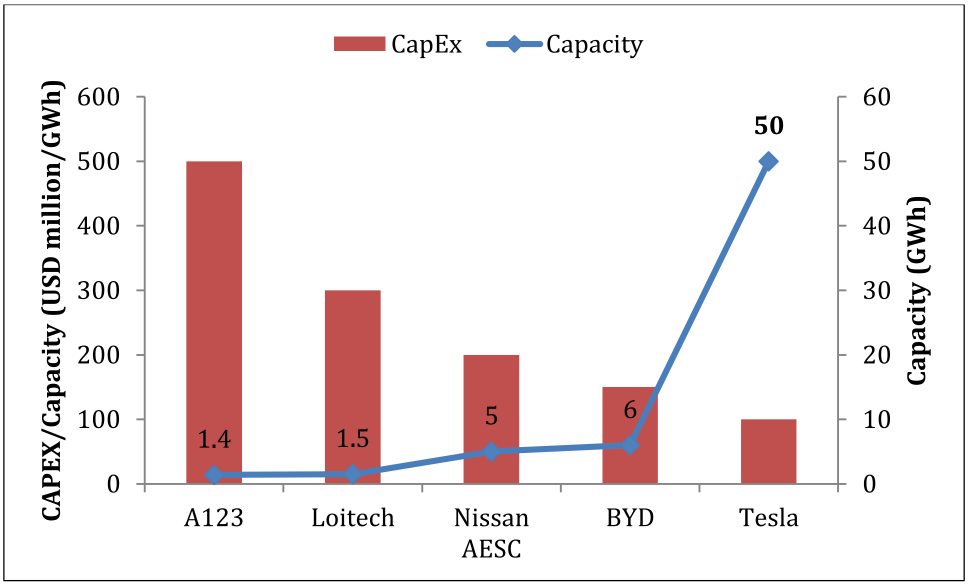

Figure 1: Change in CAPEX/Capacity with increase in production capacity (Goldman Sachs, 2016)

With further developments in technology, better optimisation of manufacturing plants and implementation of government subsidies, the cost of LIBs can be reduced significantly in the future. Different LIB technologies influence their respective costs. Berckmans et al. reported that a battery with a lithium-nickel-manganese-cobalt (LNMC) cathode and silicon alloy anode shows a cost reduction potential of 30%, as compared to a battery with a LNMC cathode and graphite anode (Berckmans, Messagie, Smekens, Omar, Vanhaverbeke, & Mierlo, 2017). Similar to the subsidy provided by the government to the semiconductor industry, a subsidy for the LIB manufacturing industry will be helpful in bringing down the price of LIBs. An optimum combination of LIB technology and subsidy will help to reduce the required CAPEX and operating expenditure (OPEX) of an indigenous LIB manufacturing facility.

In this study, we investigated the CAPEX and OPEX[3] of setting up a 50 GWh plant in India and provide an estimation of the material and labour requirements. We analysed the impact of different technologies, subsidies and economies of scale[4] on the LIB manufacturing costs. Through this study, we also identified the challenges of manufacturing LIBs in the Indian context and provide suggestions on key policy instruments to facilitate indigenous LIB manufacturing.

[3] Materials to be imported.
[4] An economy of scale defines the cumulative cost advantage of a product or service due to an increase in the size of the business, in an efficient manner.

2. Methodology

Understanding the demand for LIBs in India was a crucial aspect of this study. It provided an estimate of the current market potential and helped in assessing the right scale of manufacturing plant for India.

2.1 LIB Demand Forecast

Currently, the demand for LIBs in India's clean energy sector is modest. However, it is expected to increase several folds in the coming years because of the ambitious EV and RE targets. We estimated (Table 1) the likely demand for LIBs in EV and grid applications by 2030, using the following assumptions and methodology:

1. An exponential regression approach was used to project the number of vehicles required by 2030. As an input, the total number of registered vehicles (from 2000 to 2012) was taken from the database of the Ministry of Road Transport and Highways[5]. Out of the cumulative vehicle population, we considered a 30% penetration[6] of EVs to estimate the battery requirement. The storage requirement per vehicle was decided based on the NEMMP guidelines (Department of Heavy Industry, 2013). Based on this approach, in the transportation sector, the number of vehicles on the road by 2030 is expected to be: 200 million two wheelers, 40 million four wheelers (39 million, according to Lawrence Berkley National Laboratory report) (LBNL, 2017). The detailed assumptions have been summarised in Table 2.

2. In grid-scale applications, the energy storage demand has been determined such that it provides 1–3 hours of back-up (in the morning and evening peak hours). NITI Aayog's IESS 2047 tool[7] has been used, considering a Level 2 scenario. This scenario assumes that Vehicle-to-Grid (V2G) technologies would mature to enable a large fleet of EVs to operate as virtual power plants.

We assumed that LIBs will be the only electro-chemical storage option. Based on the above-mentioned assumptions, an estimated storage demand of 900–2300 GWh and 22 GWh will be required by 2030 for EVs and the grid sector, respectively.

Table 1: LIB demand in EV and grid sector by 2030

EV (considering 30% penetration by 2030)		
Transportation sector	**Energy storage per vehicle**	**Energy storage requirement (GWh)**
2 wheelers: 200 million	1–2.7 kWh	200–540
4 wheelers: 40 million	10–20 kWh	400–800
Buses: 3 million	100–324 kWh	300–970
Energy storage demand for EVs in 2030 (GWh)	900–2300	
Energy storage demand in grid sector by 2030 (GWh)	22	

[5] Source: https://data.gov.in/
[6] Electric vehicle can see 30–40% penetration by 2030: SIAM (2017), Economics Times
[7] User Guide for India's 2047 Energy Calculator – Electrical Energy Storage, IESS 2047

2.2 Financial Model

A LIB manufacturing plant of 50 GWh capacity has been considered for determining the economics of battery manufacturing at the kWh scale. A financial model has also been prepared to calculate the manufacturing cost of LIBs in India. The schematic for the model is given in Figure 2. The initial capital requirement, determined by the land and building requirement, is about 5%. The capital requirement for plant and machinery is about 82%, preliminary and pre-operative expenses would be about 7% and remaining is capitalised interest. We have assumed a 70:30 debt to equity ratio.

The input components in this model are capital cost, raw material costs, operations costs, etc., and the output is calculated in terms of battery manufacturing cost (USD/kWh). The manufacturing cost includes materials, labour, energy, depreciation, Selling, General & Administrative (SG&A), etc. All the assumptions used in the model are listed in Table 2.

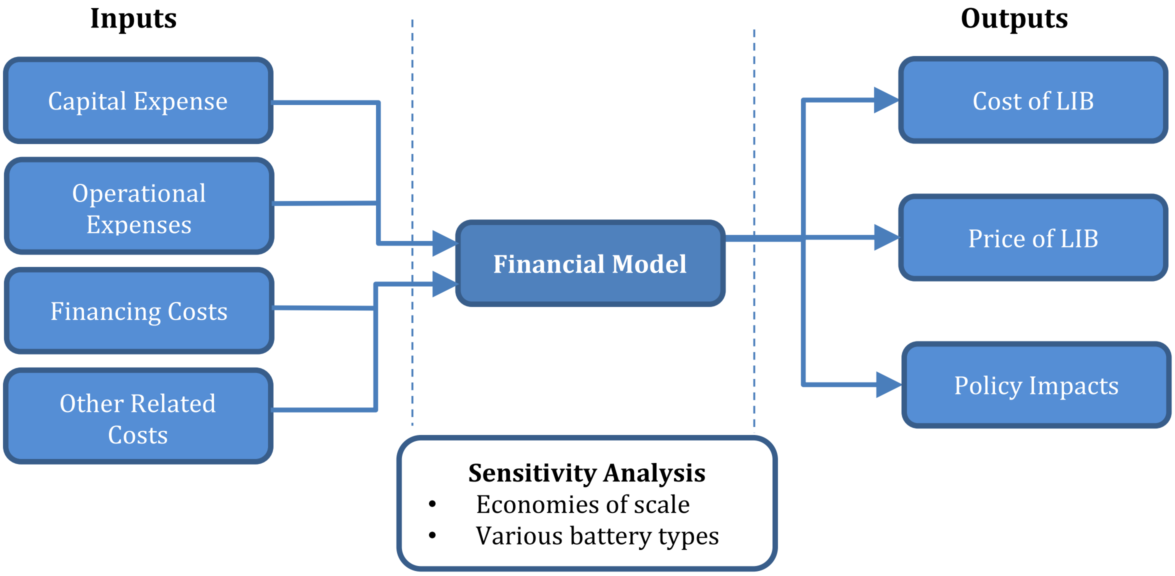

Figure 2: Schematic of financial model for 50 GWh LIB manufacturing plant[8]

This manufacturing facility would have to be built on a 500 acre plot, including a green belt area, which is mandatory for all large-scale industries. The equipment cost has a huge share in the capital cost and India needs to import most of them. The construction period of this plant would be 36 months and it can employ about 6500 full-time employees.

In the financial model, we have incorporated the following considerations while calculating the operating cost:

- The initial construction time is assumed to be three years, which is equal to the moratorium periods provided on the loans.
- The interest in the construction period has been capitalised.
- The loan is amortised over a period of 15 years.
- Depreciation has been estimated in the forecasted income statement for the entire life of the plant. The depreciation schedule was created separately for the Property, Plant and Equipment (PP&E) and buildings.

[8] Please note that the term cost refers to the input expenditures occurring during the manufacturing process whereas price denotes the market value of the commercial product i.e. LIB.

- To create the income statement forecast for a project life of 15 years, we assumed a constant manufacturing capacity of 90% of the total plant capacity. Revenues have been determined by the selling price of the LIBs.
- All resource requirements are tied to the production. The raw material costs include all the material costs incurred in the production of LIBs. The major raw materials include cathode material, electrolyte, separator, etc. The cost of raw materials is consistent across various markets. Additionally, any indirect taxes, such as import duty have been included in the material cost. The income statement and valuation have been made using real interest rates and rate-of-return rates.
- Since the labour requirement per capital is lesser than other manufacturing industries, only the salaries of the employees have been considered. The salaries are categorised into two parts, skilled and unskilled workforce. The cost of labour is cheaper in India as compared to global rates, therefore other costs, such as employee benefit costs, have not been considered as they have minimal impact on the total cost of production.

Table 2: Assumptions used in the financial model

Assumptions	
Plant capacity (GWh)	50
Total land area (acre)*	500
Equipment cost (INR crore)*	25350
Manpower*	6500
Debt : Equity	70:30
Loan repayment period (year)	10
Life of the plant (years)	20
Construction period (months)	36

Source: www.tesla.com

The initial working capital was calculated using the product of minimum number of working months and the operating costs for that duration. We assumed that the working capital would be required to cover two months of O&M costs.

Using a Net Present Value (NPV) accounting model (discounted cash flow) to analyse the manufacturing cost of LIBs in India, the following equation was used:

$$\text{NPV} = \sum_{n=1}^{\infty} \left(\frac{FCFE_n}{(1 + Re)^n} \right)$$

Where, FCFE = free cash flow to the firm = (Net income + non-cash expenses – long-term debt repayments), and Re= return on equity.

For calculating the FCFE, we assumed that the plant would not incur any new fixed capital costs, working capital costs and new borrowings. Any market price above the estimated battery price from this model will yield a positive NPV. The NPV should at least be zero in value, which would indicate that the investor can at least recover the project's costs over the lifetime of the project. A positive NPV implies that the value of revenues is greater than the cost incurred on the project, whereas negative NPV indicates that the present value of incoming revenue is lesser than the cost incurred on the project.

3. Indigenous Manufacturing of LIBs in India

3.1 Material Requirement Calculations

A typical LIB cell comprises electrodes (cathode, anode), a separator and electrolyte. Iron phosphate or a LNMC-based material is usually used as the cathode in commercial LIBs, while graphite is the most commonly used anode material.

The cathode and anode materials vary depending on the range of energy and power requirements. For our analysis, we have considered LNMC as cathode and graphite as the anode material.

Roskill estimated the material requirement for the LIB industry, considering a battery market potential of about 225 GWh globally, by 2025 (Roskill, 2017). Based on this estimation, we calculated the material requirement for a 50 GWh indigenous facility. The LIB industry will create a huge market potential for Lithium (Li) and Cobalt (Co). According to our calculations, the required amounts of Lithium Carbonate Equivalent (LCE) and Co are 38 and 13 kilotonne, respectively. Another key element, Nickel (Ni), is the fastest growing material due to the rising demand for LNMC-based cathodes. We have estimated that about 15 kilotonne of Ni would be required for the 50 GWh LIB facility. Graphite, copper (Cu) and aluminium (Al) are the other important elements and about 55, 61 and 40 kilotonne would be required, respectively. Al and Cu are used as current collectors in the battery.

3.2 Manufacuring Cost Calculations

Based on our analyses, the CAPEX required for building a 50 GWh facility would be about INR 30,000 crore (USD 4.6 billion, considering USD 1= INR 65). This includes equipement, land and building costs. The equipment cost would constitute the major share (85%) in the total CAPEX. LIB manufacturing is a working-capital intensive industry. The average operating cost per year would approx. be INR 16,231 crore (USD 2.5 billion).

Our financial calculations revealed the cost of LIBs to be around INR 9,614/kWh (148 USD/kWh). The cost share of the various components are given in Figure 3. The raw material is the biggest cost component in a LIB—66% of the total cost. Within the raw material category, the separator comprises the major share (24%) in the total cost of a battery. Once the LIB manufacturing facility has been established, and an ecosystem developed, technological innovation, dedicated R&D efforts and economies of scale can be helpful in lowering the cost of the separator. Consequently, the cost of manufacturing the LIB would further reduce. Graphite and Li contribute 10% and 5% of the cost share, respectively. Currently, China dominates the market for supply of battery-grade graphite to the LIB industry. India is the second largest producer of graphite, globally, but lacks the processing technology required to make battery-grade graphite suitable for LIB applications. Advancements in processing technology can help the industry to include Indian graphite in the LIB value chain.

The other major part of raw material cost comes from Manganese (Mn), Ni and Co which are part of the cathode component. Together, these materials contribute 7% to the total battery cost. Apart from these, Al, Co and Ni foil, Polyvinylidene fluoride (PVDF), N-Methyl-2-pyrrolidone (NMP), etc. comprise 20% of the total cost of a battery. These materials can be manufactured indigeneously. Thus, there is a scope for cost reduction.

The SG&A expenses would initially be high in this facility. However, with a better understanding of the technology, domestic or global demand and market dynamics, the effeciency of operations can be enhanced and these expenses would reduce. Therefore, the LIB cost can be further lowered.

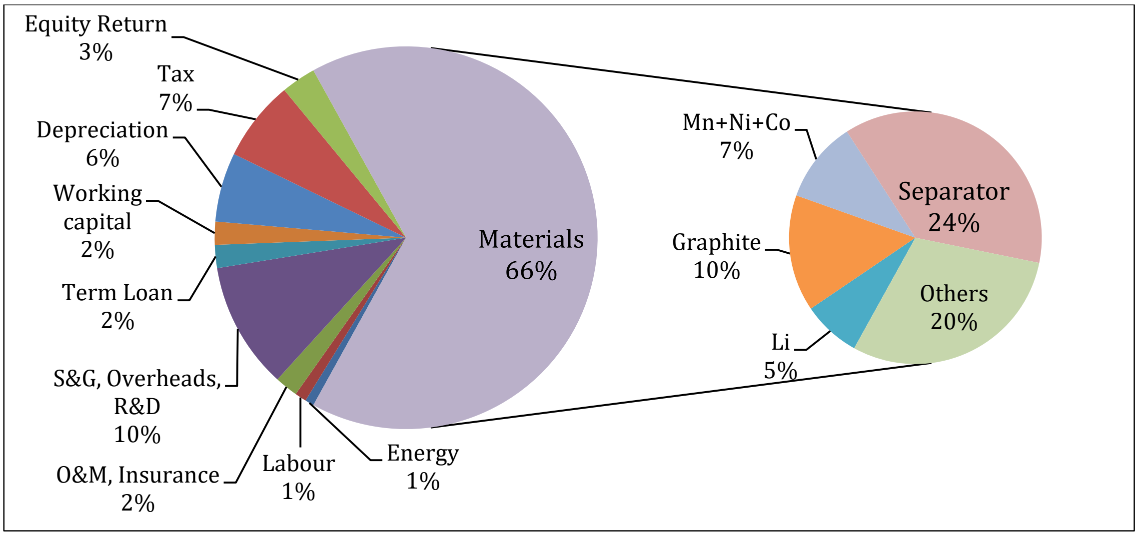

Figure 3: Cost share of various components in a LIB

As per our analysis, the cost of LIBs (USD 148/kWh) in India would be globally competitive, since Telsa has projected that their batteries would be priced at USD 150/kWh by 2020. The cost of LIBs is estimated to decline further considering the subsidies from GoI, economies of scale and introdcution of cost effective battery materials.

3.3 Sensitivity Analysis

We performed a sensitivity analysis to quantify the impact of variable parameters on the manufacturing cost of LIBs. The following three scenarios were analysed:

1. Impact of subsidies
2. Impact of economies of scales
3. Impact of different battery materials

3.3.1 Impact of subsidies on LIB cost

A 50 GWh LIB plant would incur a huge capital expenditure. Therefore, from a strategic point of view, the government can encourage investors by providing capital subsidies. Sometimes it becomes difficult to raise the working capital required for continuous operations. Therefore, we propose a subsidy scheme similar to the one currently being given to the semiconductor industry (Modified Special Incentive Package Scheme[9]). This scheme provides 25% and 10% subsidy on capital expenditure and operating expenditure, respectively. We have incorporated the same subsidy scenario in our model to check its impact on LIB costs.

If the government does provide a subsidy, on the lines discussed above, to the LIB industry, the battery cost can be further brought down to INR 9,140/kWh (USD 140.6) from INR 9,614/kWh (USD 148). This cost reduction scenario is captured in Figure 4.

[9] http://www.msips.in/MSIPS/

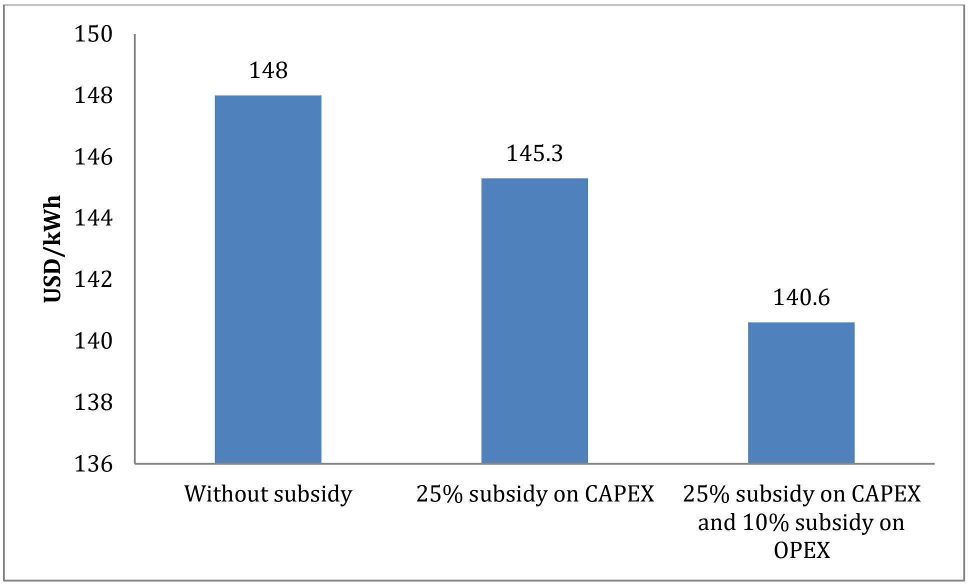

Figure 4: Impact of subsidies on LIB manufacturing costs

3.3.2 Impact of economies of scale

Economies of scale bring the following advantages to any business:

- Reduction in per unit cost of material while purchasing in bulk
- Labour economies
- Improvement in production technology
- Marketing economies by distributing the total cost over a larger number of units.

Tesla envisages to ramp-up their LIB cell production capacity to 150 GWh by 2022, if they are successfully able to run their 50 GWh LIB plant[10]. According to their projections of the economic benefits of increasing their manufacturing capacities, the manufacturing costs will reduce significantly.

A case study by Berckmans et al. shows that raw material procurement becomes cheaper by a factor of 0.765, if the manufacturing capacity is increased by twofolds (Berckmans, Messagie, Smekens, Omar, Vanhaverbeke, & Mierlo, 2017). Also, labour and overhead expenses can be optimised better. Therefore, we studied the impact of doubling the capacity on LIB costs. Every time the capacity was doubled, a decline in LIB costs was observed. Our calculations of the manufacturing cost of a LNMC and graphite-based battery in different capacity manufacturing units is shown in Figure 5. These costs are inclusive of the capital and operational subsidies mentioned in section 3.3.1. This reduction mainly happens due to a reduction in the material cost by 23% when the capacity is doubled.

[10] 21 incredible facts about Elon Musk's Gigafactory, Business Insider.

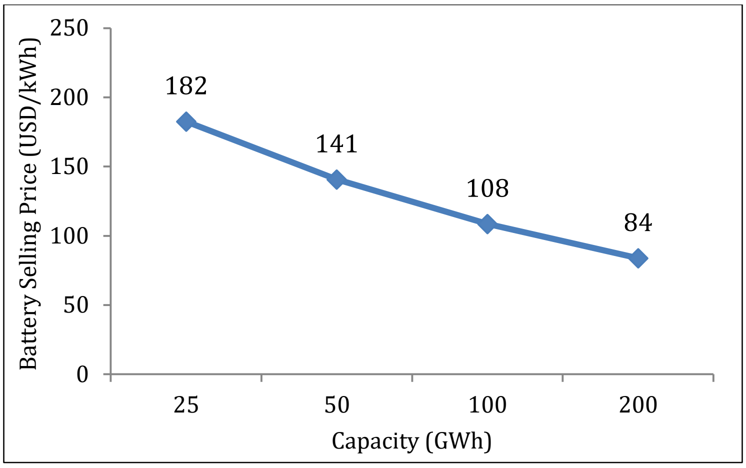

Figure 5: Impact of economies of scale on LIB manufacturing

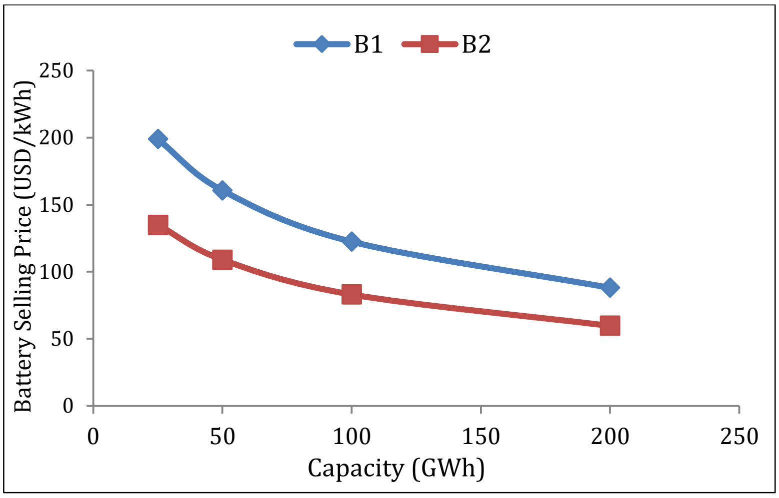

Figure 6: Impact of different battery chemistry+economies of scale+subsidies on LIB cost [i.e, B1 = LNMC cathode + graphite anode, B2 = LNMC cathode+silicon alloy anode]

3.3.3 Impact of new LIB technologies

In our financial analysis, we considered a LNMC cathode and graphite-based anode for the battery. We refer to this battery chemistry as Battery I (B1). The energy density of this battery is 155 Wh/kg., A composition of LNMC cathode with silicon alloy is believed to be a promising alternative in the near future. This composition is referred to as Battery II (B2). However, Battery II is yet to be commercialised. The energy density (205 Wh/kg) of this battery is higher than Battery I, because silicon has a higher theoretical capacity (~10 times) than graphite. Berckmans et al. have reported that by using silicon alloy, instead of graphite, the manufacturing costs can be reduced by 6% per kWh of battery. The main impact on the total cost of manufacturing a battery comes from the higher energy density of Battery II. Therefore, we assumed a scenario where the capacity of the manufacturing facility is 50 GWh and the anode material used, is silicon alloy. The overall reduction in battery cost is observed to be around 30%. The battery manufacturing costs in this scenario can come down to USD 95/kWh. Further, the same battery chemistry was used in plants with capacities of 25, 100 and 200 GWh, and the trend has been plotted in Figure 6. Our analysis shows that the manufacturing cost of Battery II, in a 200 GWh capacity facility, inclusive of subsidies, is around USD 56/kWh.

4. Challenges and Way Forward

According to this study, the LIB market potential for EVs and RE applications have been estimated at 2700 GWh and 22 GWh, respectively, by 2030. In view of this huge demand, we presented a financial assessment of a 50 GWh LIB manufacturing plant. However, the challenges discussed below need to be addressed for the successful implementation of such a LIB manufacturing plant in India.

4.1 Key Challenges

4.1.1 Low percentage of lithium reserve

The occurrences of Li ores (lepidolite, pegmatite, spodumene and hiddenite) in India are very less and concentrated in a few places. For instance, Lepidolite is present in the Bihar mica belt. Another source of Li is pegmatite, which is present in the Chitalnar, Mundwal and Govindpal areas of south Chhattisgarh. According to the Geological Survey of India, Maralagalla–Allapatna (in Karnataka), east of Srirangapatnam, contain rich quantities of spodumene (concentration of Li = 6.55–7.35%), whereas Kabbur and Doddakadanur (in Karnataka) have hiddenite (concentration of Li = 6.11%).

4.1.2 Lack of manufacturing ecosystem for battery grade graphite

India is the second largest producer of graphite. However, battery grade graphite is currently imported from China.

4.1.3 Lack of R&D

Currently, India lacks high quality R&D infrastructure to identify emerging, high performance LIB variants. R&D support will enhance the battery capacity as well as its cycle life, which will bring down the battery cost. The technical expertise on the Li recovery and recycling could be helpful for Indian context.

4.2 Policy Suggestions

The large-scale demand for LIBs has created a huge opportunity for investors to build giga-level manufacturing plants. At present, it may appear as a capital intensive investment, but it will help the country to secure the supply chain and reduce import dependence, given the huge market potential. The following policy interventions will be helpful in facilitating a cost competitive battery manufacturing facility:

- LIB manufacturing is a capital intensive industry, hence private investors can form a consortium to reduce the investment risks.
- India should consider signing a Memorandum of Understanding (MoU) with appropriate countries for a continuous supply of raw materials as the Li supply chain is limited to a few countries like Chile, Argentina, Bolivia and Australia (Figure 7). Besides Li, there should be a trade agreement with countries like Congo, Phillippines, etc. for uninterrupted supply of key battery materials, such as Co, Ni, etc.

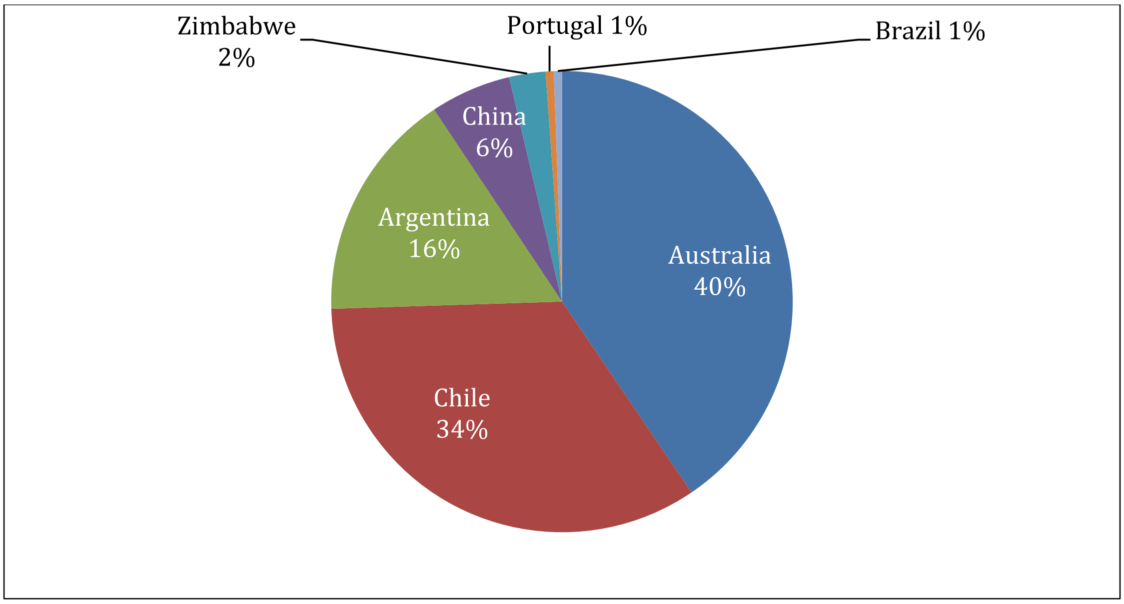

Figure 7: Global mine production of Li

- Some of the raw materials used in LIB manufacturing are scarce in India. Here, organisations like the International Solar Alliance (ISA) can play a significant role. . The ISA was formed as an international platform to aggregate demand and enable cost-effective supply chain among nations that are rich in solar potential. Many of the member countries are rich in the materials that are scarce in India. Thus, ISA can facilitate trade through bilateral agreements with specific countries. For example, Australia, Chile, Brazil, Ghana, Tanzania are rich in Li reserves. Similarly, nations such as Congo, Madagascar, Cuba, etc. can partner for supply of Co; Burundi, Brazil, Australia, etc. are rich in Ni reserves.
- Indian manufacturers should be provided with incentives to synthesise battery grade graphite indigenously since India has the pre-existing manufacturing ecosystem. At present, India imports LIB-grade graphite from China. Indigenous manufacturing will reduce costs as well as import dependency.
- Capital subsidy (25%) along with production subsidy (10%) should be provided to make indigenous LIB manufacturing cost competitive. This will help in bringing down the battery manufacturing cost to USD 140.6/kWh.
- Ensuring a steady market demand for indigenous batteries will help in creating a sustainable manufacturing ecosystem. India's national missions like NEMMP and JNNSM enable the consolidation of the LIB market in the EV and grid sectors. These policies will also help India meet the storage requirement of approx. 2700 and 22 GWh, in the EV and grid sectors, respectively.

India needs to remember the lessons it learnt from the semi-conductor industry; we are completely dependent on China for the import of solar cells and modules. This has made it difficult for India to enter the upstream supply chain. LIB is a strategic component of the clean energy and e-transport ecosystem. Timely and informed policy decisions pertaining to indigenisation will help develop a robust LIB manufacturing industry.

5. References

Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L., & Mierlo, J. V. (2017). Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030,. *Energies 10,1314*.

Deng, D. (2015). Li-ion batteries: basics, progress, and challenges. *Energy Science & Engineering*, 385-418.

Department of Heavy Industry. (2013). *National Electric Mobility Mission Plan 2020, Department of Heavy Industry.* New Delhi: Department of Heavy Industry.

Goldman Sachs. (2016). *Charging the future: Asia leads drive to next-generation EV battery market .* Goldman Sachs.

Greenwood, D., Lim, K., Patsios, C., Lyons, P., Lim, Y., & Taylor, P. (2017). Frequency response services designed for energy storage. *Applied Science*, 115-127.

Lawrence Berkley National Laboratory. (2017). *8. All Electric Passenger Vehicle Sales in India by 2030: Value proposition to Electric Utilities, Government, & Vehicle Owners .* LBNL.

Mckinsey&Company. (2017). *Electrifying insights: How automakers can drive electrified vehicle sales and profitability .* Mckinsey&Company.

NITI Aayog and Rocky Mountain Institute. (2017). *India Leaps Ahead: Transformative mobility solutions for all.* New Delhi: NITI Aayog.

Roskill. (2017, January 26). *Lithium-ion batteries: Market development and the impact on raw materials.* Retrieved March 2018, from https://roskill.com/news/lithium-ion-batteries-market-development-impact-raw-materials/

6. Appendix I

Abbreviations and Acronyms

CAPEX	Capital Expenditure
EV	Electric Vehicles
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
FCFE	Free Cash Flow to the Firm
GoI	Government of India
JNNSM	Jawaharlal Nehru National Solar Mission
LCE	Lithium Carbonate Equivalent
LIB	Lithium-ion Battery
LNMC	Lithium-Nickel-Manganese-Cobalt
MNRE	Ministry of New and Renewable Energy
MoU	Memorandum of Understanding
NEMM	National Electric Mobility Mission
NEMMP	National Electric Mobility Mission Plan
NPV	Net Present Value
O&M	Operations and Maintenance
OPEX	Operating Expenditure
PP&E	Property, Plant and Equipment
R&D	Research and Development
Re	Return on Equity
RE	Renewable Energy
SG&A	Selling, General and Administrative
V2G	Vehicle-to-Grid

CENTER FOR STUDY OF SCIENCE, TECHNOLOGY AND POLICY
18 & 19, 10th Cross, Mayura Street,
Papanna Layout, Nagashettyhalli, RMV II Stage,
Bengaluru - 560094
Karnataka, INDIA
Email: cpe@cstep.in
www.cstep.in