Exploring cost-reduction strategies for Electric Vehicle (EV) Batteries

Himanshu Shekhar

Shubham Sharma

Utkarsh Patel

Viraj Sawant

Exploring cost-reduction strategies for Electric Vehicle (EV) Batteries

December 2019

Indian Council for Research on International Economic Relations

Authors' Details

Himanshu Shekhar

PhD Student, Indian Institute of Management Bangalore

Consultant, ICRIER

hshekhar@outlook.com

Shubham Sharma

PhD Student, Division of Public Policy, The Hong Kong University of Science and Technology

Consultant, ICRIER

shubham_1717@yahoo.in; *ssharmaad@connect.ust.hk*

Utkarsh Patel

Master's (Energy) candidate, Technische Universität Berlin

Consultant, ICRIER

utkarsh@outlook.com

Viraj Sawant

Graduate Student, Institute of Environment and Sustainability, University of California Los Angeles

Consultant, ICRIER

virajsawa@gmail.com

Disclaimer: *Opinions and recommendations in the report are exclusively of the author(s) and not of any other individual or institution including ICRIER. This report has been prepared in good faith on the basis of information available at the date of publication. All interactions and transactions with industry sponsors and their representatives have been transparent and conducted in an open, honest and independent manner as enshrined in ICRIER Memorandum of Association. ICRIER does not accept any corporate funding that comes with a mandated research area which is not in line with ICRIER's research agenda. The corporate funding of an ICRIER activity does not, in any way, imply ICRIER's endorsement of the views of the sponsoring organization or its products or policies. ICRIER does not conduct research that is focused on any specific product or service provided by the corporate sponsor.*

Table of Contents

List of Tables

List of Figures

Acknowledgment

We would like to express our sincere gratitude to Shakti Sustainable Energy Foundation (SSEF) for commissioning this project. In carrying out this research, we have benefited from the experience of various experts in the field and we would like to thank them for devoting their time and energy to engage with us. We would especially like to thank Shri. Pravin L. Agarwal, Joint Secretary, Department of Heavy Industries, Government of India, for his valuable guidance. We would also like to thank Prof. Ashok Jhunjhunwala (Department of Electrical Engineering, IIT Madras), Dr. Prabhjot Kaur (Centre for Battery Engineering and Electric Vehicles, IIT Madras), Mr. C. K. Sreenath (Smart Grid and Electric Vehicle, BESCOM), Mr. Yuvraj Sarda (Sun Mobility), Mr. Swapnil Jain (Ather Energy), Ms Karthika Nair, Mr Rahul George, Mr Girish Shivakumar (Mahindra Electric Mobility Limited), Mr. Gaurav Singhal (Panasonic), Mr. Neeraj Kohli (Exide Batteries), Mr. Chetan Pathak (BSES Rajdhani Power Ltd.) and Mr. Rahul Bolini (Independent Consultant) for sharing their expertise in their respective domains. We thank Dr. Kuldip Singh Kakran(CSIR-CECRI), Ms. Chetna Nagpal (SSEF), Mr. Rakesh Kumar Yadav (Bounce), Ms. Anitha (Mahindra), Mr. Subhankar Saha (IIM Bangalore), Mr. Ravi Shankar (IIM Bangalore), Ms. Ammu Susana Jacob (C-STEP), Mr. Vinay K (C-STEP), Mr. P. R. K. Sravanana (Ashok Leyland), Mr. Adithya Srinivasan (Ather Energy) and Mr. Neel Mathews for their valuable contribution at the stakeholders' consultation workshop organised at Indian Institute of Management, Bangalore (IIMB). We would like to thank Prof. Haritha Saranga, Mr. Cedric Rebeiro and their team for helping us organise the stakeholder consultation in collaboration with the Supply Chain Management Centre at IIM Bangalore. We also thank Dr. Amrita Goldar, Ms. Manisha Mukherjee, and Mr. Manmeet Ahuja and his team at ICRIER for their valuable contributions to the study and the stakeholder workshop. Lastly, we would like to thank Dr. Rajat Kathuria (Director & Chief Executive, ICRIER) for taking his time to review the paper as well as his constant support, encouragement and guidance to our research endeavours.

Electric Vehicles (EVs) are viewed as a solution to several problems – reducing emission of greenhouse gases, sustainable economic growth, improving air quality, and reducing fossil fuel imports – in India. However, the transition from a fossil fuel-based transport system to an electric mobility system faces variety of challenges. One of the major barriers is the distinct cost disadvantage of EVs vis-à-vis traditional internal combustion engine vehicles. The battery in an EV is its most expensive component, accounting for 50 per cent of its total cost; thus, the affordability of EVs is directly proportional to the affordability of a battery. This study identifies strategies that could reduce battery costs and make EVs affordable and improve its uptake in transport and mobility system in India.

Objective

The objective of the study is to design a comprehensive strategy and recommend a mix of policy instruments that are implementable by the central/state governments and other stakeholder like Energy Efficiency Services Limited (EESL), Original Equipment Manufacturers (OEMs), etc. This objective is achieved by disaggregating the main research question into the following sub-questions:

Table 1: Sub-questions and their significance

Question	Significance
What are the major cost components of an electric vehicle battery?	The goal is to identify areas of intervention by analysing the cost component of a battery. Moreover, since technologies are an important consideration for intended application use and thus cost, this question also resulted in a comparison of different battery technologies.
What is the current status of EV battery value chain in India?	While the previous step helped in identifying the areas of intervention theoretically, this step results in analysing the applicability of the model in the Indian context in terms of the maturity of the different aspects of battery manufacturing and the interests of stakeholders. The information on ways to reduce the cost of a battery is also collected in this step.
What could be the strategies to reduce the cost of batteries? Relative importance and ranking of these strategies?	This is the culmination of the first two steps and outlines options for policy makers to reduce the cost of batteries. The ranking exercise subsumes the prime concerns of all stakeholders as it involved subject matter experts from industry, research and government. The strategies are ranked by these experts based on their effects in terms of reducing cost, the time in which they yield results and the investment required to implement them.

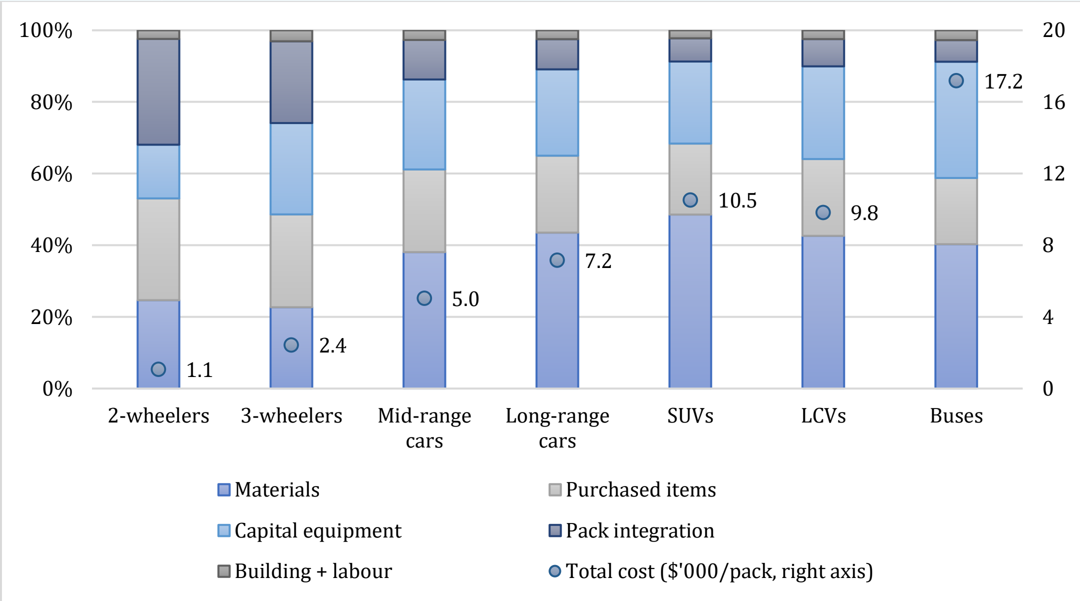
Given the technical nature of the model developed, the report also dedicates a chapter on familiarising readers with a battery, its components and functioning and discusses certain battery technologies (chemistries).

Estimating the cost of batteries:

The cost of a battery is disaggregated by building a bottom-up model of battery cost by using the BatPaC (Battery Packaging and Cost estimation) tool, a publicly available, peer-reviewed, and customisable Microsoft Excel-based computer program developed by the Argonne National Laboratory (U.S.).

The final price of the battery pack to vehicle manufacturers calculated by the model represents the estimates of both 2018-19 costs and those projected upto 2028-29 (without accounting for inflation in the future).

Figure 1: Breakdown of costs with overhead items distributed to the primary cost-factors



Source: ICRIER research based on BatPaC

The cost breakdown analysis suggests that apart from the positive active material, which has a significant contribution in all vehicles, negative active material and electrolytes account for large shares in the cost of batteries. The formation cycling, testing, and sealing or the cell finishing process is also significant in determining the final price of the pack. The shares of building and labour costs combined per pack are found to be insignificant for all the cases.

The disaggregation indicates the importance of the availability of critical cell components in managing the cost of a battery and the development of ancillary industries (module hardware, separator, etc.) that would play an important role in reducing the final cost of the battery.

EV battery value chain in India:

This outline helped in identifying the relevant stakeholders and in collecting information that was used to develop the model mentioned above and in identifying cost reduction strategies beyond manufacturing. Based on consultations with stakeholders in the value chain, it is found that cost reduction is possible beyond the manufacturing and sale of a battery.

Table 2: Cost reduction drivers in value chain

Value chain	Cost reduction drivers	Impact on cost (Short / Medium/ Long term)
Material sourcing &Component manufacturing	Access to supply chains Manufacturing, Lower transactions cost	Long Term Long Term Medium/ Long Term
Cell manufacturing	Manufacturing Lower financing, transaction & import costs	Medium Term Medium Term
Packaging	Local components and software at scale	Short/Medium-term
Vehicle integration	Standardisation of battery designs & protocols to achieve domestic scale	Short/Medium-term
Usage profile	Various business cases to reduce total cost of ownership (TCO)	Short/Medium-term
Second-life/Reuse	Extended life & alternative uses	Medium Term
After-life/recycling	Cost recovery from material recycling	Medium Term
Research & Development	Technology development	Medium/Long Term

Source: ICRIER Research, calculations based on data from secondary and primary data collection

Based on the modelling results and interviews, the study identifies a few strategies. Moreover, since the transition to an electric mobility system is a complex policy problem, electric vehicle policies of different countries are also discussed along with those adopted by India to present a comprehensive background.

Policy Perspectives and Propositions

A review of EV policies and goals in six countries, namely, Norway, China, Sweden, Germany, The United States and The United Kingdom along with current policies in India at the central level and state level is undertaken in the study. These countries have done well in promoting EVs and lessons from their experiences helped contextualise the information collected in previous steps to identify policy area and cost-reduction strategies.

These strategies are then prioritised using the Analytic Hierarchy Process (AHP) in a workshop that was attended by experts from industry, research and academia.

The analysis shows that the impact of a strategy in reducing the cost is the most important criterion, followed by time. The low weightage given to the investment criterion reflects experts' belief that investment should not be a constraint in choosing a strategy. The final ranking is provided in Table 3 below.

Table 3: Ranking of strategies

Alternatives	Rank
Incentivising Cell Manufacturing.	1
Improving the availability of critical cell components like lithium, cobalt, graphite	2
Standardisation – Battery standards, testing standards, etc., to prevent the entry of non-standardised batteries into the market and promote investments.	3
Development of ancillary industries for pack components – Battery management system (domestic production of PCBs, ICs, etc.), binder and other products used in batteries apart from cells.	4
Incentivising reverse logistics, reuse for stationary usage (grid, invertor, RE storage), recycling of batteries and recovery of critical metals/materials.	5
Demand aggregation – Aggregation of demand in case of public transport to augment overall demand for batteries and promote domestic cell manufacturing.	6
Dedicated battery research institute – which works on all aspects of batteries including cell chemistry and pack components in collaboration with the government and the industry	7
Battery as a service – Innovative business models to reduce the cost of the battery.	8

Source: ICRIER research based on the stakeholder feedback exercise

The analysis reveals that domestic manufacturing of cells must be prioritised to make batteries affordable as three out of top four strategies – incentives for cell manufacturing, availability of critical components and development of ancillary industries – are related to manufacturing. Apart from these, another prioritised strategy is standardisation. It is a relatively inexpensive policy instrument that would promote investments in the market by preventing the entry of sub-standard batteries. While most of the other options have similar properties, their potential in reducing will become significant with further development of value chains, especially in the case of reuse and recycling. However, the success of most of these efforts depends on the scale of operation and hence, initiatives to spur demand and create a market must be pursued simultaneously.

Overall, the study reaffirms the importance of domestic cell manufacturing in reducing the cost of an EV battery and identifies the need for efforts in certain areas such as reverse logistics and standardisation. It is important to understand the impact of recycling/reuse and standardisation in reducing cost and further research is needed in these areas. Similarly, further research and detailed cost-benefit analysis are required to determine the proper mix of policy instruments.

1. Introduction

The transport sector is among the highest emitters of greenhouse gases globally. The decarbonisation of the transport sector has become an integral part of the global climate change mitigation measures to limit global warming to 1.5 degree Celsius above the pre-industrial levels. It is now widely accepted that increasing the adoption of cleaner modes of transportation, such as electric vehicles (EVs), are crucial to limit the emission of greenhouse gases into the earth's atmosphere. However, the total cost of ownership remains a big hurdle in the mass adoption of EVs. The battery in an EV is its major cost component and making batteries affordable will help overcome the cost barrier. This study focusses on EV batteries and explores the strategies that will help reduce their overall cost and, hence, the cost of EVs.

Globally, the transport sector accounted for more than 20 per cent of total carbon dioxide emissions in 2017 (approximately 8 Gt of CO_2).[1] Road transport (private and commercial) alone contributed to three-quarters of the transport sector's total emissions, highlighting the potential of electric-mobility (e-mobility) to reduce greenhouse gas emissions. E-mobility includes all road vehicles (pure EV, range-extended electric vehicles – REEV and hybrid EVs) that primarily derive energy from the electricity grid instead of a conventional internal combustion engine running on fossil fuels.

With rising levels of urbanisation, particularly in developing countries with high populations, governments are faced with the dual challenge of meeting the growing demand for transportation services and simultaneously reducing greenhouse gas emissions. In such a scenario, it becomes necessary to formulate policies that are financially and environmentally sustainable to remove barriers to the more widespread adoption of e-mobility and overhaul the entire transportation system. While evolving technologies and a maturing EV market remain a challenge for policymakers, the high total cost of ownership is a significant factor restraining the uptake of EVs (Gao, Kaas, Mohr, & Wee, 2016).

EVs face competition from traditional internal combustion engine (ICE) vehicles that, at present, are comparatively affordable and convenient with omnipresent refuelling infrastructure. Traditional vehicles generally offer users good performance and cost-effectiveness. Constant efforts, including the creation of supporting infrastructure for charging and providing financial incentives for research and development, manufacturing and adoption, are being made to improve the performance and reduce the cost of EVs to make them more competitive. Most of these efforts usually narrow down to the batteries, which account for almost 50 per cent of an EV's cost (Kochhan, et al., 2014). Hence, the affordability of the battery will play an instrumental role in overcoming the cost barrier to better adoption of EVs in India's transport system.

India is a fast-growing large economy and has set for itself ambitious climate change mitigation targets. Providing better transportation and simultaneously reducing greenhouse gas emissions necessitates faster development and wider adoption of electric

[1] CO_2 emissions statistics - https://www.iea.org/statistics/co2emissions/ accessed on October, 01 2019

mobility across all segments of the transport sector, viz., private vehicles, public transport, railways and mass transit and freight, to meet the needs of a growing population. India has established itself as a major automobile manufacturer in the world. The local manufacturing ecosystem for automobile components, along with the availability of skilled labour, has made it possible to produce vehicles at a low cost both for the domestic and global markets. However, transitioning towards e-mobility will require greater support from the government. Battery manufacturing is one area that needs immediate attention because faster transition towards e-mobility is contingent on batteries being more affordable.

The transition to an electric mobility system is an essential part of sustainability transitions – processes through which traditional and prevalent socio-technical systems move to more sustainable ways of producing and consuming. Its success will depend on the ability of market systems and institutions to absorb the technological change inherent in it and, thus, complex policy strategies are required that could facilitate this change (Lehmann, 2010; Twomey, 2012; Weber & Rohracher, 2012). The study aims to inform policy makers of the complexity of the challenge by explicitly focusing on the affordability of EV batteries and possible areas that need immediate intervention. The main question of identifying cost-reduction strategies is divided into three sub-questions:

1. What are the major cost components of an EV battery?
2. What is the current status of the EV battery value chain in India? Are there any cost reduction opportunities?
3. What could be the strategies to reduce the cost of batteries? What is the relative importance and ranking of these strategies?

What are the major cost components of an EV battery?

The objective is to identify major cost components in a battery by disaggregating its cost and focus on these components and their possible role in reducing the cost of a battery. Additionally, since demand for a certain application (2-wheeler/3-wheeler/cars/buses, etc.) will determine overall battery demand and thus, the benefits from manufacturing at scale, the cost-break up for different applications is also studied. These results are obtained from the BatPac model – an excel-based tool to estimate the performance and cost of an EV battery – by values of relevant factors and inputs to match the Indian context.

What is the current status of the EV battery value chain in India? Are there any cost reduction opportunities?

The results from the first question only pertains to battery manufacturing and are theoretical in nature. Cost-reduction strategies could exist beyond manufacturing and the applicability of results from the model will depend on the readiness of different stakeholders involved in battery manufacturing and packaging. These concerns are addressed by outlining an EV battery value chain in India and interviewing concerned stakeholders. The information on cost-reduction strategies and measures taken by certain stakeholders is also collected in this step.

What could be the strategies to reduce the cost of batteries? What is the relative importance and ranking of these strategies?

Based on information from research on the first two questions, this step lists possible areas of intervention for cost-reduction. EV policies in different countries are also reviewed to understand the factors that helped faster adoption of EVs and to explain the complexity and plausible interactions of different strategies. These strategies are then ranked according to the criteria of their impact on reducing battery cost, implementation time and the investment involved in implementing them. This ranking is based on the responses provided by several experts from industry, research and policy making and reflects their priorities.

The study also dedicates a chapter on battery technologies to establish a basic understanding of a battery, its components and functioning, theoretical parameters, the rationale behind the selection of a technology and other important technical factors. The second chapter sheds light on these concepts. The next chapter deals with the first sub-question and contains modelling results and their implications for reducing the cost of an EV battery. Chapter 4 outlines the EV battery value chain in India and the opportunities and challenges in each stage of the chain. Chapter 5 and 6 deals with the third sub-question by reviewing the EV policies in different countries – Norway, China, Sweden, Germany, The United States, The United Kingdom – and in India (both at the central and state level) and listing and ranking the identified cost-reduction strategies.

Overall, the study contributes to improving understanding of the EV transition and informs policy makers of possible areas of intervention. Although it identifies strategies and ranks them, the overall feasibility and effectiveness of a policy instrument in these areas require detailed cost-benefit analysis. Similarly, battery technologies, application use (2-wheeler/3-wheeler/cars/buses, etc.), demand and recycling also need further research to assess their potential impact on reducing the battery cost and making EVs affordable.

2. Battery Development

- Viraj Sawant

A battery comprises several fundamental electrochemical units called cells. However, the two terms are often used interchangeably and hence, the discussion on battery chemistries and its properties usually refer to the chemistry and properties of a cell. The invention of the lithium-ion (henceforth Li-ion) battery was pivotal to the development of EVs as it improved the economics of the vehicles and brought EVs closer to meeting the performance expectations set by traditional vehicles. Li-ion batteries are a major improvement over previous batteries in terms of rechargeability, energy density and power capacity, durability and cost. In this chapter, the properties of Li-ion batteries and their advantages over other available battery technologies for application in EVs is discussed.

2.1 Components of a Li-ion Battery

A Li-ion battery consists of four major components – the cathode, anode, electrolyte and separator.

Cathode

In Li-ion batteries the chemical reactions inside the cell create a flow of electrons in the external circuit, generating electricity. As in any chemical reaction, the entity that accepts electrons becomes negative and the one that loses electrons becomes positive. The Li-ion battery uses lithium as the positive material, which makes up the cathode (the positive electrode). However, the cathode is made up of a compound of lithium since lithium is unstable in its elemental form. The properties of a cathode are instrumental in determining cell capacity and potential difference between the cell electrodes. The following materials are used for the cathode (Energy Alternatives India, 2019):

- Nickel Cobalt Manganese (NCM)
- Nickel Cobalt Aluminium (NCA)
- Lithium Ferro Phosphate (LFP)
- Lithium Manganese Oxide ($LiMnO_2$)
- Lithium Cobaltate ($LiCoO_2$)
- Lithium Titanate (Li2TiO3)

Anode

A majority of Li-ion batteries use graphite as the anode. Graphite can either be synthesised artificially or naturally and is used as an anode as it is stable, inexpensive, light and porous.

Electrolyte

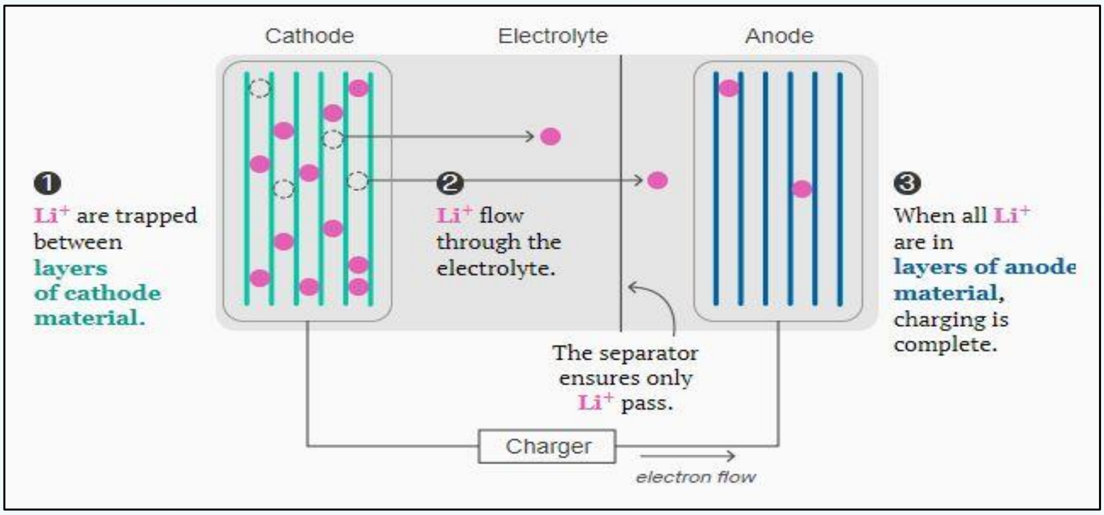
While the electrons flow between the cathode and anode in the external circuit, the ions flow internally in a cell to balance the transfer of charge. The electrolyte facilitates this reaction by providing a medium for the transfer of ions. The electrolyte in a Li-ion battery is a lithium salt, for example, $LiPF_6$ (Lithium hexaflurophosphate).

Separator

A separator is used to keep the electrodes from short-circuiting. Different insulating materials like polythene, polypropylene or ceramics can be used, depending on cell chemistry. The material should be such that it allows for the transfer of ions essential to the chemical reaction.

Chemically, an anode is the reducing electrode that provides electrons to the external circuit (positive material). It gets oxidised during the discharge while a cathode is the oxidising electrode that gets reduced as it accepts electrons from the external circuit (negative material). The exact opposite process occurs while charging. Hence, the overall objective of technological research and development is to produce a combination of cathodes and anodes that give higher voltage and energy capacity and are lighter and stable. Figure 2.1 shows a schematic of a Li-ion cell:

Figure 2.1: Schematic of a Li-ion cell



Source: (Rathi, 2019)

The schematic shows the electrochemical process that takes place inside a cell during charging. When the battery discharges through a load (e.g., an electric motor in an EV) the opposite process takes place – the Li-ions accumulated on the anode flow back to the cathode through the electrolyte and the electrons flow through the load (a motor). Both the electrodes are coated with an active binder material to facilitate the flow of electrons. The material used for electrodes and electrolytes affects the properties of the cell such as capacity, density, stability and rechargeability, and its cost, and therefore, different chemistries are used for different applications.

2.2 Theoretical considerations

The electrochemical potential of the active materials of cell – anode, cathode, and electrolyte – determine the potential output of that cell. The potential of a cell will be proportionate to the relative weights of these active materials. In its simplest format, the cell potential is described as the sum of anode potential and cathode potential:

Anode (oxidation potential) + Cathode (reduction potential) = Standard Cell Potential

The theoretical capacity of the cell is measured in coulombs or Ampere-hour (Ah). As it follows from how cells function, it depends on the type and amount of reacting material used in the cell. The total energy stored in a cell is thus calculated as the product of theoretical capacity (Ah) and the cell potential (V). The unit of this product thus is Watt-hour (Wh). However, in reality, the reported values of energy and capacity of a physical cell are well below their theoretical levels as the cell also consists of many non-active materials that are necessary for its functioning (Figure 2-3). The presence of these non-active materials decreases the relative share of active materials in the total weight of the cell. The values in Table 2.1 are the theoretical limits of different battery chemistries.

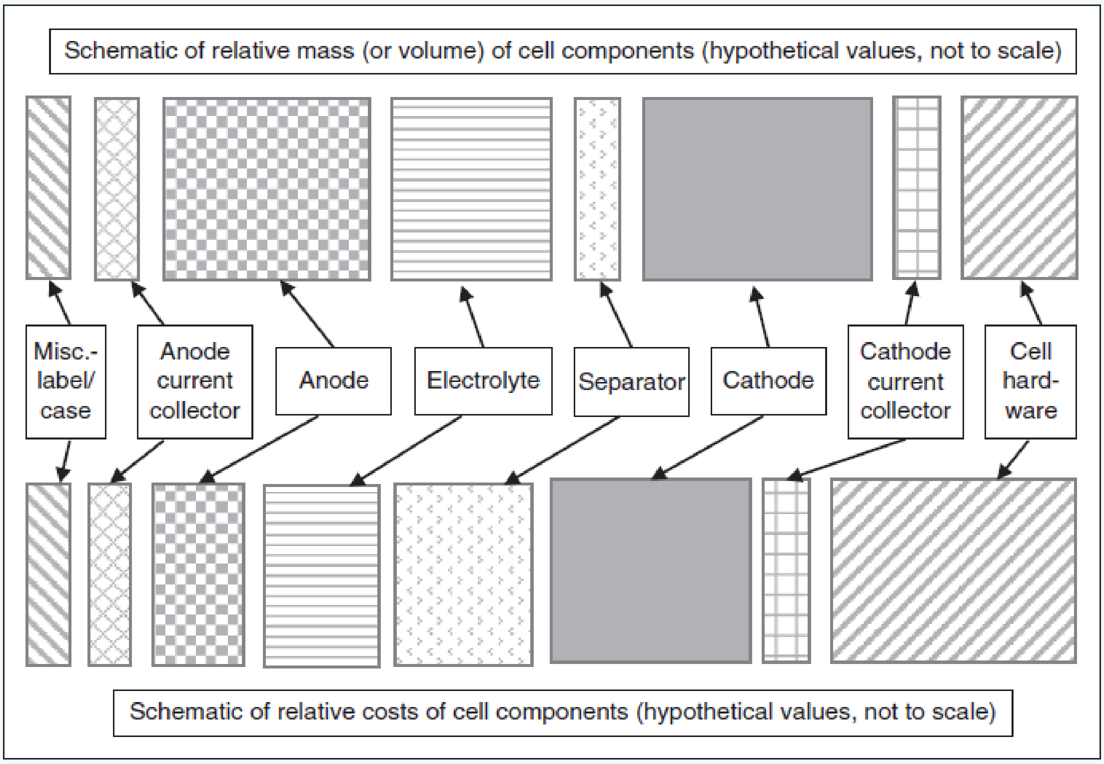
Figures 2.2 and 2.3 show the relative costs of different components in a cell and the different chemistries with respect to their gravimetric and volumetric densities respectively. The variation in costs, weights, energy density and reactivity for different chemistries and various components within a cell is the reason why cell development is still a field of continuous ongoing research and innovation. A detailed breakdown of the cost components of a cell/battery is discussed in Chapter 3.

Table 2.1: Theoretical voltage capacities for various commonly used battery types

Battery type	Anode	Cathode	Theoretical Values		Practical Battery	
			Nominal Voltage (V)	Specific Energy Wh/kg	Nominal Voltage (V)	Specific Energy Wh/kg
Lead-acid	Pb	PbO2	2.1	252	2.0	35
Edison	Fe	Ni oxide	1.4	314	1.2	30
Nickel-cadmium	Cd	Ni oxide	1.35	244	1.2	40
Nickel-zinc	Zn	Ni oxide	1.73	372	1.6	90
Nickel-hydrogen	H2	Ni oxide	1.5	434	1.2	55
Nickel-metal hydride	MHc	Ni oxide	1.35	240	1.2	100
Silver-zinc	Zn	AgO	1.85	524	1.5	105
Silver-cadmium	Cd	AgO	1.4	318	1.1	70
Zinc/chlorine	Zn	Cl_2	2.12	835	—	—
Zinc/bromine	Zn	Br2	1.85	572	1.6	70
Lithium-ion	Li_xC_6	$Li_{(i-x)}CoO_2$	4.1	448	3.8	200
Lithium/manganese dioxide	Li	MnO_2	3.5	1001	3.0	120
Lithium/iron disulphide	Li(Al)	FeS_2	1.73	493	1.7	180
Sodium/sulphur	Na	S	2.1	792	2.0	170
Sodium/nickel chloride	Na	$NiCl_2$	2.58	787	2.6	115

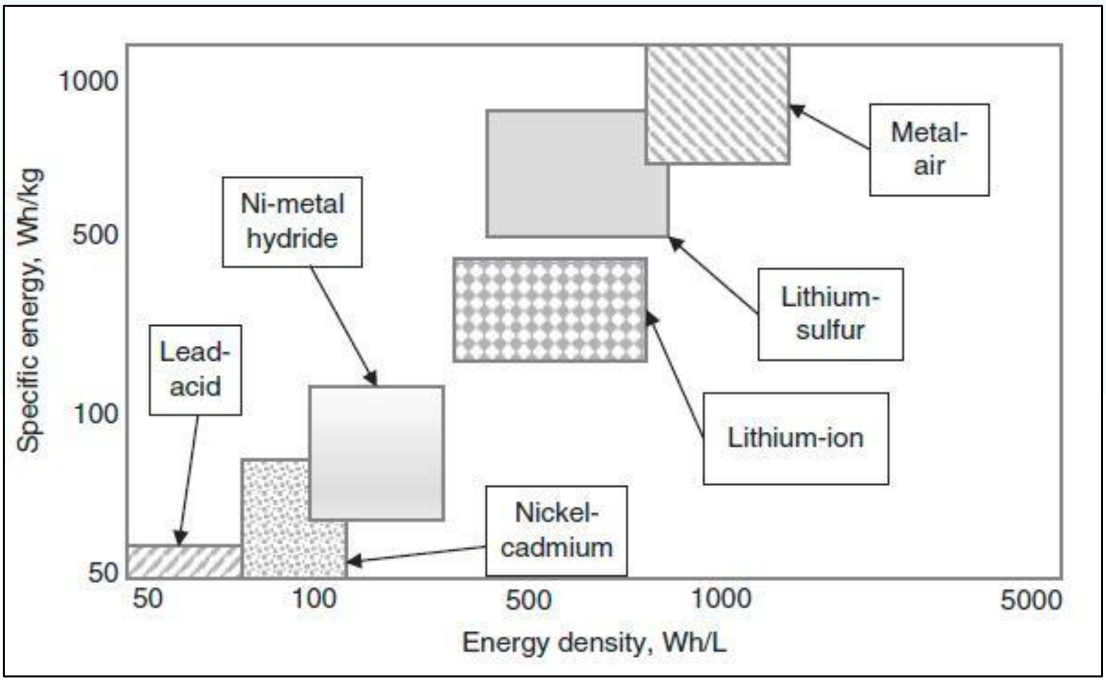
Source: (Beard, 2019)

Figure 2.2: Components of the battery compared



Source: *(Beard, 2019)*

Figure 2.3: Various batteries chemistries and their energy densities and specific capacities



Source: *(Beard, 2019)*

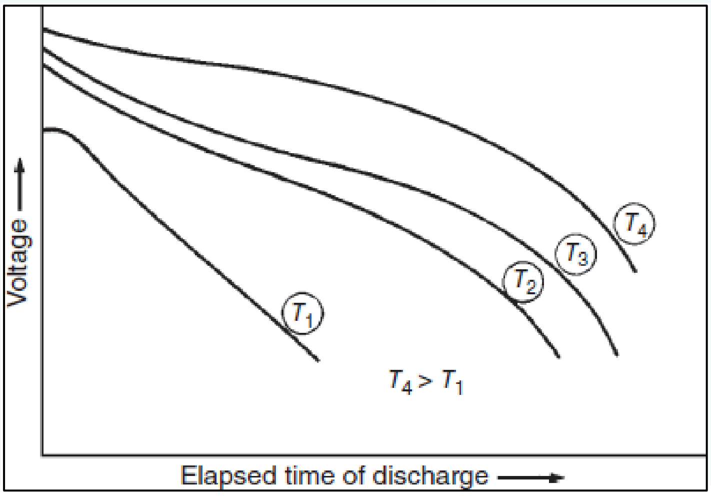
2.3 Battery Performance

As seen in the previous section, the theoretical and practical energy output of the battery system differs. So, in addition to looking at the theoretical limits of different batteries, attention must be paid to factors that affect battery performance. Batteries, when operated under less than favourable conditions, perform differently than expected. This section discusses other factors that may adversely affect a battery's performance (e.g., reduction in voltage, energy density, etc.) or shorten its life.

Individual cell and battery design are the basic structural factors that determine a battery's performance. At the cell level, electrode design comes with an inherent trade-off between the discharge rate and the electrical capacity of the cell. Changing the dimensions of the electrodes can result in different output potential, and therefore, extensive tests are carried out to determine optimal electrode design. For example, dual systems that are used sometimes for special applications combine different types of electrodes to maximise both the capacity and discharge rate, which naturally raises the overall cost of the battery.

How batteries are charged also affects battery life. Unbalanced cell performance within a battery can result in a reduction in voltage, capacity, discharge rate, etc. Recently, smart advanced algorithm techniques, embedded into a battery's state of charge monitors,2 have been developed to control cell variations (Beard, 2019).

Figure 2.4: Voltage variation at different temperatures and discharge times



Source: (Beard, 2019)

Temperature is an important factor that can significantly affect the internal resistance of a cell, which in turn can alter its capacity, voltage and charge characteristics. At the battery level, even though identical cells are packaged into a pack, each cell experiences varied physical conditions based on its location. Figure 2.4 shows variation in voltage at different temperatures. The cell geometry plays a decisive role because the heat dissipation factor depends upon the chosen geometry. Generally, for most cells in use at present, the ideal

2 State a battery parameter which measures current charge available in the battery

temperature for operation is between 20^0 and 40^0 C. Thus, it is important to ensure that cells are not exposed to external temperatures beyond this range.

Thermal management is very pertinent for battery powered EVs in India. An increase in temperature beyond a certain degree leads to accelerated activity within cells which degrades their performance and may even pose a safety hazard. Previous research on thermal management of batteries have been conducted mostly for ambient conditions that are cooler than those prevalent in India. High temperatures in some regions of India entirely eliminate the possibility of using some cooling techniques that are prevalent in colder regions. They also negatively affect the useful life of a battery. More research, therefore, is required in this area with specific attention to Indian climatic conditions (Yaqzan, Rafat, Abdullah, & Alam, 2017).

3. Estimating the Cost of Batteries

– Utkarsh Patel

As mentioned in the preceding section, several factors relating to the physical and chemical properties of the different components constituting a cell affect both the cost and performance of the battery in varying proportions and permutations. The developers have numerous degrees of freedom in terms of the parameters that they can select for making the battery, which provides them the flexibility to customise a battery according to their requirement, compromising some factors over others. For example a developer can opt for better performance even if this implies a higher cost. This makes estimating the cost of a battery a complex exercise.

Nonetheless, a reliable estimate of cost is necessary for economically sound public policy. A realistic cost estimate would help design an optimal electric vehicle policy that delivers the maximum benefits for the least cost. Given the share of expenses that goes into procuring batteries for an electric vehicle, it is imperative to estimate the costs as accurately as possible to identify measures that could lower the total cost of the batteries and, in turn, that of the vehicles. Computer simulation using mathematical models can generate reasonably robust cost estimates with high accuracy. In this case, the focus is on disaggregating the cost of a battery and pinpointing the major cost components. It will help determine the potential impact of cost components in reducing the cost of batteries and thus, identify cost reduction strategies.

The cost of batteries as reported in the following section of this chapter are estimated using BatPaC v3.1 tool – a publicly available, peer-reviewed and customisable Microsoft Excel-based computer programme.

3.1 BatPaC: Battery Packaging and Cost estimation tool

BatPaC is a battery manufacturing cost estimation software developed at the Argonne National Laboratory (US) to estimate the cost of lithium-ion battery packs for automotive applications. It is a modelling tool that helps simulate specialised battery designing. The user has the flexibility to specify technical parameters such as power, energy, cell chemistries and vehicle application and examine the trade-offs in performance, cost and physical dimensions that result from differing requirements, constrained by design parameters like density, form-factor, annual production rate, etc. It further analyses the effect of battery design and material properties on the estimated cost of the final battery pack.

The model is programmed to perform a bottom-up design and cost calculation of a lithium-ion battery, giving the user the advantage of traversing the entire chemical, physical and economical set up and examine the correlation between performance and cost. It is based on circular extrapolations, and the cost of a battery is estimated by accounting for every step in the process of lithium-ion battery manufacturing with regards to the stated design while incorporating and offsetting, if necessary, the physical limitations of the electrochemical processes.

The tool offers its users a selection from a range of pre-programmed cell chemistries, viz.:

- Li Nickel Manganese Cobalt Oxide ($LiNi_{0.3}Mn_{0.3}Co_{0.3}O_2$) – Graphite (NMC333 - G)
- Li Nickel Manganese Cobalt Oxide ($LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$) – Graphite (NMC622 - G)
- Li Nickel Cobalt Aluminium Oxide ($LiNiCoAlO_2$) – Graphite (NCA-G)
- Li Iron Phosphate ($LiFePO_4$) – Graphite (LFP-G)
- Li Manganese Oxide ($LiMn_2O_4$) – Li Titanate ($Li_4Ti_5O_{12}$) (LMO-LTO)
- Li Manganese Oxide ($LiMn_2O_4$) – Graphite (LMO-G)
- Li NMC333/LMO – Graphite

In this report, battery models designed for different application are based on LiNMC622 cell chemistry that has (i) high energy density, which makes it suitable for all passenger vehicle types, (ii) low cooling power requirement, which makes it safer for Indian climatic conditions and (iii) relatively lower cost compared to LiNCA batteries.

The model is built on the assumption that sufficiently advanced, high-volume manufacturing of Li-ion batteries for transportation applications exists. It takes into consideration the fact that manufacturers face high costs of production in part due to the lack of mass production facilities. There are options to adjust the values for factors such as materials cost, rate of yield and failure in the model. Values for costs of input materials and capital are obtained from either publicly available sources or own research. However, there exist significant uncertainties in the estimated values of point costs. From an economic policy-making perspective, information on the share of cost of specific items to the total cost of a pack and change in costs relative to changes in material properties and performance of the battery is a vital component of this exercise.

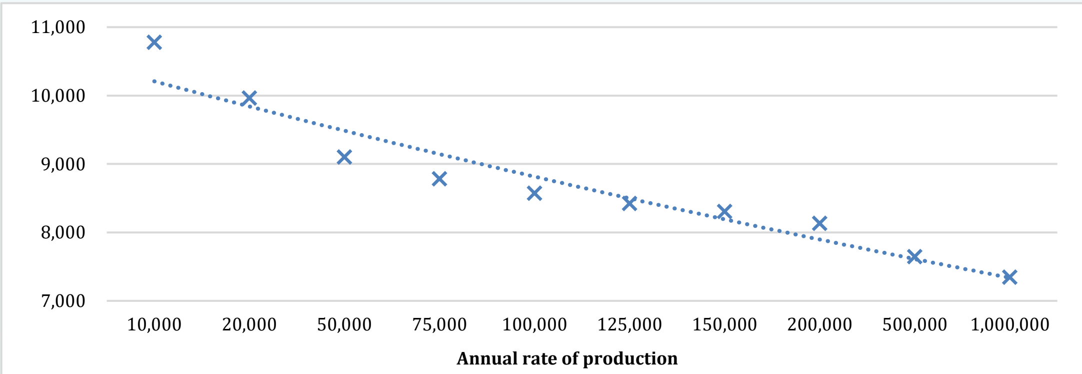
The cost of a battery pack depends significantly on the prices of both the active and inactive materials that constitute the design. The calculated total battery cost to the original equipment manufacturer in BatPaC, by default, is set to be comparable to the battery pack level goals as set by the US Advanced Battery Consortium. The prices of battery materials, viz., positive and negative electrode active material, current collector foils, electrolyte, separators, carbon and binders, purchased hardware for cells and modules, battery packaging and integration reflect 2018 international prices as reported in BatPaC. These have not been altered for the purpose of this study on the assumption that large-scale procurement cost will be similar for Indian manufacturers as well.

Costs of labour and capital have been aligned with those in the Indian market. The costs of sales, and administration (e.g., property taxes, insurance), research and development, and depreciation are fixed as a percentage of capital investment, while profits and warranty costs are proportional to the total investment and price of packs respectively. A variable overhead component (made up of indirect materials, utilities, plant maintenance, etc.) is also incorporated into the calculations.

The final price of the battery pack to vehicle manufacturers, calculated by the model, represents the cost estimate for the year 2018-19 and those projected for the year 2028-29, depending upon the designated scale of production. The model's algorithm is based on the presumption that battery manufacturing plants in the future will have very high production volumes (up to 500,000 battery packs per annum) and will deploy highly automated production processes, resulting in lower capital and labour costs per unit of output relative to present day plants. It is important to note that the cost estimates are for the year corresponding to the year of input material prices and future battery prices, which are based on current US dollars and do not account for inflation.

The user has the option to change the annual rate of production of battery packs. The rate directly affects each step of the production process and alters the final price of the output non-linearly, accounting for economies of scale, i.e., higher rates of production lead to lower costs (see Figure 3.1). To incorporate this into the program, a general approach to cost estimation of multiplying a known cost by the ratio of processing rates raised to a particular power factor has been applied to individual items including capital equipment and labour.[3]

Figure 3.1: Cost of mid-range cars with respect to annual production rate

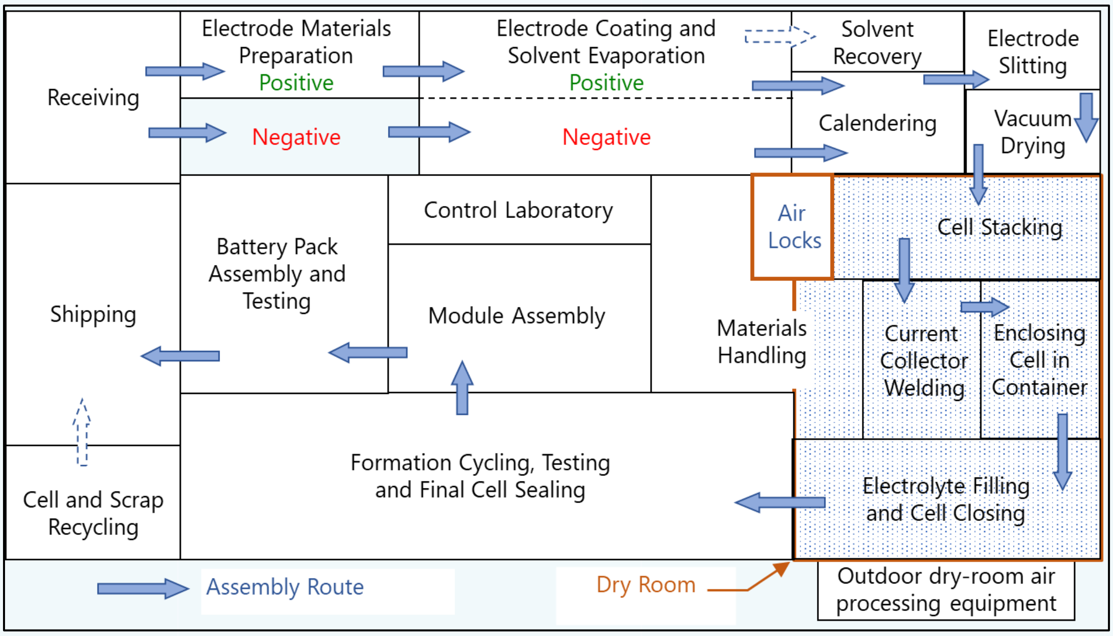


Source: ICRIER research, based on BatPaC

Figure 3.2 illustrates a schematic diagram of the flow of materials through a battery manufacturing plant, as simulated in the BatPaC model. An annual rate of production of 100,000 battery packs for each electric vehicle application is assumed (achieved by operating three 8-hour shifts per day for 300 days a year). For a detailed description of the BatPaC model and its estimation algorithms, one may refer to ANL (2019).

3 Mathematically, this can be expressed as $C = C_o(R/R_o)^p$ where, C_o is the cost of an installed item designed for the baseline processing rate, R_o is the power factor, and p, the cost and the processing rate for manufacturing.

Figure 3.2: Flow of materials through a battery manufacturing plant

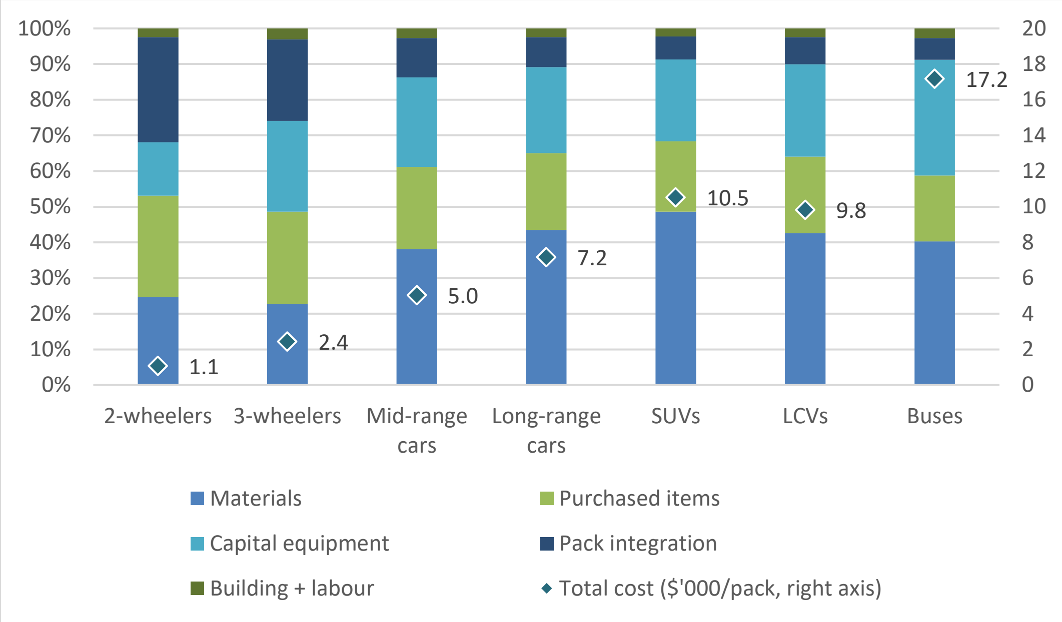


Source: ANL, 2019.

Table 3.1 provides the details of the end-use electric vehicle (two/three-wheelers, cars, SUVs, LCVs and buses) and the technical specifications of the battery designed for the respective application, including estimates of the cost of the complete battery system to the original equipment manufacturer and the total investment requirement. It is worth reiterating that there are potential uncertainties in estimating the price of lithium-ion batteries due to several factors. Therefore, apart from the point estimates of the cost, the model also generates a 95 per cent confidence interval of the cost, considering an error in input costs of materials and capital equipment, and in the limit on the thicknesses of electrode coatings and the capacity limit on cells (a combined error of +/- 15 per cent).

Figure 3.2 shows the cost breakdown of the battery packs into the cost of materials, purchased items, capital equipment, integration, building infrastructure and direct labour, along with the total cost per pack, including the overhead items.

Figure 3.3: Breakdown of costs with overhead items distributed to the primary cost-factors



Source: ICRIER research, based on BatPaC

For two-wheeler batteries, the shares of purchased items and pack integration in the total cost at 28.4 per cent and 29.5 per cent respectively are the highest among all the applications, while that of capital equipment is the lowest at 15 per cent. On the other hand, the shares of purchased items and pack integration in the total cost of bus batteries are 18.5 per cent and 6 per cent respectively and feature as the lowest across the different applications, while capital equipment cost at 32.5 per cent is the highest. The fraction of the cost of materials makes the highest share for premium car/SUV batteries (48.6 per cent), which is also the highest of all the other battery configurations; their share is the lowest for three-wheeler batteries (22.7 per cent). The shares of building and labour costs combined per pack are less than 3 per cent in all cases, which means India's demographic dividend would not be very advantageous in this case.[4]

In the following sections, the detailed cost breakdown for each EV battery is illustrated through a hierarchical chart. Further analysis of the different cost components of the batteries with respect to the transport application is essential to isolate the factors that account for a significant share in the total cost of each battery.

4 Contrary to the general notion, the employment potential of EV industry is much less as compared to traditional automobiles. On an average, the IC engine and transmission system of a traditional vehicle takes about 6.2 manhours to assemble, while on the other hand, the powertrain of an EV takes only about one manhour owing to fewer parts and higher extent of automation. (Global Automotive Outlook, 2017). [https://www.reuters.com/article/us-britain-autos-factbox/factbox-the-challenges-and-consequences-of-moving-to-electric-cars-idUSKBN1AB1RJ accessed on November 20, 2019]

Table 3.1: Technical specifications of the battery model designed for cost estimation with respect to the application

		2-wheelers	3-wheelers	Mid-range cars	Long-range cars	Premium cars/ SUVs	LCVs	Buses
Vehicle range	Km	80	129	241	402	483	241	362
Energy requirement of the vehicle	Wh/km	25	75	155	155	217	373	932
Pack energy	kWh	2.4	11	44	74	124	106	397
Battery pack power	Hp	11	25	55	103	164	166	313
Cell chemistry	-	NMC622-G	NMC622-G	NMC622-G	NMC622-G	NMC622-G	NMC622-G	NMC622-G
Cell capacity	Ah/cell	26	16	25	27	30	21	28
Number of cells	units/pack	24	96	240	360	560	672	960
Number of packs	units/system	1	2	2	2	2	2	4
Volume	L/pack	15	68	99	150	240	228	378
Mass	kg/pack	21	91	155	246	403	358	613
Gravimetric density	Wh/kg	111	124	143	150	153	148	162
Volumetric density	Wh/L	153	165	223	245	257	232	263
Cost of cell	$/cell	19	9.9	11	12	12	8.7	9.2
Cost of cell	$/kWh	199	84	62	58	54.2	55	22
Cost of cells	$/pack	467	949	2,742	4,245	6,691	5,859	8,786
Total cost to OEM for complete battery system	$/system	1,070	4,064	8,577	12,324	18,305	16,770	49,976
Plant capacity	GWh/year	0.2	1.1	4.4	7.4	12	11	40
Total investment	$, mil	57.8	224	480	670	960	962	2,342
of which, capital equipment	$, mil	41.4	160	327	446	622	656	1,438

Source: ICRIER research, based on BatPaC

Two-wheeler Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 1,070

Number of cells: 24 x 1

Cell capacity and chemistry: 26 Ah, NMC622-G

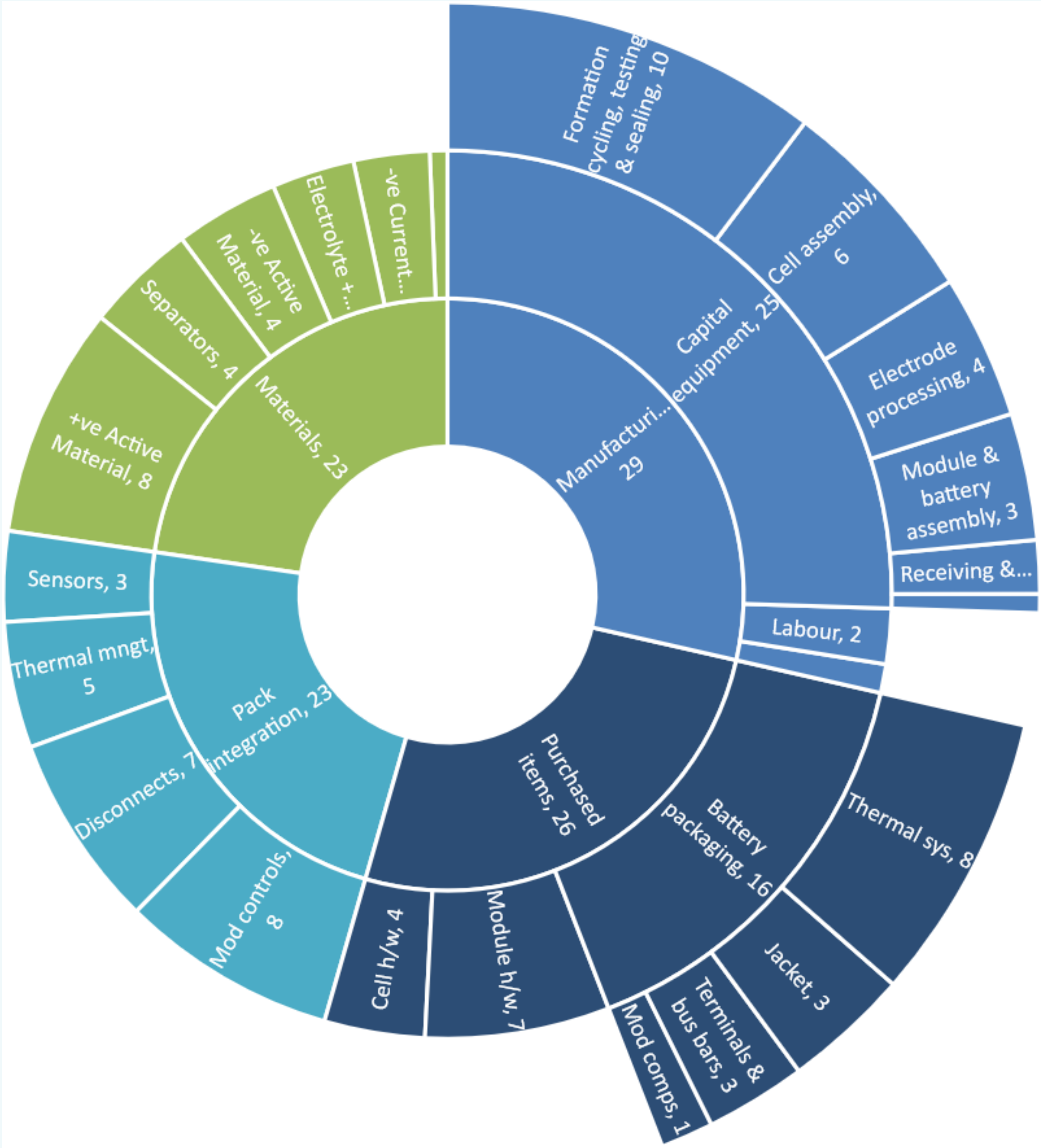
The two-wheeler battery is designed for an electric range of 80 km with a 25 Wh/km energy requirement and a power output of 11 Hp. The battery has a volume of 15 L to fit easily into a two-wheeler chassis. Disconnects, thermal systems, positive active material, sensors and formation cycling, and testing and sealing processes together make up for half the total cost of the battery pack.

Three-wheeler Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 4,064

Total number of cells: 96 x 2

Cell capacity and chemistry: 16Ah, NMC622-G



This battery model is designed to fit three-wheeler passenger vehicles, with an electric range of 130 km, and 75 Wh/km energy requirement. The total energy of the battery pack modelled is 11 kWh. Formation cycling, testing and sealing processes, positive active material, module controls, thermal system, disconnects and module hardware combined contribute to 48.3 per cent of the total battery pack cost.

Mid-range Car Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 8,577

Total number of cells: 240 x 2

Cell capacity and chemistry: 25Ah, NMC622-G

This battery is modelled for entry-level passenger cars, having a range of 240 km and an energy requirement of 155 Wh/km. The battery pack has 44 kWh of energy and can deliver 55 Hp of peak power. At 198 L volume and 309 kg mass, the design is best suited to hatchbacks and compact sedans. Positive active material, formation cycling, testing and sealing processes, module hardware, separators, negative active material and electrolyte combined make up a share of 48.3 per cent in the final battery pack cost.

Long-range Car Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 12,324

Total number of cells: 360 x 2

Cell capacity and chemistry: 27Ah, NMC622-G

This battery design is very similar to that of a mid-range car battery, except that it has 50 per cent more cells than the latter. The battery pack can store 74 kWh of energy and can be used to traverse a distance of up to 400 km per full charge. It can deliver 103 Hp of peak power. Given the higher volume and mass, the design would be fit for sedans. The same cost components, as mentioned in the case of mid-range car battery, make up for 52.5 per cent of the total cost of this battery design.

Premium Car/ SUV Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 18,305

Total number of cells: 560 x 2

Cell capacity and chemistry: 30Ah, NMC622-G

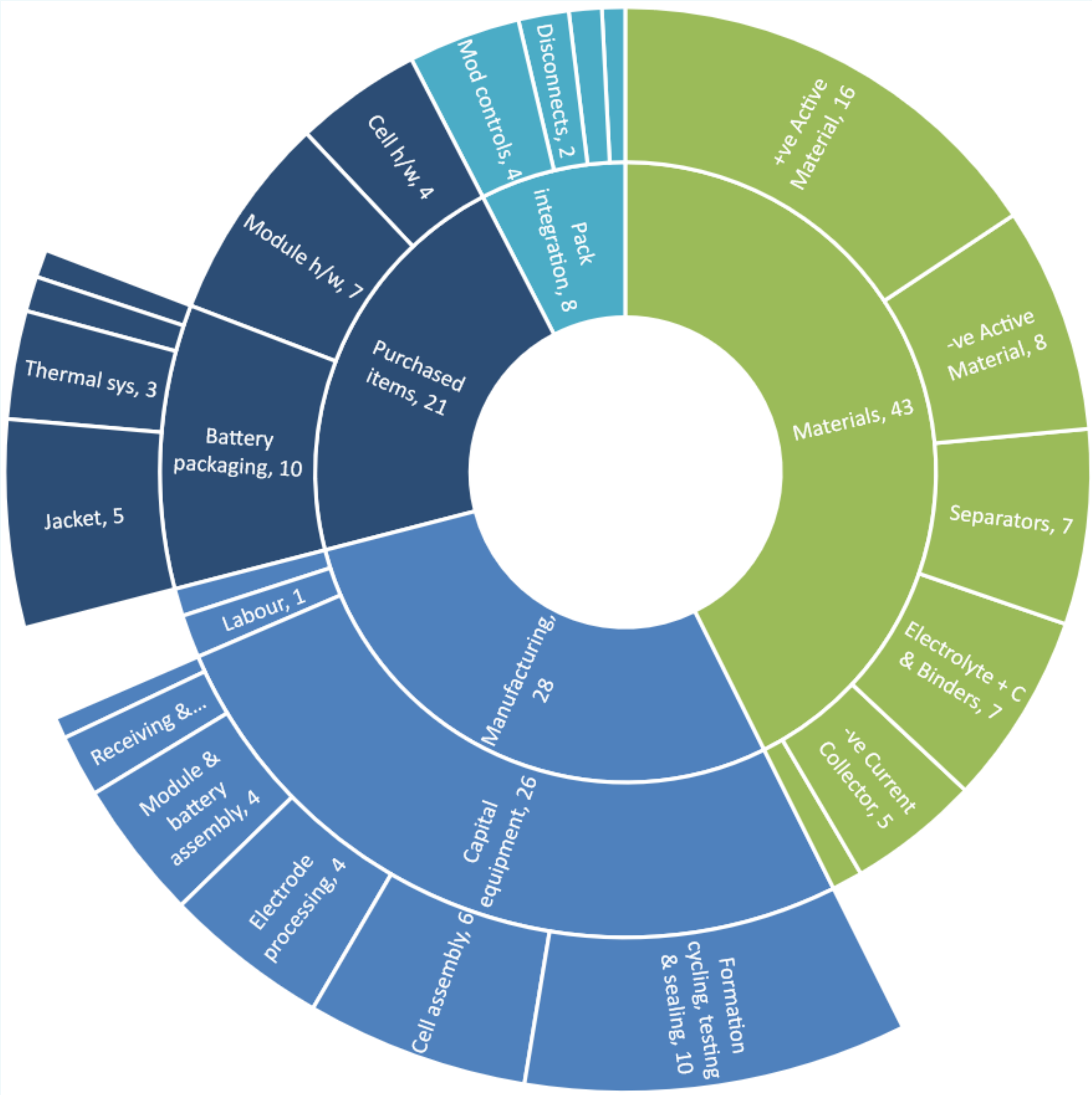
The battery for this category of vehicles is designed to have larger storage capacities and deliver much higher power but come at the cost of volume and mass. This battery is designed to store up to124 kWh of energy and has a range of 485 km between charges. Positive and negative active materials alone constitute a quarter of the total cost, while separators, formation cycling, testing and sealing processes, electrolyte and module hardware make up another third of the total cost.

Light Commercial Vehicle Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 16,770

Total number of cells: 672 x 2

Cell capacity and chemistry: 21Ah, NMC622-G



The batteries for light commercial vehicle application are designed to meet the energy requirement of 373 Wh/km. They can store 106 kWh of energy, sufficient for a range of 240 km, and deliver up to 166 hp of peak power. Positive and negative active materials, formation cycling, testing and sealing processes, module hardware, separators, electrolyte and cell assembly combined have a share of more than half in the total cost of this battery pack.

Bus Battery
(Cost breakdown with overheads distributed to primary cost-factors, %)

Total cost of the battery pack: US$ 49,976

Total number of cells: 960 x 4

Cell capacity and chemistry: 28Ah, NMC622-G

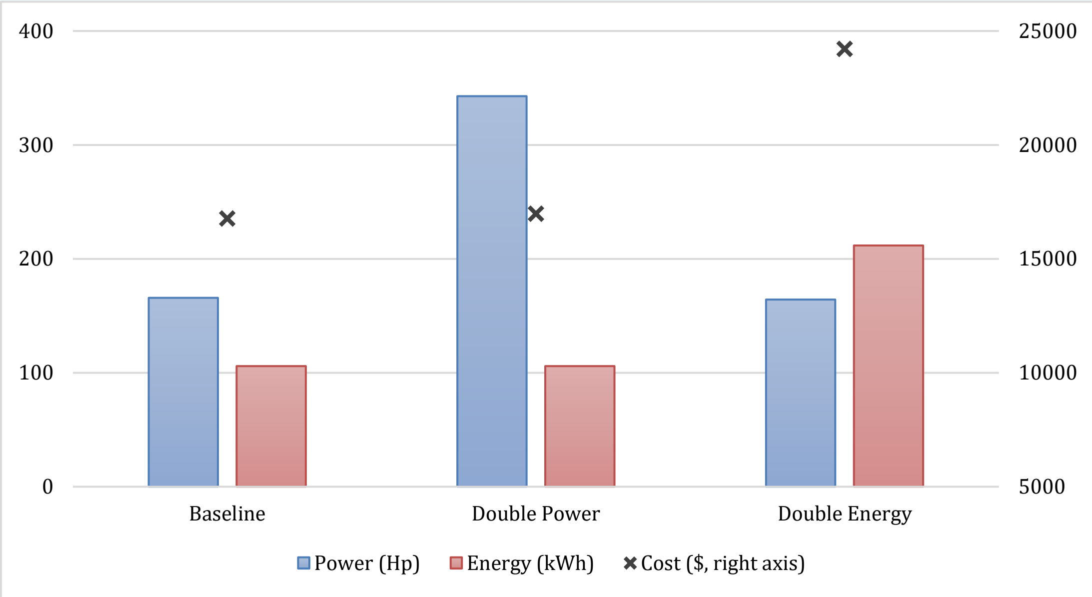
The battery design for buses simulated here comprises four battery packs connected in parallel to each other having a combined energy storage capacity of 397 kWh, sufficient for a range of 360 km at the rate of 932 Wh/km. The battery pack can deliver a peak power of 313 hp and is fit for inter- and intra-city passenger transport services. The volume and mass of each battery pack is 378 L and 613 kg respectively. Like the light commercial vehicle battery, positive and negative active materials, formation cycling, testing and sealing processes, cell assembly and electrolyte account for 47.2 per cent of the total cost of the pack.

The cost breakdown analysis for each type of electric vehicle suggests that apart from the positive active material, which has a significant contribution in all the seven cases, negative active material and electrolyte (five out of seven cases, each) account for a significant proportion of the cost of batteries. The cell finishing process (formation cycling, testing and sealing) also strongly influences the final price of the pack (all cases), along with module hardware and separator material (five and four cases, respectively). Module hardware components include aluminium thermal conductors, copper interconnects, state-of-charge regulator, terminals and an enclosure with provision for gas release. These materials and purchased items add substantially to the cost of the battery. For larger levels of production, these costs are even more dominant because the scale factors for these items are close to one.

The cell finishing process is expensive because it takes considerable time. The process comprises three steps: (1) formation cycling (2) charge retention testing and (3) final cell sealing. Formation cycling is a process to provide a stable solid electrolyte interphase on the anode to prevent irreversible consumption of electrolyte and lithium ions in a cell (An et al., 2017). To achieve this, the cells are plugged into the electric power and monitoring system, and formation cycled under precise temperature-controlled conditions. After that, the cells are charged and tested for charge-retention over a period of two weeks. At the end of the testing phase, failed cells are rejected, and the remaining cells are finally sealed. Innovation in this process to reduce the time taken would considerably decrease the final cost of the batteries.

A technical design feature that emerges from this modelling exercise is that doubling the power does not add as much cost to the materials and purchased parts as doubling the cell capacity does – a primary factor is the labour cost for electrode processing (Figure 3.4). The reason is that a double power battery involves higher labour costs, principally for coating the larger electrode area, and higher capital equipment cost for coating, calendaring, materials handling and vacuum drying. However, for a high-capacity battery, the main additional capital equipment costs are for the materials mixing, binder solvent recovery, cell stacking and formation cycling. The revelation can be instrumental in devising usage profiles for mass adoption of electric vehicles. For example, battery swapping could be the ideal model where the low capacity of inexpensive batteries can be compensated for by instant swapping systems to have extended driving range, particularly in the case of commercial applications (see section 4.2.3 for more).

Figure 3.4: Effect of doubling the power or capacity on the final cost of an LCV battery pack



Source: ICRIER research, based on BatPaC

The cost disaggregation carried out in this section highlights the significance of the cost of raw materials in the final cost of the battery pack. Additionally, the secondary items (e.g., module hardware components), which are assembled into the battery pack, also contribute significantly and must not be overlooked while considering cost minimisation strategies. The development of ancillary industries that produce these items locally to support battery manufacturing, therefore, should be emphasised.

The results presented here form the basis of a battery manufacturing policy and are dependent on the forward and backward linkages of the domestic electric vehicle value chain. The next chapter focuses on this in the context of India.

4. EV Battery Value Chain in India

– Himanshu Shekhar

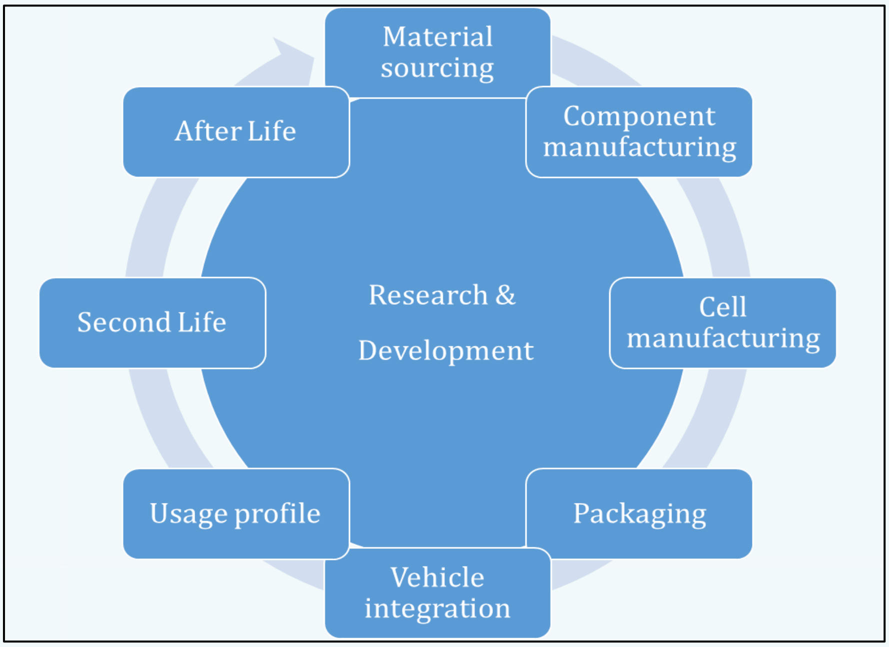
Globally integrated value chains have contributed to the development of production practices and have been pivotal to the success of manufacturing certain products in some regions of the world (UNIDO, 2015). These chains include trade, market and knowledge linkages. They not only provide value creation but also offer an efficient transfer of benefits to the end customer (Das & Hussain, 2017; OECD, 2013). An inefficient value chain, on the other hand, may create redundancies among value chain transactions, which could ultimately lead to higher costs of production.

EV batteries consist of several components from different sources and therefore, global supply chains play a greater role in its production and post end-of-life recycling. A deeper understanding of the value chain is imperative for better cost assessment and optimisation strategies. This chapter traces the value chain of EV-batteries in order to comprehend the value creation at each link in the chain and analyses it to outline cost reduction strategies relevant for India.

4.1 EV Battery Value Chain

This study follows the value-addition approach to look at the various components of EV-battery value chain. The approach allows one to have two additional components in a value chain model – usage profiles and second life. These two components, as discussed later, help in identifying the cost-reduction strategies beyond the manufacturing process of cells. These components are also essential to a market like India, where affordability is a major concern and lower battery cost is critical to faster adoption of EVs. Figure 4.1 illustrates the value chain of an EV-battery.

Figure 4.1: Value chain of an EV Battery



Source: ICRIER Research

The electric vehicle industry is relatively new to India; hence, its value chain is not yet fully developed (see Table 4.1). As in China, the battery value chain in India will require continued development and integration of each stage to fully exploit its potential.

Table 4.1: Battery value chain and their development stage in India

Stage	Description	Stage	Current/potential Companies/suppliers
Material sourcing	Raw material/metals and composites sourcing	Not started	
Component manufacturing	Manufacturing of electrodes, separators, casing, terminals	Not started	
Cell manufacturing	Manufacturing of cells from cell components, flexible with certain chemistries	Not started	Panasonic, Dentsu, Exide-Leclanche,
Packaging	Assembly of cells to packs for requisite purpose, along with battery management and thermal management systems	Started on a small scale, OEMs & independent	Mahindra, Ather, Exide, Amara Raja, Sun Mobility
Vehicle integration	Integration to vehicle and electronic communication and thermal management	In house for OEMs	Mahindra, Tata Motors, Arther, Sun Mobility, Tork Motors
Usage profile	Usage of battery in real time and associated business models	Options being tested vehicle battery, swapping, EV as a service, Mobility to grid	
Second life/Reuse	The second use of batteries in applications having lower energy and power requirements after primary usage	Not started	
After life/recycling	The recycling and recovery of purified materials from used batteries, which can become raw material for material sourcing	Mixed with E waste	TES AMM,
Research & Development	R&D is required along all aspects of the value chain especially in new chemistries and formats	Small scale interventions by labs, OEMs & Start up	IIT Madras/Kharagpur/Mumbai,[5] CECRI,[6] NPL, ISRO,[7] OEMs, Start-ups, Gegadyne

Source: ICRIER Research, based on various stakeholder discussions

5 IIT – Indian Institute of Technology
6 CECRI - Central Electro-Chemical Research Institute
7 ISRO - Indian Space Research Organisation

4.2 Opportunities and Challenges

Stakeholder discussions over the different aspects of EV-battery value chain reveal several possibilities to strengthen and ensure global integration to maximise possible cost reductions at distinct points in the value chain. The following sub-sections discusses each of the components along with the respective opportunities and the challenges associated with each.

4.2.1 Material sourcing, Component and Cell manufacturing

Cells are the primary component of a battery and account for a sizeable share in the final battery value. They are composed of several sub-components, each of which requires exclusive technologies to manufacture from different sets of raw materials like base metals, polymers, alloys and salts. These raw materials generally need to be sourced from different countries, endowed with the natural resource (e.g. Democratic Republic of Congo for cobalt), forming global supply chains.

India, with its market size, is an important economy for battery manufacturing, necessitating the creation of adequate supply chains, both domestic and global. Localised cell production and battery assembly should be the initial key steps in this direction. India could benefit by substituting the imports of cells with domestic manufacturing in the following ways:

1. Save on shipping time, which is usually up to three months, and transportation costs;

2. Greater flexibility to customise final product to local conditions; and

3. Lower cost of human capital.

Challenges:

- *Technology:*

  The technological prowess to produce world-class cell components including cathodes, anodes, separators, terminals, and packaging is not, at present, sufficient for the scale and penetration needed.

- *Materials:*

  The rare earth metals used to manufacture a Li-ion battery, like lithium, cobalt and nickel, are not found in India and, therefore, have to be imported. For other materials, like manganese, graphite and silicon, better technology is required for refining them to battery-grade quality.

- *Technological obsolescence:*

  With concerted global efforts, investments in EV-battery research and development have risen rapidly and continue to do so, and therefore, the technology is evolving rapidly. Consequently, there is the risk of newer and more innovative technologies disrupting the cost advantage of the incumbent, even before it breaks even – a prime reason behind why potential manufacturers in India have been in a wait-and-watch mode.

- *Scale:*

  Despite the vast potential demand, India is an extremely price-sensitive market, especially for capital intensive products. Higher prices make it difficult for otherwise proven and established technologies from scaling up, regardless of the other advantages. Therefore, from an international manufacturer's perspective, the domestic market is not yet mature enough to create enough demand to set up battery production plants in India.

- *Standards:*

  EV-batteries come in all shapes and sizes – differing at the cell chemistry level at one end to their physical form factor[8] at the other. The absence of set standards in such a technology space creates uncertainties for potential manufacturers since battery manufacturing facilities entail capital investment of hundreds of millions of dollars.

4.2.2 Packaging and Vehicle Integration

Battery packs are assembled from cells designed for a specific application. The major components of these packs include the cells, jacket, battery management system and thermal management system. While the cells form the functional component, the management systems form the active component that keeps the battery safe and operational. These systems have sensors and controllers to track the state of charge and health, and the temperature of the battery pack.

Packaging forms the second phase of the battery manufacturing value chain, followed by integration of the assembled battery pack into the EV. Battery packs may have independent markets and differentiated value owing to their plug-and-play nature and multiple applications. It may also be an opportunity for battery swapping as discussed later. They are also agnostic to the cell-specific characteristics such as cell chemistry and, therefore, have a lower or more limited risk of obsolescence as compared to the cells themselves. Some EV manufacturers in India have developed battery pack assembling facilities in-house and use cell units imported from China or elsewhere. However, the application of these facilities is restricted to the original equipment manufacturers (OEMs) themselves due to firm-specific designs and protocols with limited use to other industry players.

Packaging and components add to the overall cost of the battery pack, from 23 per cent in the case of SUV batteries to 44 per cent for two-wheeler batteries (Figure 3.2). The average cost of major components, i.e., the battery management system including

8 The physical size and shape of a battery is commonly referred as its form factor.

connectors/disconnects, and sensors, jackets, etc., could be minimised by exploiting economies of scale. Battery pack assembly by EV manufacturers in India is supported by several vendors supplying various components. Some traditional lead acid battery manufacturers also see this as a new business opportunity. However, the market at present is distributed horizontally, which leads to inefficiencies. It also presents an opportunity for cost reduction through local manufacturing at scale.

Challenges

The challenges posed by the limited scale and absence of standards are the same for packaging as for cell manufacturing. The absence of standards, in particular, incentivises in-house battery pack assembly by OEMs and further compounds the scale challenge. Traditional battery manufacturing firms also find it difficult to gauge the requirements of the end unit and, therefore, may not be successful in producing a standard product for all manufacturers – compounding market inefficiencies.

4.2.3 Usage profiles

Electric vehicles also offer new usage profiles that may not be possible with traditional vehicles. The unified objective of having affordable, environmentally sustainable and connected mobility draws in significant efficiency improvements in the transportation system while also offering opportunities to reduce cost for end-users. Several business models might evolve based on these opportunities:

- *Conventional (individual-use) model:*

  A single party owns the vehicle, which comes with the battery and the charger. This model gives the user the flexibility to charge their vehicle either at home or at public pay-as-you-use charging stations, available across select locations if needed. This usage profile may not be economically efficient, but, technically, leads to longer battery lifespan.

- *Battery Swapping:*

  In this model, the cost of the vehicle is separated from the cost of using the battery – in other words, the owner of the vehicle pays a service fee to get a fully charged battery and swaps it with the drained battery in the vehicle – a process similar to refuelling a traditional vehicle. The owner does not necessarily need to pay the high upfront cost of the battery. This model, however, relies on having a large number of swapping stations (just like fuelling stations for traditional vehicles) across the geography and all EV manufacturers agreeing to a uniform battery pack design, irrespective of the chemistry. Designing vehicles, especially buses, with frequent battery swapping may lower the battery size requirement as well as reduce the cost of vehicle to the owner/operator.

- *EV or Battery as a service:*

This model eliminates the upfront as well as the operating cost of the vehicle. The users pay only the monthly lease rent for the vehicle. In other cases, the supplier provides free charging with the purchase of vehicle to reduce the operating cost. This institutionalises the vehicle and battery management with the vendor extracting the most value.

- *Shared and connected:*

  A vehicle is shared by several users as in the case of public transport or a ride-sharing service, auxiliary transport or cab services (e.g., Uber), and self-driving or vehicle renting services (e.g., Jump e-bikes, Volkswagen WeShare, Coup e-scooters). The advantage of this model is that service providers gain more due to higher asset/battery utilisation and, since the average cost per unit of distance travelled is much lower for EVs as compared to traditional vehicles, service providers have a higher incentive to go electric.

- *Mobility to Grid:*

  In this model, the vehicle battery is used as a storage of intermittent renewable energy and sending it back to the grid in case of shortage of power. Germany is experimenting with such a model with idle EVs. This may also generate extra revenue for vehicle owners.

These models describe the options for reducing the cost of ownership to EV users while simultaneously giving end-users several options to choose from. The spectrum of business models may be seen as that of rent and capital as shown in the table (Table 4.2).

Figure 4.3: Business models for battery utilisation in EVs

	Shared mobility	Charging as a service/Vehicle as a service	Battery Swapping	Traditional single use
Capital	Zero	Caution deposit	Car cost	Car & Battery cost
Rent	For Driver, Capital Car, Capital Battery and Fuel (Electricity)	For Capital Car, Capital Battery and Fuel (Electricity)	For Capital Battery and Fuel (Electricity)	For Fuel (Electricity)
	Higher Flexibility	←--→		Higher Ownership

Each of the business models above have their advantages and affect the total final price to the end-user. Renting and leasing of batteries increase their utilisation and hence, reduce the average cost to the user.

The major challenges for the mass adoption of these models include the following:

- Ownership/traditional usage: The traditional way of using vehicles has been ownership. However, new options for seeking transport solutions may require some habit changes for users.

- Standardisation: The sharing models rely on multiple interoperable components, particularly batteries and charging infrastructure, making the prevalence of standards obligatory. The standards must be defined at the system level such that multiple operators can provide similar services competitively and consumers can enjoy better services at lower prices.

4.2.4 Second life/re-use

Second life is another key component of the battery's value chain. EV batteries are designed for higher performance in terms of charge/discharge rates, cycle lives, electrical impulse and thermal tolerance. All these factors constitute the state of health (SOH) of batteries. EV batteries may not come to a zero SOH before needing a replacement. These batteries at the end of life in an EV may still have considerable utility left for other options, where it can be used to extend its life. The used EV battery may be suitable for certain applications – invertor back up for homes and renewable energy storage at grid level – which require lower charge/discharge rates. This stationary usage presents great opportunities for the reuse of these batteries and recovery of some proportion of its overall cost.

The opportunity for second use/re-use of batteries may not only create new sectors but also reduce the cost of ownership of batteries. The cost reduction option for EV end-of-life batteries includes a 'resale value' much higher than the scrap value of the batteries. This higher resale value can in turn be used to reduce the replacement cost of batteries for old vehicles. OEMs may also offer buy back options and subsidised battery replacement to their customers.

However, there are challenges in the execution of such models as the reuse and recycling industry is non-existent in the country. Some of these challenges are:

- Absence of the reuse industry: Refurbishing of used Li-ion battery for second life/reuse in stationary application is a good business opportunity. However, its success will depend on the availability of channels and technologies that could facilitate reverse logistics and refurbishment of old batteries respectively. These efforts must be undertaken at the industry level. Initially, used batteries of laptop and mobiles could drive the growth of such an industry because of sufficient availability of raw material in the Indian market. Later, it could reap benefits from the availability of used EV batteries. Although the industry is already developed for lead acid batteries through both formal and informal channels, it remains virtually non-existent for Li-ion batteries. The key is to develop a reverse logistics chain and provide ample incentives to end-users to give back their used batteries.

- Unsuitable pack design for reuse: Li-ion cells available in the international market often imported by the pack manufacturers have standard form factors and capacities. However, packs are manufactured in different shapes and sizes where cells are fused so that the new form factor becomes difficult to re-use. Appropriate mechanisms to incentivise novel pack designs suitable for refurbishing of used batteries that smoothens the dismantling process are also required for obtaining maximum utility from reuse and recycling.

- Varied usage of batteries: Li-ion Batteries are used for several applications apart from vehicles, including electronics, power tools, inverter and grid storage. Each of these usages have varied energy and power demand profiles. Even in vehicles, from two wheelers to heavy commercial vehicles, the battery specification such as space available and density requirements differ. These demand profiles lead to the need for a variety of designs and form factors for cells and battery packs. Therefore, switching usage after end of life in one application may be difficult.

- Standardisation and R&D: Apart from form factors, the standards on battery specific factors like voltages and currents, terminal types, capacity measurements, interactive BMSs and others will also help. Moreover, labs for creating and testing standards must also focus on assessing the battery SOH and their suitability for refurbishing; establishing related infrastructure that helps consumers to check and sell their batteries for further use is also required.

4.2.5 End of Life/Recycling

Li-ion batteries are composed of pure metals and metal alloys along with certain chemical and plastic parts. These cells are almost completely recyclable by using appropriate technologies. The recycling rates are expected to be around 95 per cent for metal recovery from the cells. The electrodes may be leached with aqueous solutions to recover lithium, nickel, cobalt and manganese. The lithium originally in the electrolyte is added to the total lithium. The balance of the battery, about half of the total mass for most batteries, is separated into eight groups of less valuable materials: (1) graphite in the electrodes, (2) balance of electrodes (oxygen, binder, etc.), (3) electrolyte (less lithium), (4) cell separators, (5) cell containers (multilayer polymer/aluminium) (6) pack insulation, (7) pack coolant, and (8) electrical insulation, pack heaters, etc. Some of the low value metallic elements of the electrodes are included with (2); the balance of electrodes includes aluminium in NCA electrodes, iron in LFP electrodes and titanium in LTO electrodes. The aluminium foil in the multilayer cell containers is not economically recoverable, so the entire container material is considered disposable.

Recycling assumes comparatively higher importance in the Indian context than in other places as the domestic source of these metals are limited and demand continues to grow for transport services. Recovery from existing batteries may actually result in local material supply for at least a portion of the demand for batteries in the future. It can also help create a local supply chain for domestic cell manufacturing providing recycled raw material in addition to virgin raw material.

The recycling of Li-ion batteries, while feasible, also has its own share of challenges including the following:

- Lack of appropriate recycling facilities: Although mobile and electronics batteries are generally Li-ion batteries, the recycling capacity for batteries in the country remains limited. Used batteries from electronics are discarded in large numbers in the country and can be used as a starting point for recycling and material recovery. This may also present a good circular business model if sufficient cell manufacturers emerge in India to absorb the recovered materials from the recycling units.

- Reverse Logistics: Procuring discarded batteries back from the consumers is a challenge. While India may have large informal reverse logistics for non-organic household waste like paper, scrap iron, glass, etc., it is not equipped and prepped for modern wastes like electronic and battery waste. Therefore, collection points and supply chains (from end-users to recycling facilities) are necessary to develop a successful recycling industry. Government support in the form of regulations on e-waste and incentives for customers to sell their batteries to genuine recyclers will play an instrumental role in developing reverse logistics.

4.2.6 Research & Development

Research and development is the final component of the battery's value chain and probably the most important component as its role underpins the entire value chain. Battery technologies are not matured and considerable development in terms of increasing energy density, charge retention and environmental tolerance are still under development. New technologies offer promise for usage in warm and humid Indian conditions. Start-ups in India are also exploring new technologies especially suited for Indian conditions; for example, Gegadyne and Bharat Energy Storage Technology (BEST) have developed usage specific storage solutions. Specific R&D for Indian condition batteries/energy storage may provide great impetus not only to storage but also to the automotive sector. Apart from the development of newer energy storage options, R&D is also important all along the battery value chain to provide for standardised product delivery, improved pack design and reduced costs. R&D is also critical for enabling the circular battery ecosystem by providing protocols for reuse and technologies for better recovery of cell components after recycling.

The development of R & D facilities can help achieve three different functions along the batter value chain:

- Cells and energy storage options: Developing various batteries suitable for use in Indian conditions, and meeting specific requirements and cost expectations will depend on the adequacy of the R&D infrastructure. Intensive research is required not only for Li-ion technologies but also for other alternative technologies that can match its load and safety profiles for different applications. Other storage alternatives based on mineral resources available in the country may also be a motivation for the development of such technologies that can serve not only the current but also future fleet of vehicles and for other applications.

- Standardisation and testing: This component of R&D requires immediate attention. Research and testing laboratories against standards of the battery along the lifecycle is a key component. Since battery technology is still being developed, standards are also expected to evolve over a period of time. Testing and certifying products require state-of-the-art labs. Such labs need to be developed not only for testing standards but also to undertake the development of new standards for evolving cell and storage technologies. These labs could also certify other components important for refurbishing the batteries for their second life.

- Recycling: Although material recovery is quite significant for the current Li-ion batteries, recycling may be an important area of research in term of both reducing the cost of recycling and improving recovery rates.

4.3 Cost impact of each value chain component

As discussed above, the EV battery value chain plays an important role in determining the overall cost of a battery beyond its manufacturing. Some of the stages in the EV battery value chain could reduce the cost of a battery if appropriate infrastructure is present. Based on the estimates provided by industry participants and from the modelling exercise in Chapter 3, Table 4.2 below summarises the cost of different components in terms of the cell cost, battery cost and vehicle cost.

Table 4.2: Battery cost split between various components of EVs

Value chain	Cost Component (Cell)	Cost Component (Battery)	Cost Component (Vehicle)
Material & Components	50-60%	30 - 40%	12 – 20%
Cell manufacturing	40-50%	24 – 35%	10 - 18%
Cell Total	100 %	50 - 70%	24 - 35%
Packaging & Components		30 – 50%	12 – 25%
Battery total		100%	40-50%
Vehicle manufacturing			50-60%
Vehicle total			100%

Source: ICRIER research; Based on modelling exercise in Chapter 3

The above segregation not only helps in visualising the cost of the vehicle in terms of its components but also in terms of the potential options to reduce the cost of batteries and consequently of EVs. As each stage in the value chain becomes more efficient, the cost of the battery and vehicle falls. However, at present, it is difficult to assess the impact of these developments on the battery or vehicle cost. Table 4.3 below presents some of the cost reduction drivers along the value chain, their impact on the cost of the vehicle/battery and the time within which this can be achieved.

Table 4.3: Cost reduction potential in the value chain of EV batteries

Value chain	Cost reduction drivers	Impact on cost (Short/Medium/ Long term)	Potential Impact
Material sourcing & Component manufacturing	Access to supply chains Manufacturing, Lower transactions cost	Long-term Long-term Medium/Long-term	Only significant with scale
Cell manufacturing	Manufacturing, Lower Financing, Transaction & Import costs	Medium-term Medium-term	Only significant with scale 5-10% of cell (3-5% battery) cost
Packaging	Local components and software at scale	Short/Medium-term	10-15% of battery cost
Vehicle integration	Standardisation of battery designs & protocols to achieve domestic scale	Short/Medium-term	~5% with higher scale
Usage profile	Various business cases to reduce total cost of ownership (TCO)	Short/Medium-term	Based on Usage profile on TCO
Second life/Reuse	Extended life & Alternative usage	Medium-term	~20% discount on new battery (refer annexure I)
After life/recycling	Cost recovery of Material	Medium-term	~13% discount on new refurbished battery (refer annexure I)
Research & Development	Technology development	Medium/Long-term	Reflects in the cost reductions listed above

Source: ICRIER Research

It may be observed that the value chain offers many opportunities to reduce cost beyond the manufacturing of cells. This observation also suggests that a holistic approach needs to be taken for understanding the development of new technologies like EVs and batteries. One of the key areas of cost reduction that cannot be directly observed is the scale of operations. Higher scales of operation will boost all other components of the supply chain and may improve the viability of setting up local operations for cell manufacturing. It might also help realign global value chains of batteries towards India because of the cost advantage.

Many of the factors listed above need an integrated approach by local industry and support from the state in the form of favourable policies. The next chapter reviews the policies that have been successful in promoting EVs in transportation systems.

5. Overview of EV Policies

– Shubham Sharma

State support for the promotion EVs in India has grown with the National Electric Mobility Mission Plan (NEMMP) and other similar policies at the state level, targeting financial support for vehicle manufacturers and consumers to spur demand for EVs. The proposed new policy also aims to support the development of the EV manufacturing base in India. The uptake of EVs faces a variety of challenges and entails the development of an e-mobility system. The government will have to play an important role in developing such a system by designing non-traditional policies. According to an International Energy Agency (IEA) report on deployment strategies for new technology vehicles, the policy instruments should go far beyond traditional direct state regulations and financial incentives, with priority given to network management[9] with the state acting as a facilitator (Muntwyler, 2002).

Leurent (2011) suggests a typology of possible governmental measures to promote electric mobility – command and control instruments, economic instruments, procurement instruments, collaborative instruments, and communication and diffusion instruments. A summary of these policy measures is presented in Table 5.1 below:

Table 5.1: Summary of various policy measures

S. No.	Instrument	Description	Example
1	Command and control	Initiatives undertaken by state authorities to promote adoption of alternative technologies by framing policies – stringent environmental regulations and exemptions for environment-friendly technologies. Less costly and time-consuming.	Exemptions for EV users (parking, registration, etc.), inclusion of EVs in public service/government fleets, etc.
2	Economic	Subsidies, direct financial support, investment in R&D, tax incentives, financing schemes, etc.	Financial incentives to end-consumer on buying an EV, tax benefits to industry, etc.
3	Procurement	Instruments to reduce the price of EVs by aggregating demand at some level of the value chain to achieve economies of scale.	Procurement of EVs on a large scale for government fleets; demand aggregation by industry consortium.
4	Collaborative	State/government assumes the role of network manager between manufacturers, authorities, researchers, consumers, etc.	Standards, certification and labelling etc.
5	Communication and diffusion	Instruments to increase public awareness about EVs to	Marketing activities, training for mechanics, support staff, conversion shop, addressing

[9] Platforms that include all actors of the mobility system should be established to develop a joint, economically viable strategy for EV deployment. Such an approach is likely to be more time consuming but also more successful than massive programmes aimed at selected, stand-alone targets.

S. No.	Instrument	Description	Example
		encourage change in mobility behaviour.	the anxiety of end-users about the electric mobility system, etc.

Source: *Adapted from Leurent, F. & Windisch, E. (2011). Triggering the development of electric mobility: a review of public policies.*

Any policy to promote EVs can be a mix of the instruments mentioned above. A brief review of policies in some major countries shows how most programmes and policies to promote EVs have focused on these instruments. The objective of this review is to learn from the experiences of countries that have done well in promoting EVs and use these lessons to identify strategies from the information provided in Chapter 3 and Chapter 4.

5.1 EV policies in different countries

This section reviews the policies to promote EVs in several countries to understand the effectiveness of these strategies and measures. It also helps in understanding the mix of policy instruments for the promotion of EVs. The policies of six countries are discussed below. These countries are selected based on criteria such as the extent of domestic manufacturing of EVs, their penetration in mobility systems and early formulation of favourable policies.

5.1.1 Norway

Norway has the highest percentage (46.6 per cent) of the electric car market share in the world.[10] It is the result of incentives and policies that evolved over 25 years because of interactions among national and international networks. The opportunities created by these policies enabled stakeholders to integrate the battery EV regime with the traditional (ICE) vehicle regime. Although several incentives existed since 1990, the production of EVs by traditional vehicle manufacturers from 2010 onwards led to a significant change in the market. Overall, the successful adoption of EVs in the country has been achieved by creating purchase incentives, technology improvements, availability of several vehicle models, reduction in price and marketing (Figenbaum, 2017). Aasness (2015) attributes the increase in EV uptake to economic incentives other than purchase incentives such as toll charge exemptions, purchase duty exemptions, etc., and other non-economic incentives such as permitting EVs on transit lanes.[11] However, some of these strategies have led to the loss of revenue (e.g., toll collections). Thus, it has been argued that duplication of these efforts may or may not be successful, depending upon the economic feasibility of these policy instruments in local circumstances.

5.1.2 China

The tremendous growth of EVs in China is a result of direct purchase subsidies based on battery capacity. These subsidies also found support from local governments, thus increasing the incentive for end-users. Another critical aspect of policy instruments to spur demand is the government procurement of EVs in China. From 2009 to 2012, the

---

10 https://www.iea.org/tcep/transport/electricvehicles/ accessed on September 23, 2019

11 A transit lane or a high occupancy lane is a restricted traffic lane for use by buses, taxis or any vehicle containing more than one occupant (thus carpools etc.) and emergency service providers.

main models sold were sanitation vehicles.[12] Logistics EVs constituted the largest market share at 50 per cent as of 2015 (Du & Ouyang, 2017). Observations from China clearly highlight the importance of government procurement and commercial vehicle procurements as well as local policies in spurring overall demand.

The importance of local policies is also highlighted by Li (2016) in their work on EV promotion in Shenzhen, China. The success of Shenzhen holds several vital lessons for policymakers and industries for the widespread promotion of EVs. An important lesson is the assimilation of business innovation and regulation. Like the recommendation by IEA on deployment strategies for EVs, the paper also calls for network management and consistent interchange between stakeholders in the value chain of innovative technologies. The success of EVs in Shenzhen has been a result of its affordability for mass transit systems, but the paper recognises two important areas for improvement – private investment in charging infrastructure and standardisation of technologies to weaken local protectionism.

Despite such successes, Zhang (2017) finds significant scope for improvement in China's EV policies in terms of their effectiveness. The study identifies policy concerns – insufficient subsidies and R&D investments, impossibly high targets for charging infrastructure[13], incomplete standardisation, etc. – where poor implementation has reduced policy effectiveness. The study recommends stricter regulations on users of traditional vehicles and oil companies along with continuous subsidies for EV users. In the case of charging infrastructure, the development status of the region and EV demand must determine the target. The study recognises the importance of investment in R&D to improve the performance price ratio of EVs. It also emphasises that EV policies are interlinked with each other and therefore, it is important to choose an optimum mix of policy instruments.

5.1.3 Sweden

Sweden took an innovative approach to determine financial incentives for non-ICE vehicles by launching the super-green[14] car premium programme in 2011 (IEA, 2019). The programme had appropriations to provide subsidies on the purchase of super-green cars. The initial funds were utilised entirely by July 2014 as more than 5000 new cars were bought under the scheme, signifying its success.[15] In addition to financial incentives, which have played a crucial role, Egnér (2018) studied the role of policy instruments adopted by the local government to promote EVs. As expected, charging infrastructure played a significant and positive role in enhancing EV adoption rates by directly addressing the issue of range anxiety. Policy instruments like free parking had a positive impact on the adoption rate but were not very significant. However, these are inexpensive and politically more feasible than other options. Another inexpensive instrument could be the visibility of EVs, which may have positive externalities. The study finds that regions

---

12 Electric Sanitation Vehicles – Light to heavy motor vehicles that are used for municipal waste collection and sweeping of roads. Local governments in China went into agreements with manufacturers such as BYD, FOTON etc., to procure electric sanitation vehicles. Recently, there have been initiatives to use self-driving electric vehicles to sweep streets in Beijing.

13 49,000 charging poles were set up in 48 cities in China against the previously set goal of 238,559 by the end of 2015.

14 Super green cars were defined as vehicles that emit less than 50 grams of carbon dioxide (CO_2) per km.

15 https://www.dn.se/ekonomi/supermiljobilspremien-ar-slut/ Accessed on October 8, 2019

where local governments have EVs in their fleet show better adoption rates than others. Having EVs in the government fleet results in knowledge spill-overs by spreading awareness and information about EVs. Thus, it is argued that government procurement policies could be an effective instrument. Like many other studies, this study also recommends that financial subsidies or incentives alone will not be able to increase the share of EVs in transportation. Such initiatives must be supported by other policy instruments that are inexpensive, politically feasible and effective. These policy instruments could include improvement of charging infrastructure, visibility of EVs and charging infrastructure, government procurement, etc. Moreover, the study highlights the need for further research to determine the causal relationship between charging infrastructure and EV adoption rates.

5.1.4 Germany

In 2010, a national platform for electric mobility ("Nationale Plattform Elektromobilität") was set up to establish Germany as a lead supplier and market for EVs and create an additional 30,000 jobs in the sector. The platform included members from industry (10 members), politics (6 members), science (3 members), associations (3 members) and unions (1 member), and functions as an advisory council to the German federal government. It has six working groups, each focusing on vehicle technology, battery technology, charging infrastructure, standardisation, information and communication technologies, and the general framework (National Platform Elektromobiltat, 2019). Financial stimulus was provided for projects in 15 areas by several government agencies. However, the target of one million EVs by 2020 seems unattainable.

Massiani (2015) finds that even aggressive policies might not result in the achievement of the target in the case of pure EVs. However, the performance of plug-in hybrid EVs (PHEV) and range extenders seems promising and could trigger the growth of EVs in the German market. The cost-benefit analysis of EV policies in the study raises doubts over the effectiveness of EV policies in Germany. The overall objective is to reduce emissions and thus stricter emission regulations on ICE vehicles act as drivers of growth of EVs. For example, EU regulation 443 sets a limit of 95 gm/km by 2020, i.e., emissions from all vehicles together (ICE, EVs and others) must not exceed this limit. As the share of EVs and other low emission vehicles in transport systems increases, it will contribute far more towards the target (95 gm/km) than ICE vehicles. Thus, increase in EVs may reduce pressure on traditional ICE vehicles to reduce their tailpipe CO_2 emissions. Thus, in the long run, financial incentives to promote EVs may benefit ICE vehicles and oil companies. Despite this assertion in the paper, the low market share of EVs in most markets might not benefit traditional vehicles in the near future. While the profitability of financial incentives may be debatable, inexpensive policy instruments could help convince early adopters of EVs.

Plötz et al. (2014) in their paper identify early adopters of EVs. According to the study, middle-aged people with families who commute considerable distances will be more tempted to buy EVs. However, in another study on market diffusion, it is argued that commercial car fleets are early adopters (Plötz P. G., 2014). Nevertheless, it is important to understand that the relevance of market diffusion strategies is contingent upon the affordability of EVs.

5.1.5 The United States

The cumulative sales of EVs in the United States (US) exceeded one million by October 2018.[16] However, the goal to have one million EVs was initially set to be achieved by 2015.[17] EV adoption in the country is heavily supported by subsidies and grants from the local, state and federal governments. In 2009, as part of the American Recovery and Reinvestment Act, the Department of Energy called for applications for a federal grant of USD2 billion for the manufacture of advanced batteries and other drive components and another grant of USD400 million for demonstration projects on electrification of transportation. Moreover, the Energy Improvement and Extension Act, 2008, provided more support to new EVs in the form of tax credits. A prominent aspect of these initiatives took the form of support from regional and local governments.[18] These financial incentives have been responsible for 30 per cent of total plug-in EV sales in the US (Tal, 2016). As far as government fleets are concerned, the share of alternative fuel vehicles has increased by 65 per cent until 2017 from 2008 levels. However, most of these vehicles (about 87 per cent as of 2017) are flexi-fuel vehicles.[19] Hybrid vehicles constituted 11 per cent of the total alternative vehicles, while EVs constituted a tiny number (about 1000 vehicles) (GAO, 2019). Lutsey et al. (2015) assess the leading initiatives to promote EVs in the US in their white paper for the International Council on Clean Transportation. The study finds that cities that offer incentives to end-users and have adopted programmes such as California's zero-emission vehicles have done better than others. Other initiatives such as carpool lane access, planning and outreach, and most importantly, a vast network of charging infrastructure also promote EVs. The study also shows the importance of an 'ecosystem approach' that involves all stakeholders – private, public, state and local. Another important finding is the success of strategies focusing on a city.

5.1.6 The United Kingdom

In 2009, the Office for Low Emission Vehicles (OLEV) wrote a policy paper on ultra-low carbon vehicles that focused on plug-in hybrid electric vehicles (PHEVs). It outlined a short-term strategy (until 2015), a medium-term strategy (2015-2020) and a long-term strategy (from 2020 onwards). The paper focused on demonstration projects, cities as EV centres and consumer incentives to spur demand in the first phase. The medium-term strategy focused on improving the efficiency of cars and charging infrastructure. After 2020, the strategy emphasised continued improvement in charging infrastructure to create a mass market (OLEV, 2013). An important aspect of the strategy was to allow the market to determine the development of the technologies without advocating specific technologies. The government was to provide financial incentives to buyers of EVs through grants for plug-in cars/taxis/vans/motorcycles.[20] Financial incentives were not to be applied to premium hybrid and electric cars. According to a report by the Business, Energy and Industrial Strategy Committee on EV transition, the targets set by the

---

16 https://www.energy.gov/eere/vehicles/articles/fotw-1057-november-26-2018-one-million-plug-vehicles-have-been-sold-united Accessed on October 11, 2019

17 https://www.scientificamerican.com/article/one-million-electric-vehicles-by-2015/ Accessed on October 11, 2019

18 https://pluginamerica.org/why-go-plug-in/state-federal-incentives/ Accessed on October 11, 2019

19 A flex-fuel vehicle has an internal combustion engine that could run on more than one fuel, usually ethanol or methanol.

20 https://www.gov.uk/government/collections/grants-for-plug-in-vehicles Accessed on October 12, 2019

government were too ambitious and did not account for the relative maturity of relevant technologies. It also found that there was lack of co-ordination among different government entities that would adversely affect the efficiency of the strategies. The report pointed to the need to consider support for local governments to empower them for an EV transition. It also identified increasing infrastructure and co-ordination between government and business as essential factors that could help in promoting EVs and ensuring economic benefits from the transition (Business, 2018).

5.2 EV policies in India

India has an ambitious EV target, and the transition to electric mobility is viewed as an opportunity to enhance its existing automobile industry (SIAM, 2017). The focus in policy is on promoting local manufacturing as well as increasing penetration of EVs in the country by providing financial incentives. The Department of Heavy Industry (under the Ministry of Heavy Industries and Public Enterprises) released the 'Automotive Mission Plan 2006-2016' in 2006 to make the country a global hub for designing and manufacturing automobiles and its components. The plan also included the development of hybrid and alternative fuel vehicles but with a primary focus on hydrogen and biofuel.[21] However, the next plan (Automotive Mission Plan 2016-2026) explicitly focused on providing charging facilities and fiscal incentives to the automotive industry to promote EVs in the country.[22] In 2011, a proposal to set up a National Mission for Electric Mobility (NMEM) to promote the manufacture and use of EVs in the country was approved. The setting up of a national board for electric mobility and a national automotive board was also approved.[23] The National Board for Electric Mobility (NBEM) was finally set up in 2017 with a total of 25 members (including six nominated members from industry).[24] A short-term plan – National Electric Mobility Mission Plan (NEMMP) – was launched in 2013 to sell 6-7 million units of EVs (2-wheelers and 4-wheelers) by 2020.[25] However, the total number of EVs sold as of 2019 remains at approximately 280,000, according to the government portal.[26] NITI Aayog[27] identifies two key areas for improving EV uptake in the country – charging infrastructure and vehicle efficiency. In case of vehicle efficiency, the selection of appropriate batteries and exploring new battery chemistries have been identified as areas for improvement.

Following the NEMMP, the government formulated a scheme – FAME (Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India) – that was notified in 2015. The scheme had four focus areas – technology platform (including testing infrastructure), demand incentives, charging infrastructure and pilot projects. The scheme was restricted to cities under smart cities, major metro agglomerations, all state capitals and other urban agglomerations/cities with 1 million plus population (as per 2011 census) and cities of north-eastern states. The objective of demand incentives is to reduce the total cost of

---

21 https://dhi.nic.in/writereaddata/Content/Automotive%20Mission%20Plan%20(2006-2016).pdf Accessed on October 13, 2019

22 http://www.siamindia.com/uploads/filemanager/47AUTOMOTIVEMISSIONPLAN.pdf Accessed on October 13, 2019

23 https://pib.gov.in/newsite/PrintRelease.aspx?relid=71403 Accessed on October 13, 2009

24 https://dhi.nic.in/writereaddata/UploadFile/Notification%20NBEM.pdf Accessed on October 13, 2009

25 https://dhi.nic.in/writereaddata/Content/NEMMP2020.pdf Accessed on October 13, 2019

26 https://www.fame-india.gov.in/ Accessed on October 13, 2019

27 NITI Aayog (National Institution for Transforming India) is the policy think tank of the Government of India to promote co-operative federalism and evolve a shared vision on national development priorities.

ownership of an EV to end-users. The second phase of this scheme, FAME 2, was announced in 2019 and continued the incentives to EVs but excluded private cars. There is more focus on local manufacturing of cells, components, batteries and packs. The subsidy to vehicles is based on battery power and is limited to advanced batteries (to be defined later) only.[28] The focus on batteries culminated in the National Mission on Transformative Mobility and Battery Storage. The mission was approved by the cabinet in March 2019 to promote clean, connected, shared, and holistic mobility initiatives. The mission was tasked to come up with phased manufacturing programmes of 5 years (until 2024) to support large scale battery and cell manufacturing plants and localise production across the entire EV value chain. [29]

Apart from incentives for manufacturing and upfront financial incentives to end-users, these policies have found support from several state governments. An essential aspect of the strategy is the government procurement of EVs. Energy Efficiency Services Limited (EESL), a joint venture public sector unit (PSU) under the Ministry of Power, plans to procure 10000 EVs for government ministries and departments and to set up charging stations.[30]

State governments are supporting these efforts. Several states have come up with policies on the promotion of EVs by providing several benefits, including additional financial incentives to end-users. Andhra Pradesh launched a five-year plan (2018-2023) to become one of the three best states in India by 2022, best by 2029 and a leading global destination by 2050 in terms of the electric mobility ecosystem. The plan is to support manufacturing, develop the charging infrastructure, create demand, and promote research and development. It covers financial support for manufacturing firms to set up manufacturing plants (including battery plants), capital subsidy, external infrastructure subsidy, land, power, water, tax incentives, marketing, etc. The policy also incentivises the recycling of used batteries. To enhance demand, registration charges and road taxes on EVs will be reimbursed until 2024, and for service providers, the state component of goods and service tax will be reimbursed. The policy also has a financial component to support research and development. To further spur demand, the government proposes to fully convert state transport buses to run on electricity by 2029 (the first phase has a target to convert all public buses in the top four cities by 2024) and all other government vehicles by 2024. The policy has a city approach with an explicit focus on developing Vijayawada, Vishakhapatnam, Amaravati and Tirupati as model electric mobility cities.[31]

The Government of the National Capital Territory of Delhi released a draft EV policy in late 2018 to improve air quality, reduce noise pollution and reduce GHG emissions. The scheme proposes to incentivise the purchase of two-wheeler vehicles and electrification of public transport. Other benefits include waivers of road tax, registration fees and one-time parking fee. Three-wheeler autorickshaws have also been included within the ambit

28 https://dhi.nic.in/writereaddata/UploadFile/publicationNotificationFAME%20II%208March2019.pdf Accessed on October 14, 2019

29 https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1567807 Accessed on October 14, 2019

30 https://eeslindia.org/content/dam/doitassets/eesl/pdf/programmes/eVehicles/EV_brochure_trifold_emailer.pdf Accessed on October 14, 2019

31 http://www.cogitasia.com/wp-content/uploads/2019/02/ANDHRA-PRADESH-EV-Policy-Document.pdf Accessed on October 14, 2019

of the scheme. The electrification of public transport is proposed on the lines adopted by Andhra Pradesh.[32]

The Government of Karnataka launched its EV policy in 2017 to make Bengaluru the EV capital of India. The policy includes special incentives such as EV manufacturing parks/zones, waiver of taxes and provision of financial incentives for EVs in the transportation system (both public and private) along with support for charging infrastructure. There is provision for research and development, and skill development to support the transition.

Similarly, other states – Jharkhand, Kerala, Maharashtra, Rajasthan, Telangana, Uttar Pradesh and Uttarakhand – have released their policies to promote EVs and attract EV manufacturing. The overall idea is to promote EVs in transportation systems and the manufacture of EVs and related components.[33]

This review of policies along with information available from Chapter 3 and 4 resulted in identifying the key policy areas as presented in Table 5.2. This identification led to the formulation of cost reduction strategies discussed in the next chapter.

Table 5.2: Key policy areas and their implication on battery cost

Key policy areas	Type	Source			Implication on battery cost
		Modelling exercise	Value chain analysis	Policy Review	
Support for domestic manufacturing and related linkages	Economic	Yes	Yes	The US, The UK, Germany, India (Andhra Pradesh and Karnataka).	Direct
Government Procurement	Procurement, and communication and diffusion (due to visibility of EVs)	No	Yes	The US, China, India (Andhra Pradesh, Delhi), Sweden	Indirect through EV demand – manufacturing of batteries at scale to meet increasing demand.
Support for charging infrastructure	Economic, and communication and diffusion (due to visibility of EVs)	No	Yes	All	Indirect through EV demand
Support for Innovative business models	Role of government is limited. Type of policy instrument is not defined	No	Yes	No	Direct
Reuse and recycling	Command and control	No	Yes	Andhra Pradesh	Direct
Standardisation	Collaborative	No	Yes	China and Germany	Indirect through promotion of

32 http://transport.delhi.gov.in/sites/default/files/All-PDF/Electric%20Policy%202018.pdf Accessed on October 14, 2019

33 http://www3.weforum.org/docs/WEF_EV_Ready_India.pdf Accessed on October 14, 2019

Key policy areas	Type	Source			Implication on battery cost
		Modelling exercise	Value chain analysis	Policy Review	
					investments in a safer market
Network Management	Collaborative	No	Yes	All	Indirect

Source: ICRIER research

6. Cost Reduction Strategies, Ranking and Recommendations

– Shubham Sharma and Himanshu Shekhar

The complexity of the transition from the existing fossil fuel-based mobility system to an electric system requires a mix of strategies. This chapter discusses strategies that draw on secondary desk research of policies worldwide and primary research in the form of the modelling exercise in Chapter 3 and interviews with stakeholders involved in the EV value chain. It also includes prioritisation of these strategies and recommendations based on a ranking exercise discussed later.

6.1 Cost Reduction Strategies

The following strategies to reduce the cost of batteries and thus, that of the EVs have been identified (Table 6.1):

Table 6.1: Cost reduction strategies

Strategy	Policy Area
Incentivising cell manufacturing	Support for domestic manufacturing and related linkages
Development of ancillary industries for pack components	Support for domestic manufacturing and related linkages
Incentivising reverse logistics, reuse for stationary usage	Reuse and recycling
Improving the availability of critical cell components	Support for domestic manufacturing and related linkages
Standardisation	Standardisation
Battery as a service	Support for innovative business models
Demand aggregation	Government procurement
Dedicated battery research institute	Network management

Source: ICRIER Research

6.1.1 Incentivising Cell Manufacturing

Domestic cell manufacturing is viewed as an option to not only reduce the cost of batteries but also to reap economic benefits from the transition. The option has attracted attention in most policies formulated at both the central and state levels. The idea is to take advantage of relatively low-cost labour, and provide financial support on capital expenditure to manufacture cells at scale. Manufacturing at scale along with efforts to improve the efficiency of value chains and resource utilisation will help reduce the cost of batteries. However, the investment in cell manufacturing will depend on an assurance of demand for batteries, and hence, it is important that demand creation policies are effective.

6.1.2 Development of ancillary industries for pack components

It is evident that cell manufacturing needs rare earth metals and one option could be to manufacture ancillary components domestically as a support act. The idea is to develop and integrate with global value chains that are easier to enter. Battery pack and components constitute around 30-50 per cent of the total cost of a battery and there is scope to reduce this price by providing incentives and developing domestic industry. India has successfully achieved this in the case of the traditional automobile industry where it is an important part of the global value chain. Hence, it might be possible to emulate this by developing the ancillary industries for pack components and utilising spill-overs from it to manufacture cells and batteries. For example, in the case of battery management systems and battery packs, significant developments have already taken place.

6.1.3 Incentivising reverse logistics, reuse for stationary usage

Since batteries could have a second life for stationary use and costs can be recovered from recycling too, this explored the option of reducing cost once a battery is acquired. The increasing share of renewable energy increases the demand for storage and vehicle batteries and could offer a solution that would result in a reduction in the cost of ownership. Since the volume of batteries will grow with increasing uptake of EVs, a strategy to incentivise reverse logistics could help reduce the initial cost of batteries to end-users and manufacturers.

6.1.4 Improving the availability of critical cell components

As discussed above, even with financial assistance, manufacturing of cells domestically is contingent upon the availability of key elements that are used in manufacturing a cell. This option prioritises political and trade-related efforts to ensure entry of domestic manufacturers in global value chains to procure rare raw materials.

This option can be viewed as part of the first option that is too broad and may be deemed redundant. But it distinctly focuses on geopolitical efforts to ensure availability of raw materials and also serves the purpose of ensuring consistency and objectivity of the ranking exercise (discussed later in the chapter). Domestic manufacturing of cells will depend on the availability of raw materials and hence, these options must have similar priority.

6.1.5 Standardisation

Standards for cell manufacturing, battery pack assembling, and testing are important to prevent the entry of non-standardised batteries and dumping of technology in the market. Sub-standard batteries are cheap but unsafe; the uptake of EVs is highly contingent upon the end-user's perception, and unsafe batteries would have adverse effects. Standardisation is not only a low-cost strategy but will also help improve investors' confidence in the market.

6.1.6 Battery as a Service

This option is an example of innovative business models to reduce the cost of batteries to end-users in the short-term. The rationale is to transfer the cost of a battery as a service to the end-user and promote the concept of circular economy. However, the business model in such a case could be complicated. For example, in the case of public transport, the buses could be bought by transport companies and batteries by electricity distribution companies. Transport companies could pay the distribution companies service charges during the first life of the battery, and the distribution company could recover the remaining cost during the second life and recycling of the battery. Similarly, in the case of passenger cars or two-wheelers, users can pay a part of the battery cost upfront when they buy a vehicle, which will reduce the initial cost of ownership, while the remaining cost can be recovered during the lifecycle of the battery.

6.1.7 Demand aggregation

Demand aggregation or bulk procurements reduce cost and could help in creating further demand. Assured demand is important to attract private investment and aggregation in case of government procurements, and public transport could result in assurance of demand. EESL in India has already undertaken initiatives to aggregate demand for government vehicles and public transport. The aggregation may not only help in reducing the unit cost of vehicles but because of a greater battery utilisation rate in the case of public transport vehicles, it will also increase the demand for batteries in the future.

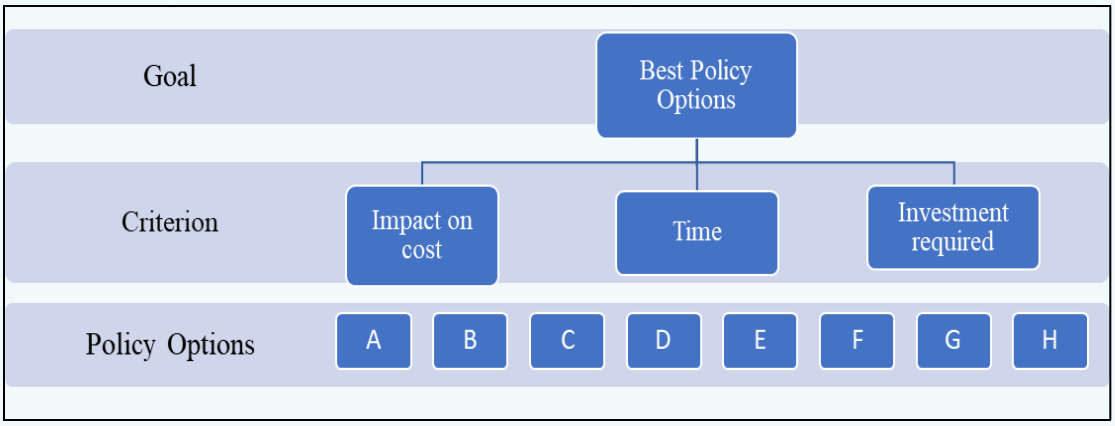
6.1.8 Dedicated Battery research institute

From policy analysis, it is evident that a network approach that brings stakeholders together is important, and so is the information on technologies. This option is included to assess the need for an institution that ensures availability of information on technologies to industry and adapts imported technologies to suit Indian conditions and application use. The purpose of such an institute may go beyond research and development activities to include identification of opportunities for and improvement in sensitivity of businesses and stakeholders to rapid technological change in the area of battery technologies. For example, the National Institute of Wind Energy was established to develop the technical aspects of wind energy in India.

6.2 Ranking of Strategies and Recommendation

These eight strategies have been assessed based on three criteria – their impact on reducing cost, investment required, and time taken to show results. This exercise was carried out with experts from industry, academia, research, etc., where they ranked these criteria for their relative importance and then ranked these strategies based on their relative importance with respect to a criterion. Although these strategies are not mutually exclusive and the overall efforts may include a mix of these strategies, it is important to understand their relative importance. The study utilises the analytical hierarchy process (AHP) to rank the strategies (Saaty, 1998). AHP defines a problem as a hierarchy. In this case, the structure of the problem is as follows (where A to F are the strategies discussed in the previous sub-sections):

Figure 6.1: AHP - Problem hierarchy



An AHP was conducted based on the responses of experts to compare the strategies discussed above and subsequently, calculate their relative importance. The first step determined the relative importance of these criteria, i.e., what is most important for a strategy – is it the impact on reducing cost, time taken, or the investment required. Table 6.2 below shows the weight of these criteria:

Table 6.2: Weight of criteria[34]

Criteria	Weight
Impact	0.64
Time	0.22
Investment	0.14

Source: ICRIER research based on the stakeholder feedback exercise

The analysis shows that the impact of a strategy in reducing cost is the most important criterion, followed by time. The low weightage to the investment criteria reflects experts' belief that investment should not be a constraint in choosing a strategy. However, it might be difficult to undertake certain measures in India solely with government investments. Government support in the country might not be able to match the volume of financial resources dedicated by governments in other developed countries; for example, financial support extended by the US government for R&D in battery technologies and EVs (discussed in previous chapter). Experts also compared each strategy across the criteria. The results from the comparison exercise after factoring in weights from the previous table are presented in the Table 6.3 below.

34 These results were calculated afterwards. During the exercise, experts filled four tables – comparison of criteria, comparison of strategies on impact, comparison of strategies on time taken and comparison of strategies on investment required simultaneously. Please refer to Annexure II for the structure of the questionnaire.

Table 6.3: Ranking of strategies

Alternatives	Priority	Rank
Incentivising cell manufacturing	23.18%	1
Improving the availability of critical cell components like lithium, cobalt, graphite	18.88%	2
Standardisation – battery standards, testing standards, etc., to prevent entry of non-standardised batteries in the market and promote investment.	15.07%	3
Development of ancillary industries for pack components– battery management system (domestic production of PCBs, ICs, etc.), binder and other products used in batteries apart from cells.	11.43%	4
Incentivising reverse logistics, reuse for stationary usage (grid, invertor, RE storage), recycling of batteries and recovery of critical metals/materials.	9.09%	5
Demand aggregation – Aggregation of demand in case of public transport to augment overall demand for batteries and promote domestic cell manufacturing.	7.58%	6
Dedicated battery research institute – which works on all aspects of batteries including cell chemistry and pack components in collaboration with the government and industry	7.41%	7
Battery as a service – Innovative business models to reduce the cost of battery.	7.38%	8

Source: ICRIER research based on the stakeholder feedback exercise

Cell manufacturing and improving availability of critical cell components are the most prioritised strategies followed by standardisation and development of ancillary industries. These results agree with the general intuition that domestic manufacturing of cells will reduce the cost of batteries and thus, among the top four priorities, three are about promoting cell manufacturing and battery packaging in the country. A similar prioritisation of cell manufacturing and availability of critical raw material reflects the consistency of responses from experts beyond the otherwise calculated consistency ratios in the mathematical process of AHP. Standardisation is a relatively inexpensive policy area that can play an important role in preventing the entry of sub-standard batteries in the market. It will act as a barrier to entry in the market and will encourage investments by providing a fair and competitive market for everyone. Standards will also help end-users in decision making and will address anxieties over the safety of batteries and EVs.

However, assured demand and the creation of a market will play an important role in encouraging investments. Hence, financial assistance to end-users, mass procurement, charging infrastructure and awareness about EVs are important as these will play an essential role in creating demand and must continue.

Among other options, incentivising reverse logistics (recycling and secondary use of battery) is not highly prioritised. This result is contrary to the discussion on these options in Chapter 4 where it shows that they could reduce the battery price significantly. It shows that while such options are important in the long term, their immediate impact on cost is not very significant as the value chains and demand necessary for the profitability of such initiatives are not yet available. Similarly, other options such as innovative business models to provide the battery as a service, demand aggregation for government procurement and establishing a dedicated battery research institute are found to be less significant.

Demand aggregation is an important option to reduce the procurement cost of government vehicles and could also help in spurring the demand for batteries by increasing the overall demand for EVs. From the discussion of policies in Chapter 5, EVs procured by the government help in increasing information and awareness about EVs, resulting in more demand for EVs and batteries and facilitates strategies for domestic manufacturing. The case of innovative business models could have a significant effect once the market and demand have matured, but currently have insignificant effects on reducing the cost of batteries. Similarly, the need for a dedicated battery research institution might not have any remarkable effect on reducing the cost of batteries. Overall, the need of the hour is to focus on ensuring incentives to develop domestic cell manufacturing and ancillary industries, with these efforts being supported by policies that increase overall demand and safeguard markets (by creating standards).

7. Conclusion

Battery is the major cost component of EVs and makes it unaffordable, which is holding back the imminent transition to an electric mobility system in India. India as a developing country must handle this transition cautiously as the new set of automobiles that drive the country towards development has to be both affordable and environment friendly. Batteries are at the centre stage of this dichotomy. Batteries are complex in terms of their components and chemistries, integration in vehicles as well as end-of-life utility. The affordability of batteries will play an important role in the smooth transition from a conventional fossil fuel-based system to an electric mobility system. This study attempts to identify cost reduction strategies by answering the three questions posed in Chapter 1.

What are the major cost components of an EV battery?

The study uses the BatPac v 3.1 tool developed by the Argonne National Laboratory (US) to assess the cost of EV batteries for different applications. The cost disaggregation is done for batteries based on NMC622-G for six applications – 2-wheelers, 3-wheelers, mid-range cars, long-range cars, SUVs, LCVs and buses. The total cost of a battery is divided into six categories – materials, purchased items (battery jacket, terminal, conductor, connections, etc.), pack integration and manufacturing (building, labour and capital equipment). The cost of materials in batteries ranges from 23 per cent to 49 per cent for 3-wheelers and SUVs respectively. Similarly, the range for purchased items is from 18 per cent to 28 per cent for buses and 2-wheelers respectively, for pack integration from 6 per cent to 30 per cent for buses and 2-wheelers respectively and for manufacturing, from 17 per cent to 35 per cent for 2-wheelers and buses respectively. All other applications have intermediate cost proportions for these categories. Further disaggregation of cost of within these categories is presented in the Chapter 3. The modelling exercise helped in recognising the role of end-use in determining battery cost. Materials constitute the highest proportion of the cost along with purchased items and pack integration to varying degrees.

What is the current status of the EV battery value chain in India? Are there any cost reduction opportunities?

The study envisages a circular chain with nine stages – material sourcing, component manufacturing, cell manufacturing, pack manufacturing, vehicle integration, usage profile, second life/reuse, after life/recycling, and research and development. Research and development supports each stage. Interviews with stakeholders reveal that some of these stages are almost non-existent in the country, namely, material sourcing, component manufacturing and cell manufacturing. However, recently, there have been efforts to promote the development of these stages in the country. These stages could together result in a cost reduction of 3-5 per cent but it will significantly depend on the scale of production. Pack manufacturing has already started on a small scale in the country and efficiencies in the value chain and scale of operation could help reduce battery cost by 10-15 per cent. Similar efforts along with standardisation at the vehicle integration stage could result in a reduction of approximately 5 per cent. Unlike traditional value chains, the value chain presented here in the study identifies three unique stages – usage profile, second life and after life. All these three stages are in the experimentation stage with little to no development at all. The potential cost reduction from these stages is difficult to determine. For example, the second life of battery could help in recovering 20 per cent of the cost but is subject to the willingness of refurbishing companies to pass on the benefits to end-users. Similarly, in the case of recycling or after-life cost recovery, 13 per cent of the cost can be recovered but this will depend on the development of these stages and their integration with the entire value chain in the long term. Innovative business models (usage profile) could result in immediate cost reductions but to what extent will depend on the ability of businesses involved to innovate such business cases and models.

What could be the strategies to reduce the cost of batteries? Relative importance and ranking of these strategies?

In addition to the information available from answers to the questions mentioned above, policy reviews of different countries also helped in identifying cost-reduction strategies. Governments in the US, the UK and Germany have focused on providing financial support to encourage the development of domestic manufacturing and related linkages. Similar provisions have also found attention in policies in India at the central and state levels (Andhra Pradesh and Karnataka). Government procurement has also played an important role in improving the uptake of EVs as is evident in the US, China, and Sweden. Almost all policies have focused on creating charging infrastructure, providing incentives such as exemptions (parking fee, toll charges, registration fee, etc.) and direct financial incentives to EV buyers. All these efforts will create the demand necessary for the scale of operation needed to reduce the overall manufacturing cost of EVs and batteries. Overall, the study identifies eight key strategy areas and assumes three criteria to judge these options. Among the three criteria – impact on reducing cost, investment required, and time taken by a strategy – the impact on reducing cost is the most important criteria followed by the time taken. Investment is not viewed as a major constraint. When the strategies are ranked for relative importance based on these criteria by experts, incentives for domestic manufacturing, availability of critical components, standardisation, and development of ancillary industry take the top four positions.

It is evident that the focus in the country is on cell manufacturing and development of related ancillary industries. The current policies (both at the central and state levels) recognises this and therefore, have focused on providing incentives to manufacturing but the availability of critical raw materials and assurance of demand will play an important role in the success of current initiatives. Despite the current provisions of incentives to EV buyers in the country, the desired sales volume is way behind the set target. The low demand along with lack of standards and strong enforcement of existing regulations have also inhibited investors. While manufacturing may take time, standardisation at various stages of the value chain will help in boosting investors' confidence in the Indian market. The explicit focus on cell manufacturing and battery packaging in policy is justified but a holistic approach that focuses on other ancillary industries – battery management systems, sensors, connectors, etc. – may also reduce the cost of batteries, given their contribution to cost as shown in the modelling exercise.

In the long term, development of reverse logistics and infrastructure to enable refurbishing and recycling will help reduce the cost of batteries; support in these areas must be provided as early as possible. Meanwhile, businesses could innovate their business models to provide battery as a service and have their own infrastructure for refurbishing and recycling on a small scale. The low ranking of these options reflects current priorities but the overall impact and applicability of these initiatives and others require comprehensive cost-benefit analysis. The study reaffirms the current focus on domestic cell manufacturing but outlines other areas that could promote investment, spur demand and facilitate a sustainable transition to an e-mobility system in the country. These other areas – reverse logistics, recycling and refurbishing infrastructure, ancillary industries, and relevant R&D infrastructure at every stage of the value chain – need further research.

EVs present a critical opportunity for India, both in terms of transition to sustainable mobility and in terms of the development of local industry for better technology adoption. EV batteries are costly and makes EVs unaffordable vis-à-vis conventional ICE vehicles but have substantial cost reduction potential and require a holistic approach. This study addresses certain critical concerns in the adoption of EVs and informs policymakers and industry to design better policies.

References

Aasness, M. A. (2015). The increase of electric vehicle usage in Norway—incentives and adverse effects. *European Transport Research Review, 7*(4), 34.

Beard, K. W. (2019). *Linden's Handbook of Batteries, Fifth Edition.* McGraw-Hill Education.

Bloomberg New Energy Finance. (2018). *Electric Buses in Cities - Driving towards cleaner air and lower CO2.* BNEF.

Business, E. a. (2018). *Electric vehicles: driving the transition.* House of Commons.

Das, A., & Hussain, Z. (2017). *Global Value Chains: Asymmetries, Realities and Risks.* New Delhi: Centre for WTO Studies (CWS), Indian Institute of Foreign Trade.

Du, J., & Ouyang, D. (2017). Progress of Chinese electric vehicles industrialization in 2015: A review. *Applied Energy, 188*, 529-546.

Egnér, F. &. (2018). Electric vehicle adoption in Sweden and the impact of local policy instruments. *Energy policy, 121*, 584-596.

Energy Alternatives India. (2019). *India EV expert guide.* Energy Alternatives India.

Figenbaum, E. (2017). Perspectives on Norway's supercharged electric vehicle policy. *Environmental Innovation and Societal Transitions, 25*, 14-34.

GAO. (2019). *FEDERAL VEHICLE FLEETS Agencies Have Continued to Incorporate Alternative Fuel Vehicles into Fleets, but Challenges Remain.* U.S. Government Accountability Office (GAO) .

Gao, P., Kaas, H.-W., Mohr, D., & Wee, D. (2016). *Disruptive trends that will transform the auto industry.* McKinsey & Co. Retrieved October 2019, from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry

IEA. (2019, 10 08). *The Super-Green Car Premium*. Retrieved from International Energy Agency web site: https://www.iea.org/policiesandmeasures/pams/sweden/name-47931-en.php

Kochhan, R., Fuchs, S., Reuter, B., Burda, P., Matz, S., & Lienkamp, M. (2014). *An overview of costs for vehicle components, fuels and greenhouse gas emissions.* Retrieved from UC Davis STEP.

Lehmann, P. (2010). Using a policy mix to combat climate change—an economic evaluation of policies in the German electricity sector,. Universität Halle-Wittenberg.

Leurent, F. &. (2011). Triggering the development of electric mobility: a review of public policies. *European Transport Research Review, 3*(4), 221-235.

Li, Y. Z. (2016). Business innovation and government regulation for the promotion of electric vehicle use: lessons from Shenzhen, China. *Journal of Cleaner Production, 134*(Part A), 371-383.

Lutsey, N. S. (2015). *Assessment of leading electric vehicle promotion activities in United States cities.* International Council on Clean Transportation.

Massiani, J. (2015). Cost-Benefit Analysis of policies for the development of electric vehicles in Germany: Methods and results. *Transport policy, 38*, 19-26.

Mosquet, X., Dinger, A., Xu, g., Anderson, M., & Tominaga, K. (2018). *The Electric Car Tipping Point.* Boston Consulting Group. Retrieved October 2019, from https://www.bcg.com/publications/2018/electric-car-tipping-point.aspx

Muntwyler, S. K. (2002). *Deployment Strategies For Hybrid, Electric and Alternative Fuel Vehicles .* IEA.

***National Platform Elektromobiltat*. (2019, October 9).** Retrieved from National Platform Elektromobiltat: http://nationale-plattform-elektromobilitaet.de/en/

OECD. (2013). *Interconnected Economies: Benefitting from Global Value Chains.* Paris: Meeting of the OECD Council at Ministerial Level.

OLEV. (2013). *Driving the Future Today: A Strategy for Ultra Low Emission Vehicles in the UK.* Office for Low Emission Vehicles).

Plötz, P. G. (2014). Working Papers on Sustainability and Innovation No. S 04/2014, . *Modelling market diffusion of electric vehicles with real world driving data. Part I: model structure and validation.* . Fraunhofer ISI, Karlsruhe.

Plötz, P. S. (2014). Who will buy electric vehicles? Identifying early adopters in Germany. *Transportation Research Part A: Policy and Practice, 67*(C), 96-109.

Rathi, A. (2019). The complete guide to the battery revolution. Quartz. Retrieved October 2019, from https://qz.com/1582811/the-complete-guide-to-the-battery-revolution/

Saaty, T. L. (1998). What is the analytic hierarchy process? *Mathematical models for decision support*, 109-121.

SIAM. (2017). *Adopting Pure Electric Vehicles:Key Policy Enablers.* New Delhi: Society of Indian Automobile Manufacturers.

Tal, G., & Nicholas, M. (2016). Exploring the impact of the federal tax credit on the plug-in vehicle market. *Transportation Research Record, 2572*(1), 95-102.

Twomey, P. (2012). Rationales for additional climate policy instruments under a carbon price. *Econ. Labour Relat. Rev., 23*, 7-30.

UNIDO. (2015). *Global Value Chains and Development: UNIDO's Support towards Inclusive and Sustainable Industrial Development.* Vienna: UNIDO.

Vergis, S. &. (2015). Comparison of plug-in electric vehicle adoption in the United States: A state by state approach. *Research in Transportation Economics, 52*, 56-64.

Weber, K., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. *Research Policy, 41*, 1037-1047.

Yaqzan, M., Rafat, Y., Abdullah, S., & Alam, M. S. (2017). Thermal Management Solutions of Lithium-ion Energy Storage Batteries for xEV Development in North India. *ISGW 2017: Compendium of Technical Papers* (pp. 179-191). Singapore: Springer.

Zhang, X. L. (2017). Review of electric vehicle policies in China: Content summary and effect analysis. *Renewable and Sustainable Energy Reviews*, 70, 698-714.

Annexure I

I. Cost reduction calculation for packaging (prices are illustrative)

Particulars	Values	Assumptions & Calculations
Current Battery market price	250	*$/kWh*
Cell Cost	175	70% of Battery cost
Pack components	75	30% of Battery cost
Proposed cost reduction with local engineering	30 -37.5	40-50% of pack components
Cost reduction percentage	***12 - 15%***	***of Battery cost***

Source: ICRIER Research; Based on ball park figures collected from various interviews and secondary data

II. Calculation of cost reduction due to second life/reuse option (prices are illustrative)

Particulars	Values	Assumptions & Calculations
Current Battery market price	250	*$/kWh*
5-yr Battery market price	200	*20% reduction in 5 years*
Market rate of refurbished battery	100	*50% of 5-yr price*
Entrepreneur Share	60	*60% of market price of refurbished*
Customer Share	40	*40% of market price of refurbished*
Customer discount on new Battery	***20%***	***of new battery***

Source: ICRIER Research; Based on ball park figure collected from various interviews and secondary data

III. Calculation of cost reduction due to recycling (prices are illustrative)

Particulars	Values	Assumptions & Calculations
Current Battery market price	250	$/kWh
5-yr Battery market price	200	20% reduction in 5 years
10-yr battery market price	160	20% reduction in 5 years
Refurbished Battery Cost (5-yr)	100	50% of battery cost
Refurbished Battery Cost (10-yr)	80	20% reduction in 5 years
Cell cost as percent of battery cost	70%	
Component cost as percent of cell cost	60%	
Recovery Rate	80%	
Future value of recovery	53.8	10-yr cost X cell ratio X component ratio X recovery rate
Processing cost	43.0	80% of recovery cost
Benefit to Customer	10.8	20% of recovery cost
Customer discount	***13.4%***	***of new refurbished battery***

Source: ICRIER Research; Based on ball park figure collected from various interviews and secondary data

Annexure II

Responses for pairwise comparison:

Verbal	Numeric Value
Extremely important	9
Very strongly more important	7
Strongly more important	5
Moderately more important	3
Equally important	1
Less Important to Least important	1/3, 1/5, 1/7, and 1/9.

Table 1: Comparison of criteria:

Criterions	Impact	Investment	Time
Impact	1		
Investment		1	
Time			1

Table 2: Comparison of strategies on Impact:

Comparing on Impact	Incentivising Cell Manufacturing	Development of ancillary industries for pack components	Incentivising reverse logistics, Recycle and Reuse	And so on
Incentivising Cell Manufacturing	1			
Development of ancillary industries for pack components		1		
Incentivising reverse logistics, Recycle and Reuse			1	
And so on				1

Table 3 and Table 4 were similarly constructed to record experts' inputs on comparison of strategies over the other two criteria.

Indian Council for Research on International Economic Relations

Core 6A, 4th Floor, India Habitat Center, Lodhi Road, New Delhi 110003

T: +91 11 43112400, F: +91 11 24620180

www.icrier.org