A GUIDANCE DOCUMENT ON ACCELERATING ELECTRIC MOBILITY IN INDIA

Written for Shakti Sustainable Energy Foundation
by IIT Madras (CBEEV) & WRI India

(For private circulation only)

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This guidance document is written for Shakti Sustainable Energy Foundation by a team from WRI India, and Center for Battery Engineering and Electric Vehicles (CBEEV) at IIT Madras, under the guidance of Dr. OP Agarwal and Professor Ashok Jhunjhunwala respectively. The team that put together this output comprised Dr. Prabhjot Kaur (CBEEV), Neha Yadav (WRI India), Subrata Chakrabarty (WRI India), and Dr. Parveen Kumar (WRI India). Madhav Pai and Amit Bhatt at WRI India gave additional guidance.

The document is primarily drawn from the research of Professor Ashok Jhunjhunwala, with some supplementary analytics done at WRI India.

Shakti Sustainable Energy Foundation (Shakti) seeks to facilitate India's transition to a sustainable energy future by aiding the design and implementation of policies in the following sectors: clean power, energy efficiency, sustainable urban transport, climate policy and clean energy finance.

SHAKTI SUSTAINABLE ENERGY FOUNDATION

WRI INDIA

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CONTENTS

FOREWORD

Electric mobility is grabbing attention globally. Leveraging this wave will bring multiple environmental and economic gains for India. These include improved air quality, reduced dependence on imported fuel, reduced emission of greenhouse gases (GHG), improved plant load factor for the electricity grid, and the opportunity to be a leader within a rapidly growing global market. While policy guidelines that prescribe a quantified electrification target by a certain date for India are yet to be set, the many policies that have been adopted thus far demonstrate a clear intent of growing the share of electric vehicles in the country.

Many recent developments are persuading this emphasis. These include advances in battery technologies that are reducing battery prices, increasing energy density of batteries that are increasing the driving range on a single charge, concerns about global warming and the urgent need to forgo fossil fuels, in which the transport sector remains one of the largest consumers, and finally, the growing share of clean energy in the overall electricity mix. Transitioning to electric mobility will require a carefully planned strategy. It needs an ecosystem approach that is comprehensive and relevant to the local context. It requires policymakers, regulators and other stakeholders to clearly identify the technologies and approaches that fit the needs of their regions.

In this context, it is important to recognise that India has its own unique features. Only about 2% of its vehicle fleet comprises high-end cars and nearly 70% are motorised two-wheelers. Besides, average trip lengths are small compared to the developed regions of the world. A large share of trips only involves walking and cycling. The fact that the Indian consumer is very cost conscious, the high ambient temperatures and low Indian driving speeds as compared to other countries, are other unique features that have to be kept in mind while designing a transition strategy. Merely replicating others may not work. Through this guidance document, we present a strategy that would be relevant for India. For instance, in the case of batteries we argue that smaller batteries are a better fit for Indian travel behaviour than larger batteries. Small batteries require lesser raw materials, are cheaper, and keep the vehicle lighter to enhance the driving range on a single charge. Further, our suggestions for encouraging the option of battery swapping stems from the potential for charging to happen in a controlled environment leading to improved battery life.

Therefore, to put this principle into practice, this guidance document has a three-fold objective:

1. Inform state and local level officials who have embryonic knowledge about the basics of EVs and what it entails.

2. Present pros and cons of different options (such as hybrid Vs Pure EV or Swapping Vs Charging) in a neutral manner for more informed decision making.

3. Present an ecosystem-wide transition strategy, followed by a road map to operationalise the actual deployment of electric vehicles in a city.

We have arranged the document in five parts. The first part presents the potential gains from India's adoption of electric mobility and the unique features of the Indian context, highlighting how it differs from the situation in the developed world. It argues that India's plans for electric mobility will have to be thought through differently.

The second part highlights the components of the electric mobility system, comprising electric vehicles, batteries, battery re-energising systems, and other factors like manufacturing facilities, research and development etc.

The third part presents a strategy for transition in the Indian context. It highlights the challenges of transition and presents a multi-pronged strategy for effecting the transition. Finally, it presents a road map for electrification of transport – in the form of a template for a city – by proposing three phases comprising a pilot phase, a scale-up phase and a self-propelled phase.

The fourth part covers policy measures that have so far been adopted at the central, state and local levels and also presents some measures adopted internationally towards the electrification of transport. In the last part, we present potential business models for different components of the electric mobility system.

To achieve these objectives, we conducted some in-house research and analysis in WRI, apart from sourcing a lot of the information from Prof. Ashok Jhunjhunwala and his work. We also conducted a stakeholder workshop in Delhi on February 21, 2019, which was attended by over thirty participants from major auto makers, service providers, fleet operators, government bodies, academia and research.

We hope that this guidance document will serve as a reference point for stakeholders aiming at accelerating electric mobility in their regions. It would help new entrants make a start by understanding the fundamentals of electric mobility, while those at advanced stages will benefit by finding detailed insights on policies and technologies.

Dr. OP Agarwal
CEO, WRI India

INTRODUCTION

Electric mobility brings multi-dimensional benefits for India. Improved air quality, reduced dependence on imported fuel, reduced emission of Greenhouse Gases (GHG), improved plant load factor for the electricity grid, and the opportunity to be a leader within a rapidly growing global market, are among some of these benefits.

While electric vehicles have been talked about for several decades, it is only in the last few years that it has seen a significant growth, largely due to:

Rapidly falling battery prices which are making EVs increasingly more cost competitive with ICE vehicles.

Increasing energy density of batteries that enables EVs to travel longer distances on a single charge.

Emergence of battery swapping, in addition to charging, as a way of re-energising batteries and enabling the use of smaller batteries so that EV costs are reduced.

The emergence of shared mobility options like Uber and Ola, which involve longer daily travel distances for vehicles thereby making EVs a more viable option than ICE vehicles.

The increasing concerns relating to climate change coupled with the increasing share of clean renewables in the electricity mix of countries.

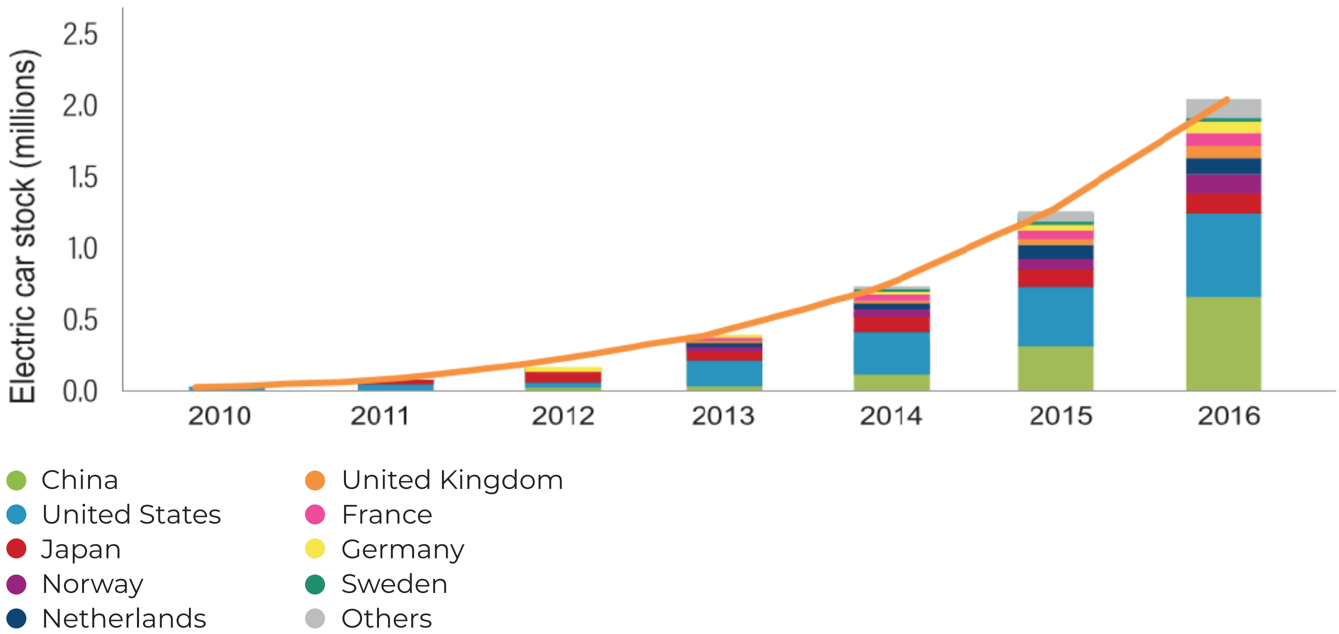
Today, the fastest adoption of electric vehicles is taking place in China followed by United States and Europe. China became the world leader in EV sales, outranking the US, in 2016. As per Bloomberg New Energy Finance (BNEF), China will continue to lead electric vehicle sales up until 2040. There were 1.1 million electric vehicles[1] world-wide in 2017. BNEF forecasts that the population of electric vehicles will increase to 11 million in 2025, further leaping to 30 million in 2030, when electric vehicles will become cheaper than Internal Combustion Engine (ICE) vehicles (BNEF, 2018). Figure 1 on the next page shows the growth in global stock of EVs since 2010 and Figure 2 shows the growth in EV registrations in China, Europe and the United States.

Although there has been impressive growth, the stock of EVs is still barely 0.2 percent of the total stock of motor vehicles[2] (IEA, 2017, p. 22). So, there is still a long way to go. In fact, electric vehicles are being projected as the future of transport and to increasingly replace ICE vehicles. The key reasons for this are that:

- They have no tailpipe emissions, thereby being good for local air quality.
- They improve the energy security of countries that depend very heavily on imports to meet their petroleum fuel needs.
- They are almost four times more energy efficient than ICE vehicles.
- They have a lower operating cost, thereby resulting in lower cost for vehicles that see longer miles of travel in a day.
- They have only 25 to 30 moving parts as opposed to over 2000 moving parts in an ICE vehicle, thereby being more reliable, with fewer breakdowns.
- They are cleaner from a GHG perspective, especially if the share of clean renewable energy in the electricity grid goes up (IEA, 2017, p. 44). They are quiet and make very little noise.

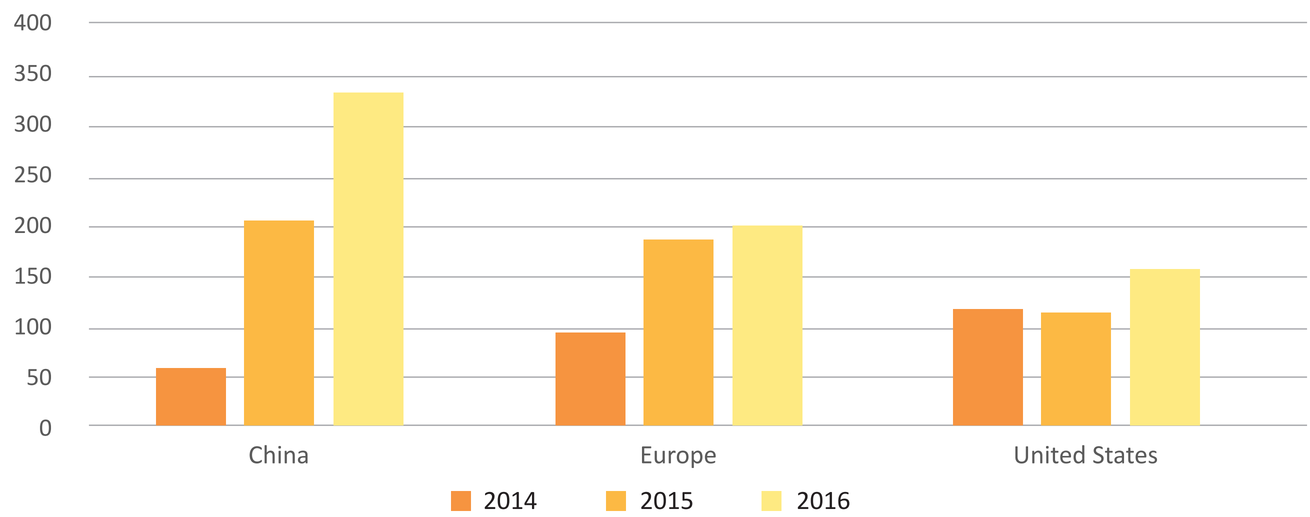
[1,2] This number reflects only cars and does not include 2/ 3-wheelers etc. However, 2 /3-wheelers are equally, if not more, important for rapid electrification in India.

Figure 1
Growth in Global Stock of Electric Vehicles



Source: (IEA , 2018)

Figure 2
Growth of new EV registrations (in thousands)



Source: (BNEF, 2018)

It is in the above context that this paper seeks to highlight the measures that India needs to take for accelerating the adoption of electric mobility. The paper also uses this opportunity to discuss some fundamental concepts, relating to electric mobility, so that decisions can be taken with a good understanding of the tradeoffs and nuances relevant to the Indian context.

The paper is divided into five parts, followed by a series of annexures that contain additional details of the issues discussed in the main paper:

Part 1 presents the potential gains from India's adoption of electric mobility and also presents some unique features in the Indian context, highlighting how it is different from the situation in the developed world. It argues that India's plans for electric mobility will have to be thought through differently.

Part 2 highlights the pillars of the electric mobility system, comprising electric vehicles, batteries, battery re-energising systems and other factors like manufacturing facilities, research and development etc.

Part 3 presents a strategy for transition to electric mobility in the Indian context. It highlights the challenges of transition and presents a multi-pronged strategy for effecting the transition. Finally, it presents a road map for electrification of transport in a city, proposing three phases comprising a pilot phase, a scale-up phase and a self-propelled phase.

Part 4 discusses the economics of different components of the electric mobility system.

Part 5 presents a summary and a way forward.

Annexures detail several of the issues discussed in the main paper.

It is hoped that this paper will become a reference document and a potential guide for any state or city seeking greater electrification of its transport system. It has been written in a simple style, to the extent possible, so that those who are new to this sector will get a better understanding of the basics for more informed decision making.

PART 1

WHY SHOULD INDIA ADOPT ELECTRIC VEHICLES

1.1 POTENTIAL GAINS FOR INDIA

India benefits immensely through a transition to electric mobility. Primarily it will enjoy the following gains:

1 **Improved Air Quality**	**2** **Reduced dependence on imported fuel**
3 **Reduced emission of Greenhouse Gases (GHG)**	**4** **Contributes to improved Plant Load Factor (PLF)**
5 **Increased share of renewables with EV batteries**	**6** **Be a leader in a rapidly growing global market**

Each of these is discussed in the sections that follow.

1.1.1 Improved Air Quality

At present air pollution is one of the most serious health hazards in the country. Fourteen out of the twenty most polluted cities in the world are in India. Many of these cities exceed the WHO outdoor pollution limits by 5–15 times. Vehicular emissions from road transportation (both passenger and goods) contribute a large share of this. A study conducted by IIT Kanpur in December 2016 found that in Delhi vehicles account for 9 percent of PM10 emissions, 20 percent of PM2.5 emissions, 36 percent of the NOx emissions and 83 percent of the CO emissions (Sharma & Dixit, 2016). Table 1 shows the share of two-wheelers and four-wheelers in the total emission load of Delhi in 2016.

Urban air pollution depletes public health, increases medical expenditure for families, results in missed days from work/school, loss in productivity, and physical and mental well-being. All of these are escalating the social and economic costs for the country. Besides, since India is likely to have over 50 percent of its population in urban areas, it is imperative that urban air quality improves significantly (UNDESA, 2018). EVs release no emissions from their tail pipes unlike their conventional counterparts. Adopting electric vehicles will, therefore, help in improving the air quality in cities.

Concerns have been raised about the pollution that would be generated by coal fired power plants to produce the additional electricity. However, mitigating pollution from coal plants at fixed locations, often outside city boundaries is easier than mitigating pollution from millions of motor vehicles that are moving all over the city. Besides, an increasing share of the electricity is projected

Table 1: Share of 2 and 4-wheelers in Delhi's total emissions load in 2016

	PM10	PM2.5	NOx	CO
Two-wheelers	33%	33	9	43
Four-wheelers	10%	10	17	37

Source: (Sharma & Dixit, 2016)

to come from cleaner sources. In fact, the batteries that are integral to EVs enable electricity to be stored and used, when needed. This is extremely useful for enhancing the share of renewable energy which is not available at a steady rate but is dependent on weather conditions to a large extent. Storage allows steady use even when generation is intermittent (more on this in section 1.1.4). Therefore, the need for improved air quality makes a strong case for the adoption of EVs.

1.1.2 Reduced Dependence on Imported Fuel

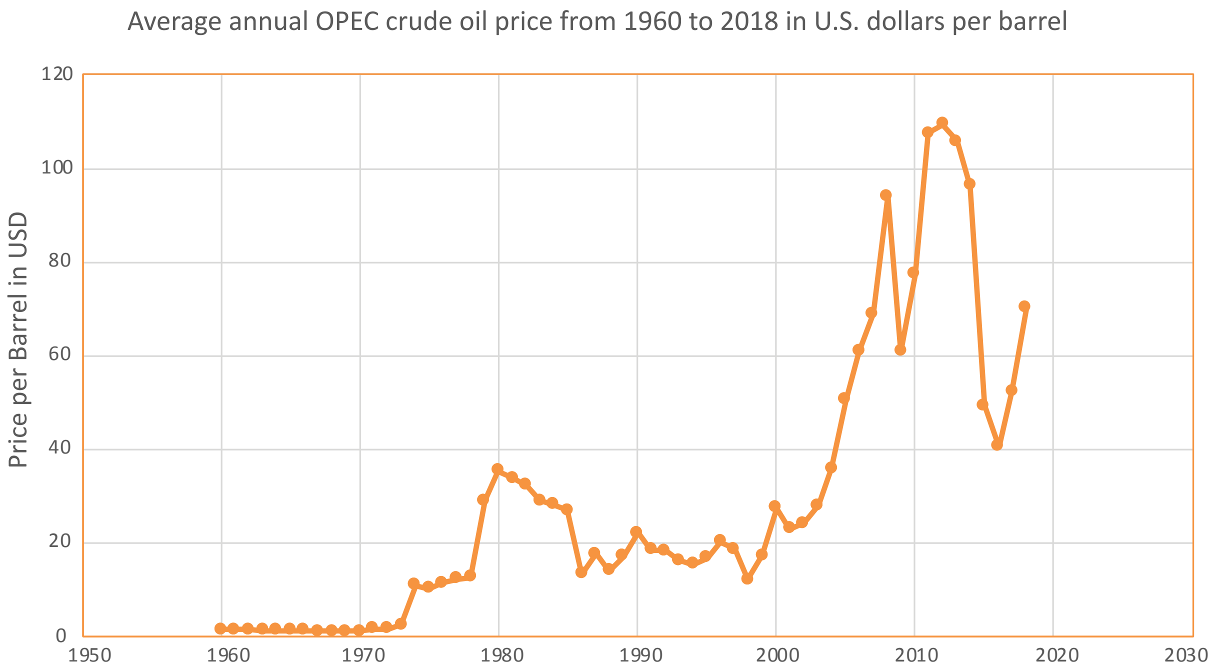
India has been largely dependent on oil imports for its transportation fuel needs. Its consumption of petroleum fuel went up from 32.5 million tonnes in FY 1981- 82 to 204.9 million tonnes in FY 2017-18[3] (Ahluwalia , 1986) (MoPNG, 2018, p. 11). The outgo of foreign exchange in this period went up from INR 16.4 billion in 1981 to INR 869.46 billion in 2017-18 (MoPNG, 2018, p. 11) (Goldar & Mukhopadhyay, 1990). Further, this import dependence is also impacted by the fact that the international price of crude oil has often fluctuated significantly thereby adversely impacting India's energy security. Figure 3 shows how the international price of crude oil has changed since 1971, often for purely geopolitical reasons. Figure 4 shows how the import bill of petroleum products has increased in the last three decades.

1.1.3 Reduced Emission of Greenhouse Gases (GHG)

A shift to electric mobility helps reduce GHG emissions. This is more so as the share of electricity from clean sources goes up. India already has 35% of its electricity coming from non-coal sources and, as part of its Nationally Determined Commitments (NDC) to the Paris accord on climate change, it has committed to increasing this even further. The net result would be reduced GHG emissions from the transport sector (MoEFCC, 2015) (MoP, 2019).

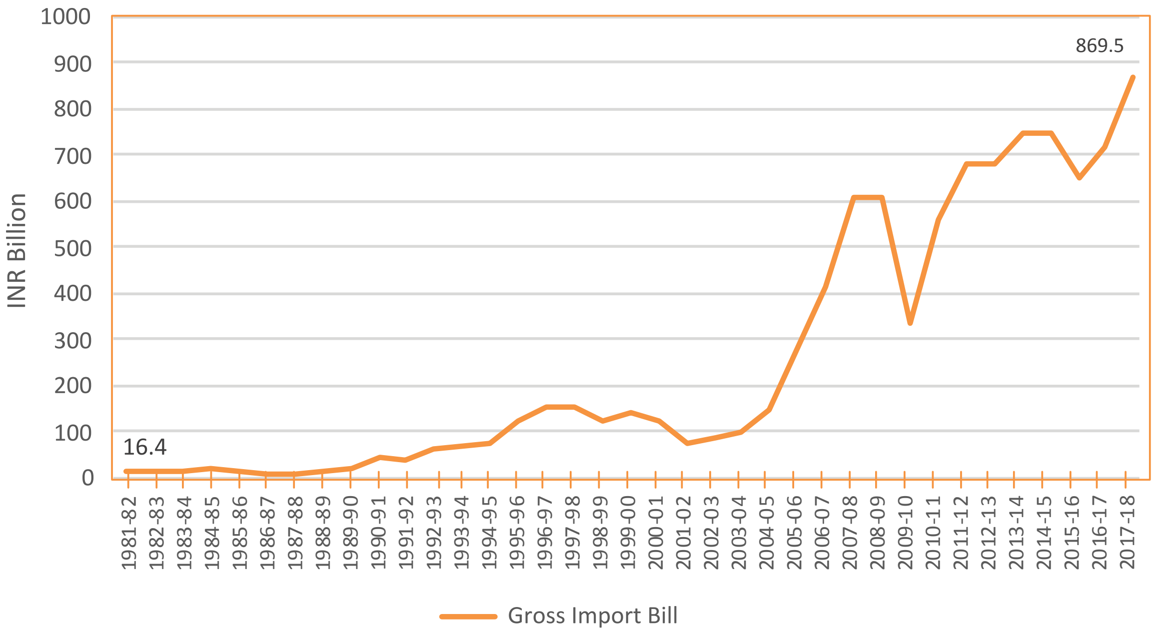
Studies done to compare the amount of GHG released from cradle to grave for an electric and a conventional (gasoline or diesel) vehicle show that even when electric vehicles use entirely coal-fired electricity, they emit lesser greenhouse gases than their conventional

Figure 3
International crude oil prices from 1960 to 2018



Source: (Statista, 2018)

Figure 4
India's import bill of petroleum products from 1981-82 to 2017-18



Source: (MoPNG, 2018), (Goldar & Mukhopadhyay, 1990) and (Ahluwalia, 1986)

counter parts. For example, in the United States, a mid-size electric car with a range of 84 miles, emits 51% lesser CO_2 than a mid-size gasoline car (UCS, 2015, p. 21). Looking at the example from the United States, as the share of renewables in electricity generation increased, the CO_2 emitted during manufacturing and operation of the electric vehicle decreased.

India has already committed to increasing the share of renewable sources in its energy mix. The share of renewables in India is projected to grow from 10.7% in 2017 to 12.1% by 2023 (IEA, 2018).

1.1.4 Increased Share of Renewables with Battery Storage Systems

An increase in the number of EVs will mean an increasing availability of batteries. Batteries serve as electricity storage devices. They are key to increasing the share of solar and wind energy considering renewable sources are only intermittently available and are weather dependent. Grid operators can store renewable energy in batteries and can supply it back to the grid in the case of instability. As the cost of battery packs fall, using batteries for electricity storage will become a viable proposition for grid operators. In addition to this, as the generation of renewable energy goes up in India, more batteries will be needed to store this electricity.

Further, there is a potential secondary use of batteries largely as static storage devices. With prolonged use in vehicles, batteries get replaced when they have 70 to 80% of their capacity consumed. These batteries can then be used in a stationary environment as energy storage systems for renewables. With this begins the second life of a battery, in which they can last till they have about 40% of their capacity. Aptly using batteries in their second life is important for expanding the share of renewables in the energy mix of India. Thus, a large-scale adoption of electric mobility also contributes to enhancing the share of renewable energy in the country.

1.1.5 Contributes to Improved Plant Load Factor (PLF)

Electricity needs to be used as soon as it is produced, since there is no large-scale, and convenient storage option today. Unlike water, which can be stored in tanks when not needed, electricity cannot be stored. Typically,

[3] *Data for 2017-18 is provisional*

power generating stations produce less electricity than they could as the demand for electricity varies over the day. There are peak periods and off-peak periods. The ratio of what they produce against what they could, is referred to as the Plant Load Factor or PLF. As per Central Electricity Authority (CEA), the all-India PLF up to February 2019 was only 61.01 percent (MoP, 2019).

Electric vehicles have the potential for creating an additional off-peak demand that would help improve the efficiency of generating stations by improving their PLF. Besides, the storage created by the second use of batteries would create demand for electricity during off-peak periods and can be used during peak periods. Surplus capacity, that is available during off-peak hours, can be used for charging EVs at times when there is no alternative use. Many state-owned power utility companies are planning to enter the business of setting up charging infrastructure to help improve their performance and adjust themselves to the muted demand for electricity (Raj & Bhaskar, 2017).

1.1.6 Be a Leader in a Rapidly Growing Global Market

To remain competitive and at the forefront of a rapidly evolving market, India needs to proactively innovate today, do things differently from the way it is being done elsewhere, and use India's large potential market to get technology leadership in at least some segments of the EV ecosystem. It could build upon this to create an EV industry in India, which could match, or even exceed the present ICE vehicle and fuel-industry in terms of GDP and jobs. Timely shift to electric mobility will ensure that India's automotive sector is able to secure competitiveness and relevance in global and domestic markets. India's auto industry creates about 30 million jobs and accounts for 7.1 percent of the country's GDP (SIAM , 2017). Processing of fuels for vehicles also creates jobs. In addition, several more indirect jobs are created in the distribution and marketing of these fuels. These jobs can be under threat, if alternatives are not found rapidly. These are vital contributions to the economy and demand preservation. World over, EVs are gaining prominence, with several automakers committing to selling only electric vehicles in the next 5-10-year period. Transition to EVs will require manufacturers to invest in new assembly lines, to manufacture these vehicles, and the parts needed for them. This will require not just retooling of machinery but also reskilling workers who only have the know-how of ICE vehicles. Additionally, electrification will need the auto industry and the electricity and energy sector to work together for the first time in India. Forming partnerships now will provide adequate time to both sectors to jointly prepare for the upcoming changes.

The new subsystems that will emerge with EVs, include electrical batteries, drive-trains and charging-cum-swapping systems. Besides, EVs will bring a new thrust to vehicle light-weighting and accessories, as they will naturally be powered from electricity. Batteries are the most expensive element of the subsystems. Unfortunately, India does not have mineral reserves for the chemicals (lithium, cobalt) that EV batteries are currently made out of. High performing and reliable batteries directly impact the performance and cost – capital and ownership - of electric vehicles. Creating a competitive market for battery manufacturing would be equally important for independence from battery imports. Battery recycling to recover materials form used batteries and to reuse them for new use could be another thrust.

The electrical drive-train consisting of motors, drives, chargers and control systems for EVs are yet another market segment that has potential for the Indian industry to manufacture and obtain global leadership in. Other subsystems, like electric power-steering, power-brakes, air-conditioners and other subsystems for small and large electric vehicles are also areas for potential leadership. Annexure 1 lists key firms that are manufacturing electric vehicles, making and/or assembling batteries, electronic components and charging infrastructure in India.

India has to innovate to overcome high costs of several EV subsystems and optimise the technologies for higher ambient temperatures. It has to optimise the design of these vehicles to give high performance even at the lower average speeds in our congested cities. India has to try out innovative techniques to overcome range anxiety, including battery-swapping and top-up charging and find solutions most suitable for our conditions. It is these innovations that will give it leadership within a growing market in the developing world, where the conditions are more akin to those in India as against those in the developed world.

1.2 India's unique features

The transportation sector in India is very different from other parts of the world, including other developing countries. Differences are largely in terms of:

1 The composition of the vehicle fleet	**2** Dominant travel modes
3 Trip lengths and travel speeds	**4** Price concerns of the Indian consumer

These differences require that the strategy for electrification of transport be thought through in the unique Indian context and not be a replication of the path adopted in developed countries. The following sections highlight the unique features of the Indian context and also how these would influence our strategies.

1.2.1 Composition of the Vehicle Fleet

Of the 230 million registered vehicles in India as of March 2016, two-wheelers constitute the dominant share at 73.5%. Cars constitute about 13%, buses 1%, goods vehicles 4.5% and others (including 3-wheelers) 8% of the vehicle fleet (MoRTH, 2018).

Table 2 below shows the number of vehicles of different categories that were sold in India over the last six years (Society of Indian Auto Manufacturers, 2018). It indicates that two-wheelers continue to dominate, even the current sales in the Indian market, with their percentage exceeding 80%.

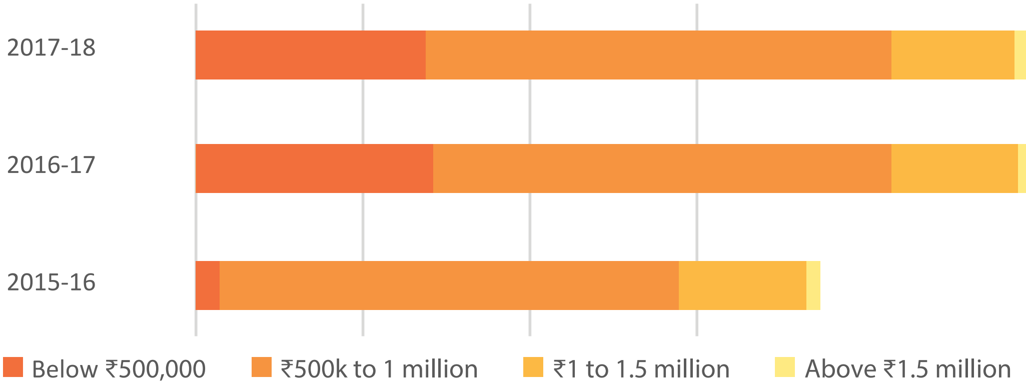
Cars itself are of two types – economy and premium. The first, which costs less than INR 1 million constitutes about 80 - 85% of the total and the second, which costs more than INR 1 million, constitutes only about 15 - 20% of the total Indian vehicle fleet. Thus, within the car segment, the pre-dominant share is of variants priced between INR 0.5 to 1 million. Figure 5 gives the share of car sales at different price bands.

Table 2: Domestic auto sales in India from 2012 to 2018 (in Millions)

Category	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	Average share (%)
Passenger Vehicles	2.67	2.50	2.60	2.80	3.05	3.29	13.71
Commercial Vehicles	0.79	0.63	0.62	0.69	0.71	0.86	3.49
Three Wheelers	0.54	0.48	0.53	0.54	0.51	0.64	2.63
Two Wheelers	13.8	14.80	16.0	16.5	17.6	20.2	80.17
Grand Total	17.8	18.4	19.7	20.5	21.9	24.9	100.00

Source: Society of Indian Auto Manufacturers, 2018

Figure 5
Percentage of car sales in different price bands



Source: (Jhunjhunwala & Kaur , 2018)

The important message is that 98% of the vehicles are either small and affordable vehicles (two-wheelers and economy cars) or public transport and goods vehicles (three-wheelers, small goods vehicles, buses and trucks). Only 2% of the vehicles are high-end cars - unlike in developed countries where such vehicles constitute the dominant segment.

1.2.2 Per Capita Ownership of Motor Vehicles

Furthermore, the per-capita ownership of motor vehicles is much lower in developed countries, as seen in Table 3 below. In India, for every 1000 persons, there are 19 passenger cars and more than five times as many two- wheelers. The reverse is true for developed countries, such as Australia and Japan and others, as highlighted in the table below (MoRTH, 2018).

Table 3: International comparison of motorcycles, mopeds and passenger cars per 1000 persons

Country	GNI per capita (US $) for 2014	Per 1000 persons	
		Passenger Cars	Motorcycles and Mopeds
Developed			
Australia	64620	567	33
Germany	47500	548	51
Japan	41900	472	92
U.K.	43350	455	19
U.S.A.	54400	357	26
Developing			
Brazil	11790	233	112
China	7400	76	70
India	1560	19	102
Korea Republic	26970	312	—
Malaysia	11120	382	389
Mexico	10080	209	18
South Africa	6790	122	7

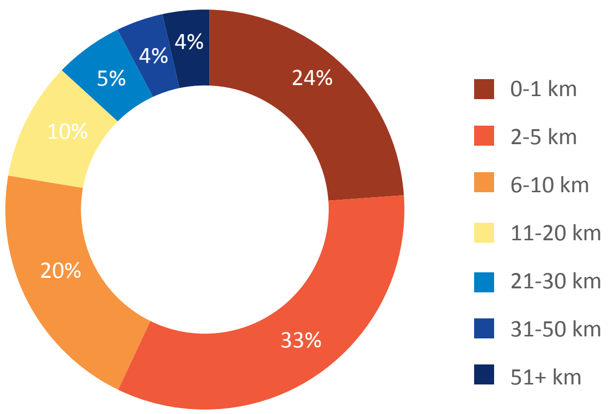
Source: Road Transport Year Book 2015-16 (MoRTH, 2018) | Note: some data points are from 2013

1.2.3 Trip Lengths and Travel Modes

Average trip lengths in India are shorter, than that in the developed world, primarily due to higher urban densities. This impacts the choice of travel modes.

Higher urban densities mean that trip lengths and mode of travel are also unique in the Indian context. 71% of the population travel less that 5 kms a day, with 31% not even requiring to travel. Another 14% travels less than 10 kms per day. Only about 15% travels more than 10 kms a day. Thus, trip lengths are relatively short.

Figure 6
Share of different trip lengths in India



Source: Census, 2011

The relatively short trip length also impacts the choice of travel modes. While travel modes vary across cities, walking and public transport are the dominant modes. In the larger cities of over 5 million people, the share of walking ranges from 15% to 35% of all trips whereas the share of public transport ranges between 30% and 60%. Share of motorised two-wheelers ranges from 10–22% and motorised 3-wheelers from 5–15%. The mode share of cars is only 5-15% (NTDPC, 2013, p. 387). As city sizes come down, the share of walking, motorised 3-wheelers and motorised 2-wheelers goes up whereas the share of cars and public transport comes down, often because many of these cities do not have a structured public transport system and shared autorickshaws tend to substitute for public bus services.

An important factor that needs to be kept in mind is that an average vehicle would travel much less in India per day as compared to other parts of the world, especially when compared with developed countries. This has implications for an EV's battery size and range as carrying undue or dead weight, with a high range battery, will be inefficient and a needless drain on the battery power.

1.2.4 Driving Pattern and Speeds

It is also important to recognise that the driving pattern in India is different from that in the US, Europe or even China. The average vehicle speed in an Indian city is less than 25 kmph as compared to 40 to 60 kmph elsewhere. The heterogeneity of traffic on India's roads, comprising several types of vehicles that travel at different speeds, limits the overall speed of the traffic to that of the slowest vehicle. Besides, there are several starts and stops as the traffic moves.

1.2.5 Ambient Temperature

The ambient temperature in many parts of India exceeds 40°C and sometimes even 45 °C. This has an impact on battery-life unless battery-cooling is used. Excessive battery cooling draws energy from the battery, and reduces the level of charge available, thereby impacting the range that the batteries may provide.

1.2.6 Characteristics of the Indian Consumer

Fuel economy is one of the primary concerns of the consumer mindset in India (Deloitte, 2014). Fuel economy is often the first question that a consumer asks when purchasing a motor vehicle. The competitive price offerings of the automakers also indicate a recognition of the price sensitive mind-set of Indian consumers. The resale value or trade-in value of the vehicle is also an important factor in their purchase considerations.

1.3 India's approach needs to be different

Given the unique features in India, as presented in the above section, our approach to electric mobility will need to be different, from that adopted in the developed countries, in the following ways:

- India's goal should be to make EV capital costs similar to that of conventional vehicles and EV operational costs equal or lower than that of conventional vehicles with swapping.
- Most of the world uses large batteries to overcome range anxiety. However, this increases costs and weight. Since typical travel distances in India are much shorter, smaller batteries would be adequate for a large part of our needs. For the rare occasions when a longer trip is required, arrangements for swapping or adding an extra battery will be more appropriate than having a large fixed battery.
- Range anxiety can also be reduced by focusing on the energy efficiency of the overall vehicle, beginning with batteries, as well as emphasising lightweighting of vehicles, aerodynamic design, better quality tyres, motors and drives that attain peak efficiency in the Indian driving cycle, etc. such that smaller (and lighter) batteries are able to meet most of our travel needs. More details on the drivers of energy efficiency of batteries is given in Annexure 2.
- Since range would not be a major concern in most cases, slow charging can be the dominant mode of charging to ensure longer battery life.
- Given the higher ambient temperatures, charging under a controlled and conditioned environment will help improve battery life. This is easier if batteries are swapped rather than charged in the vehicle.
- Given the cost consciousness of the Indian consumer, efforts at reducing the capital costs could be by way of separating the vehicle cost from the battery cost, with the batteries being leased instead of being bought with the vehicle.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PART 2

PILLARS OF AN ELECTRIC MOBILITY ECOSYSTEM

The electric mobility ecosystem comprises six main components:

1 The electric vehicle	2 Batteries
3 Battery re-energising system	4 Other ancillary factors

In the following sections we present each of them in greater detail.

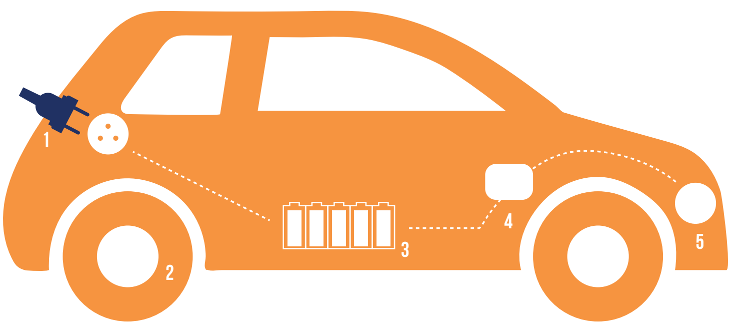
2.1 Electric Vehicle (EV)

An EV is a motor vehicle that runs, at least partially, on electricity, unlike conventional motor vehicles that run entirely on liquid fuels such as petrol or diesel. An all-electric car has a rechargeable battery, an electric motor, controllers and a plug for charging. Regenerative braking systems capture the energy that is lost in braking and plough it back to the battery. These components are shown in Figure 7 below.

Typically, onboard batteries store the electricity that provides the power for the motor. As the vehicle moves, the battery drains out and needs to be re-energised to provide the required power for continued movement. The distance it is able to travel on a single charge is referred to as its "Range". This is similar to conventional vehicles, where a fuel storage tank stores a certain amount of energy. After a certain distance of travel, this energy runs out and the fuel tank has to be re-filled. Liquid fuels like petrol and diesel are re-filled at petrol stations and other liquid fuels like CNG can be refueled by exchanging an empty tank with a filled-up tank. Similarly, batteries can re-energised either by charging at fixed charging points or by swapping a discharged battery with a charged one at a swapping station.

Electric vehicles can be pure electric (also known as Battery Electric vehicles - BEV), or Hybrid Electric vehicles (HEV) or Plug-in Hybrid vehicles (PHEV) or Fuel Cell Electric vehicles (FCEV). A comparison of the pros and cons of each is shown in Table 4 below. This table also compares conventional vehicles with EVs. More details on each type of EV is at Annexure 3.

Figure 7
The components of an all-electric car



1. Plug
Used for plugging electric outlets ar home or at a public charging station.

2. Regenerative Brakes
Capture energy lost when braking and store it in battery.

3. Rechargeable Battery
Energy storage unit of the car, Built from chemical cells.

4. Controller and electronics
Regulates the supply of power from the battery to the electric motor.

5. Electric Motors
Obtains electrical energy from the battery to move the steering and power the vehicle.

Source: Authors

Box 1: How does regenerative braking work?

Moving vehicles have kinetic energy. Frequent braking to slow down the speed of the vehicle, as is common in city traffic, dissipates this energy as heat from the brake pads. Regenerative brakes store at least part of the lost energy in the vehicle battery. By depositing the lost energy back into the battery, regenerative braking expands the range of the vehicle. Heavier vehicles (trucks, buses, cars) have greater kinetic energy while moving and therefore lose more energy during braking. Hence, regenerative braking is more effective in larger vehicles (Electrek, 2018).

Table 4: Pros and cons of different types of electric vehicles and conventional vehicles

	Battery Electric Vehicle (BEV)	Plug-In Hybrid Vehicle (PHEV)	Hybrid Electric Vehicle (HEV)	Conventional Vehicle
Key mechanism	Powered by an electric motor and a battery that can be recharged by plugging into an electric outlet	Powered by a conventional engine (petrol/diesel), along with an electric motor and a battery that can be plugged-into an electrical outlet for recharging	Along with a conventional (petrol/ diesel) engine, HEVs are powered by an electric motor and a battery that is recharged by regenerative braking	Powered by an internal combustion engine (petrol/diesel)
Propulsion	Electric motor drive	Electric motor drive; Internal Combustion Engine (ICE)	Electric motor drive; Internal Combustion Engine (ICE)	Internal Combustion Engine (ICE)
Energy source and infrastructure	Charging stations drawing power from electric grids	Charging stations drawing power from electric grids plus Petrol/ diesel stations	Petrol/diesel stations	Petrol/diesel stations
Advantages	• Higher efficiency • Home/workplace charging • Low engine noise • Few auto parts	• Higher efficiency • Home/work place charging • Many refueling stations	• Higher efficiency • Many refueling stations	• Wide variety of models • Many refueling stations
Disadvantages	• Range anxiety • Long-time to recharge • Fewer recharging stations • Battery management in Indian context where temperatures go up to 45-50 degree centigrades	• Technologically complex • Fewer recharging stations	• Tail-pipe emissions • Oil dependency • Engine noise • Technologically complex	• Low efficiency • Tail-pipe emissions • Oil dependency • Engine noise

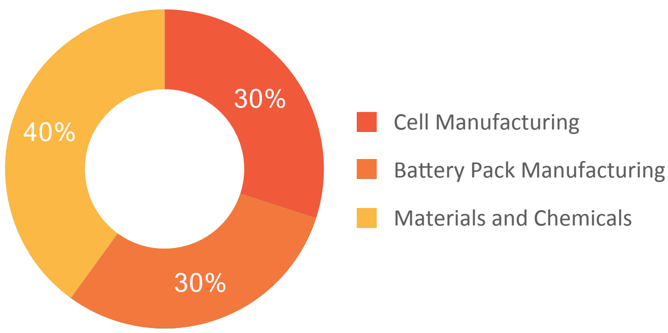
Adapted from: (Chan, 2002) and (European Environment Agency, 2016)

Note that HEV uses only petrol/diesel and the only advantage is lower fuel consumption per km. PHEV uses both electricity as well as petrol/diesel and is more expensive as there is a petrol engine plus an electric motor.

2.2 Batteries

Batteries store the energy that drives an EV, just like a fuel tank stores the energy that drives a conventional ICE vehicle. In a battery pack, the simplest unit is a cell. A cell contains chemical materials from which the chemical energy is converted to electrical energy. A series of cells put together form a module. A series of modules, packed together form a battery pack. Figure 8 below gives the cost of different components of a battery.

Figure 8
Cost break down of the EV battery system



The raw and processed material (referred here as Battery Materials) contributes to about 40% of the total value of the battery. Component and cell production, taken together (referred to here as Cell – manufacturing) constitutes about 25% to 30% of the total value. The Cell to pack, consisting of module production and battery assembly, contributes another 30% to 35% to the total value of the battery.

Battery cells have an anode, a cathode, electrolyte and case material. This involves choice of right chemistry for the cell and a controlled process to manufacture cells using materials and chemicals. Chemistry is critical and determines the price-performance of the cell.

2.2.1 Types of Batteries

Cells made out of lithium are known as Lithium-Ion Batteries (LIB). These are the most commonly used energy storage technology currently.

There are three prominent sub-categories of LIB:

- Lithium Nickel Manganese Cobalt (NMC) or Lithium Nickel Cobalt Aluminum Oxide (NCA) or Lithium Cobalt Oxide (LCO)
- Lithium Titanate Oxide (LTO)
- Lithium Phosphate (LFP)

These sub-categories have variations in specific energy, costs, life cycle, rate of charging/discharging, depth of charge and size. Each battery type has been described in Annexure 4. A comparative analysis (Jhunjhunwala , 2017) of these types of LIBs is also presented in Table 5 below.

As seen from the above table, Energy density (Watt-hour per kg) is the most important parameter because it contributes to the weight of the battery in a vehicle. It also gives a measure of the amount of material used in the battery per kWh and therefore, the cost of the cell. Higher the energy density, lower is the cost in high-volumes. Thus, cells having an energy density of 300 Wh/kg would be half the cost of those with 150 Wh/kg. In fact, the increasing energy-density is the primary cause of falling Li-Ion cell prices in the international market.

LTO cells can charge-discharge faster and have high-temperature tolerance. They also have a much higher cycle-life and are safer. They should, therefore, be the natural choice. But with much lower energy density, they are three to four times more expensive than NMC cells. Therefore, its usage would tend to be limited to special situations where a much smaller battery with many more cycles is required. LFP cells have a maximum theoretical limit for its energy-density as 150 Wh/kg. In other aspects, they fall between NMC and LTO in terms of temperature-tolerance and safety. But as its energy-density has already reached its theoretical maximum, its costs are not likely to fall any further. NMC stands out in terms of energy-density and costs, with energy-density expected to touch 300 Wh/kg in the near future. It cannot, however, be fast charged and has poorer temperature tolerance apart from having safety issues. The Battery Management System (BMS) has to ensure that the cells stay within the right temperature range and within safe limits.

Table 5: Comparison between LIB technologies

	Unit	NMC	LTO	LFP
Cost of Cells	USD per kWh	$130	$400	$175
Energy-density	Wh per Kg	250	<100	125 -150[4]
Charging-Discharging Cycles	Number over the course of life	2500	10000 and more	2500
Charging Time without impacting life	Minutes	45 to 60 minutes fast charge	10 to 20 minutes	45 to 60 minutes
Impact of Fast Charging	--	Impacts life cycle appreciably	No impact on battery life	Impacts life cycle appreciably
Bulkiness (Size and Weight)	--	Compact and low weight	Large Size and weight	Medium Size and Weight
Impact of high temperature (45 deg C)	--	High	Low	Medium
Inherent Safety	--	Low	High	Medium

[4] *LFP has a theoretical limit of 150 Wh/kg energy density*

The impression that prices are falling and charging speeds are going up is not entirely correct for all types of batteries, at least as of now. Cost of NMC (or NCA) is falling rapidly and charging rate of expensive LTO battery is going up. NMC/NCA are likely to dominate the EV market in the foreseeable future.

2.2.2 Components

Materials and chemicals constitute about 40% or more of the value of a battery system. The Lithium batteries prevalent today need Lithium (Li), Manganese (Mn), Cobalt (Co), Nickle (Ni) and Graphite besides other materials. Unfortunately, India does not have any mines for critical materials like Li and Co and has to import them. Fortunately, some Indian startup companies have shown that 95% of Li, Mn and Co and 90% of graphite is recoverable from used batteries in an environmentally friendly manner. Therefore, India will have to focus on a strategy centered around urban mining of these critical materials through battery-recycling.

2.2.3 Battery Management System (BMS)

The cell to pack making process consists of using cells to make a battery pack. It is not mere assembly. It involves:

- Right thermal design so that cells operate within a temperature range (required for maximum life of the battery).
- Right mechanical design, so that cells are always at the right pressure while charging and discharging, thus enhancing cell-life.
- Battery Management Systems (BMS) wherein each cell operates in the right manner, ensuring safety and maximum life of the battery.

BMS is the most critical element of a battery pack. It manages not only the entire battery, but also each cell in the battery, ensuring that the cells are utilised optimally. It monitors the charging, discharging, cell-balance and temperature of each cell. Based on the BMS design, a battery pack's life cycle may increase or decrease several fold even while using the same cells.

Thus, the BMS facilitates the following:

- Improved safety though early warning systems.
- Easy access to real-time information and data collection on battery performance.
- Reduced maintenance and replacement costs through periodic assessment of the battery performance.
- Proactive protection against extreme temperatures.
- Cell balancing against equal voltage.

2.2.4 Importance of Battery Performance

Since batteries are a dominant component of the cost of EVs, their performance is critical for the success of EVs. Optimal performance of batteries and their proper maintenance can be the key for successful adoption of EVs. Some important tradeoffs in managing batteries is in ensuring that vehicles do not carry unnecessary battery weight as these can reduce the distance that a vehicle travels on a single charge. Charging is also best done in controlled conditions where the batteries can be safely handled, to avoid damage, and temperatures can be properly regulated.

Annexure 5 highlights some important determinants of the performance of batteries and it would be good to keep these in mind to make optimal use of a high cost component of an EV.

2.2.5 Future Batteries

Battery R&D is now being carried out at a vigorous pace and new technologies are emerging every year. Yet, one may conclude that in the mid-term (may be up to the ten years), NMC/NMA battery will be at the forefront - both because of their energy-density and costs per kWh. LTO batteries may become useful in special situations. Lithium–Metal battery may be the technology to keep an eye on, whereas the promise of Metal-Air battery is fading away. Annexure 6 describes this in greater detail.

2.3 Facilities for Re-energising Batteries

Electric vehicles use batteries as their source of energy. Batteries store a limited amount of energy and vehicles can move only a limited distance before this energy runs out. Hence, the battery in a vehicle provides a limited range, namely the distance it can travel before the battery runs out of charge. The range of the vehicle depends upon the usable capacity of the battery installed in the EV, measured in Kilo Watt Hour (kWh), and the energy consumed by the vehicle, measured in Watt Hour per Kilometer (Wh/km). When a battery runs out of charge, it needs to be re-energised. This can be done in two ways:

- **Batteries are recharged either through slow charging or fast charging.**
- **A discharged battery is exchanged for a charged battery at swapping facilities.**

2.3.1 Battery Charging

Charging facilities can be set up at home, work places or parking lots. They can also be created in areas which have a cluster of vehicles, such as bus depots or locations where taxis tend to collect when they are not being used.
Charging can be slow or fast. Batteries behave best when slow charged to their full capacity (commonly during the night-time at lower temperature in most parts of India), ready to be used for its full range. But if the vehicle needs to go for more than this range in a day, it will either have to be recharged mid-way or swapped with a charged battery. If recharged mid-way, this will need to be done at fast charging stations or if swapped, it will need access to a battery swapping station. An intermediate option is to have a mechanism for adding a battery, over and above a fixed battery, on the few occasions when a vehicle needs to travel more than the distance that the fixed battery can power. This is known as "Range Extension".

An important concern is the time required for charging. Different types of chargers take different times to charge a battery fully. There are three types of chargers:

- **Slow charger:** If the charger charges the battery to 80-90% of its capacity in 4 to 8 hours, it is referred to as a slow charger.
- **Fast charger:** If the charger charges a battery in one hour, it is referred to as a fast charger
- **Ultra-fast charger:** If the charger charges a battery in 30 minutes or less, it is referred to as an ultra-fast charger.

The use of slow, fast or ultra-fast charger does not just depend upon the availability of the chargers. Instead, chargers must be matched with the specific battery chemistry to ensure minimum impact on the life cycle of the batteries during charging. The life cycle of a battery depends upon the battery chemistry used, depth of discharge (DoD) used (impacting the usable capacity of the battery), its rate of charging/discharging and the temperature at which it is charged/discharged. For example, a low-cost graphite-NMC battery available today cannot be fast charged to full usable capacity in less than an hour without impacting the number of life cycles, even when charged at 25°C. On the other hand, the higher cost LTO battery can be fully charged within 20 minutes without any appreciable impact on battery-life, even if the temperature goes up to 45°C. These facts, as well as the type of vehicle used and the battery-size and chemistry, need to be understood well while building public charging infrastructure.

Some more details on different charging and swapping methods are given below.

Slow Charging

For slow charging of 2-wheelers (battery size of 1 kWh to 2 kWh), 3-wheelers (battery size of 3 kWh to 4 kWh) and cars (battery size of 10 kWh to 30 kWh), the single-phase supply is adequate. For home charging, a 15A plug on the home-supply (also used for heavy home appliances like washing machines) can be used. For public slow chargers, it may be best to use the 15A industrial plug used in India.

Fast Charging (EV-F)

Fast chargers are those that can charge a vehicle fully in about an hour. Thus, if the vehicle has a battery of 15 kWh with 80% usable capacity, a 12 kW charger will charge it in an hour and will be referred to as a fast charger. On the other hand, a vehicle with 50 kWh battery would need a fast charger of about 50 kW for charging to take place in 45 minutes to an hour. Using about 75 kW charger, it would also be possible to charge the vehicle-battery in less than 30 minutes; this however requires that the battery-cells are capable of being charged in 30 minutes, without significantly impacting the life of the battery. Fast chargers can be AC or DC. AC fast chargers would need an external charger (which converts AC input to DC output for charging the battery) as the vehicle is unlikely to have a built in fast charger. AC-002 would be an AC fast charger.

2.3.2 Battery Swapping

Unlike charging, in battery swapping a discharged battery is replaced with a charged one. The discharged battery is then separately charged in a controlled environment.

EVs with Swapping (EV-S)

The time needed for charging can be a problem and many more charging points will be needed compared to the number of petrol/diesel dispensing units. Adequate space, for accommodating the number of charging stations needed, may not be easily available. In such cases, the alternative is to swap the discharged battery with a charged one. Swapping takes only a few minutes, which eliminates the need for drivers to wait for too long while the vehicle is being charged.

Battery swapping can also help in addressing the issue of high upfront cost of EVs. In the swapping option, the battery is separated from the vehicle and need not be owned by the vehicle owner. Instead, it can be owned by an Energy Operator (EO). An EO will provide a charged battery, in exchange for a discharged one, as a service. S/he will buy the batteries, charge them and lease them to vehicle owners at convenient charge-cum-swap centres. A vehicle-owner can sign up with one such EO and lease the charged battery from them. Swapping can be done manually for small vehicles, such as two and three-wheelers, since they have light batteries. However, 4-wheelers and buses, with heavier batteries, will need mechanical or automated swapping.

EVs with Slow Charging Plus Range-extension Swapping (EV-RE)

Yet another option could be that a vehicle is designed to have a small built-in “fixed” battery. This battery will be charged every night. But since the battery is small, the range will not be large. Since most personal vehicles in India are driven only for short distances, this small range may be good enough for most days. For the few occasions when the vehicle needs to travel longer distances, the vehicles can have a slot for a second battery called range-extension swappable LS batteries (or RE battery). When vehicles need to be driven for ranges longer than what is offered by the fixed battery, they will need to go to a swapping station to install an additional RE battery.

A detailed note on how different charging and swapping arrangements work is in Annexure 7.

2.3.3 The pros and cons of EV-F, EV-S and EV-RE

Table 6 below gives the pros and cons of using EVs with fast charging or EVs with swapping or EVs with range extension swappable batteries.

As indicated in the table, EV-S has the lowest vehicle costs, EV-RE is slightly higher whereas EV-F is likely to have the highest costs as range-anxiety and long waiting time for fast charging will push manufacturers to develop larger battery-sizes. On the other hand, operation costs for EV-F is the lowest (a fifth of similar petrol vehicles). EV-RE will have same costs as EV-F for 90 to 95% of time, but the costs become half of that for petrol vehicles for the 5% to 10% when the RE battery is used. EV-S would have operational costs half of that for petrol vehicles today, but with falling costs of the batteries, it would come down. Wait-time for EV-F during fast charging is a big problem and so is the problem of fast charging at high-temperature. On the other hand, EV-S and EV-RE avoids these as swapping is done within minutes. As compared to EV-F, EV-S and EV-RE give relief from the time needed for charging to extend the driving range.

Table 6: The pros and cons of EV-F, EV-S and EV-RE				
	EVs with slow + fast charging (EV-F)	**EVs with swapping (EV-S)**	**EVs with slow charging plus range-extension swapping (EV-RE)**	**Comments**
Battery Size in kWh	Medium to large to avoid fast charge wait-time	Small	Small	Question is how small can one make the battery in an EV-RE and still gain user acceptance
Cost of battery for the vehicle-owner	Medium to Large	Nil (Energy company will invest in battery)	Small	Swapping and range-extension battery will need re-engineering of the car to make space for the battery
Home Charging time and impact on Battery-life	Night time 6 hours: best for battery	NA	Night time 6 hours: best for battery	Vehicle parking problem on the road-side is solved in EV-S. For EV-F and EV-RE, roadside 15A charging points required; viable for DISCOM to add -- night-time charging will help them
Infrastructure required at home	15A power plug	None	15A power plug	Vehicle parking problem on the road-side is solved in EV-S. For EV-F and EV-RE, roadside 15A charging points required; viable for DISCOM to add -- night-time charging will help them
Range Extension by	Fast Charge	Swapping	Add-on battery swapping	
Wait-time for range extension and impact on battery life	1.5 hours and low impact, 1 hour and limited impact, Half hour and high impact, Less than 30 min + severe impact	Few minutes	Few minutes	There are battery chemistries (LTO) where fast charging even in 20 minutes will not adversity impact battery life. But they are three times more expensive
High temperature (45°C) Impact	High	Low	Low	
How often range extension required	Could be less than 5%, if vehicle has a large battery	Frequently	5 to 10%	Without slow charging built-in, battery needs to be swapped in EV-S each time one runs out of battery
User Convenience	Range extension pain	Daily swapping pain, but no home charging	High	Waiting for EV-F while fast charging is a pain; EV-S may be acceptable mostly for commercial vehicle
Can you go unlimited range?	Not unless you keep stopping for fast charge	Yes, with repeated swap	Yes with repeated swap of range-extension battery	
Engineering challenge	Fast chargers now available	Common battery for multiple vehicles desirable; vehicle has to be designed for swapped battery	Common battery for multiple vehicles desirable; vehicle has to be designed for second battery	Common battery will help in inventory at swapping stations. Will make business viable. Swapping mechanism needs to be standardised
Number of vehicles served per charger/ swapper in 10 hours	10	120	120	Each petrol outlet pump serves about 120 vehicles in a day filling petrol / diesel

Infrastructure for charging / swapping	Fast charger at many locations as one charger can charge (full-charge) only 8 to 10 vehicles in a day	Battery swapping at reasonable number of locations as vehicles require frequent swaps): existing petrol pumps inadequate	Battery swapping at limited locations (swap in minutes); existing petrol pumps will do	Existing 57000 petrol pumps can have life beyond petrol with EV-S and EV-RE. Jobs will be retained.
Infra-investment	Investment for fast charger at many locations: Medium	Battery investment + charging and swapping at reasonable locations: Very High	Battery investment + charging and swapping at limited locations: High	We need to add appropriate spread-sheets for demonstrating this
Business viability in India	Not clear unless charges for fast charging is high	Viable	Viable	We need to add appropriate spread-sheets for demonstrating this
Vehicle Capital Cost for user	Large (large to medium battery included)	Low	Medium (small battery included)	Largely dependent on battery-size
Vehicle Operation Cost	Low (cost of electricity) for 90 to 95% time, for range extension fast charging plus electricity costs	About half of that for petrol vehicles	Low for 90 to 95% of time (electricity cost only), but half of that for to petrol vehicles for range extension (5 to 10% of time)	Cost in EV-S will go down over time, as battery cost falls.
Business of existing (57000) petrol pumps and jobs	Fast chargers cannot sustain petrol pumps and jobs	Will preserve: more infra needed	Will preserve	Refineries, distribution and petrol pump revenue can be preserved by battery ownership and swapping
Multi-storied parking lots business	Strengthen by adding fast charge	Strengthen by adding swappers	Not needed as petrol pumps adequate; can add slow charge	
EV batteries as Grid-storage	Difficult	Swap-batteries in charger-cum-swapper station can be used as storage	Swap-batteries in charger-cum-swapper station can be used as storage	Difficult to use In-vehicle batteries as grid-storage

As against this, fast charging is well proven and has been tried out in many parts of the world, thereby placing EV-F at an advantage. Swapping is not as well proven and to that extent EV-RE and EV-S have some engineering challenges.

The number of fast charging stations required would be large as only 10 vehicles can use it in about ten hours. On the other hand, the existing petrol pumps alone could handle EV-RE completely. For EV-S, one can begin with petrol pumps, but if most vehicles become EV-S, one would need new swapping stations. Infrastructure investment in EV-F is moderate whereas EV-S and EV-RE require much larger investment (as the investment will include the cost of batteries). Battery swapping seems to have strong business viability, whereas the business viability of fast chargers is debatable, unless the charger costs significantly reduce. In fact, the existing petrol pumps in India can retain their business and employment, when petrol vehicles recede, if they diversify into EV-RE or EV-S. EV-F may be more suitable for parking lots, whereas slow chargers would make business sense for EV-RE in these places. Finally, batteries in EV (as in EV-F) are difficult to use as grid-storage, whereas EV-S and EV-RE will have batteries at charge-cum-swap centres that can be used as grid-storage and thereby help stabilise the grid.

India's drive to have 30 percent EVs by 2030, depends heavily on providing an ecosystem that helps in this mission. One of the cornerstones of this ecosystem is providing EV owners with adequate and economical charging infrastructure. Typically, both slow and fast public chargers will be needed.

To sum up, India needs to attempt to use all the three kinds of battery re-energising techniques. Different segments of vehicles may find one or the other more useful. It should be left to the market to decide what works. Swapping's disadvantage is that it is not extensively used elsewhere but it is a promising model where India can lead by example.

2.4 Other Factors

Rapid electrification also needs focus on developing local manufacturing capabilities, research and development, and teaching the workforce of the automotive industry the skills needed through the supply chain of an electric vehicle. Furthermore, to ensure that battery storage systems benefit the power sector, it is vital that smart grids be set up. This document discusses these important concepts only briefly, in line with its scope.

A strong manufacturing base would include manufacture of vehicles, batteries, re-energising equipment, cells and battery packs, power electronics, powertrains and other components. Appropriate incentives will go a long way in building up a strong manufacturing base and propel India to a leadership position in this industry, especially since the unique features of the Indian mobility sector are prevalent in much of the developing world for whom India can be a major supplier of electric mobility systems and vehicles. Encouraging local manufacturing and assembly units will contribute significantly in creating a reliable supply of spare parts needed to make electric vehicles, batteries and re-energising infrastructure. This will prevent any breakages in the supply chain, and thereby minimise the costs of transition for the auto makers and original equipment manufacturers.

It is also important to develop close collaborations between industry, academic and research institutions. This is important for the development of a workforce that is equipped with the requisite knowledge and skills to address various processes throughout the supply chain of the electric vehicle. Electrified transportation systems will draw energy from the power grids to charge their batteries. Bi-directionally integrating the vehicles and grids are known to bring many benefits. These include exporting electricity, stored in batteries, to the grid in times of outages and natural disasters, improved grid stability, supplying renewable energy to the grid, and managing charging load during peak times.

Another important pillar in the smooth transition of the auto industry is the supply and value chain of electric vehicles and the workforce - people who work on the assembly lines to manufacture vehicles and their spare parts, give after-sale service and maintenance, interact with customers at the dealerships, and drivers and fleet operators who are attuned to IC engines. For manufacturing and fixing wear and tear in conventional vehicles, mechanical skills are needed. However, for electric vehicles, knowledge of electrical, electronics and mechanical components of the electric vehicles will be needed. Increasingly, many after-sale auto services will be digitised. Evolving the skills of the workforce, in step with these developments, will be crucial for making electric vehicles the vehicle of choice for consumers.

Transitioning to new technologies bring risks that can be fairly distributed through contractual mechanisms. Contracts can also make new stakeholders a partner in the emerging ecosystem. In this, international cities offer worthy lessons. Take for example the case of Bogota, Colombia. The city contracted the manufacturer of its hybrid buses for an additional period of 5-years for assisting the fleet operators in maintenance and repair of the buses and providing training to the operators' in-house technicians. This way the operator, who only knew how to repair diesel buses, had a trusted agency to reach out to in case of break downs in the new vehicles. The goal was to make the operators' technicians self-sufficient in servicing electric buses, eliminating the need of further contracts at the end of five years (Li, Castellanos, & Maassen, 2018). Strategies like these can avert risks that are a natural by-product of adopting new and alternative technologies.

0 km/h
1:35
POWER
PS
1
To 100% Charge
--:--
(Est. Time)
416 km
P
ECO
291.6 km
143
km
0

PART 3

STRATEGIES FOR TRANSITIONING TO ELECTRIC MOBILITY

In discussing potential strategies and a road map, for transitioning towards the electrification of transport in India, we first discuss some of the challenges facing such a transition. Thereafter, we highlight a multipronged strategy that needs to be taken up, covering policies and regulations, standards, awareness building, demand creation, financing and other supporting actions. Finally, we suggest a three-phase road map, giving details of what needs to be done during each phase.

3.1 CHALLENGES WITH ADOPTION OF ELECTRIC MOBILITY

While there are wide-ranging benefits, the adoption of electric mobility faces some challenges that need to be overcome. The more prominent among these challenges are the following:

1 Comfort with the existing system and resistance to change	**2** Lack of public awareness
3 High vehicle and battery costs	**4** Limited driving range and long recharge time
5 Lack of charging and swapping stations	**6** Import dependence for batteries
7 Managing batteries post-use in EVs	

3.1.1 Comfort With the Existing System and Resistance to Change

Nearly all stakeholders are comfortable with the current set of motor vehicles and do not see a need for change to meet their travel needs. As for the customers, ICE vehicles have served them well for over a hundred years and they are used to it. Any change means a learning curve and changing current ways of living that no one is happy about. As for manufacturers, they have made heavy investments in car manufacturing facilities and any change in technology will need significant additional investments. Oil companies have also invested heavily and stand to lose the entire investment if motor vehicles move to electricity. Retail outlets will also lose their investments or will have to invest in charging/swapping facilities as a new line of business. There is a large auto repair industry that stands to lose business as electric vehicles have fewer parts and therefore, fewer breakdowns.

As a result, there is resistance to change and unwillingness to get out of the current comfort zone.

3.1.2 Lack of Public Awareness

Electric vehicles are relatively unknown to the normal customer. They do not know what its benefits and challenges are. They are not aware of why it is important to make the transition. Others, who have some idea, are concerned about the limitations of the technology and do not know how these limitations really don't hurt them too much. In fact, any new technology needs a sustained awareness campaign. The introduction of LED bulbs was successful due to a sustained campaign informing people about its low energy consumption and its longer-term economic benefits. It is such a campaign that persuaded people to move towards LED bulbs, even though the capital costs were higher. A similar campaign is needed for electric vehicles as well.

3.1.3 High Vehicle and Battery Costs

One of the major barriers for switching to EVs is its cost. The capital cost of EVs is still about 50% or more expensive compared to petrol/diesel variants. In countries like USA, China and in most countries in Europe, substantial subsidy is provided to encourage purchase of EVs. Batteries dominate the cost of an electric vehicle. Even though the costs of the electric batteries are falling year after year, as seen from Table 7 (Jhunjhunwala & Kaur, 2018), the present cost of batteries is high and may contribute to as much as 50% of the EV cost. Also, specific energy density (measured in Wh per Kg) of the battery is low (Jhunjhunwala , 2018), implying that the weight of the battery will be high. The high cost of the battery makes the initial cost of an electric vehicle high, even though the operating cost may be lower[5]. Anyone buying an electric vehicle will be concerned about the high capital cost. The possibility of this being more than made up from future savings in operating costs would be uncertain until there is adequate experience in the market to reassure a consumer that savings indeed do accrue. In five to seven years, as seen from Table 7, costs of a battery will come down and the batteries will become lighter. EVs will then make economic sense and could compete well with petrol vehicles. Till then, the high capital costs will be a deterrent to any customer.

3.1.4 Driving Range and Recharge Time

Batteries have a lower energy density than liquid fuels like petrol and diesel. So, while a full tank of petrol can drive a vehicle for a rather long distance, battery based EVs always have a limitation on how far they can be driven on a single charge. In other words, EVs can only be driven for a limited distance on a single charge as compared to the distance that a petrol/diesel vehicle covers on a single filling (US Department of Energy, 2018). The higher driving range is possible with a larger battery (Tesla uses a battery which gives about a 600 km range), but this increases the cost of the vehicle and also the weight that the vehicle has to carry.

If the driving range is limited, it becomes important to find an electric outlet or a public charger at frequent intervals, or alternatively limit the distance for which the vehicle is driven. This is different from what consumers are used to, with petrol and diesel vehicles, where the distance they can drive on a single filing is a lot more than they can drive with a single charge of an onboard battery. Hence, the limitations of driving range are a concern area.

The problem gets further compounded with the significant time needed to recharge a battery. The ideal recharging time for a battery is 5 to 8 hours compared to a few minutes for filling up a petrol tank. It is possible to have fast charging facilities, but even with such charging the time taken would be 45 mins to an hour. Higher cost batteries could be charged in 20-30 minutes up to 60-80 percent of their capacity, with fast charging facilities (US Department of Energy, 2018). Besides, fast charging, especially at the kind of ambient temperatures one encounters in India, can adversely impact battery life which is a high cost component of the electric vehicle[6].

Table 7: Improvements in the cost and specific energy density of batteries

Year	Lithium Ion battery costs per kWh	Specific Energy Density per Kg
2012	USD 600	70 – 100 Wh
2015	USD 370 - 400	100 – 130 Wh
2020	USD 150 - 200	270 Wh
2025	USD 90 - 100	300 Wh
2030	USD 60 - 70	500 Wh

Source: (Jhunjhunwala & Kaur, 2018) (BloombergNEF, 2019) (Jhunjhunwala, 2018)

[5] Vehicles that travel longer distances in a day will see greater savings in operating costs and thereby a low total cost of ownership.

[6] One can use much higher-cost LTO batteries as discussed earlier, which may be charged in ten to fifteen minutes, even at higher temperatures. But such higher cost batteries are unaffordable for mass use EVs in India

Hence, charging time for batteries is yet another challenge. Using smaller batteries can surmount the cost and affordability challenge, but it would significantly enhance the range anxiety.

3.1.5 Lack of Charging and Swapping Stations

There is a wide network of petrol and diesel filling stations already. As against this, a network of battery charging and swapping stations is yet to come up. In fact, a challenge with the adoption of electric mobility is dealing with the classic chicken and egg problem of which should come first – the charging/swapping facility or the EV. People will not buy an electric vehicle unless there are charging/swapping facilities. However, charging/swapping facilities will not make business sense unless there are vehicles to charge. The question of where to begin is therefore an important one.

India needs policy measures and standards that enable creation of a high-density network of swapping and public recharging infrastructure.

3.1.6 Import Dependence for Batteries?

EVs mostly use Li-ion batteries and use materials like Lithium, Cobalt, Nickel, Manganese and Graphite. Unfortunately, India does not have any of these materials. Hence there is a concern relating to the import dependence for batteries and the possibility that battery imports may just replace oil imports.

Fortunately, Indian startups have done an appreciable work in taking used batteries and recovering almost 90 to 95% of these materials using a zero-effluent process. There is little reason for India not to scale up these processes. If appropriate incentives are created for this, India not could well become the Li-Ion battery recycling capital of the world. What would be needed is a policy that makes it compulsory to recycle every cell-phone, laptop or vehicle battery with a zero-effluent process. It must become obligatory for every user to deliver the used batteries to a place from where the recycler could then pick-up the spent batteries. This will also answer the question of what to do with used batteries, discussed in the next section.
Furthermore, startups in India are quickly mastering the technology for cell to pack and large Indian battery companies, like Exide and Amar Raja, are associated with these startups and are in the process of manufacturing batteries from cells.

Cell-technology is complicated and the chemistry changes very rapidly. In fact, this is the primary contributor to the falling costs of cells. Therefore, cell manufacturing has to continuously depend on R&D to come up with new chemistry and processes. Unfortunately, India is not strong in this area and may have to set up joint ventures with international companies.

3.1.7 Managing Batteries Post Use in EVs

With an increasing number of EVs, the number of batteries that will need to be disposed, post use in EVs, will increase. This creates a waste hazard and methods of secondary use or waste disposal need to be found. Options are:

Battery Recycling

Battery recycling is when batteries that can no longer be used in EVs are stripped of usable components and the rest is disposed off. This allows continued use of important material like Lithium whose demand is projected to go up as the share of electric vehicles, and hence batteries, surges in the future. Recovering materials from waste batteries can create a reverse supply chain, which in turn will reduce the uncertainties in the availability of raw materials and their prices. Another advantage of battery recycling is that it limits the amount of waste generated for management. Recycling of batteries includes sub-processes such as collection of waste batteries, logistics, discharging, disassembly/dismantling and recycling (Steward, Mayyas, & Mann, 2019).

Methods of recycling are a mix of mechanical or chemical and heat (pyrometallurgical) treatments. The choice of method depends on battery chemistry and the material to be recovered.

International examples show how some countries have laid down laws for mandatory recycling of waste batteries. E.g. under Japan's End of Life Vehicle Recycling Law, which came into force in 2005, customers pay an additional amount that is credited towards battery recycling programs. The law also defines roles of various actors including vehicle owners, auto makers and enterprises who will collect and dismantle the vehicle and battery (Ministry of Economy, 2002). In Europe, the parliament has specified a directive on waste battery and pack recycling which is known as the Directive 2006/66/EU (Commission, 2019). The directive specifies the collection targets, financing instruments, and the baseline requirements of the recycling techniques. Europe also has one of the highest battery recycling capacities in the world. In contrast, the United States does not have a federal law on recycling but many state laws on electronic waste disposal apply to battery recycling as well.

Battery Re-purposing

Battery re-purposing is where batteries that are no longer useful for EVs are used in other applications like secondary storage. This is possible as EVs tend to discard batteries, when they reach 80% of its initial capacity. This is because use of such batteries in EVs reduces the range to about 80% of the initial value which is not viable. But this battery can be used for fixed storage. The battery can still store energy and deliver in a stationery environment, except that it stores lesser amount of energy as compared to what it did initially. Energy storage decreases in terms of weight and size. But as weight and size is not as much of a constraint, in a stationery environment, the batteries could be used for many more cycles till the capacity goes down to about 50%.

Table 8 below highlights the potential and challenges of recycling and re-purposing batteries.

Table 8: Potential and challenges of recycling and re-purposing

Battery Recycling	**Battery Repurposing for fixed storage**
Potential	*Potential*
• Generating secondary raw - material for new batteries • Decreasing reliance on importing battery raw materials • Mitigating negative ecological impacts of mineral extraction • Industrial innovation and market development – on setting of patented technologies • Preventing land-fill waste generation	• Reducing peak load levels • Filling-in for intermittent power supplies and grid stability • Integrating variable renewable energy into the grid • For use with micro-grids
Challenges	*Challenges*
• Safe disposal of slag and waste water is needed if recycling processes release effluents • The number of battery packs reaching end of their useful life will remain low for the next couple of years - “low demand” for recycling infrastructure • Complex and varied chemical composition and form (pouches, cylinders and pyramidal) makes it difficult to standardise mineral separation process. Appropriate technologies need to be promoted.	• Lack of performance guarantees • Cost of logistics • Non-standard architectures of batteries • Lack of large supply of EV batteries (timing) • Lack of clarity on economic savings

3.2 Multi-pronged transition strategy

Given the challenges outlined in the previous section, a successful transition to electric mobility will require a multi-pronged strategy comprising the following actions, all taken up in a synchronised and coordinated manner:

1 Awareness campaigns	2 Formulation of policies and regulations
3 Establishing standards	4 Demand creation
5 Setting up the charging and swapping infrastructure	6 Workforce skill development
7 Financing	8 Institutional Arrangements

Each of these is highlighted in the sections that follow.

3.2.1 Awareness Campaigns

Lack of awareness is a big challenge. The high capital costs and uncertain benefits of lower operating costs, coupled with the concern relating to range, need to be overcome. Much like the aggressive campaigns that persuaded people to shift to LED bulbs, it will be critical to have large awareness campaigns relating to electric mobility. These campaigns must inform people about the larger social benefits of electric vehicles, the savings in operating costs, from where these vehicles can be bought, the charging and swapping infrastructure available etc. In short, it must work towards allaying all the concerns that a new customer is likely to have.

3.2.2 Formulation of Policies and Regulations

As seen earlier, most stakeholders do not see a need to shift to electric mobility.

Manufacturers will have to make additional investments that may not be justifiable from a purely business perspective, re-energising facilities will not see adequate business potential to make their investments attractive and consumers will not see value in moving away from a tested and reliable product to something that is uncertain and less known. However, a shift to electric mobility has public value in terms of improved air quality, reduced carbon emissions and reduced dependence on imported fuels. Therefore, a strong case exists for public agencies to formulate policies and regulations that encourage a shift to electric mobility. These policies and regulations must promote a shift by:

- Establishing standards that ensure safety and permit economies of scale as well as the convenience of inter-operability.
- Making the cost of electric vehicle ownership (and use) cheaper than conventional vehicles by enabling appropriate price differentials in the capital and operating costs of these vehicles.
- Mandating some degree of electric vehicle manufacture and sale; and ending the sale of ICE vehicles for certain vehicle segments by a certain date.
- Supporting investments in associated infrastructure until the industry reaches a commercial scale.
- Supporting the early stage price disadvantage of a new technology over established technologies till such time as economies of scale kick in to offer a level playing field.

Clearly, some of these policies and regulations will have to be introduced by the Central Government and others by the state and at the local level. Examples of actions required from each of these levels is given below:

Central Government

Examples of policy and regulatory actions that can be taken by the Central Government are the following:

- Establish a tax structure within the national tax system, that recognises the need to allow emerging technologies to compete with established technology and help create a price advantage for technologies that are in the larger public interest.

- Provide fiscal concessions, in the early stages, to allow electric vehicle technology to compete with the more established conventional technology.
- Require national government agencies to procure EVs for use by national government agencies as a way of creating an initial pool of EVs.
- Mandate an increasing share of EVs in the sale of motor vehicles, with a time frame for complete switch to EVs – to create pressure on the manufacturing industry to produce electric vehicles.
- Provide tax incentives that encourage scrapping of vehicles that emit greater levels of pollution.
- Promote and attract investments in the manufacture of EVs and their components in India through financial and other concessions
- Promote a technology agnostic approach that equally favors all electric vehicle technologies. Later, market mechanisms can determine the fittest players. The unfit technologies will automatically fall through.
- Enter into strategic international tie-ups for the procurement of battery chemicals that are not available in India and thereby establish safe and reliable sources of critical chemicals
- Invest in exploring the likely availability of key materials, like Lithium, in India as a systematic effort at assessing its availability locally has perhaps not been made.
- Invest in research and development of EV and battery technologies that could use materials available in India.
- Offer a platform for innovative ideas to be exchanged, and to scale-up to commercial size, by facilitating innovations to secure finance and come to the market.
- Promote industry, academia and government partnerships to help scale up EVs across the country.
- Fund R&D of EV subsystems with a target of commercialisation within a certain time-frame.
- Design course curricula in universities and institutes of national importance (IITs, NITs and IIMs) that impart applicable knowledge on electric vehicles to graduates thus creating a highly skilled workforce essential to the value chain of electric vehicles.

State and Local Government

Examples of actions that the state and local governments can take:

- Create the necessary infrastructure for re-energising batteries by setting up charging stations and offering facilities for swapping stations to be set up.
- Establish a regime of preferences for EVs, such as preferential permits and tax exemptions, that would help it in the pilot and scaling stages.
- Require the procurement of EVs for state and local government use so that an initial pool of vehicles helps create confidence by showing others that EVs do work.
- Mandate the registration of certain types of vehicles only as EVs from a certain date, for example the registration of autorickshaws and taxis; this could be done on a region by region basis.
- Procure electric buses for the use of state-owned transport companies to create a base for mandating all buses to be electric; experimenting with buses of various sizes including small 12-15 seaters.

Existing Policy Actions

Several policies have been designed in India to support the uptake of electric vehicles. Annexure 8 describes the different policies that have been adopted by the Government of India to support the scaling-up of EVs. It also highlights some of the state level policies in India.

Annexure 9 gives the policies adopted in other countries.

3.2.3 Establish Standards

Standards are norms that define the procedures and specifications to ensure that the materials, products, methods and services used by people in their daily lives are safe and reliable. Important reasons that justify the need for standards are the following:

- Helps in commercialising new technologies.
- Increases the acceptability of products by establishing consistent protocols that can be widely understood – by consumers, producers and regulators.

- Simplifies the process of comparing different products within a segment.
- Increases the reliability of products and ensures consumer health and safety.
- Enables inter-operability.
- Helps products achieve economies of scale by simplifying product development and speeding up production time.

In India, automotive industry standards (AIS) are developed by the Automotive Research Authority of India (ARAI) which is an autonomous research body under the Ministry of Heavy Industries. ARAI also designs and conducts tests to check conformity. E.g. for testing emission levels, noise levels for road worthiness of vehicles etc. In the case of electric vehicles, there are several other standards that have been drawn – e.g. communication protocols for AC and DC chargers of EVs by the department of heavy industries. Some of these also follow international norms.

In this context, it is useful to recognise that standards are of the following types:

- Technical, which define the specific materials, processes and components to be used in products.
- Performance based, which establish the expectations of performance in measurable terms.

The choice of technologies to meet these performance requirements is left to the manufacturers. Examples include required limits on emissions released from tail pipes of conventional vehicles (e.g. BS IV and BS VI), CAFÉ norms to limit the CO2 emissions, safety requirements for various parts of the vehicle etc.

Standards can also be voluntary or mandatory. Mandatory standards are governed by regulators in the country who define the specifications and authorise agencies to design tests to verify conformity. Standards that are supported by law ply within the geographical ambits of the legislation. This applies to both locally made and imported products. As against this, voluntary standards are not regulated but are designed by individual members of the industry, or associations, to proliferate practices that help grow the sector as a whole.

Every country follows their own standards, regulations and codes to drive performance and ensure safety in their modes of transport. These are guided by the regional contexts and defined by the Standard Development Organizations (SDOs).

It will, therefore, be important for India to define standards for:

- The full vehicle
- Electric Vehicle Supply Equipments (EVSE)
- Battery packs
- Plugs, receptacles and couplers

Standards for some of these exist in India. Table 9 below briefly presents the standards that are available in India and what more needs to be considered.

Aside from the AIS, there are some global standards for transportation that India and many other countries follow. These include those by the International Electrotechnical Committee (IEC) and the International Organization for Standardization (ISO). These norms are followed for several components of electric vehicles in India.

In sum, designing and enforcing standard practices can ensure safety and durability of the vehicle and performance of the batteries. Consumers will also benefit from interoperability, across a range of chargers and swappers, without any harm to the vehicle or themselves. Manufacturers will benefit from achieving economies of scale that can be attained easily with standards.

Possible Drawbacks of Standards

Finally, it is important to keep in mind that while standards will contribute in developing the market for batteries, they can, potentially, discourage further developments in battery technologies. This is the downside of standardisation and is likely when manufacturers or startups, who innovate and exceed the current offerings (in terms of battery chemistry, or energy density or additional safety features etc.) of the market, are not recognised with financial rewards (Stavins, 2003). Policies and markets that

Table 9: Existing standards for various parts of the electric vehicle in India			
	Institution	**Existing standards**	**Possible additions**
Full vehicle (these standards vary for 2-wheeler, 3-wheeler, 4-wheelers and buses)	ARAI – AIS 131	Type approval of EVs and HEVs – braking, mass emissions and fuel efficiency, construction and functional safety, measurement of electrical energy consumption, measuring the range, vehicle weight Components based tests for – tyres, steering, speedometer, noise, lighting Conformity of production	Use tests that match the real-world driving conditions (including use of air-conditioning, over loading, frequent acceleration and deceleration etc.) and accurately measure the EV performance (in terms of Wh/km)
EVSE(s)/Charging and swapping ports	These have been defined in Bharat EV Charger specifications, and include AIS, IEC, ISO and IS	Bharat DC001 and AC001	Standards for wireless chargers Standards for swapping and range-extension mechanisms
Battery packs	BIS's IS and ARAI's AIS 048	Electrical and mechanical abuse tests to verify safety requirements	Standards to be pursued when it comes to secondary use, recycling, how to deal with a battery after shock or fire
Plugs, receptacles and couplers	These have been defined in Bharat EV Charger specifications	Bharat DC001 and AC001	

recognise such players, through financial benefits or other rewards and platforms, help scale-up offerings and ensure they thrive. This is important for an emerging market like India where on one hand, standards are needed for economies of scale and safety, while on the other hand there is a need to innovate to come up with better products. The standard development organisations (SDOs) should keep track of new innovations and periodically update the standards.

3.2.4 Demand Creation

As stated earlier, the automobile manufacturing industry will have to make significant investments to change the vehicle product base in moving from the IC engine to EVs. However, they will not be willing to do so unless there is some compulsion or there is a visible demand. It will be necessary for the government to take the initiative in creating an initial demand for EVs so that the auto industry sees commercial value in making the investment to manufacture EVs. This could be done by the government mandating some category of vehicles to move to EVs. For example, it could mandate all government vehicles to only be EVs from a certain date. Alternatively, it could require all para-transit vehicles to be EVs. Creating some initial demand, through such measures, would go a long way in encouraging the manufacture of EVs.

An initial effort towards this was made when the EESL invited offers for a certain number of EVs for use by government agencies. However, there has been no follow-up to this and further orders are not visible. It will be important for this to be done.

3.2.5 Setting Up Charging and Swapping Infrastructure

As in the case of vehicle manufacture, investments in re-energisng infrastructure, by way of charging facilities or swapping facilities will not take place unless there is visible demand. The government will have to take the lead in setting up an initial set of charging and swapping facilities so that it encourages the purchase of EVs and adds to the demand for charging and swapping. It will be an area where public investment will be needed to break the chicken and egg cycle.

Charging facilities at government offices and other commercial centres, parking lots and residential locations will be a good starting point. Public transport depots and vehicle fleet depots would also be good locations, especially to serve dedicated vehicle fleets. For such fleets the savings in operating costs could justify the investment in charging/swapping infrastructure.

3.2.6 Workforce Skill Development

As India adopts electric mobility, the skills of the workforce will need to be suitably aligned to ensure a steady and reliable supply and value chain. These jobs exist in manufacturing the parts of electric vehicles, their maintenance and after sales, and as services provided by drivers, operators and technicians in State Transport Unions (STUs) and private fleets, along with energy suppliers at retail outlets who will electrically charge vehicles or help customers swap batteries.

Rapidly closing the skills gap, that arises with the onset of a new technology, creates a strong labor market. This contributes to innovation, research and development and manufacturing domestically, and at par with the industry that exists internationally. The gap can be closed through actions taken by the employer and by policymakers at the central and state government level. As the manufacturing of electric vehicles expands in India, many existing jobs will have to adapt to the new system.

To adapt to the changing employment requirements in the sector, some state governments in India have proposed creating new skill centers and introducing coursework in state engineering schools and polytechnic institutes – as part of their EV policies. Similarly, in the private sector, some automakers in the country have begun the process of re-skilling their employees to prepare for the changes in the auto sector. They are partnering with local educational institutes to create customised courses that their employees can take up to upgrade their skills. These are steps in the right direction.

Table 10 below presents strategies that can be used to re-skill workers across a range of occupations within the EV labor market.

Table 10: Strategies for re-skilling the labour force for electric mobility

	Occupation	Job duties	Ways for re-skilling
1)	Research and development	Chemists and material scientists	Creating a pool of funds for research on battery chemistry and electric vehicles to attract researchers, innovators and students in this field
2)	Design and development	Chemical, electronics, electrical, mechanical, material engineers; technicians and drafters, software developers and industrial designers	Employers can conduct in-house training modules, guest seminars and demonstrations for employees Making certified courses available online or in person at local universities or those outside India
3)	Manufacturing	Electrical and electronic equipment assembler, engine and machine assemblers, machinists, production managers, tool operators and final product assemblers	Tying up with established automakers – located domestically or internationally for peer-to peer-learning (site visits, demonstrations etc.) Employers can tie up with international universities who are doing research and development on electric mobility; similar exercise can be done with universities that exist domestically Policymakers, at state and central government levels, can set up new public institutes that impart technical skills pertinent to electric mobility or extend the curriculum of existing institutes Automobile associations can design certified courses that employers can use to acquire the right talent and employees can use to increase their employability

4)	Vehicle maintenance	Automotive service technicians and mechanics	Setting up courses and training modules in credible institutes and encouraging existing workforce to enroll in them; certify those enrolled Employers can count the credits earned in these courses towards the performance of employees
5)	Fleet services	Operators, dispatch, planners, drivers, technicians, accountants	Public fleet operators (such as STUs and government fleets) and private fleet operators (ride hailing and logistics businesses) can tie-up with vehicle manufacturers for training, demonstration and field-testing sessions In the case of public fleets, one way could be to tie up with the regional engineering and technology institutes and develop training programs that give practical learning to the employees
6)	Sales and support	Retail persons, customer support representative and auto dealers	Creating training modules to teach sales and support staff in customer interface
7)	Energy suppliers and retailers	Staff at battery swapping and charging centers	Tie ups with battery manufacturers to get the workforce at the energy supplying stations accustomed to handling equipment and addressing consumer concerns
8)	Infrastructure developers	City and regional planners, electrical power line installers and repairers, electricians	Upgrading the course curriculum of planning and infrastructure related courses at universities Making certified courses available for the existing workforce

Adapted from (WEF, 2018) and (US Bureau of Labor Statistics, 2011)

3.2.7 Financing

Transitioning to electric mobility will require innovative financing solutions. These will be required for:

- Financing charging and swapping infrastructure
- Purchase of vehicles

Financing Charging and Swapping Infrastructure

One of the problems that is constraining a transition towards electric mobility is the classic chicken and egg problem. Vehicles are not getting sold because charging/swapping facilities are not available. Similarly, charging/swapping facilities are not coming up as there is not enough demand for them. This situation needs to be corrected by some charging/swapping facilities to come up to help catalyse the demand for electric vehicles. However, without a business proposition, private entrepreneurs will not set up the facilities.

It is therefore essential for some kind of financial support to be made available for enterprises to set up charging/swapping facilities. Alternatively an initial set of facilities need to be set up through public funding. A certain threshold number, which will depend from city to city, should be set up either with public financial support or by public agencies.

Financing Purchase of Vehicles

As of now, the Total Cost of Ownership (TCO) of EVs is higher than for ICE vehicles in most vehicle segments, especially if the daily usage is not high. As the daily usage goes up, the TCO for electric vehicles comes down and begins to approach that of ICE vehicles. At very high usage, it becomes more economical than ICE vehicles.

Even if the TCOs become comparable, the capital cost of an EV is significantly higher. This higher cost is generally recovered through lower operating costs. However, the high capital cost is a deterrent to EVs as few are willing to take the risk with untested and untried technology. This calls for innovative financing options or business models, that de-risk the higher capital cost of an EV, by reducing the higher capital costs and increasing the operating costs. Loans to cover the higher capital costs, that can be repaid with savings in operating costs, would be one way of dealing with this problem.

Typically, financing models that could combine public subsidy with commercial loans would be required. Subsidies could be given to the extent of the difference between the TCO for both types of vehicles and commercial loans could cover the higher capital costs. Loans would be paid back out of the annual savings in operating costs.

There could also be innovative business models that can achieve the same objective. Some possibilities include:

- OEMs could lease the EVs instead of selling them. There could be a lease fee, that is equivalent to the saving in operating costs and the loan repayment instalment.
- EVs could be sold to a customer but batteries, which are a significant component of the cost, could be leased. This will help bring down the capital cost to levels similar to
- ICE vehicles and lease fees could be paid out of savings in operating costs.
  An interest subsidy could be a way of reducing the cost of capital and could be extended in the initial years as a way of attracting people to the use of EVs.

3.2.8 Institutional Arrangements

One of the biggest challenges of a comprehensive transition towards electric mobility is the need for coordinated action on several fronts. Unfortunately, the institutional fragmentation that exists does not allow for coordinated action. Table 11 below shows the different agencies of the government that would have to be involved to effect such a transition:

Table 11: Role of various agencies

	Agency	Role
	Central Government	
1	Ministry of Heavy Industry	Incentives/directions to the auto industry to manufacture EVs
2	Ministry of Road Transport	Amendments to the MV Act to allow preferential treatment to motor vehicles
3	Ministry of Science and Technology	Supporting research in battery technologies Establishing standards
4	Ministry of Environment	Establishing emission standards
5	Ministry of Power	Policy on establishing charging facilities and determination of tariff policies for EV charging
6	Ministry of Finance	Offering fiscal incentives at the EV development stage
7	Ministry of Housing and Urban Affairs	Coordination with the state and local level entities in promoting electric mobility and establishing charging and swapping facilities
8	Ministry of Petroleum and NG	Promoting the idea of petrol stations diversifying into adding charging and swapping facilities
9	Niti Aayog	Developing an action plan and coordinating implementation with different agencies of the national government
	State Government	
10	Transport Department	• Leading the introduction of electric buses, through the state transport corporations • Modifying the relevant rules to encourage the use of EVs for taxis and autorickshaws • Promoting the use of EVs for government vehicles

11	Environment Department	Enforcing the emission standards
12	Urban Development Department	Coordinating with cities and local government in the setting-up of charging/swapping infrastructure
13	Finance Department	Offering fiscal concessions to make EVs financially viable in the initial years
14	Home Department	Supporting enforcement
	Local Government	
15	Municipal Corporation	Planning and investing in public charging/swapping infrastructure at strategic locations for use by taxis and autorickshaws
16	Development Authority	

As seen from this, far too many agencies are involved and getting them together through standard government processes would be near impossible. It would, therefore, be important to develop an institutional mechanism that is able to effect the needed coordination and is empowered to do so. While a better coordinated institutional set-up will be essential, there needs to be a recognition that academic institutions, research institutes, manufacturers, think tanks and civil society will play a critical role in the successful transition to electric mobility and their capabilities need to be harnessed effectively. This will ensure that the ministerial committees spend their effort on the most advanced and fitting technologies relevant to the Indian context.

An Electric Mobility Mission, headed by a person of eminence, and well respected by all, seems to be the way forward. This should have representation from the government, industry, academia, civil society so that the best talent in the country can be leveraged. This has worked in the past. Examples are the mission to setup Aadhar, the telecom mission etc. Such a mission could be established separately at the national, state and city levels, for specific actions. The national level mission would coordinate national policies and the state level mission could coordinate both state level policies and implementation. The city level mission could coordinate between the city level agencies. These missions have to be well funded and professionally manned and should uphold knowledge-based actions.

3.3 ROAD MAP FOR ELECTRIFICATION OF TRANSPORT

Given the challenges highlighted earlier and the transition strategy outlined, a detailed road map for electrification needs to be put in place, ideally at the city level. This road map should consider measures that will help overcome these challenges. Accordingly, a 3-phase road map is being suggested as below:

Pilot Phase
where an initial set of vehicles are deployed to create a quick demonstration value; this phase should be short.

Scale-up Phase
where incentives and persuasion help reach a tipping point.

Self-propelled Phase
where the technology has established itself and people take to it in the normal course.

The strategy needs to identify a starting point and thereafter facilitate scaling-up to a tipping point. Thereafter, the market mechanisms would take over. Further details on this are given in the following sections:

3.3.1 Pilot Phase

For a starting point, vehicles that have the following features could be thought of:

- Vehicles that use swapping
- Vehicles that can be charged at home
- Vehicles for which investing in captive charging facilities would make commercial sense
- Vehicles that have visibility value for people to see and then adopt
- Vehicles that have optimal usage during the day – not too long to require multiple charging in a day and yet long enough for the lower operating cost of EVs to offset the higher capital cost
- Vehicles with usage patterns that would permit mid-day charging
- Vehicles where public agencies can take up demonstration
- Vehicles where public agencies can lead by example
- Vehicles that aggregate volumes for manufacturers to produce.

If we were to look at the different types of motor vehicles in a city and map them against the above features, we get Table 12, which is as follows:

An examination of the below table would show that intra-city and suburban bus fleets, operated by a public agency, would be ideal candidates as a starting point. Fleet cars, especially those owned by public agencies, are also good candidates as a starting point. Also, 2-wheelers and 3-wheelers with RE-swap and battery-swap may work quickly and could be the next best options.

For these starting points, the operator would need to buy the vehicles and set up captive or third-party charging facilities/swapping. In doing so the following need to be kept in mind:

1. For buses, charging/swapping facilities should be set up in the depot where the bus is parked at night. In addition, charging facilities will also be required at terminal stations where the bus can halt for 30 mins or more to allow the crew to rest.
2. For fleet cars, like government owned cars, charging facilities at office locations where the vehicles are parked at night would be enough as these vehicles typically have short trips but several of them – mostly returning to a single location. Swapping or RE-swap may be ideal.
3. 2-wheelers will work with RE-swap and three-wheelers with swapping centers set up by energy operators.

Table 12: Vehicle type and charging/swapping modes for pilot phase

Vehicle type	Home charging	Value in Own charging facility	Optimal use distance	One charge per day is enough	Mid-day charging at own location possible	Can public agencies lead by example	Demo value	Swapping
Personal 2-wheeler	Y	N	N	Y	Y/N	N	N	Y, RE-swap
Personal car	Y	N	N	Y	Y/N	N	N	Y, RE-swap
Fleet cars	N	Y	Y	Y	Y	Y	Y	Y
Small owner taxi	Y	N	Y	Y	N	N	N	Y
Autorickshaw	Y	N	Y	Y	N	N	Y	Y
Fleet buses intracity	N	Y	Y	N	Y	Y	Y	Y
Fleet buses inter-city	N	Y	Y	N	Y	Y	Y	N
Small freight vehicles intra city	Y	N	Y	Y/N	N	N	Y	Y
Small freight vehicles suburban	Y	N	Y	N	N	N	Y	Y
Freight vehicles intercity	N	N	N	N	N	N	N	N

To kickstart the market for electric vehicles and their ancillary parts, vehicle segments that can automatically generate volumes will allow manufacturers to reduce the unit cost of production and attain viable returns on their investment. Vehicle segments that can give volumes include commercially operating ride hailing fleets, logistics businesses (e-commerce) that have two and three-wheeler fleets and public fleets that are used by government offices. For vehicle segments such as two-wheelers and compact cars that are meant for individual or private ownership, focused demand creation exercises should be done. These could be in the form of fiscal (tax breaks, rebates on excise duties, GST etc.) and non-fiscal incentives (rebates on parking, easier permit process, power tariffs, regulatory support for electric retrofitting etc.)

3.3.2 Scale-Up Phase

Once a beginning is made, it will be necessary to scale-up by getting other vehicles to adopt electrification till we reach a tipping point. This is not easy as it would require electrification of vehicles that are owned by individuals or small organisations. This will need some set of incentives and regulatory restrictions. It will also need public investment in charging/ swapping infrastructure, at least till the tipping point is reached.

Good candidates for a scaling effort would be autorickshaws and small owner taxis. These have a long enough travel distance to see benefits of lower operating costs. They also have good demonstration/visibility value.

Persuading such vehicles to adopt electrification will either require financial incentives, to make the shift attractive, or will need certain regulatory restrictions on petrol/diesel fueled vehicles. This could be in the form of limiting the number of permits issued to petrol/diesel vehicles and a significantly higher fee for them vis-a-vis an electric vehicle. A shift based on persuasive incentives and limited restrictions will be less disruptive and will find wider acceptance. This will also need intensive marketing and publicity to encourage the shift. Incentives could be by way of:

- Reduction in the capital cost through capital subsidy or lower taxes
- Reduction in electricity charges, especially for off-peak use
- Public investment in charging facilities and low electricity tariffs
- Free parking and other preferences of this nature
- Easier permits and greater flexibility in routes

Cost sensitive personal motor vehicle owners, who have relatively longer travel distances in a day in a city environment, can then be persuaded to take up electric vehicles. This will also need intensive campaigning and investments in a wider network of charging/ swapping facilities. Catalysing the setting-up of a distributed charging network across the city would add to attractiveness and confidence, even though most personal vehicles can be charged at home. Catalysing a battery swapping industry, especially at existing petrol stations, will add to the confidence of personal motor vehicle owners.

Promoting innovations to develop electric vehicle kits will go a long way in reducing the capital cost during the initial stage as use of these vehicles will help build confidence.

A network of charging and swapping stations across a city will also ensure scaling-up takes place conveniently. In setting up such facilities, it would be good to look at the best options for re-energising different types of vehicles. This is discussed in a detailed note at Annexure 10. In addition, Annexure 10 also describes the strategy India should adopt for setting standards for AC chargers and DC fast chargers.

Setting Up the Re-energising Infrastructure

Given a high share of two-wheelers, and a lower share of cars, the charging-cum-swapping infrastructure that Indian cities would require would be quite different from that used in developed countries. If we map the optimal re-energising mechanisms for different types of vehicles, and the relative share of such vehicles in the over-all fleet, the requirements of re-energising infrastructure would be as given in the Table 13 below.

Table 13: Vehicle type and suitable battery re-energising means and locations							
Vehicles	**% of Indian vehicles**	**Home charging**	**Charging at parking lots / office**	**Streets/ shops (every 1.5 kms)**	**Petrol-pumps**	**Highway eateries**	**Highways petrol pumps**
2-W	79%	AC 15A plug	AC001: 1-3 hours	RE-swap	RE swap	x	RE-swap
3-W (small)	4%	x		Swapping	swapping	x	Swapping
3-W (goods /large)	1%	x	AC001: 3 hrs DC001: 45 min	Swapping		DC001: 45 min	Swapping
Economy cars	12%	AC 15A plug	AC001: 3-6 hrs DC001: 45 min	RE-swap	RE swap	DC001: 45 min	RE-swap
Premium Cars	2%	Top-up: AC 15A plug	IEC-CCS2: 30 min	x	x	IEC-CCS2: 30 min	x
Buses	1%	Swapping at bus-terminus for intra-city and IEC-CCS2 fast charging at highway bus-terminus that fall on the way of inter-city bus routes					

Note: AC001 is essentially AC charging using 230V 15A plug as is common in India. DC001 is a fast DC charging using power upto 15 kW, as defined by DHI (DHI, 2017). IEC-CCS2 is commonly used European Charging standard.

Need for Fiscal Incentives

Persuading a shift to EVs will require that these vehicles become cost competitive with the ICE vehicles. During the initial phases, EVs will not be cost competitive with the well-established ICE vehicles. Policy interventions that allow an emerging technology to compete with an established one may be necessary. This will primarily entail creating a price differential between the two technologies and can be implemented either by way of subsidies to EVs, or fiscal concessions, or by levying a fee on the traditional technologies. Possibilities are:

- Outright grants that subsidise the purchase of a new EV.
- Differential tax rates for EVs and ICE vehicles that make EVs cheaper.
- Feebates that levy a charge based on the level of carbon dioxide emissions and pollution caused.
- Lower electricity charges for charging during off-peak times.

It is expected that this would be a limited period requirement. Once volumes pick up, economies of scale will kick in and EV/EV components will be able to compete with ICE vehicles.

3.3.3 Self-Propelled Phase

In the self-propelled phase, all components of the electric mobility ecosystem should function as sound business propositions and should not need any special treatment vis-a-vis other technology. Exceptions may be by way of mitigating externalities like air pollution and green house gas emissions or even the national energy security concerns. However, concessions to enable a new technology to compete with an older one will no longer be necessary.

PART 4

ECONOMICS OF THE ELECTRIC MOBILITY ECO-SYSTEM

While the adoption of electric mobility and a shift away from conventional ICE vehicles may need some initial public financial and policy support its longer-term stability can be ensured only if it becomes self-sustainable in the market. This means that there should be viable business models for charging, swapping and the use of electric vehicles themselves. The manufacturing industry should be able to see profits and a sound business opportunity.

In Annexure 11 we present an analysis of the following:

- Economics of a battery swapping facility for 4-wheelers at a petrol station
- Economics of a battery swapping facility for 3-wheelers at a petrol station
- Economics of a battery swapping facility for electric buses at a bus depot
- Economics of AC 001 charging facility at a parking lot
- Economics of DC 001 charging facility at a parking lot
- Economics of IEC-CCS2 charging facility at a parking lot

The analysis highlights that swapping facilities are inherently viable but must have adequate demand to fully utilise the capacity created. Capital costs can be recovered within a reasonable period. Even the AC 001 and DC 001 charging facilities are financially viable but need adequate demand. IEC-CCS2 charging facilities, which are used for charging premium cars, are however unviable as they will find it difficult to recover the capital investments.

PART 5

SUMMARY AND WAY FORWARD

Thus, as can be seen, India stands to secure immense benefits from moving towards electric mobility. Improved air quality, reduced dependence on a non-renewable and imported fuel, reduced GHG emissions, the opportunity to become a leader in the global EV industry, the increased demand for electricity and the possibility of improved plant load factors are benefits that India should not pass up.

However, in making such a move, it is important to recognise some of India's unique features, namely:

- The profile of its vehicular fleet where only 2% of its vehicles are premium cars and nearly 75% are two-wheelers.
- The travel pattern with a very high share of less than 10 km trip lengths and a high share of walking, public transport and 2-wheeler trips.
- An economy conscious consumer who accords a very high priority to price.

The unique features of the Indian context would mean that the types of vehicles that could more easily go electric, and the most suitable mechanisms for re-energizing batteries, will be different from the rest of the world - especially the developed countries.

Public transport, two-wheelers, fleet vehicles, autorickshaws, and taxis would be the primary targets for electrification instead of high-end cars.

Besides, both charging and swapping would be equally good options for re-energising batteries in the Indian context. It will be necessary to facilitate both in the electric mobility ecosystem. Existing petrol pumps will be good locations for an additional business line of swapping. As IC engine vehicles decline and EVs pick up, the petrol stations can also slowly transform their businesses from being largely petrol dispensers to becoming battery dispensers.

Users of electric vehicles should have the option of choosing which re-energising method they find more convenient. Some may find it easier to use charging as a more convenient option and others may prefer to swap. Market forces should determine which among them, or possibly both, do well and survive.

Range extension batteries are a good option and reduce the number of trips one has to make for battery swapping. It also helps reduce the size of the fixed battery in a car, thereby reducing the need to carry unnecessary deadweight that adds to range anxiety.

Questions also come up about whether India should wait for further reduction in battery prices to move heavily towards electric mobility. If it did so, the need for subsidies may come down, and market forces could be adequate to persuade a shift to electric vehicles. However, this is clearly a rapidly emerging market and, given the larger public benefits that will accrue to India, it would not be advisable to wait. USA, Europe, and China are not waiting but are subsidising their EVs massively. As a result, EV markets are flourishing in these countries – they are likely to master the technology and would naturally become leaders in the field. India runs the risk of being left behind and losing a possible leadership position in this market. India's auto industry, which contributes to 7.1% of India's GDP, could be adversely impacted and become dependent on imported technology in the future. On the other hand, if India can establish a low-affordability, low-cost EV market today, it can potentially become a world leader in low-cost EVs. To do this, we will have to look for alternatives to providing subsidy and we will need to do things differently in the Indian context.

A comprehensive and well-coordinated set of policies and regulations, that promote a shift to electric mobility will be required from the central, state and local governments, with the common objective of providing the needed initial stage support for new technologies to compete with established ones.

Investments in research to allow greater use of locally available materials, coupled with investments in exploring the availability of critical material within India, will be called for. Clear roadmaps of electrification will need to be developed in a few pilot cities to demonstrate a credible pathway, and then scale-up to a tipping point where market forces could take over, with EVs moving ahead on their own as viable options - without the need for supporting concessions.

The national government has already made its intent clear by way of several policy statements that have come, including the FAME program and the National Electric Mobility Mission.

Several states have also come up with state-level policies. In the case of Kerala, the state-level policy identifies three cities where electric mobility would be introduced in a comprehensive manner.

The next step clearly is to take the work to the city level and have a set of electric vehicles on the road. Buses are a good, and relatively easy, starting point. However, stopping with buses will not give us the outcomes we desire, and it is important to go beyond them. Government vehicles, cab aggregators and 2-wheelers are a good next segment to focus on. Getting about 1–2 % of the vehicles in any city to be electric will be good for a pilot phase that needs a lot of government push and attention. This should be the immediate next target.

The next, or scale-up phase, will not need as much government attention, but will need a comprehensive marketing effort, along with some facilitation in expanding the ecosystem till things reach a tipping point.

This effort needs significant coordination between different departments in a state. In particular, transport, power, industries, general administration, police, and finance will have to coordinate closely.

The effort also requires significant contributions from academia, industry, think tanks, civil society and other stakeholders. Setting up an Electric Mobility Mission to lead the effort and bring all partners together, would be an effective way of moving this forward.

Such a mission could be headed by a highly respected person in the state and function directly under the Chief Minister or the Chief Secretary. It could be given a 5-year term to achieve a certain share of electric vehicles in the city/state.


P

ANNEXURE 1

ELECTRIC MOBILITY PLAYERS IN INDIA

Developing an electric mobility ecosystem requires cooperation between multiple players – vehicle and battery manufacturers, power distributors, electronics system providers, charging technologists and service providers, to name a few – who together make the supply chain of the electric mobility systems. As a consequence of an increased interest, and need for electric mobility in India, the number of new startups and businesses in this domain is increasing. The net result is the range of product offerings and technological capacities are expanding. Table 14 to 17 list both private and state-run companies that are manufacturing electric vehicles for various segments, making and assembling lithium-ion battery packs, chargers and motors, and those serving as battery recyclers and energy operators in India.

VEHICLE MANUFACTURERS

Table 14: Firms manufacturing electric vehicles

	Name of the company	**Key offerings**	**Projects in the pipeline**
1.	Ashok Leyland	• EV segment – heavy commercial vehicles such as trucks, buses (e.g. developed Circuit-S – India's first electric bus with a swappable battery – developed in partnership with Sun-Mobility)	• Supplying 50 Circuit-S buses to Ahmedabad for its BRT corridor • Developing three lines of charging technologies – battery swapping, fast charging (6 hours) and flash charging (5 mins)
2.	Tata Motors	• EV segments – four-wheelers (e.g. Tigor EV) and buses (Tata Ultra 9m)	• Creating electric or hybrid solutions in small commercial vehicles such as Iris, Magic, Ace, Super Ace; in bus segment, fuel cell electric bus, pure battery-operated electric bus, a diesel hybrid bus, CNG hybrid, diesel-parallel hybrid bus. • Developing a battery pack with a range of over 300 km • Supplying 190 buses to six cities under the FAME 1 scheme
3.	Mahindra Electric	• EV segments – four wheelers, electric rickshaws, three-seater auto rickshaws, cargo/passenger van	• Jointly manufacturing Lithium-Ion batteries with South Korea's LG Chemicals beginning in the last quarter of 2020 • Setting up a manufacturing hub with a capacity to produce 70000 EVs in Bengaluru
4.	Eicher (VE Commercial Vehicles Ltd)	• EV segments - Joint venture with Volvo, VE Commercial Vehicles, to provide electrified public buses	
5.	Bajaj Auto Limited	• Vehicle segments – two wheelers with internal combustion engines; three-seater autorickshaws	• Evolving the recently launched quadricycle 'Qute', for last mile segment, into electric and hybrid formats • Launching electric motorcycles and scooters by 2020

6.	Kinetic Green Energy and Power Solutions Limited	• EV segments – electric rickshaws and electric autos with Lithium-Ion batteries	
7.	Lohia Autos Limited	• EV segments – two-wheelers and three-wheelers (e-rickshaws) with Lead Acid batteries	
8.	Electrotherm India Limited	• EV segments – two-wheelers, sold under the brand YoBykes that was launched in 2008	
9.	Goenka Electric Motor Vehicles Private Limited	• EV segments – electric three-wheelers (e-rickshaws, school vans, autorickshaws, loaders)	
10.	Hero Eco	• EV segments – electric two-wheelers (scooters), sold under the brand Hero Electric	
11.	Okinawa Autotech Private Limited	• EV segments – two-wheelers (scooters) • Provides swappable Lithium-Ion batteries	
12.	Ather Energy	• EV segments – two-wheelers (scooters); two variants on offer Ather 450 and 340 currently only in Bengaluru • Provides vertically integrated services which include after-sales and roadside assistance, home and public charging facilities, etc. • Sets up public charging stations known as AtherGrid Network	
13.	Avon Cycles	• EV segments – electric rickshaws, cart and auto, and electric two-wheelers (bikes) with Lead Acid batteries	

ENERGY OPERATORS

Table 15: Firms operating battery charging and swapping stations

	Name of the company	Key offerings	Projects in the pipeline
1.	Essel Green Mobility Limited	• Constructs and invests in infrastructure for electric and shared mobility	• Constructs and invests in infrastructure for electric and shared mobility
2.	Sun-mobility	• Provides Lithium-Ion batteries, battery-vehicle integration, battery charging and quick-interchange stations and end-to-end platform software management for 2 and 3-wheelers and buses	
3.	Bharat Petroleum Corporation Limited (BPCL)	• Refines and explores oil and markets it at retail fuel service stations • Recently ventured into creating EV charging stations at existing fuel service stations for EV owners in cities (e.g. in Nagpur)	
4.	National Thermal Power Corporation (NTPC)	• Generates power, and works on the entire value chain of power generation from fossils, hydro and renewables • Designs and sets-up public charging infrastructure for EVs in a range of segments, from public buses to 2/3 wheelers	• Developing public charging stations jointly with vehicle aggregators - Ola, Lithium, Shuttl, Bikxie, Bounce, Electrie and Zoom Car • Setting up charging infrastructure for public transport jointly with the cities of Jabalpur, Navi Mumbai and Bhopal
5.	Power Grid Corporation of India Limited (PGCIL)	• Plans, coordinates, supervises, and controls the transmission of power between states, and operates national and regional power grids • Develops smart grids for two-way exchange of power between electric vehicles and power grids	• Setting up 26 EV charging stations with a charging capacity of 15MWh each – in Hyderabad, Gurugram and Chennai
6.	Kerala State Electricity Board Limited (KSEBL)	• Generates, transmits and distributes electricity supply in the state of Kerala	• Partnering with BPCL to set up EV charging stations across the state
7.	Hindustan Petroleum Corporation Limited (HPCL)	• Refines and explores oil, and markets it at retail fuel service stations located across the country • Develops and sets up publicly available EV charging stations	• Planning, developing and operating charging stations at HPCL's retail fuel service stations across the country jointly with Tata Power Limited

LITHIUM-ION BATTERY AND RECYCLING

Table 16: Firms making and assembling Lithium-Ion batteries			
	Name of the company	Key offerings	Projects in the pipeline
1.	Indian Space Research Organisation (ISRO)	• Develops technologies to produce space grade Lithium-Ion cells that have so far been used to power various satellite and launch vehicle applications, but will now be adapted for use in EVs	• Transferring ISRO's lithium-ion cell technology to the Indian EV industry/startups on a non-exclusive basis as per a decision announced in June 2018 • Manufacturing space grade Lithium-Ion cells with Bharat Heavy Electrical Limited (BHEL), as per a Technology Transfer Agreement signed in March 2018
2.	Amara Raja Batteries Ltd	• Makes automotive batteries, for domestic markets and supplies batteries domestically, also exports to Africa, Asia Pacific and Middle East (under the name Amaron)	• Building a Lithium-Ion battery pack assembly plant with a capacity of 100 mega-watt hour in Andhra Pradesh
3.	Exide Industries Limited	• Manufactures batteries of power capacities as low as 2.5Ah to as high as 20,500 Ah	• Making Lithium-Ion batteries and energy storage solutions with Leclanche, as per a joint venture inked in 2018
4.	Exicom Power Solutions	• Designs and supplies stationary Lithium-Ion battery solutions	
5.	Grintech	• Offers locked smart Lithium -Ion battery solutions for automobiles, battery management systems and swapping solutions	
6.	Sun-Mobility	• Designs solutions for Lithium-Ion batteries, battery-vehicle integration, battery charging and quick-interchange stations and end-to-end platform software management for 2 and 3 wheelers, cars and buses	
7.	Eon Electric Limited	• Manufactures Lithium-Ion batteries	
8.	Attero Recycling	• Provides electronic asset management, end-to-end electronic waste and battery recycling solutions, urban mining for Lithium, Tungsten, Copper, Gold	

CHARGERS & MOTORS

Table 17: Firms making chargers and motors for electric vehicles

	Name of the company	Key offerings	Projects in the pipeline
1.	Delta	• Makes AC and DC chargers with real time monitoring and control, smart grid capabilities for energy management and cost optimization • Creates Energy Storage Systems (ESS): bi-directional power conditioning and battery devices, site control-lers, cloud management system for energy storage applications, Li-Ion battery cells and modules	
2.	ACME Group	• Creates Lithium-Ion based energy storage solutions for stationary and mobile applications • Offers battery charging and swapping solutions for 2 and 4 wheelers	
3.	Exicom	• Designs stationary Lithium -Ion battery solutions	
4.	Consul Neowatt Power Solutions Private Limited	• Manufactures a full range of power conditioning and power back-up products and services	
5.	Compage Automation System Private Limited	• Manufactures Brush Less DC motors (BLDC) that add to the energy efficiency of e-rickshaws and other electric vehicles	

ANNEXURE 2

DRIVERS OF ENERGY EFFICIENCY IN ELECTRIC VEHICLES

GAINS FROM ENERGY EFFICIENCY

Enhancement of energy efficiency in EVs will result in significant gains. The two most important factors that influence the success or failure of EVs are the costs associated with the battery and the range that these vehicles offer. Both of these are heavily influenced by the energy efficiency of the vehicles. Therefore, this is a very important factor to be borne in mind while developing EVs. Design of new motors and controllers which suit Indian requirements will also be a priority.

There has already been an increasing focus on energy efficiency, in 3-wheelers and large buses in India, over the recent past. The 3-wheeler autorickshaw started with an energy consumption of 80 Wh/km. A target was set to reduce this to 45 Wh/km. Several companies now have autorickshaws with energy consumption close to 50 Wh/km. This is indeed a creditable achievement. Similarly, e-rickshaws used about 65 to 70Wh/km in March 2017. Now the manufacturers have come up with vehicles consuming about 40Wh for a km. Similarly, in April 2017, 12-meter buses consumed as much as 1600 Wh per km. A target was set to reduce it to 850 Wh/km. As per sources, the industry is today close to 1000 Wh/km and further improvements are expected. These are great developments demonstrating the fact that Indian industries are capable of achieving very difficult goals when they are convinced that it would give large gains (Jhunjhunwala , 2017). These energy efficiency improvements can go a long way in making EVs competitive and efforts at making such improvements in other vehicle segments are important.

MECHANISMS DRIVING ENHANCED ENERGY EFFICIENCY

Manufacturers often take energy-efficiency of an EV for granted, either not considering it to be important or thinking that what they have got is the best they can get. But this can be improved with some additional spending. They are reluctant to do so as EVs are already expensive. However, it is not often realised that the additional investment will be easily paid back with a smaller battery requirement.

Electric motor and drive

To get higher energy efficiency, they first need to focus on the electric motor and drive. Better motors will help immensely. However, the single point efficiency of the drive (like 90%) which they often hear is not enough. They need to have a motor, which would give the best efficiency considering the Indian drive cycles. For example, many motors imported for EVs have their peak efficiency at 50 kmph, which drops down considerably for 25 kmph. Now the 50 kmph may indeed be the average speed of the vehicle in most western cities and the motors would have been designed to have their peak efficiency at this speed. But average speed in Indian city conditions drops down to 25 kmph. Therefore, the efficiency specified will not be realised in Indian conditions. It is necessary to design motors for India taking into account its drive-cycles.

Quality of tyres

The second factor that could enhance energy efficiency of a vehicle is the quality of tyres. The work carried out to develop better tyres for petrol vehicles could be straight away applied to EVs as well. However, there is one difference. Better tyres cost more and at times, depending upon the price-range of the vehicle, the best tyres may not be used. The specific tyre used for a petrol vehicle has been optimised weighing the value of enhanced fuel-efficiency and the extra capital cost incurred for the enhanced tyres. It is a trade-off between capital costs associated with tyres and operational costs when better tyres are used. When one uses better tyres for EVs the trade-off will be different. On one side there will be capital expenses associated with better tyres and on the other side, there will be capital expense saving associated with a smaller battery. The equation needs to be reworked for electric vehicle.

Lightweighting

Other factors that would help energy efficiency of EVs are light-weighting of vehicles and better aero-dynamics. The work in these areas has barely begun. Over the years, we will see new materials developed for EVs (Jhunjhunwala, 2017).

REDUCING COSTS BY REDUCING BATTERY-SIZE

An obvious way of reducing the cost of an EV is to reduce battery-size. But reduced battery-size implies lower driving range. The key is to optimise the battery size to bring the driving range it can offer to be as close to the typical driving distance. Oversized batteries may give a higher driving range, but they are an unnecessary weight and drain energy from the battery resulting in a drop in the driving range expected from the vehicle. An ideal battery size would be one where the vehicle has 10-20% of energy left when it returns at the end of the day.

MEASUREMENT OF ENERGY-EFFICIENCY

It is important to understand how the average energy used per km in a petrol vehicle and EV is measured. In India, Automotive Regulatory Authority of India (ARAI) defines a drive-cycle and the vehicle is tested as per that drive-cycle. The drive-cycles are different for different kind of vehicles (2-wheeler, 3-wheeler, 4-wheeler and buses) as each category of vehicle is driven in a specific manner. For example, ARAI has defined a Modified Indian Drive Cycle (referred to as MIDC) for Indian 4-wheelers. To obtain the mileage of a petrol vehicle, it has to be driven with specific load as per MIDC to obtain average kms per litre of petrol. There are six such government authorised laboratories, in the country, where such tests are conducted. These measurements are done in a laboratory set-up with the help of a programmed chassis dynamometer. A dynamometer is a device that can measure force, power, or speed of a vehicle engine.

The EVs can be tested with similar procedures to get the standard value of energy used per km in units of Wh/km. This will indicate how much battery-energy (Wh) the vehicle will consume on an average for each km of drive. In a similar manner, drive-cycles are defined for other vehicles, such as Indian drive-cycle for 3-wheeler autos or Indian drive-cycle for 3-wheeler e-rickshaw. Similarly, buses use what is referred to as the Delhi drive-cycle.

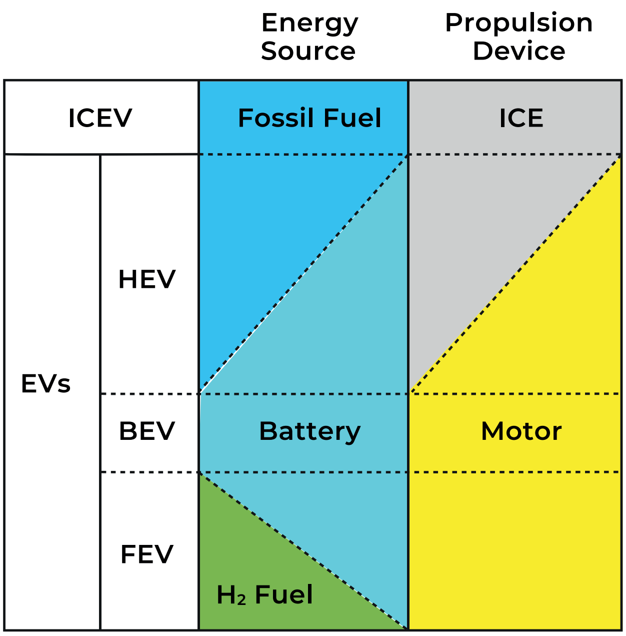
It is important to note that the actual energy efficiency level (Wh/km) that a battery achieves, during use in real-world conditions, would likely be different from this standard number. This is because laboratory conditions differ from city driving conditions in which drivers tend to accelerate, decelerate, frequently brake or over-load the vehicle. Whether a driver is driving in a city or on the highway also makes a difference. Hence, the actual Wh/km used by the driver will be more than the laboratory measurement. The same is the case with petrol vehicles. Test results are accurate if the test procedures resemble, as much as possible, real world driving conditions. For instance, by including the use of air-conditioner, lights, wipers and other accessories during the test. When they are used, they will consume more power. Since air-conditioning does consume significant amount of power, it is best that the Wh/km be measured with, and without, the air-conditioner.

ANNEXURE 3

TYPES OF ELECTRIC VEHICLES

Electric vehicles (EVs) can operate wholly or partially on electricity, whereas Internal Combustion Engine (ICE) vehicles depend entirely on fossil fuels to power them. Figure 9 summarises the energy source and propulsion device in ICE Vehicle (ICEV), Hybrid Electric Vehicle (HEV), Battery Electric Vehicle (BEV) and Fuel Cell Electric Vehicle (FEV). BEV runs only on an electric drivetrain powered by batteries, whereas HEV has both an electric motor as well as ICE.

Figure 9
Comparison of Internal Combustion Engine Vehicle (ICEV) with different types of Electric Vehicles (EVs).



Source: (Cheng & al., 2015).

Details of different type of electric vehicles have been discussed below:

BATTERY-ELECTRIC VEHICLES (BEV)

These vehicles only use electricity stored in an on-board battery pack to power the electric motor and propel the vehicle. On a full charge, the low-cost vehicles are designed to travel around 110–160 kms, though recent developments in battery technologies are enhancing the driving energy. More expensive vehicles have much higher driving range, some exceeding 500 kms. The batteries can be charged either at home or at the workplace or even at publicly available charging or swapping stations (Union of Concerned Scientists, 2018).

HYBRID-ELECTRIC VEHICLES (HEV)

These vehicles combine an ICE diesel or gasoline powertrain along with an on-board small battery and an electric motor (European Environment Agency , 2016). The electric drive train is generally used for shorter driving distances whereas the diesel/gasoline drive train is used for long distances. HEVs have a battery but it is recharged automatically during regenerative braking or while the vehicle is idling. Most of the power to propel a HEV comes from the ICE but the addition of an electric motor increases fuel efficiency, reduces the use of petrol/diesel, and decreases emissions. Use of regenerative braking, and idling power to feed the battery are additional features that increase fuel efficiency (Union of Concerned Scientists, 2018).

PLUG-IN HYBRID ELECTRIC VEHICLES (PHEV)

Like HEVs, these vehicles also have both an internal combustion engine and an electric motor (IEA HEV, n.d.). However, unlike in an HEV, the electric drive train can also be charged using an electricity outlet and does not depend entirely on regenerative braking or idling. As a result, they can use the electric drive train for longer distances and are more efficient in the use of petroleum. Consumers have the option to switch to gasoline if they cannot recharge the batteries. The amount of electricity stored in the battery determines the distance it can travel using electricity. But typically, this is around 16 to 60 kms (Union of Concerned Scientists, 2018). They are cheaper to run and create lesser pollution than their conventional counterparts.

FUEL CELL ELECTRIC VEHICLES (FCEV)

These vehicles combine hydrogen and oxygen to make electricity that powers the electric motor. Producing electricity from hydrogen only leaves water and heat as by-products. This means FCEVs don't have any tail pipe emissions. It takes about ten minutes to refuel pressurised hydrogen. Driving ranges are around 300 – 500 kms. Regenerative braking can be used for capturing lost energy (Union of Concerned Scientists, 2018).

ANNEXURE 4

CATEGORIES OF LITHIUM-ION (LI-ION) BATTERIES

The primary components of Li-ion batteries are cathode, anode, electrolyte and separator. Li-ions move from anode to cathode during discharging and cathode to anode during charging of the battery as described in Figure 10 below. In commercial Li-ion batteries, the carbon-graphite anode is most commonly used with various metal-oxide type cathode (e.g. Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt oxide (NMC) and Lithium Nickel Cobalt Aluminum Oxide (NCA)). Lithium Titanate Oxide (LTO) is an alternative anode material for commercial Li-ion batteries.

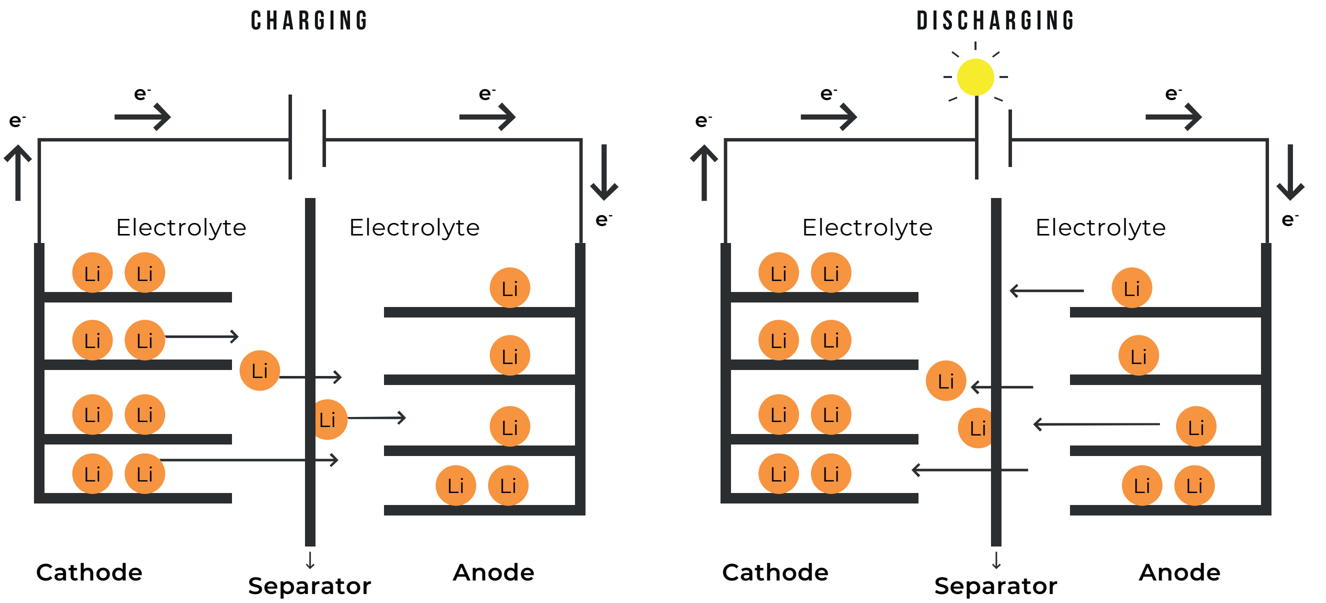
The important performance parameters of batteries for electric vehicle application includes energy density, cost, cycle life, and safety. The cathode, anode and electrolyte material play an important role in determining the battery performance. Figure 11 summarises key performance characteristics of different types of Li-ion batteries. The selection of Li-ion battery type for EV application is a trade-off between cost and other performance parameters. NMC provides a good trade-off between important battery performance parameters.

Detail of most prominent sub-categories of Li-ion batteries have been described below:

LITHIUM NICKEL MANGANESE COBALT (NMC) BATTERIES

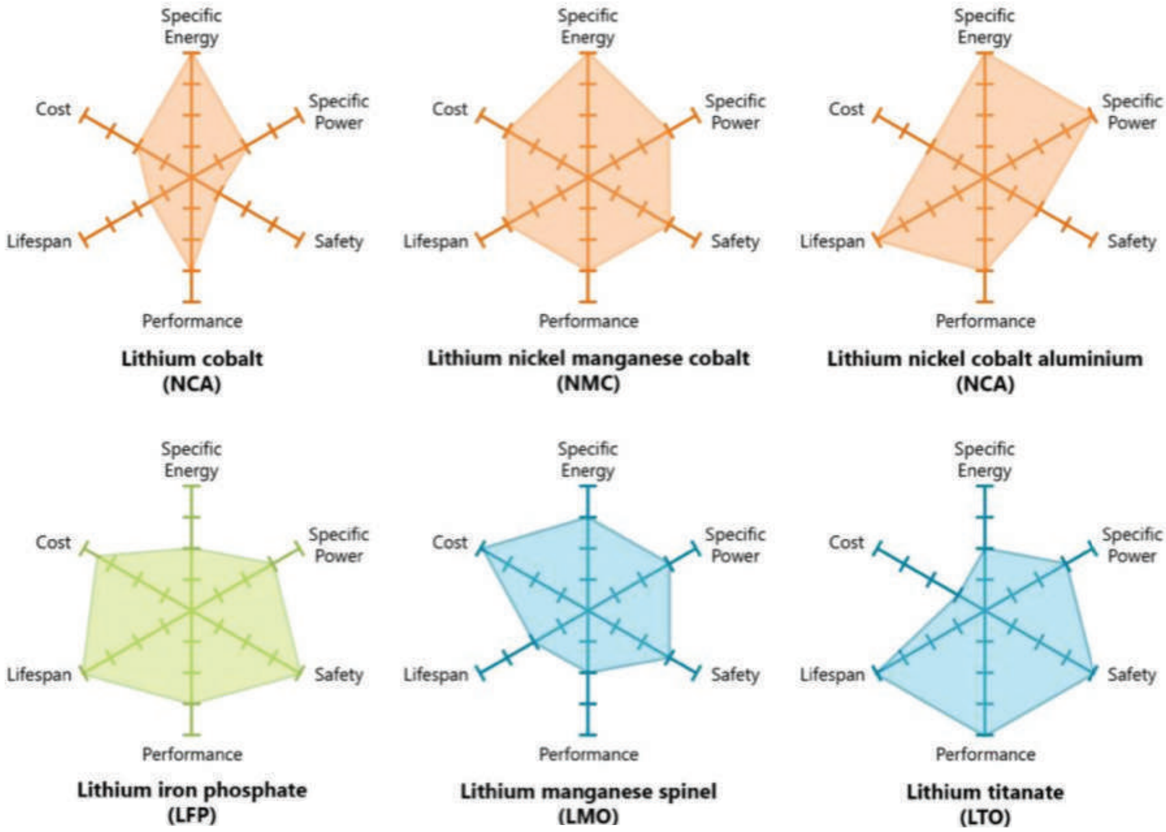
NMC along with LCO, LMO and NCA are the lowest cost, have the highest specific energy (Wh per kg) and are the lowest weight battery-cells today. They mostly use Graphite as anode. They are used in most EVs today. Tesla manufacturers use NCA. Rest of the battery chemistries are manufactured by LG Chem, Samsung SDI, a few other Korean and Japanese companies, several Chinese companies and a few European companies. However, one cannot charge them fast (in less than 60 minutes) without damaging their life cycles. Similarly, when charged at ambient temperatures higher than 40°C, the battery life may get impacted. Cost of the cells can be lower than $140 per kWh (cost of battery-pack will be closer to $200 per kWh) in volumes and specific energy is touching 250 Wh per kg

Figure 10
Charging and discharging of Li-ion battery.



Source: (Heidari, 2018)

Figure 11
Comparison of key battery performance characteristics for different Li-ion chemistries for EV application. Source: (Lemon & Miller, 2013)



(size is also small, exceeding 250 Wh per litre at the pack level). Such batteries with about 80% depth of discharge (implying 80% of capacity is available for use at a time), can last for about 2500 charge/discharge cycles, but only when they are charged in about six hours and discharged in two or more hours. Occasional charging in about 60 minutes is fine as long as the temperature is below 40°C. Charging faster can severely damage life.

LITHIUM TITANATE OXIDE (LTO) BATTERIES

The other extreme is the LTO battery, where LTO is used as an anode instead of Graphite. Well-designed LTO batteries can be charged and discharged fast, in about 20 minutes and that too at 45°C, without any significant damage in life cycles. They can last for 10000 or more cycles. But the cell cost for LTO is about three to four times that of NMC batteries and hovers close to $500 per kWh today (battery-pack costs will be even higher). Furthermore, their energy density is 50% to 60% of the best NMC batteries and their size is also larger. There is no visibility that their price will come close to that of NMC cells in the near or medium-term future. These cells are used in specialised electric vehicles only (like top-up charging for a bus).

LITHIUM IRON PHOSPHATE (LFP) BATTERIES

These batteries fall somewhere in between NMC and LTO. They can charge-discharge faster and have higher-temperature tolerance, compared to NMC batteries, but much less than LTO. Their energy-density and costs are also in between NMC and LTO. They were widely used in Chinese vehicles two years ago. Their energy density cannot theoretically go over 160 Wh/kg. China is therefore in the process of shifting fully to NMC.

ANNEXURE 5

DETERMINANTS OF THE PERFORMANCE OF BATTERIES

There are several determinants of the price and performance of a battery pack. These include specific energy, volume of the battery pack, chemical composition of the cells and battery management system. Each of these is explained below.

SPECIFIC ENERGY OF THE BATTERY

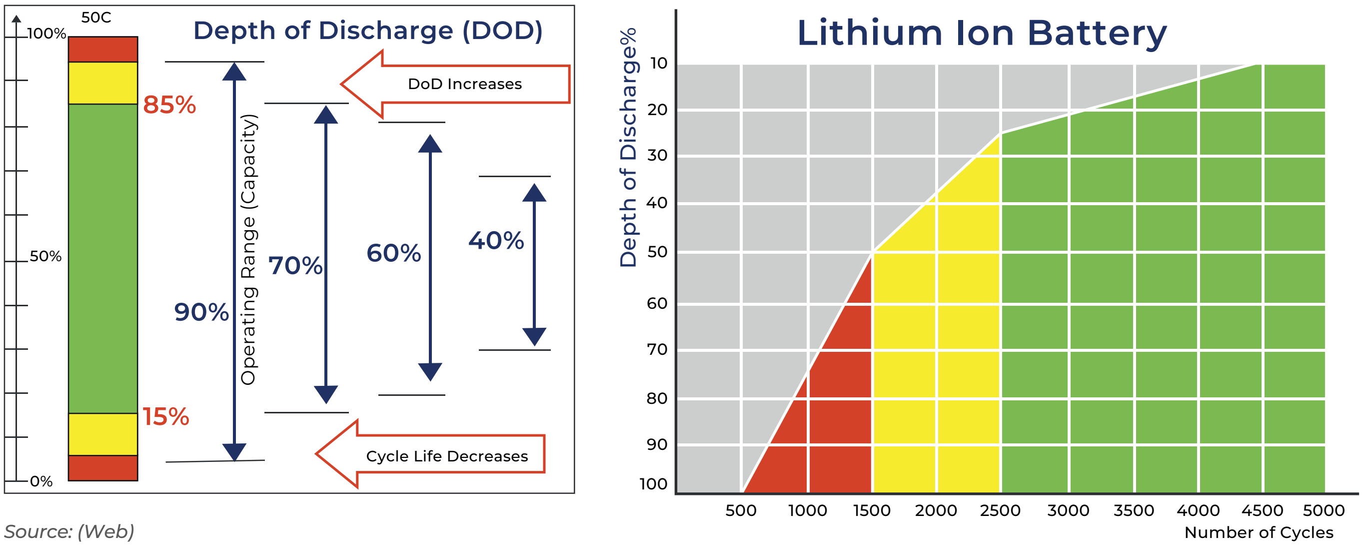
Specific energy of the battery, measured as Wh/Kg, is one of the key performance parameters of the battery of an electric vehicle. Higher specific energy means a higher driving range of the vehicle and fewer recharging stops for the consumer. Batteries that are larger in size offer higher performance but increase the weight of the vehicle. For example, a 100 kWh battery weighs 1000 Kg. The increased kerb weight of the vehicle, in view of the high weight of the battery, reduces the fuel efficiency of the vehicle because increase in weight needs greater power for moving the vehicle. When EVs are installed with large rather than small batteries, the upfront costs of the vehicle increase. Specific energy of the batteries also varies with the chemical composition of the cell.

Volume of the Battery Pack

Volume of the battery refers to the size of the pack. To achieve a particular level of specific energy (Wh/kg), the volume of the battery will vary with the chemical composition of its cells. E.g. from amongst the prominent technologies in LIBs, NMC cells will weigh more than LTO cells to achieve a particular level of specific energy. It is commonly assumed that increasing the size of the battery will increase the range of the vehicle, reduce the frequency of charging and reduce range anxiety for the consumer. However, there are downsides as well. Larger battery sizes increase the upfront cost of the vehicle. Full recharging of larger batteries take more time than smaller battery packs. This requires either fast charging (DC based) or long hours of slow charging (AC based). Fast chargers only partially recharge the batteries (50-80% capacity). This is detrimental for the health of cells as high amounts of heat are generated during fast charging. Additionally, leaving sizeable share of battery capacity unused for long periods leads to automatic discharge and shortening of battery life.

The cycle life of a battery also depends on the Depth of Discharge (DoD). In a commercial Li-ion battery, 80% DoD or less is recommended to maintain balance between battery size, cost and cycle life. Figure 12 shows how the cycle life of a Li-ion battery decreases with increasing DoD. The discharge cycle of the Li-ion battery increases from ~500 cycles at 100% DoD to more than 4700 cycles at 10 % DoD.

Figure 12
Effect of Depth of Discharge (DoD) on cycle life of a Li-ion battery.



Source: (Web)

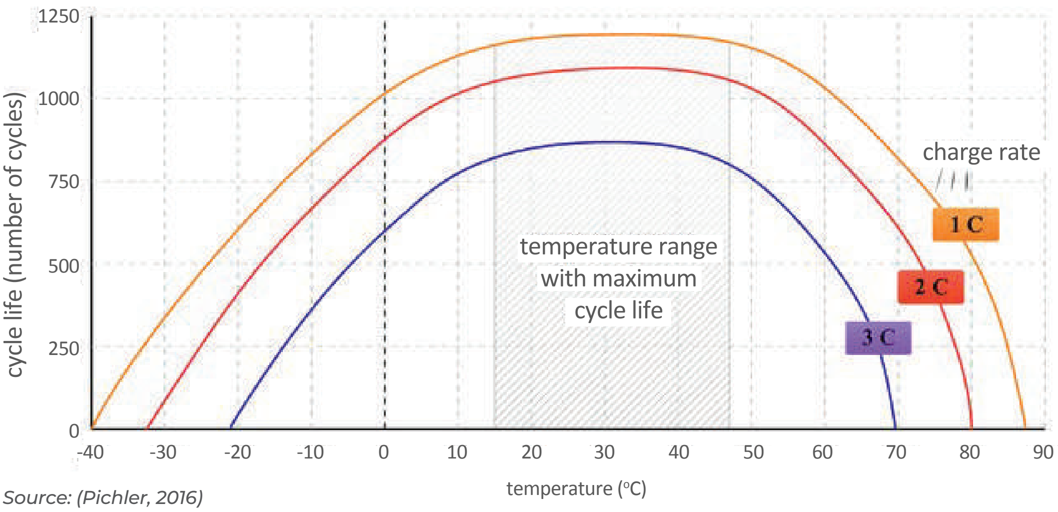
Rate of charge and discharge: The life cycle of a battery depends upon the battery chemistry used, depth of discharge (DoD) used (impacting the usable capacity of the battery) as well as on its rate of charging/discharging and the temperature at which it is charged/discharged. For example, a low-cost Graphite-NMC battery available today cannot be charged at a rate above 0.8C (implying full charge up to usable capacity in about an hour) without impacting the number of life cycles even if charged at 25°C. On the other hand, the higher cost LTO battery can be fully charged at 3C (in 20 minutes) or even faster without any appreciable impact on battery-life, even if the temperature goes up to 45°C. These facts, as well as the kind of vehicles and their battery-size and type, need to be understood well while building public charging infrastructure. Figure 13 shows the effect of charge rate and temperature on the cycle t of the battery. The cycle life of a battery decreases on the charge and discharge of the battery at higher charge rate as well as at temperature beyond the optimal range (15°C – 45°C).

Battery Management System (BMS)

A battery pack is a complex and expensive system. For optimal performance of the pack, it is essential that all the cells in the pack perform uniformly during the charging and discharging process. Monitoring the performance of battery cells requires a Battery Management System (BMS). BMS is a set of electronic sensors that gather real-time information from the cell chemicals, adjust the charging and discharging parameters and communicate this information to the vehicle user. These sensors measure battery voltage, state of charge, state of health, temperature, etc. and display this information in an easy to read format for the user.

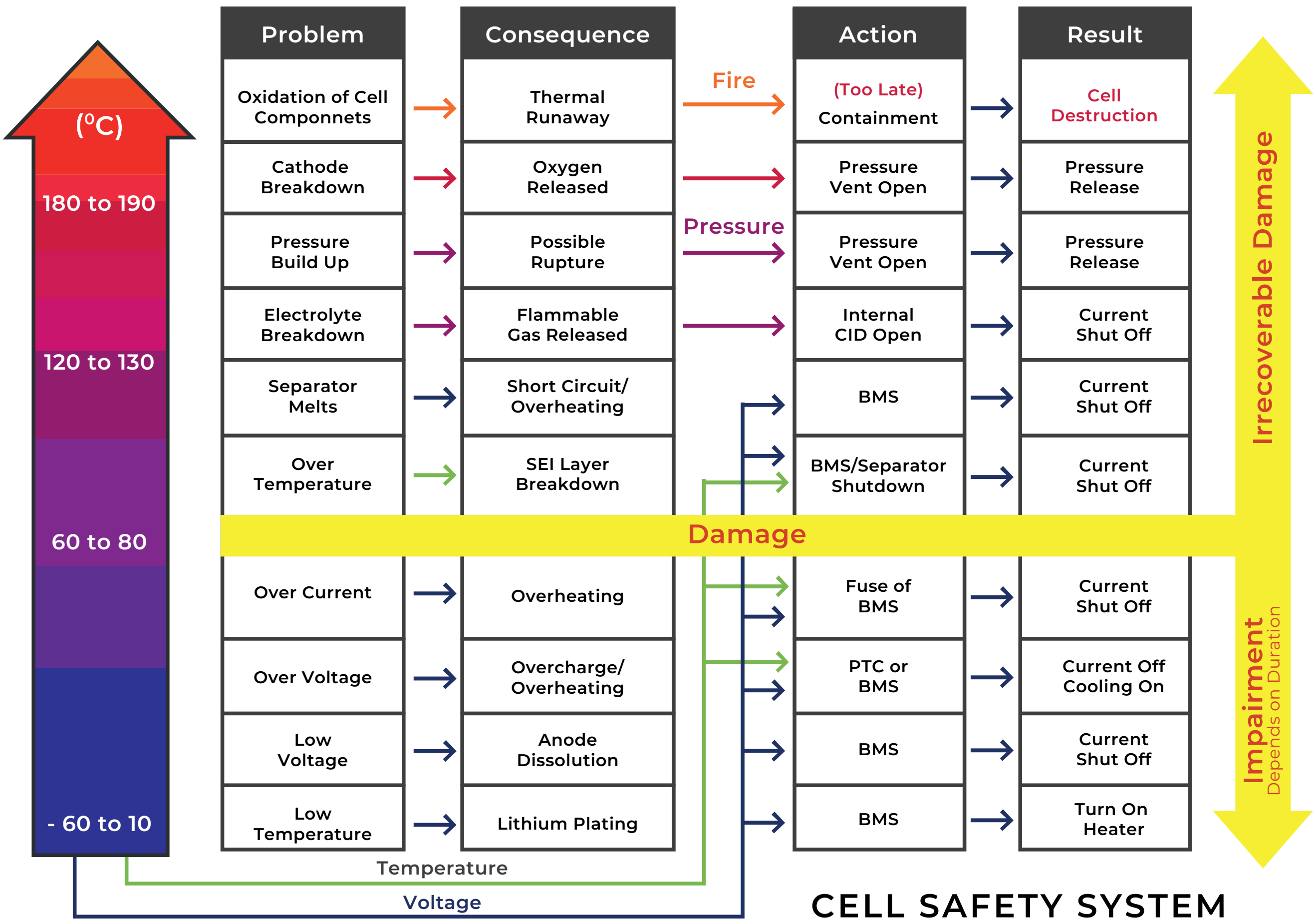
BMS is critical for battery packs of all chemical compositions, but for LIBs they are an absolute necessity. This is because LIBs are prone to catching fire at high temperatures. Many states and regions in India experience extreme temperatures in summer. Electric vehicles used in such regions will have higher risk of the battery catching fire. For a battery pack to yield consistently optimal performance requires real-time monitoring and predictive analysis on cell degradation, ambient temperature and electrolyte levels. Figure 14 summarises possible actions of BMS to maintain the battery in safe operating conditions.

Figure 13
Effect of charge rate and temperature on the cycle life of the battery.



Source: (Pichler, 2016)

Figure 14
Summary of possible cell failures, its consequences and action taken by BMS for the protection.



Source: (BMS)

ANNEXURE 6

FUTURE BATTERIES

We briefly discuss here some of the recent developments which may impact EVs in the middle to long-term future.

1. Enhancing energy density of NMC/NCA - Graphite battery: The developments have been going on in two directions:

- Reducing Cobalt and enhancing Nickle in Cathode: Early NMC cells were NMC111, implying Nickel, Manganese and Cobalt were in equal proportion (1:1:1). Over the last five years, one saw NMC433, where the ratio of Nickel was enhanced; One saw reduction of Cobalt content as opposed to Nickel and this reduced cell costs and increased energy density. Then came NMC532, where Cobalt content further went down, and costs decreased whereas energy-density increased. Then emerged NMC622, where the Nickel ratio was further enhanced. The latest cells are NMC811, where the Nickel ratio was enhanced to 80%, further reducing costs and enhancing energy density. Some recent work has given Nickel-rich Cathode, where Nickel is up to 95% and Cobalt reduced to 4%. This has pushed up the energy-density to 300 Wh/kg. However, the cells cannot be fast charged at high temperatures. At 45°C, charging is to be limited to 0.2C (full charge in about five hours).
- An alternative was to use Silicon along with Graphite in the Anode. One can get energy density of 280 Wh/kg, but the problem is that Silicon can expand 400% in volume during charging. As a result, one must charge very slowly (limiting to 0.5C). Discharge rate is however not a problem. Also, the life cycles considerably go down.

In effect, while enhancing energy-density decreases costs, it has an impact on the safety and charging rate.

2. An alternative is to use LTO. The nergy-density is unlikely to cross 100 Wh/kg, implying this will be significantly higher weight and size as well as higher costs as compared to NMC. However, as mentioned earlier, it is remarkable as far as safety and charge-rate is concerned.

3. A few years ago, the Metal-Air battery was touted to be a better alternative as compared to Lithium batteries. But the promise has largely faded away. One may see Lithium–Metal anode in the future. But to become competitive with today's NMC battery may take several years.

ANNEXURE 7

WORKING OF CHARGING AND SWAPPING SYSTEMS

SLOW CHARGERS

For slow charging of 2-wheelers (battery size of 1 kWh to 2 kWh), 3-wheelers (battery size of 3 kWh to 4 kWh) and cars (battery size of 10 kWh to 30 kWh), the single-phase supply would be adequate. For home charging, a 15A plug on the home-supply (also used for air conditioners and washing machines at homes) can be used. For public slow chargers, it may be best to use the 15A industrial plug used in India. Public chargers may also have a built-in meter. While communication between Electric Vehicle (EV) and charger (also referred to as Electric Vehicle Supply Equipment or EVSE) is not envisaged for slow chargers, the public slow chargers (EVSE) need communication with a Central Monitoring System (CMS). This is given in Figure 15. World-wide, such communication takes place using the OCPP protocol. India has defined an AC-001 standard for public AC slow chargers, using OCPP for EVSE-CMS communications. The charger standard allows metering-rate to vary with time and day through CMS, and has payments through mobile payment and/or bank-accounts. This is illustrated in Figure 16. This can be used when the vehicles have built-in chargers up to 3.3 kW. The chargers should be low-cost and deployed widely by the power distribution company or its franchisees. Even street parking could have AC-001. At volumes, an AC-001, charging up to three vehicles simultaneously, should cost no more than INR 25000.

Larger vehicles may have larger batteries of size 25 kWh to 50 kWh. The 3 kW AC charger will take too long to charge them. Higher power AC chargers like 6 kW or 11 kW is typically used. These will need three phase supply and special chargers. There are some European, American and Chinese standards for such high-power AC chargers. For vehicles with large batteries, slow chargers would be used.

FAST CHARGING (EV-F)

Once a vehicle runs out of energy, and one needs to go further, slow charging is not an acceptable option as it takes several hours. Vehicles then must be fast charged. The rate of charging however is limited by the kind of battery that the vehicles has. For example, if the vehicle has low-cost batteries like NMC, LCO, NCA and LMO, one may be able to charge 80% of the battery in about 60 minutes or even at 45 minutes. Any attempt to charge these

Figure 15
Communication protocol between EV and Central Management System (CMS) for fast chargers

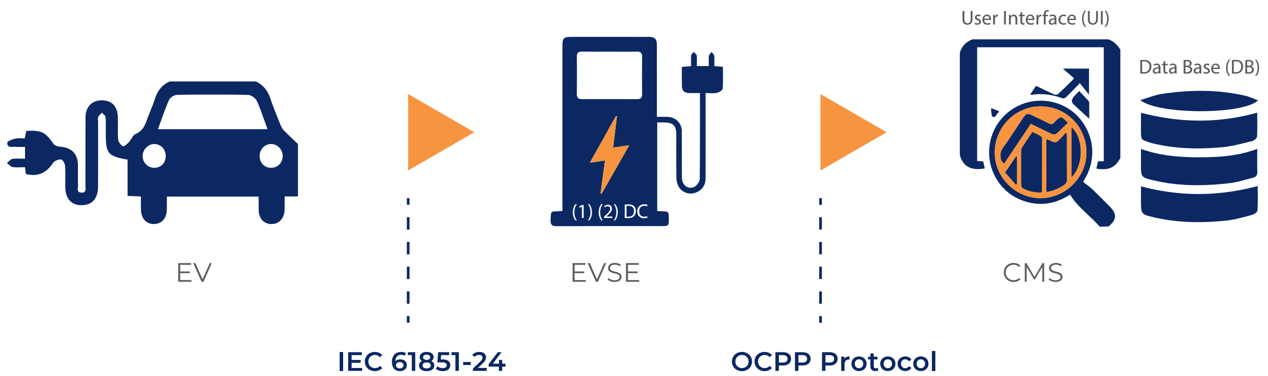
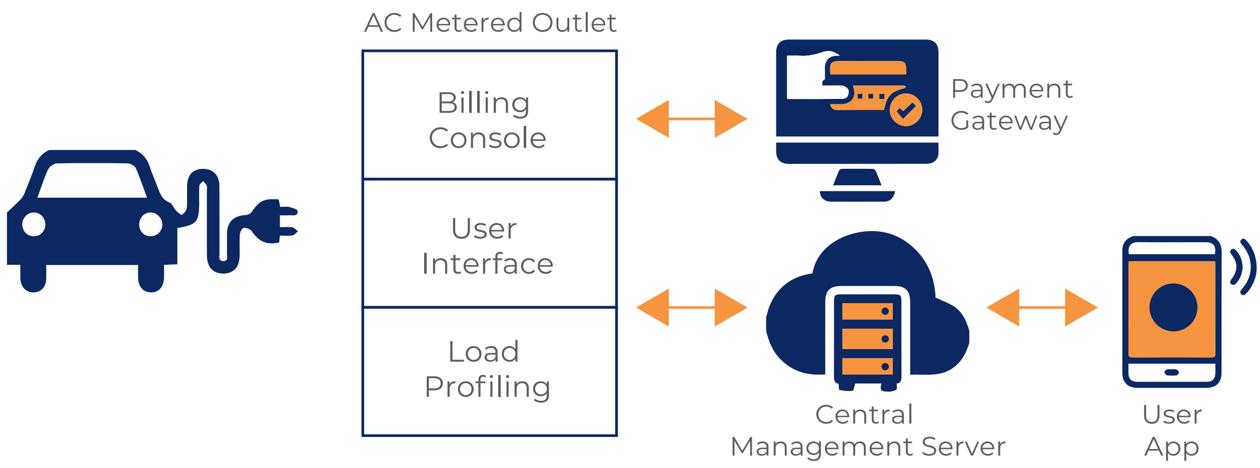


Figure 16
Communication between an EV, a public slow charger and mobile payment technology



batteries faster, will have an adverse impact on the life of the battery. Further, if the ambient temperature exceeds 40°C it becomes very difficult during fast charging to keep the cell temperature to acceptable limits despite cooling. This can cause problems. On the other hand, if the vehicle has a well-designed LTO battery, fast charging even in 15 minutes and even at higher ambient temperature becomes possible. The problem is that these batteries are expensive, weigh much more and are larger in size.

Furthermore, the fast charger must be located where vehicle owners need them and must be available for use. Since a fast charger will typically be utilised by a vehicle owner for about an hour, the number of fast chargers and location at which they are installed must be sufficiently large. Just having fast chargers at petrol-stations is not enough, as petrol-pumps have capacities that are designed for vehicles to be serviced in less than 5 minutes and not an hour as may be needed with fast charging. However, it is possible to use parking-lots and car parks in buildings as possible locations to install fast chargers. Lastly, the business viability of a fast charger in India needs to be adequately established. Lowering the capital cost required for a fast charger will help in this regard.

To overcome the problems of fast charging, one may design the vehicle to have larger batteries, and thus extend the driving range. This would however increase the cost of the vehicle. This is what is done in countries like USA, where Tesla cars may have a range of 500 kms. In this case, a fast charging facility is not needed often, and locations of such chargers could be fewer. Furthermore, even if these vehicles have low-cost NMC kind of batteries, which are to be charged in about 75 minutes, charging these vehicles at fast chargers for 30 minutes give an added range of about 200 kms. Thus, if one can afford larger batteries, then fast charging may make more sense, as in the west.

SWAPPING BATTERIES (EV-S)

Another option for energising a discharged battery would be to swap it with a charged one, at a swapping station. In this case, the vehicles do not need to be fast charged or carry very large batteries.

Here the battery can be separated from the vehicle and will not be owned by the vehicle owner. Instead it will be owned by an Energy Operator (provider of charged battery as a service), who will buy the batteries, charge them in a conditioned environment and lease them to vehicle owners at convenient charge-cum-swap centres.

The cost of leasing the battery could be based on kWh consumed and the time for which the vehicle-owner keeps the battery. The leasing-costs would be designed taking into account the depreciation of the battery (for its life), the finance costs and cost of charging and swapping. The energy-operator will have to buy a larger number of batteries, than the number of vehicles it services, as the charged batteries must be available when a vehicle needs it. At volumes, this factor could be 1.3 to 2, depending upon the average time within which a vehicle owner will come back for swapping and the average time for the discharged battery to be ready for reuse in another vehicle. This extra cost of an additional stock of batteries needs to be considered in determining the lease charges. The advantage is that the battery used could now be small, as swapping takes little time. Also, the investments required for energy operators will be lower with smaller batteries. However, as the vehicle owner now has to come to a charge-cum-swap station, user convenience needs to be taken into account.

Finally, these batteries can be designed as Locked-Smart batteries (LS-Batteries) such that they will not be chargeable except by an authorised charger of the energy operator and will not be usable in any vehicle other than in the one it is swapped-in. Besides these batteries would be designed to record the exact condition in which it is used and the state of cells in every short interval. This information can be passed on to a central management server to ensure that the batteries are used in a manner that maximises its life cycle and gives the user the best value for money.

EV manufacturers would mount one such LS battery into a vehicle. These batteries are programmed with a unique encrypted key to be used for authenticating the specific vehicle and chargers - where such a battery will be charged. These keys are generated in such a manner that they cannot be changed, except by authorised personnel. When LS batteries are used by a charging-cum-swapping operator, a discharged LS battery can be swapped with another charged locked smart battery. The new swapped LS battery shall be specifically authorised again, at the time of swapping, to be usable with this specific vehicle only. The returned discharge battery shall go for charging to the bulk charging station.

Locked-smart batteries will be able to (i) distinguish batteries used in an EV from other batteries used elsewhere (ii) ensure that the battery cannot be charged–discharged except by authorised entities, thus preventing misuse of the battery. The latter is crucial for the energy operator's business to succeed. It will also make the battery useless for anyone who steals it. Finally, the standard communication protocols for the LS-batteries will enable battery vendors to make batteries independent of vehicle designers and still enable strong management of vehicle performance, driver performance and the performance of the batteries.

Some of the key considerations that influence battery-swapping options include:

- Vehicles are not purchased with the battery. ***This would significantly reduce the cost of a vehicle.*** In volumes, an EV would now cost as much as petrol vehicles today and would become lower in a few years.
- When the battery is made small, range of the vehicle is low, and the vehicle owner may have to go to charge-cum-swap centres more frequently. Convenience of the vehicle owner becomes important in such a case. For public vehicles like 3-wheelers, 4-wheeler taxis and intra-city buses, this may be more acceptable. Acceptability in the personal vehicle segment is likely to be lower and needs examination.
- The problem of where to do slow charging in the night, when vehicles are not parked in a garage but on the road side is overcome, as the LS-batteries are not to be charged by a vehicle-owner.
- The vehicle can now be driven for an unlimited range with repeated swaps, each carried out within minutes. The only thing that needs to be ensured is that the user is able to find a center, belonging to the energy operator, whenever she/he needs it.
- In the beginning, the petrol pumps may be used as charge-cum-swap centres. As the number of vehicles in the EV-S category grows, and as the rate of frequent swaps increases, the existing petrol pumps may not

be adequate.

- The investment of the energy operators will be high. But as the business is viable, such investments will be attractive. As battery costs keep coming down, the business will become more and more profitable.
- The EVs must be designed to have high energy efficiency, implying that their energy consumption per km (Watt-hours per km) is kept low. It is possible that the lease costs of the LS-batteries per km could become close to petrol costs per km today. Over time, as the battery costs come down, the lease costs per km of travel will become lower than that for petrol.
- The fact that the swappable battery is made small, implies less weight for a vehicle to carry. This will improve the vehicle energy-efficiency.

RANGE-EXTENSION BATTERIES (EV-RE)

For the few occasions when the vehicle needs to travel longer distances, the vehicles can have a slot for a second battery called range-extension swappable LS batteries (or RE battery). This will be aside from the existing fixed battery. This slot will not be used on most days when the fixed battery in the vehicle is enough and so EVs will not have to carry needless dead-weight. However, on the few occasions when the vehicle has to travel a longer distance than in addition to what we fixed battery can support, the vehicle can swap-in a RE-battery. As the RE battery will be designed to have nearly the same range as the fixed battery, the range of the vehicle gets doubled. The range-anxiety disappears. In fact, if on some day, one does need to travel longer than two times the range that the fixed battery supports, the RE-battery is simply swapped again and again to travel as far as one needs to.

There are multiple advantages of an EV with RE-battery (EV-RE). The battery used could now be small as in EV-S. But the fixed battery, charged overnight, eliminates the need to go to a swapping station on most of the days. The vehicle does not carry the dead-weight of the second battery on these days. One needs to go to a swapping station only when one drives longer than the range offered by the fixed battery. Need for fast charger infrastructure is reduced significantly. The RE-battery mounting, or swapping, can be limited to existing petrol pumps. The duration for RE-battery mounting/swapping is similar to the time taken to fill petrol. The current capacity of petrol stations could suffice to serve as swapping stations as vehicles will come at less frequent intervals if they already have a fixed battery in their vehicles and will need to come only when they need to swap in a RE battery. In fact, as IC engine vehicles recede from the market, these pumps could become battery swapping stations. Today the RE-battery leasing-cost for the customer is almost equal to the cost for a petrol vehicle per km (as long as the EV is designed to have high energy efficiency). This cost will go down over time.

ENERGY OPERATORS (EO)

A good model for dissociating the costs of the battery from an electric vehicle is through an energy operator. An Energy Operator (EO) will be a company which will own the batteries and will provide them on lease to vehicle owners. It will allow them to replace spent batteries with charged batteries from their locations (battery as a service). This will bring the one-time cost of the vehicle down significantly. Good candidates for such EOs will be the current fuel distribution companies (like BPCL, HPCL, IOCL, etc. in India) since they already own a network of petrol pumps, and a nation-wide distribution network. The EO will purchase batteries, place them at the petrol stations and set-up charging-cum-swapping facility at each petrol station. The vehicles that need to swap a battery, or add an RE-battery, would come to the petrol pump and avail of the service. Battery mounting or swapping should take no more than 3 to 4 minutes.

It is assumed that the vehicle owner would subscribe to the service with the desired EO. This would imply guarantee for the leased battery and a mechanism for automatic (or mobile-based) payment for the charges incurred, based on kWh of battery used and the time for which a battery was leased out. Once the battery is used (nearly discharged), the battery would be returned (or swapped with a charged battery) at any of the petrol station of the EO.

CHARGING/SWAPPING ARRANGEMENT AT DIFFERENT LOCATIONS

EV charging at home

The 230V 15A AC outlet, available at Indian homes, would charge 2-wheelers in about two to three hours. The economy cars could be charged in about 6 hours. It is possible to install the equivalent of AC001 at home and get the benefit of time of day metering. The city can encourage use of AC001 at homes and can provide special tariff, including ToD metering, for EV charging. In fact, cities should mandate that multi-storied buildings should have AC001 installed at its parking areas. Premium cars can also use this for top-up charging as full-battery charging can take 10 hours to 25 hours.

Swapping infrastructure in a city

The 3-wheelers and 2-wheelers (range extension) would benefit if battery charging-cum-swapping infrastructure is set up all over a city, preferably at distance no more than 1.5 kms apart. City governments should provide space and electricity connections, and also offer incentives to energy operators.

Petrol pumps could have Charging-cum-swapping stations for economy cars. As the swapping will take no more than the time required to fill up petrol.

Public charging infrastructure in a city

Low cost AC001 chargers can be installed in all city-parking lots and in office parking areas. In fact, cities should mandate that each parking lot install AC001 charging facilities in an increasing share of its parking area. This would enable top-up charging for 2-wheelers in about 1-2 hours, economy cars in about 4-5 hours, and premium cars in 6 to 8 hours.

Similarly, a city parking lot should set up a limited number of DC001 charging for economy cars and goods vehicles and some CCS2 charging for premium cars. Office parking space should also have some DC001 and/or CCS2, depending upon the number of electric economy and premium cars being parked. This will enable 15-minutes to 1-hour fast charging (full-charging or top-up charging) for these vehicles.

An important consideration for the city and energy-operators is the number of chargers to be deployed. Today, the ratio of public slow chargers and fast chargers deployed in the world is about 5:1. Efforts should be towards making all these deployed chargers financially self-sustainable at the earliest possible.

CHARGING AND SWAPPING INFRASTRUCTURE ON HIGHWAYS

Highways petrol pumps would be ideal for 2-wheelers, 3-wheelers and economy-car battery swapping. Since the time required for swapping would be similar to that required for filling fuel, most petrol-pumps would be suitable for use as swapping facilities to serve small vehicles. They may not be equally suitable for EV charging, as this would require vehicles to be parked for much longer. Table 18 highlights EV infrastructure requirements at different locations in an Indian city.

Eateries on the highway, where vehicles stop for 30 minutes to an hour would be good locations for fast charging infrastructure like DC001 and IEC-CCS2 chargers.

Long distance buses would require high-end CCS2 at select long distance bus terminals or at eateries, where the buses would be parked for refreshments. These buses may require about 40 minutes for full charging. The extra-long distance (Inter-state) buses may require even larger batteries and higher power chargers. One may consider IEC-CCS2 charger with power output up to 250 kW to charge a 250 kWh bus-battery in about 45 minutes at these highways stops.

Table 18: EV Infrastructure requirements at different locations in an Indian city	
Homes	AC 15A outlet or AC001 (Time of Day metering) Charges 2W in two hrs, economy cars in 6 hrs; can partial charge premium cars
Office parking / Public parking	AC001 for partial charging 2W, large autos and economy cars DC001 to charge economy cars and large autos in 45 minutes; IEC-CCS2 to charge premium cars in 30 minutes
Street swapping	2W and 3W swapping in 3 to 4 min
Petrol-pump	Charging: not desirable 2W and 3W swapping + 4W swapping in less than 5 min
Intra-city bus terminus	Battery swapping for bus in 5 to 7 min
Highway eateries + bus-stops	AC001 for partial charging 2W, large autos and economy cars DC001 to charge economy cars and large autos in 45 min; IEC-CCS2 for premium car-charging in 30 min; IEC-CCS2 inter-city bus-charging in 45 min
Highway petrol-pumps	2W and 3W swapping + 4W swapping in less than 5 min

ANNEXURE 8

POLICY MEASURES ADOPTED FOR PROMOTING EV IN INDIA

The Government of India has adopted a number of policies to promote EVs in India, which include:

1 National Electric Mobility Mission Plan (NEMMP) 2020	**2** Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles - FAME 1 and 2 Schemes	**3** Charging standards for slow and fast chargers, communication protocols - Department of Heavy Industry	**4** Electricity as a Service- Amendment of Electricity Act 2003 by Ministry of Power, Government of India
5 National Auto Policy (draft) of Department of Heavy Industries (DHI), Government of India	**6** Charging infrastructure for Electric vehicles – Guidelines and Standards, Ministry of Power, Government of India	**7** State level policies for adopting EVs	

Some of these are summarised below.

NATIONAL ELECTRIC MOBILITY MISSION PLAN (NEMMP) 2020

The Government of India launched the NEMMP 2020 in 2013. This plan set an ambitious target to achieve 6-7 million sales of hybrid and electric vehicles year on year from 2020 onwards. The government aims to provide fiscal and monetary incentives to spur this nascent technology. The cumulative sale is expected to reach 15-16 million by 2020. It is expected to save 9500 million liters of crude oil equivalent to INR 62000 crores in savings (Ministry of Heavy Industries and Public Enterprises, n.d.).

NEMMP 2020 has a composite approach with multiple policy levers (Ministry of Heavy Industries and Public Enterprises , n.d.). The levers are as follows:

- Creating both demand side and supply side incentives to increase uptake of hybrid/electric vehicles.
- Promoting research and development for spurring new technologies in batteries, power electronics, motors, systems integration, battery management system and testing infrastructure.
- Encouraging inputs and participation of industry players.
- Promoting charging infrastructure.
- Encouraging retro-fitment of on-road vehicles with hybrid kits.

FASTER ADOPTION AND MANUFACTURING OF (HYBRID &) ELECTRIC VEHICLES (FAME) SCHEME

FAME 1 scheme

The Department of Heavy Industries (DHI) of the Government of India launched the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME India) scheme under NEMMP 2020 in the Union Budget for 2015-16 with an initial outlay of INR 795 crore. The scheme will provide a major push for speedy uptake of both hybrid and electric technology vehicles and forge a market in the country. The thrust of this scheme is to make hybrid and electric vehicles the mode of choice for consumers and hence, replace the conventional vehicles. Incentivising consumer demand, speedy market creation, domestic technology development and manufacturing will together serve as the launch pad for the domestic industry and encourage it to reach economies of scale by 2020.

As of May 2019, 278691 vehicles have been sold and about 50 million litres of oil have been saved[7] (DHI, 2019).

FAME 1 has been instrumental in promoting electric buses (UITP , 2018). Beneficiaries include 11 million-plus cities and special category states that were selected for running pilot projects. For electric buses, there are two levels of subsidy as given in Table 19 below.

10 cities floated tenders to procure electric buses, out of which 8 had (excluding Ahmedabad and Jaipur) finalised their tender before 31 March 2018. Table 20 shows the list of the cities. Out of the total contracts handed out, Tata Motors will supply 240 electric buses to 5 cities, Goldstone-BYD will supply 120 buses to 2 cities.

FAME 1 has been extended for another six months until March 2019. However, vehicles with conventional batteries have been excluded for subsidy, with effect from October 1, 2018, and so have vehicles not requiring registration such as battery two-wheelers.

FAME 2 scheme

The union cabinet of the Government of India approved the FAME 2 scheme in February 2019. The second phase is an extension of the first phase of FAME that was launched in April 2015.

Table 19: Levels of FAME subsidy

Percentage of localisation	Level 1 – minimum 15% localisation	Level 2 – minimum 35% localisation
Subsidy available	60% of purchase costs or INR 85 lakhs (whichever is lower)	60% of purchase cost or INR 1 crore (whichever is lower)

[7] *This estimate is from the FAME dashboard and numbers are updated periodically.*

Table 20: Electric buses procured through FAME 1 scheme						
City and State	**Number of Buses**	**Contract Type**	**Length (meters)**	**Battery Capacity**	**Range**	**Seating Capacity**
Bengaluru, Karnataka	60	Gross Cost Contract	12	320 kW	300 km	40
	20	Gross Cost Contract	9	210 kW	200 km	31
Hyderabad, Telangana	40	Gross Cost Contract	12	320 kW	300 km	40
Mumbai, Maharashtra	80	Gross Cost Contract	9	—	200	31
Indore, Madhya Pradesh	40	Outright Purchase	9	125 kW	150 km	31
Lucknow, Uttar Pradesh	40	Outright Purchase	9	125 kW	150 km	31
Kolkata, West Bengal	40	Outright Purchase	9	125 kW	150 km	31
	40	Outright Purchase	12	125 kW	150 km	40
Jammu, J&K	40	Outright Purchase	9	125 kW	150 km	31
Guwahati, Assam	15	Outright Purchase	9	125 kW	150 km	31

Source: (UITP , 2018)

The FAME 2 scheme will invest a fund of INR 10000 crore over a period of three years. The scheme will be implemented from April 2019 and will run till 2022. The scheme plans to support:

- Electric two-wheelers – 1000000
- Electric three-wheelers – 500000
- Electric four-wheelers – 55000
- Electric buses - 7000

The objective of the scheme is to give upfront purchase incentives to consumers buying electric vehicles and also to set up charging infrastructure.

The details of the scheme include the following:

- A special focus on electrification of public transport (electric buses). This also includes shared means of travel.
- In three and four-wheeler segments, incentives will be applicable to vehicles registered for public and commercial purposes.
- The scheme also focuses on incentivising purchase of electric two-wheelers for private purposes.
- The scheme favors vehicles with advanced battery technology such as those using lithium-ion.
- 2700 charging stations will be created in metros, one million plus cities, smart cities, cities in hilly areas, with the goal of having at least one charging station in a 3 X 3 Sq km grid.
    - Creating charging locations every 25 km on both sides of major highways that connect major city clusters

Source: (PIB , 2019)

CHARGING STANDARDS FOR SLOW AND FAST CHARGERS, COMMUNICATION PROTOCOLS - DEPARTMENT OF HEAVY INDUSTRY

DHI has formulated a standardised protocol for public EV chargers. These include both AC and DC chargers. Requirements for both on-board chargers (fitted in the vehicles by the vehicle manufacturer) and off-board chargers have been specified. The AC charger standard is known as Bharat EV AC Charger (BEVC-AC001) and has two levels – Level 1 and Level 2. The DC charger is known as Bharat EV DC Charger (BEVC-DC001). Specifications include environmental conditions for use of chargers, communication, safety, performance, mechanical and billing and payment requirements (DHI, 2017).

ELECTRICITY AS A SERVICE - AMENDMENT OF ELECTRICITY ACT 2003 BY MINISTRY OF POWER, GOVERNMENT OF INDIA

In April 2018, the Ministry of Power clarified that electricity falls under the service sector and that anyone setting up a charging station doesn't need a license to do so. This is because setting up a charging infrastructure doesn't require trading of electricity - which needs a licence under the Electricity Act of 2003 (MoP, 2018).

NATIONAL AUTO POLICY (DRAFT) OF DEPARTMENT OF HEAVY INDUSTRIES (DHI), GOVERNMENT OF INDIA

The national automotive policy is likely to be amended to support widespread uptake of electric vehicles and a synchronous ecosystem of charging infrastructure (MHI, 2018).

CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES – GUIDELINES AND STANDARDS, MINISTRY OF POWER, GOVERNMENT OF INDIA

To accelerate the adoption of electric vehicles in India, the Ministry of Power has established certain standards with the objective of enabling faster adoption of electric vehicles. This is to ensure a safe, reliable, accessible and affordable charging network, promoting affordable tariff for EV owners and charging station owners and operators. This is likely to generate employment, or income opportunities, for small entrepreneurs. This will in turn produce an enabling environment to initiate creation of charging infrastructure while simultaneously resulting in a self-reliant EV charging market. Furthermore, it will also simultaneously prepare the electrical distribution system to adopt EV charging infrastructure.

Public charging infrastructure will be rolled out in two phases. In phase 1 (1-3 years), public charging stations will be set up in all mega cities with population of 4 million plus as per census 2011, including all expressways connected to mega cities and important highways connected to these mega cities. In phase 2, (3-5 years), public charging infrastructure in state capitals, UT headquarters and highways connected with these cities will be set up. The Ministry of Power will be creating a central nodal agency for the roll out, which will be supplied support through pertinent agencies such as the Central Electricity Authority. Similarly, the guidelines indicate that every state government shall appoint a nodal agency, such as the state DISCOM or a PSU. The state nodal agency will be responsible for installation, operation and maintenance of the charging infrastructure as per the parameters stated in the standards and guidelines.

The standards permit private residences and offices to set up charging stations in which DISCOMS may act as facilitating bodies. Next, setting up of public charging stations is a de-licensed activity as long as charging stations meet the standards and guidelines stated by this policy and any other pertinent ones by the Central Electricity Authority and Ministry of Power. The standards specify the minimum requirements for public charging infrastructure – such as charger type (fast and slow), connectors, voltage, and number of charging points. Further, the standards indicate the requirements for charging infrastructure for heavy duty electric vehicles such as buses and trucks, location and tariff structures that promote use of electric vehicles (Ministry of Power, 2018).

SUMMARY OF STATE LEVEL POLICIES FOR ADOPTING EVS

Table 21 to 25 below summarise the electric vehicle policies adopted by the state governments of Telangana, Kerala, Delhi, Maharashtra and Karnataka.

Telangana

Table 21: Telangana State EV Policy	
Name	**Telangana**
Policy name	Telangana Electric Vehicle Policy 2017
Policy targets	● 100% electric buses by 2030 for intra-city, intercity and interstate transport (key milestones – 25% by 2022, 50% by 2025 and 100% by 2030) ● Attracting investments worth USD 3 billion dollars and creating employment for 50000 persons by 2022
Funding source	● Allocated through the budget of the state government ● In-kind grants such as easy access to purchasing land for setting up EV manufacturing and battery manufacturing/assembly units.
Demand side interventions	
Public transport	● Telangana State Transport corporation's target - 100% electric buses by 2030 for intra-city, intercity and interstate transport (key milestones – 25% by 2022, 50% by 2025 and 100% by 2030) ● Airport flight shuttles and PUSHPAK buses to be electrified on priority ● Government vehicles (owned and contractual) to switch to all electric by 2025, in phased manner. ● Contract carriage permits for private operators with EV fleet operations ● Electric mobility in and around tourist places (national parks, ecological sites) in the state by 2025
Shared Mobility	● Battery operated last mile shuttle services at all Hyderabad metro stations ● A time bound mandate for all auto rickshaws to switch to EVs ● Encourage cab aggregators to electrify fleets in phased manner. ● Permission for corporate ownership of e-autorickshaws/e-ricks to enable entrepreneurship and create jobs for the economically backward segments. ● Extension of transport department retro fitment rule for existing vehicles to cover Electric kits for passenger vehicles, Auto Rickshaws and e-Rickshaws ● Permission for ARAI certified E-rickshaws in fringe areas at the periphery of GHMC limits in predefined zones and routes. Similar permission will be granted in other cities across the state
Personal mobility	● Exemption of registration charges on personal vehicles purchased till 2025 ● Interest-free loans up to 50% of the cost to all state government employees for purchase of EVs ● Only electric vehicles will be allowed in high traffic density areas, heritage zones, IT SEZs and similar EV zones in cities of the state by 2025. ● Free parking in public parking places and toll exemption on state highways for EVs till 2025
Charging infrastructure	● Government will set up first 100 fast charging stations in a phased manner. ● Charging points for personal vehicles of government employees would be provided at government office parking lots ● A separate category of power tariff will be created for EV charging, both public and private. Duty exemption on power tariff will be extended to public charging stations for a duration of 5 years ● Government land to be offered to private players on long term lease at sub sidised rates and 2-year moratorium period on rental payment for setting up charging/swapping stations, through a transparent bidding process. ● Mandatory provision of charging spots in all commercial buildings. ● Amendment to building and construction laws to integrate charging infrastructure in all new constructions. ● All existing apartments with 200+ families will be supported by capital subsidy of up to 25%, capped at 5 lakh to provide charging points in parking lots; For existing Residential Townships with 1000+ families will be supported by capital subsidy of up to 25%, capped at 10 lakh for each station with 4 fast chargers ● 75% of SGST paid on the fast charging equipment/machinery procured by any entity for setting up private/public/institutional charging stations will be reimbursed. ● Zero connection cost and wheeling charges for supplying renewable energy to charging stations ● Charging/swapping station will be provided at every 50 kms within state boundaries on highway to cities like Bengaluru, Chennai, followed by other national/state highways ● Reserved parking and free charging stations for two-wheelers in parking zones of metro stations and bus depots

Supply side interventions	
Battery and Energy Storage Supply	● A battery disposal infrastructure model will be created to facilitate deploy ment of used EV batteries ● Encouraging manufacturing and assembly of Lithium-Ion batteries (or other chemistries with higher energy densities) to be given special status and incentives by the state; preferential allotment to be given to units making such batteries and related electronics in the automotive electronics park
Manufacturing and Industrial capacity	● Attracting investments worth USD 3 billion dollars and creating employment for 50000 persons by 2022. ● Creation of a mega automotive park spread over 1500-2000 acres catering to EV/EV component manufacturing for two-wheelers, cars, buses & trucks ● Other provisions for facilitating EV cluster in Telangana will include creation of an Automotive Electronics Cluster that will be developed within the proposed Electronics City near Hyderabad with incentives ● Other infrastructural facilities will include: Allotment of land in the form of plots in Automotive Park developed for purchase or on lease or through PPP modes of investment ● Industrial water at subsidised rates, 24/7 power supply with subsidy and duty exemption for EV manufacturing units. EV units will be allowed to avail renewable energy under open access system from within the state
Skills and Research and Development	● Creation of a Smart Mobility Technologies Cluster, Mobility Engineering clusters, EV Research Hubs, EV testing facility, setting up Telangana EV Innovation Fund

Source: (Government of Telangana , 2017)

Kerala

Table 22: Kerala State EV Policy	
Name	**Kerala**
Policy name	Government of Kerala Electric Vehicle Policy
Policy targets	2022: 1 Million electric vehicles on the road 2020: 200,000 two wheelers, 50000 three wheelers, 1000 goods carriers, 3000 buses and 100 ferry boats
Mechanims of creating the policy draft	Government appointed special task force that was headed by a highly respected academician. The task force drafted the policy and submitted it to the government, which evaluated the details and made amendments before finalising the final draft.
Demand side interventions	
Funding source	● Public grants – cash sourced from taxes and in-kind grants in the form of land and infrastructure for auto manufacturers, energy and electronics businesses
Public transport	● Buses will be electrified on priority basis; to be charged at bus depots using 3-phase AC connections for each parked bus, with top-up charging en route ● Three types of charging systems for public buses – fixed battery systems, replaceable battery systems, and automated bus charging systems. ● For bus trip lengths up to 35 km – battery swapping systems at bus depots will be deployed ● Upgrading bus fleets – transition a part of the 6000+ buses of KSRTC to electric by 2025 ● Schemes would be devised to procure electric three-wheelers in bulk from 2019 onwards to catalyse local manufacturing ● Revival of Kerala Automobile Limited (KAL) for manufacturing electric three-wheelers ● Promoting e-bikes for tourists in key coastal and hilly destinations ● Incentives of INR 30000 or 25% of the EV, whichever one is lower, for the 3-wheelers for the initial period of one year
Corporate and Institutional fleets	● Promoting electric cars for government use ● These cars will have built in batteries that could be charged overnight at home/slow chargers or in instances of use for longer distances through range extension

Personal mobility	• Turning environmentally fragile regions, such as Munnar, into 100% electric mobility and pollution free zones, with mandates to convert all four wheelers into electric • Promoting e-scooters with batteries of 50 km range that are suitable for charging at home; with a provision to extend the battery range for another 50 kms for long distance travel • Road taxes may be fully exempted for the initial three years for new electric vehicles
Charging infrastructure	• Kerala State Electricity Board Limited (KSEBL) would be responsible for setting up the entire charging infrastructure and will supply the power to the charging infrastructure; for battery swapping stations, KSEBL will help in identifying suitable players through a transparent process • KSEBL will focus on three districts initially: Trivandrum, Ernakulam and Kozhikode, as pilots, to set up 60 charging stations and 150 swapping stations across the three districts • Organisations such as KSEBL and IOCL to jointly or independently provide battery swapping infrastructure at existing petrol pumps • Fast charging and swapping stations will be established in cities and on highways to create infrastructure for EVs • DISCOMs will set up AC charging stations (as per DHI standard AC-001, 15A outlets) on streets and parking lots, including locations where vehicles are parked over-night • Time of day metering, payment mechanisms and facilities where EV users can charge their vehicles • Encouraging employers to allow their employees to charge vehicles at subsidised rates • Demand aggregation of home and workplace charging (AC charging) at reduced rates • For city buses, charging and swapping mechanisms to be deployed at bus depots upon assessment of techno-economic feasibility • Creating charging and swapping stations on priority basis for public buses and three-wheelers
Electricity tariffs	• Using EVs as an option for generating demand during the off-peak hours • Subsidised electricity tariff of INR 5-5.5 per unit for EV charging stations
Supply side interventions	
Manufacturing and Industrial Capacity	• Companies manufacturing electric vehicles will be eligible for incentives under the Electronic System Design and Manufacturing (ESDM) and Information Technology (IT) Policy of the state • The state will be focusing on boosting manufacturing in the following areas: drive technology, electric drive train and power electronics, energy systems and storage and charging mode and technologies (promoting battery swapping as the preferred mode of re-energising vehicles) • Creating a fund for acquiring key technologies from global players for local manufacturing • Providing concessions in electricity tariff and property taxes as per existing industrial and information technology policies • Providing investment allowance to EV manufacturers under the ESDM policy • Setting up of EV clusters to give speedy land allotment and reliable infrastructure such as roads, power supply and water to manufacturers
Skills and Research and Development	• Creating Centre for Excellence for Electric and Autonomous Vehicles • Updating curriculum of schools in engineering and science to impart skills and knowledge on emerging technology to students • Skilling program for EV and AV industry • Building a mobility corridor in Trivandrum equipped with high-capacity fiber optic connecting various road infrastructure

Source: (Government of Kerala, 2018)

Delhi

Table 23: Delhi EV Policy	
Name	**Delhi**
Policy name	Delhi Electric Vehicle Policy 2018
Policy target	● To make battery electric vehicles account for 25% of new vehicle registrations in National Capital Territory of Delhi by 2023 ● To make 50% of the public bus fleet to be zero emission by 2023
Funding source	● Majority of the funding will be gathered through a feebate system, in which the more polluting a vehicle, the higher surcharge (fee-) it incurs. ● For this, GNCTD will create a non-lapsable umbrella fund – State EV Fund which will include a number of charges on polluting vehicles. Such as a Pollution cess (beginning April 2019), Air Quality parking surcharge, Road tax (higher taxes for diesel and petrol and luxury cars), Congestion fee up to 2.5% on the fare generated from trips done with ride hailing services or cab aggregators and those that are originating or terminating in Delhi; no taxes for rides taken in an electric 2-wheeler, auto or cab. ● While the State EV Fund will be the primary source of funds, if needed, GNCTD will use funds that are being collected under the Environment Compensation Charge (ECC), with approval from the Hon'ble Supreme Court. Beyond this, the GNCTD can also use budgetary funds, however, with the other funding sources, only a minor sum will be needed from the budget.
Demand side interventions	
Personal Mobility	● Purchase incentive for two-wheelers equivalent to 50% of the demand incentive offered by FAME scheme; this will be inclusive of the subsidies offered as per the Air Ambience fund of the Delhi Pollution Control Committee (DPCC) ● Top-Up incentive of up to 50% of the FAME scheme to be provided to vehicles with swappable batteries for a period of three years from the date of notification of the policy ● Road tax, registration fees and MCD one-time parking fee will be waived for all electric two-wheelers with an 'Advance Battery'. ● Existing ICE two-wheeler (below BS IV) owners will get a scrapping and de-registration incentive of up to INR15,000 per vehicle
Corporate and shared fleets	● Ride hailing and two-wheeler rental service providers will be allowed to operate electric two-wheeler taxis subject to obtaining a commercial vehicle registration in Delhi
Public Transport	● Focus on three-seater autorickshaws "autos" – purchase and use of electric autos with swappable batteries ● Creating an open permit system for obtaining e-auto permit with no limits on the number of permits, provided the e-autos fall under the FAME scheme and use advanced, swappable batteries ● Exempting e-autos from road tax, registration charges, MCD one-time parking fee and permit fees ● Supporting the individual ownership of e-autos with 5% down payment (max INR 25000) subsidy on the purchase price, and 5% interest subvention on loan amount, being capped at INR 2.5 lakhs for a maximum of 3-year loan period ● Providing a scrapping incentive of INR 15000 ● Hire-Purchase Scheme for e-rickshaws (with swappable batteries) – drivers procure the e-rickshaw with 5% down payment and pay the remaining sum with 5% interest spread across a period of 36 months. ● Down payment subsidy and interest subvention on loan amount for e-rickshaw owners ● Promoting app-based aggregation of e-auto and e-cab rides; cash back rewards for first and last mile rides booked through the app, maximum 20% of the trip cost ● Ensuring that at least 50% of all new state-carriage buses are all-electric, starting with 1000 pure electric buses in 2019 ● Providing reasonable incentives to private stage-carriages of all sizes

Charging infrastructure	● Public charging – creating a public charging station every 3km of the city ● Energy Operators (EOs) will be invited to set up charging stations for each of the eleven travel districts, based on GNCTD guidelines and existing BEVC-AC001 and DC001 specifications ● Providing concessional locations and lease rentals at bare minimum rates ● Allowing EOs to sublet 20% of the space for retail purposes ● Providing capital subsidy for purchasing and installing chargers to the winning bid ● Creating a publicly accessible database for real time information on availability of charging stations for citizens
	● Private charging – at least 20% parking spots in non-residential buildings with more than 10 Equivalent Car Spaces (ECS) to have conduits for EV charging ● All new and renovated residential buildings with more than 10 ECSs to make 100% of the parking to be EV ready ● Encouraging one EV AC charger (complying with BEVC AC001 standard) for every three ECSs in residential buildings, co-ops, non-residential buildings and market associations – reimbursing 100% cost of the charging point, up to INR 30000, for the first 10000 charging points
	● Battery swapping – inviting bids from 3 battery swapping operators (BSOs) from battery manufacturers and other interested parties ● Bidding will be on the basis of charge per kWh and number of swapping kiosks to be set up within a two-year period ● Giving rights to set up swapping kiosks at public parking, bus depots and metro stations at bare minimum rentals BSOs ● Reimbursing BSOs for 100% of the state goods and services tax accrued from purchase of advanced batteries
Electricity tariffs	● Using EVs as an option for generating demand during the off-peak hours ● Subsidised electricity tariff of INR 5-5.5 per unit for EV charging stations ● Encouraging use of renewable sources of energy through open access system
Supply side interventions	
Energy storage systems	● EOs and BSOs to operate as end of life battery recycling agencies ● Creating a nodal agency for aggregating batteries that have at least 70% of the rated capacity; retired batteries to be used for storing renewable energy
Skills and Research and Development	● Creating vocational courses for imparting skills to EV mechanics and charging station staff ● Setting up World Class Skill Centers (WCSC) – short trainings for ICE mechanics ● Creating a center for excellence to test new EV designs and technologies

Source: (Government of NCT Delhi, 2018)

Maharashtra

Table 24: Maharashtra State EV Policy

Name	**Maharashtra**
Policy name	Maharashtra's Electric Vehicle Policy – 2018
Policy target	● Increase number of EV registered in Maharashtra to 5 lakhs ● To generate an investment of INR 25,000 crores in EV and component manufacturing, battery manufacturing/assembly enterprises and charging infrastructure equipment manufacturing in the state ● To create jobs for 1,00,000 persons.
Funding Source	● Allocated from the state government budget/public grants ● In-kind grants – land, infrastructure for manufacturers of electric vehicles and their parts (electrical and electronics), batteries, etc.

Demand side interventions	
Personal Mobility	● Limiting incentives only to pure electric vehicles ● Exemption from road tax and registration fees ● Providing first 1,00,000 EV (2 wheeler-70,000, 3-wheeler-20,000 and 4 wheeler -10,000 all categories combined) registered in the state, private transporter and individual buyer with end user subsidy over policy period of 5 years. ● Providing 15% subsidy (maximum limit of INR 5,000 for 2-wheeler, INR 12,000 for 3-wheeler, and INR 1 lakh for 4-wheeler) per vehicle to private transport and individual buyer for EVs registered in the State, on base price will be paid to buyer.
Public Transport	● Promoting electric public transport in six cities - Mumbai, Pune, Aurangabad, Thane, Nagpur and Nashik. ● Providing first 1,000 EV private/public passenger bus buyers to register their vehicles in the state with user subsidy over policy period of 5 years. ● Providing 10% subsidy for passenger buses registered in the state to private/ public bus transport buyer, on base price (maximum limit of INR 20 lakh per vehicle) will be eligible to buyer.
Charging infrastructure	● Common charging points in residential areas, societies, bus depots, public parking areas, railway stations and fuel pumps etc. will be allowed. ● Applications for setting up of charging stations will be approved by concerned planning authority & electricity supplying agency within 15 days. ● Development Control Rules (DCR) of all local self-government & special planning authorities will be suitably modified to allow for setting up of common public charging facilities in parking areas of malls, residential properties & parking areas etc. ● Petrol pumps will be allowed to set up charging stations freely subject to qualifying fire & safety standard norms and rules ● Commercial public EV charging stations for 2-wheelers, 3-wheelers, cars and buses will be eligible for 25% capital subsidy on equipment/machinery (limited up to INR 10 lakhs per station) for first 250 commercial public EV charging stations ● Automated battery swapping stations for buses will be created at bus stations
Supply side interventions	
Energy storage systems	● Incentives for manufacturers and assemblers of batteries, and manufacturers of battery chargers
EV manufacturing	● Incentives for EV manufacturing, EV component manufacturing and EV battery manufacturing/assembly enterprises, manufacturers of electrical battery chargers ● Incentives to Pioneer Units, Mega Units & Ultra Mega Units and to MSME and Large units manufacturing electric vehicles
Skills and Research and Development	● Establishing center of excellence and research and development centers, finishing schools and other employment-oriented centers. ● Promoting joint efforts by Maharashtra State Board of Technical Education (MSBTE), Maharashtra State Skill Development Society (MSSDS) and other agencies to create training-based certification and placement programs.

Source: (Government of Maharashtra, 2018)

Karnataka

Table 25: Karnataka State EV Policy

Name	**Karnataka**
Policy name	Karnataka Electric Vehicle and Energy Storage Policy 2017
Policy target	● Making Karnataka the preferred destination for manufacturing electric vehicles ● Attracting investments worth INR 31000 Cr and create employment for 55000 persons from both supply and demand side ● Providing a conducive environment for transition to electric vehicles from internal combustion engines ● Creating opportunities for research and development in electric mobility

Funding Source	● Allocated from the state government budget/public grants ● In-kind grants – land, infrastructure for manufacturers of electric vehicles and their parts (electrical and electronics), batteries, etc.
Demand side interventions	
Personal Mobility	● Exempting all electric vehicles, including e-rickshaws and e-carts, from payment of taxes on vehicles
Public Transport	● BMTC, KSRTC, NWKSRTC and NEKRTC to introduce 1000 new electric buses during the policy period ● Conducting pilot project with EV Vayu Vajra services in select routes to Kempegowda International Airport ● Encouraging adoption of electric buses through a short route public transport policy
Shared and corporate fleets	● Encouraging 100% electrified fleets of auto rickshaws, cab aggregators, corporate fleets and school buses and vans ● Encouraging autorickshaws to undergo retro-fitment and move to electric drive trains ● Encouraging electric two-wheeler taxis for short distance rides
Charging infrastructure	● Identifying parcels of land belonging to the government or government agencies and leasing them out on long term basis for setting up fast charging and battery swapping infrastructure ● Providing subsidies on investment into the first 100 fast charging stations, 100% stamp duty exemption, capital subsidies on fast charging and battery swapping station equipment
Supply side interventions	
Energy storage systems	● Inviting investments in setting up to 5 GWh of EV battery manufacturing; this is expected to generate 5000 direct jobs and 7500 related ones ● Exempting stamp duty, electricity duty for all EV cell manufacturing, battery pack/module manufacturing and assembly enterprises ● Reimbursing 100% of the land conversion fee for all cell and battery manufacturing and assembly units ● Providing interest free loans to manufacturers and assemblers of batteries, and manufacturers of battery chargers ● Encouraging manufacturing of modular design of Lithium-Ion batteries with higher mileage per charge
EV manufacturing	● Creating EV manufacturing parks and zones under PPP mode – ready infrastructure (land, power, water, testing facilities) for manufacturing companies ● Providing incentives and concessions for EV manufacturing, EV component manufacturing and EV battery manufacturing/assembly enterprises, manufacturers of electrical battery chargers – exemption from stamp duty, concession on registration, reimbursement of land conversion fee, tax exemption on electricity tariff ● Providing incentives to charging stations, lithium ion battery swapping infrastructure
Skills and Research and Development	● Creating working groups for developing technologies from concept to market ready – drive trains, batteries, charging infrastructure and network, recycling ● Commissioning a Karnataka Electric Mobility Research and Innovation Center, through public private partnership, with state-of-the-art laboratory and incubation center for engineers and entrepreneurs ● Introducing electric mobility related curricula in polytechnics, regional institutes and vocational training institutes ● Encouraging in plant training by EV manufacturers in the state by offering 50% rebate on the cost of the training, limited to INR 10000 per month per trainee; this benefit will be available for 1000 trainees per annum

Source: (Government of Karnataka, 2017)

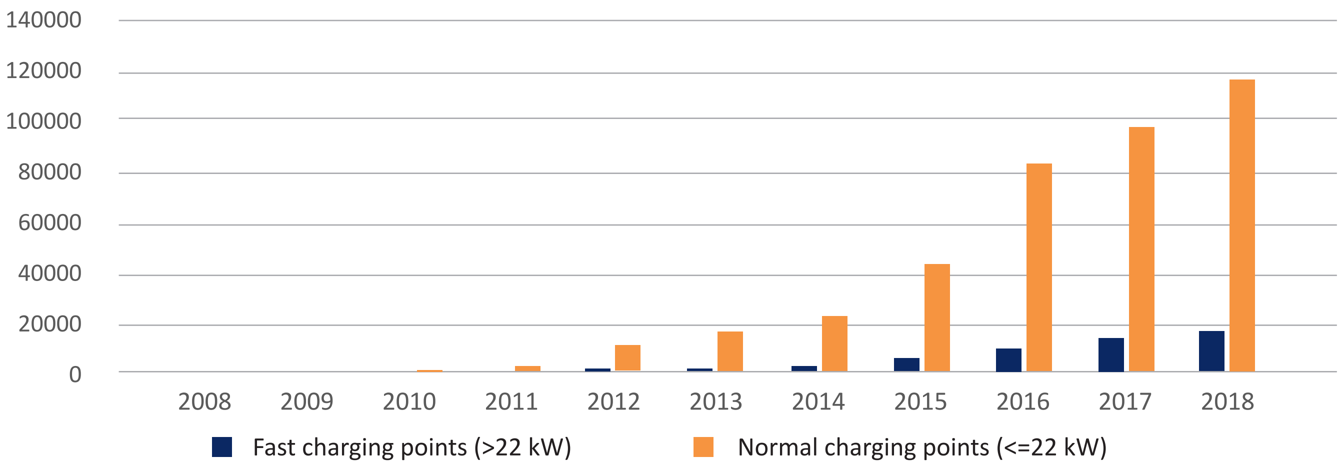
ANNEXURE 9

EV POLICY AND PROGRAMS ADOPTED IN OTHER COUNTRIES

Norway

Norway has put in place a set of policies and incentives to grow the share of zero emission vehicles since the1990s. Today, the world looks up to Norway as the champion of electric vehicles. Reaping the advantage of intervening with generous funding at an early stage, battery electric and plug-in electric vehicles combined represented 47% of the total fleet mix in 2018 (EAFO, 2018).

Figure 17
Total number of fast and normal charging points in Norway



Source: (Europe Alternative Fuels Observatory, 2018)

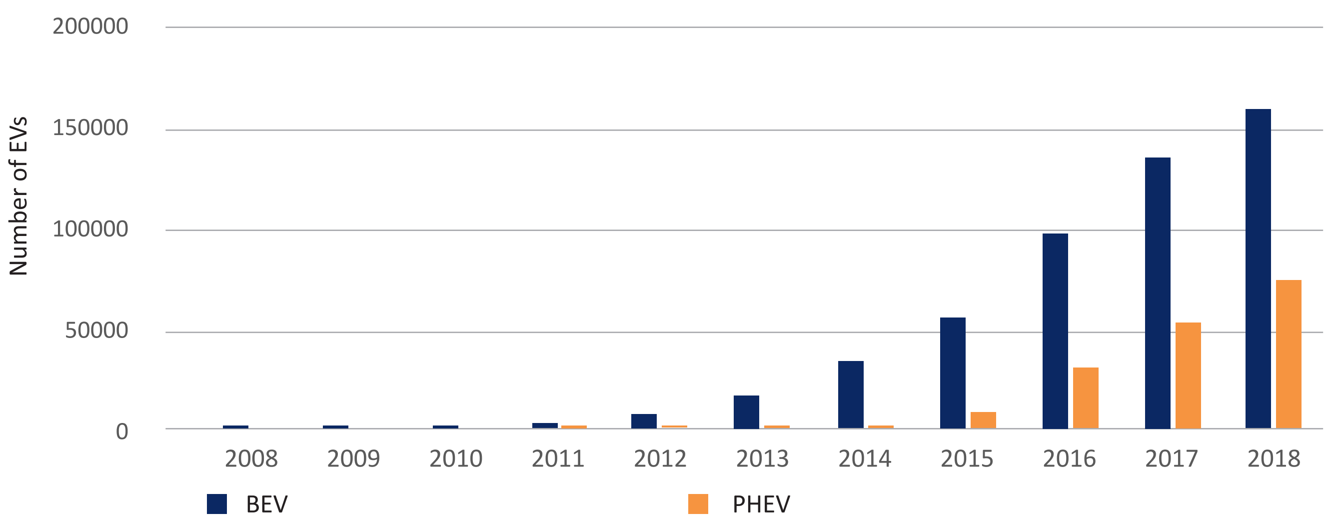
Table 26: Electric Mobility in Norway	
Country details	
Name	**Norway**
National population	5.2 million
Share of electric vehicles in the national fleet*	46.63%
	28.13%, Battery Electric Vehicles (BEV)
	18.50%, Plug-In Electric Vehicles (PHEV)
Total number of publicly accessible charging stations*	9000 (Normal power charging, 3.6 kW)
	2535 (High power charging)
Major source of electricity	Hydropower
***As of November 2018**	
Financial Incentives	• No purchase/import tax • Purchase tax exemption for BEVs/FCEVs, reduction for PHEVs (Up to 10000€) • Exemption from 25% VAT while purchasing or leasing • Low annual road tax • Access for BEVs in bus lanes in Oslo require carpooling with at least one passenger during rush hours • 50% reduced company car tax • 50% price reduction in ferries • Zero re-registration tax for used zero-emission cars • No fuel taxes for electricity or hydrogen fuels

Infrastructure Incentives	● Normal charging: 100% financial support on installation cost; as a result, 1800 household sockets spread across the country ● High power charging: 100% financial support on installation cost but no sup port on operational cost ● Public funding for fast charging stations every 50km (around 7,500km road network); ● Government is funding 2 multi-standard fast chargers (CHAdeMO and CCS) + two 22kW type 2 points for every charging location ● NOBIL, a charging station database, allows consumers to locate available charging spots while driving (Nobil, 2018)
Shared and Non-Motorised Modes	Cities such as Oslo are pursuing a multi-pronged approach for reaching zero transport emissions. These include: ● Environmentally differentiated congestion zoning ● Reducing passenger traffic by encouraging public transport ● Bicycle and pedestrian pathways ● Carpooling and cutting down parking spaces

Norway's goal is to reduce the greenhouse emissions by 50% in comparison to 1990 levels; to achieve total carbon neutrality by 2050 and to achieve an average CO2 emissions rate of 85 g/km for new passenger vehicles by 2020. The EV policy of Norway has been built with political unity on the 'polluter pays principle' for taxing cars. Imposing monetary costs on polluting vehicles generates funding for zero emission vehicles and EV policies without any loss in revenues. The Norwegian parliament has decided to pursue a more stringent green tax system – rather than a vehicle ban – such that all new cars sold by 2025 are either zero (electric or hydrogen) or low (plug-in hybrids) emission (Norsk elbilforening, 2017).

Oslo, the capital of Norway, accounts for 40% of EV sales in the country. Oslo had the highest number of public charging and fast charging stations in the world in 2015. Bergen, the second largest metropolitan area, accounted for 38% of the country's EV sales. To expand EV sales in other cities, located on nearby islands, the government is pursuing massive cuts in tolls on bridges, tunnels and ferries (Hall , Moultak, & Lutsey, 2017, pp. 15-17).

Figure 18
Total number of electric vehicles in Norway



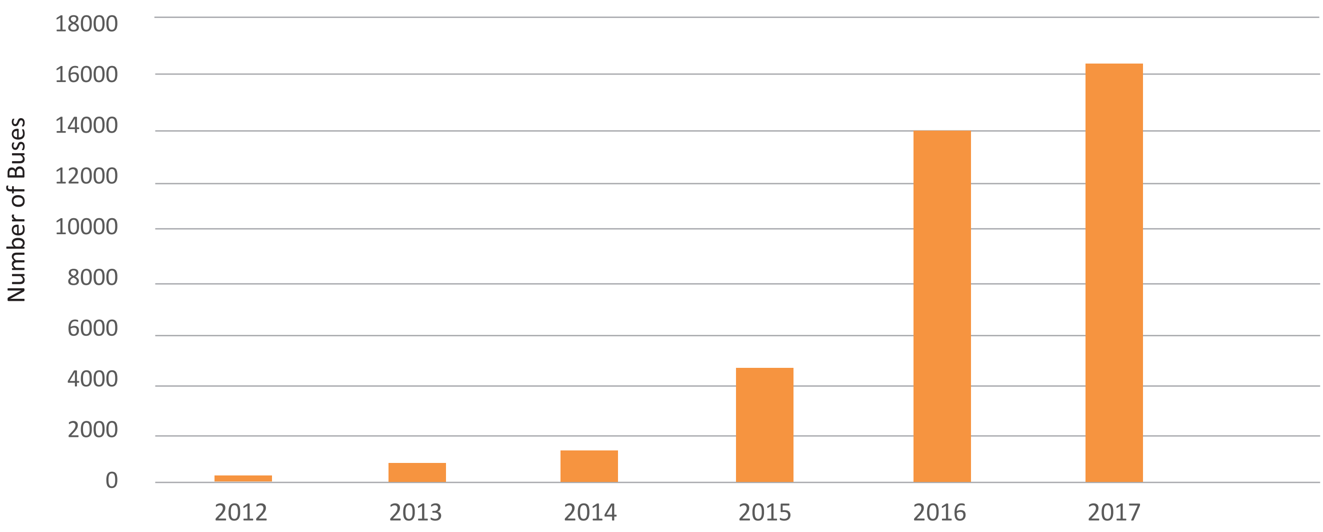
Source: (Europe Alternative Fuels Observatory, 2018)

Shenzhen, China

Shenzhen's policies and programmes have led to making the city's bus fleet 100% electric. Shenzhen was also one of the pilot cities for China's 'Ten Cities, One Thousand Vehicles' that was rolled out in 2009 (Marquiz , Zhang, & Zhou, 2013). Previously, this region used diesel buses that accounted for 0.5% of the total fleet but contributed 20% of the emissions load. While the upfront costs of electric buses are high, Shenzhen controlled the costs for operations and maintenance and used leases instead of direct purchases (Lu, Xue, & Zhou, 2018). Public grants formed the predominant source of funding for electrification in Shenzhen. This was followed with capital expenditure grants, a public transport budget and bus scrappage payment (Li, Castellanos , & Maassen , 2018, p. 479). Shenzhen also used contractual agreements and legal frameworks that clearly defined the responsibilities of various stakeholders and helped in controlling risks that are a natural by-product of the shift to a new and alternative technology. The case of Shenzhen offers important business and investment insights for other cities aiming for large-scale uptake of electric buses.

Characteristics of Shenzhen's electric bus strategy have been captured in Table 27 below.

Figure 19
Growth of electric buses in Shenzhen from 2012 to 2017



Source: WRI China, 2017

Table 27: Electric bus system in Shenzhen	
Regional details	
Name	**Shenzhen, China**
National population	12.5 Million
Number of Electric Buses	16359 (As of 2017)
Policies and programs	
Sources of funding	• Public grants – central and local subsidies • Capital expenditure grants • Public transport budget • Bus scrappage payments • Electric buses are counted as low carbon transport that can access funding from China's Green Bond market. Low carbon transportation projects are the second most funded projects after renewable energy.

Financial Incentives	● National and local subsidies: Federal subsidy of up to 54,000 CNY and tax exemptions; regional subsidy up to 60,000 CNY for purchase of passenger vehicles and taxis and purchase tax exemptions (Hall , Moultak, & Lutsey, 2017, pp. 5-7) ● Subsidies for the operation of electric public buses ● New Energy Vehicle (NEV) policy that subsidises electric vehicles with focus on EE in EVs, and varies with the range and speed of the vehicle ● Reduction in subsidies (EVs with >200km range eligible for incentives) – this spurs innovation ● Lease to reduce upfront investment – Instead of procuring e-buses at subsidised rates - leased buses from manufacturer reduced upfront cost, saved debt financing, shifted the risks of new technology to the manufacturer with the operator only left to focus on delivering service in a high-quality fashion.
Infrastructure Incentives	● Optimised charging and operations ● Adopted special e-bus wherein 5-hour charge supports 250km of driving that operates for an entire day ● Collaboration b/w bus operators and charging infrastructure provider to furnish bus routes with charging facilities ● Charging facilities open to private cars as well thereby, improving financial performance of charging infrastructure ● Time of charging: overnight charging & re-charged at terminals during off-peak travel times ● Lifetime warranty of batteries to manage financial risks: Bus manufacturers provide a lifetime warranty for vehicles and batteries as one of the clauses in the contract during procurement by operators
Legal support and contract	● Bus leases ● Battery leases ● Lease purchase contract ● Transportation plan

Thailand

Greenhouse Gas (GHG) emissions based excise duty on vehicles

Electric vehicles were launched in Thailand in 2009-10 when the automakers in the country launched Hybrid Electric Vehicles (HEVs). In January 1, 2016, the Government of Thailand began taxing vehicles on the basis of the amount of CO2 emitted instead of their engine sizes (FIA Foundation, 2015). This was to expand the auto market beyond HEVs and towards more fuel-efficient technologies such as BEVs and PHEVs. Yet, the rate of adoption remained low and did not meet the expectations of the government - 84236 units of hybrids (plug-in hybrids and hybrid electric vehicles) and only 63 units of battery electric vehicles were registered as of June 2017.

Therefore, in 2017, the Board of Investment of the Government of Thailand revised the excise tax rates for electric vehicles. The rates vary by fuel technology (battery electric, plug-in hybrid, and hybrid) and, car type and CO2 emission. Battery electric vehicles are the most favored and Original Equipment Manufacturers (OEMs) using locally built batteries will get additional rebate on excise taxes (LMC Automotive , 2018). Rebates on excise duty would reduce the production costs for manufacturers and simultaneously reduce the capital costs for consumers, building confidence in both to invest in electric vehicles.

The revised tax structure is presented in the Table 28 below:

Table 28: Revised excise taxes for electric cars in Thailand				
Car Type		**CO2 emission**	**Cylinder**	**New tax rate**
HEVs/PHEVs	Pick up Passenger vehicle (PPV)	<= 175 g/km	<= 3250 cm3	18%
	Double – cab pickup truck	<=175 g/km	<= 3250 cm3	8%
	Passenger car	<=100 g/km	<=3000 cm3	4%
		101-150 g/km	<=3000 cm3	8%
		151-200 g/km	<=3000 cm3	10.5%
		>200 g/km	<=3000 cm3	13%
BEVs		--	--	2%

Source: (KPMG, 2018)

Taiwan

The Case of Gogoro: Proliferating shared use of batteries through electric scooters in Taiwan

At the first look, Gogoro may only seem to be a startup focused on selling electric scooters in Taiwan, a country whose 23 million residents own more than 16 million scooters for commuting. However, the bigger innovation of the company has been in popularising the concept of battery swapping for re-energising scooters in Taiwan, in which the vehicle owners do not own, manage or maintain the battery. But Gogoro allows owners to share batteries. This in turn has triggered a fundamental shift in the way consumers will use electricity in the future and is paving the way towards a fossil-free future for the country (Wired , 2017). The following passages show the internal and external factors that contributed to the success of Gogoro and the impact of its offerings.

Gogoro was launched in 2015, as a startup that would make and sell electric scooters – SmartScooters – and create a publicly accessible infrastructure network wherein consumers would not have to charge the batteries, but instead subscribe to a plan with the company and return the discharged batteries in exchange for charged ones at public vending locations, known as 'GoStations'. These vending stations are easy to set up and cost close to USD 10000 each.

The design, management and pricing of GoStations has contributed in allowing Gogoro to set up a dense network of swapping stations. In this, the company took a lesson from Better Place, a company that created automated battery swapping system for cars in Israel but failed due to a host of issues, which included the high capital costs of a swapping station, each of which costed nearly USD 2 Million (E27, 2016).

Thus far Gogoro has created 1,180 GoStations, one station every kilometer in the dense urban areas of Taiwan. It takes consumers six seconds to swap a battery at the station, which gives them 110 kilometers of range to drive. Each SmartScooter comes with two 20 pound (9.07 kilograms) Panasonic lithium-ion batteries. They pay a fixed monthly charge for swapping. Since its opening in August 2015, scooter riders have ridden 620 million kilometers. This has saved 56623 tons of CO_2 emissions (Gogoro, 2019).

In 2017, Gogoro opened its first solar powered GoStation in the Bali district of Taiwan.

To manage demand and making charged batteries available in high demand locations, the GoStations rely on data recorded by each battery. This includes data on the number of swaps, time of swaps, distance travelled and the number of days the battery was used. All the GoStations upload these data to a cloud-based platform, making it visible to the entire network of swapping stations, which Gogoro terms as the 'Gogoro Energy Network'. Analysis drawn from this data helps in ensuring that there are enough charged batteries to meet the demand at peak times at a given location (New Southbound Policy Portal, 2018).

Since launching its first product in Taiwan, in 2015, Gogoro is now the fourth largest two-wheeler brand in the country. While a nation-wide network of portable and swappable batteries is one of the contributors to this success, the user-centric and technologically sensible design of its scooters is just as important. The technological sensibility of the scooters is the reason most cited by owners when probed on their purchase. Unlike conventional scooters, Gogoro uses racing-grade alloy frame, bold colors, and digital features such as being able to operate the scooter through a smart key iQ System that is connected through a smartphone app (known as Gogoro app) making the scooter digitally encrypted and immune to thefts. The app also enables riders to locate GoStations and allows wireless updates to its features. Ergonomically designed for maximum safety and comfort, the scooters come with features such as expandable seats and storage.

While introducing the scooters in 2015, the company priced them at USD 4100 and positioned the product as an environmentally friendly design. However, this did not attract as many buyers as expected. The company then decreased the price point to USD 2700-2900 and added several perks such as free subscription of GoStations, insurance to cover vehicle theft, and convenient servicing at a nation-wide network of service centers. The company also framed the product as a user-centric, technologically forward means of commuting.

The widespread adoption of Gogoro's products didn't happen without favorable external factors. Taiwan, also known as an island of technology, has a foothold in industries such as computing, smartphone and semiconductors. An industrial base such as this has allowed the company to locally make/ source the parts of the scooter, except for the lithium-ion batteries which it gets from Panasonic. Owing to its history, Taiwan has been porous to experimenting with technologies, which naturally favored the induction of battery swapping mechanisms and the SmartScooter in Taiwanese society. The second factor is policy related that comes from Taiwan's goal of not selling any fossil dependent two-wheelers from 2035 onwards. This deadline has sprouted many alternative transportation technologies.

Outside of Taiwan, in Paris, Berlin and Japan, Gogoro has adapted its offerings based on the mobility needs of the cities. Hence, it provides a scooter-share service (analogous to bike-share service) known as GoShare. Consumers swap batteries and many incentives from the company encourage them to do so. Users pay based on how long and far they drive the rented scooters.

Selling the scooter has allowed the company to create a nation-wide network of battery swapping stations in Taiwan. This back-end development has augmented sales of electric scooters on one hand while on the other hand it has spawned the use of batteries – in stationery and mobile forms – in the energy system of Taiwan. Through the electric scooters, consumers are learning to interact with batteries as a new source of electricity storage. To further this, the company has launched 'GoCharger' – a device in which consumers can charge two batteries at a time and share it with the larger community - for domestic or retail purposes in exchange for a payment. In future, as the price of lithium-ion battery packs fall, more and more batteries will be used for storing electricity – from renewables – to power domestic and commercial activities. Therefore, Gogoro's battery swapping system for scooters is not only bringing electric mobility, but it is using both technology and social change to put the energy infrastructure for the future into motion.

ANNEXURE 10

OPTIMAL RE-ENERGISING OPTIONS FOR DIFFERENT TYPES OF VEHICLES

There are different re-energising options for batteries. Each of these would be optimal for different types of vehicles. These options are discussed below.

Two-wheelers

Economy two-wheelers use small sized batteries (1 kWh to 1.5 kWh) providing a range of about 50 kms. Home charging, using 15A AC outlet during night-time, would enable the vehicle to ply on most days for the average user. The day users need to travel longer, they would have two options. If the vehicle is parked for a few hours in a parking lot, they could use AC001 to charge during the day. The charging could take one to three-hours. Alternately, they could drive to a swapping station to lease and add a range-extension battery for a further 50 kms range. This range-extension battery can be swapped in about three minutes and can be done as many times as needed, providing unlimited range to the vehicle. The key public infrastructure that they would require is public AC001 public charging facilities in parking lots and swapping stations all over the city. Public parking places, as well as petrol stations and popular eateries on highways, are ideal locations.

Three-wheelers

All kinds of three-wheelers, e-rickshaw, e-auto, e-auto (large) and e-auto (goods)are economically viable today, if they use battery swapping. They would normally use swappable 3 kWh battery. These vehicles would require public swapping infrastructure all over the city, preferably at distances no more than 1.5 kms apart. The large auto and goods autos may use larger sized batteries like 6 kWh to 8 kWh and may use swapping or charging. They could use public AC001 for charging during the night as well as day, requiring three to four hours to fully charge. Alternatively, they may sometimes prefer to use DC fast charger such as DC001, which would enable the batteries to fully charge in about 45 minutes. Thus, a city would require AC001 and DC001 deployed at parking lots in the city and at eateries on highways, in addition to three-wheeler swapping infrastructure, all over the city and on highways as public infrastructure.

Economy cars

A small and medium sized car, costing less than INR 10 lakhs, will inadvertently have small batteries of size 10 kWh to 15 kWh, providing a range of about 100 kms. For most consumers, this range would be enough for a large majority of the days and the battery can be charged at home in about five to seven hours using a 15A AC outlet. The day they need to travel longer distances, they could swap-in a range-extension battery providing another 100 kms. If they need to travel even longer distance (like inter-city), they could go again to a petrol pump on the highway and swap the Range extension battery. Range limitation is therefore overcome. The swapping can be done in less than five minutes. The second option would be to use DC001 at city-parking lots, in office-buildings and at highway-eateries. This would require about 45 minutes wait-time to fully charge the battery. City parking lots or office buildings with AC001 could also supplement the charge for these vehicles for about two to three hours, when the vehicles are parked there. Thus, the economy cars require range-extension battery swapping infrastructure in the city and in highways petrol-pumps, DC-001 at city-parking lots, office buildings and highway-eateries and AC001 at city parking lots and office buildings.

Premium cars

These are cars which would be in the higher price segment – more than INR 1 million - and could therefore afford to have larger batteries. The size of the batteries may vary from about 30 kWh to almost 75 kWh or even larger, giving a driving range between 200 kms to 500 kms.

It will be difficult to charge these vehicles at home using AC001 chargers, as it would take anywhere from 10 hours (for 30 kWh battery) to about 25 hours (for 75 kWh battery) to charge. The vehicles would have to be fast charged. The batteries they use would be somewhat expensive and will allow faster charging so that the full battery could possibly be charged in about 30 minutes. Partial charge would be faster. For example, a car with batteries offering a range of 500 kms may have a top-up charge of 200 kms in as little as 12 minutes. The fast chargers to be used will invariably be DC and would require output from 30 kW to about 80 kW.

Buses

Buses will be of two types. First will be intra-city buses. These buses will make multiple trips (say 8 to 10) in a day between two points (depots or bus-terminus) in a city. The single distance will rarely be over 30–50 kms, depending on the area of the city. It is possible to use a battery of about 60 kWh giving as much as 50 kms range for a twelve-meter AC bus. One could swap batteries at each end. Alternatively, they could be fast charged at locations where they stop at the end of a trip and where the crew is allowed some time for rest. All that the city would then need is charging-cum-swapping infrastructure at depots/bus terminus or fast charging facilities.

The second type of bus would be intra-city long-distance buses. One could then use larger batteries of 150 kWh to 250 kWh having a range of 125 kms to 200 kms. The buses would leave the originating station fully charged. Before they run out of charge, they would recharge for about thirty to forty minutes (or little more) at an intermediate bus-terminus on the route. These bus terminals would need CCS fast chargers, which would charge at 750V, commonly used by buses and at rates of 200 kW to 300 kW. They would be able to charge the bus batteries to about 80% of the capacity in 30 to 40 minutes. The bus routes have to be planned taking this into account.

India's imperatives for standardisation of AC chargers and DC fast chargers

For a vehicle to be charged at the rates required by its battery, it is important to establish communication between EV and EVSE (Electric vehicle supply equipment). For an off-board charger, responding to the battery needs is critical from not only the appropriate charging point of view but also from the safety point of view. Controlling the threshold limits and making decisions to control the required charge/discharge rates is important. Equally important is the connector compatibility between EV and EVSE. Where communication between EV-EVSE helps in controlled charging of batteries and helping record its health, the communication between EVSE and the central management server (CMS) helps in maintaining logs of all transactions – i.e. charging, all sessions, reservations, time of day metering, etc. Specifying the communication protocols such as between EV-EVSE and EVSE-CMS ensure inter-operability of charging infrastructure. Hence, India's strategy for these protocols recognised that EV-EVSE connection and EVSE-CMS connection must be standardised for India. For the latter, broadband over a dedicated wired/a wireless link is used or mobile services provided by 2G/3G/4G are used. Most of the protocols defined between EV-EVSE are derived from IEC 61851-24 as system A, system B and system C. As the world has converged upon Open Charge Point Protocol (OCPP) as a standard communication protocol to be used for EVSE-CMS communication, a standardisation committee set up by the Department of Heavy Industry (DHI - Government of India) adopted this without any variation. As AC charging needed only this protocol, AC-001 mentioned earlier, was defined by the committee along with user authentication and payment gateway option. This way the charger measures the use of energy per transaction and bills all the transactions and at the same time provide flexibility to users to reserve the charging slots, reschedule, cancel and monitor their own transactions. The standard was adopted by the Government. As was discussed, Bharat Charger

AC-001 can charge three different vehicles simultaneously, each using a single-phase AC-input at 230V and a 15A plug. The charge rate for each of the three vehicles is limited to 3.3 kW. The payment mechanism used are those prevalent in India. The committee also recommended that an AC-002 standard be specified in the future, once data is obtained from the industry about the power rating of the onboard chargers that are likely to be available in vehicles in India. The standardisation committee would need the power ratings to be used, expected volumes, estimated costs of chargers and the business case for such chargers. AC-002 is expected to have either 6.6 kW or 13 kW or 21 kW power output. It may need 3-phase AC inputs and may be termed as AC fast chargers. OCPP would continue to be used for EVSE-CMS communications. The DC chargers need definition of both EVSE-CMS and EV-EVSE communications. For definition of the EV-EVSE communication and corresponding connector and the definition of standards for the DC charger, two considerations are paramount. One is affordability and business case of the chargers in India and the other is voltage, power and communication set of protocol and connectors that India's different vehicles need.

For such DC chargers, China uses GB/T-27930 and several other countries (including USA) use CCS and CHAdeMO chargers widely. The costs of CCS and CHAdeMO chargers however are upward of INR 10 lakhs. Chargers at these costs will not have a business case, when two-wheelers, three-wheelers and small/medium sized cars have to be charged. India needs lower cost chargers, especially for low-end vehicles. Low-end vehicles available today, and those that are likely to be available in the near-future, are the ones where the charging voltage is under 100V and the maximum power that they can use is 15kW. Chargers limited to 100V and to 15 kW can be made in India at a low cost of about INR 1.5 lakhs in volumes. Chargers at such costs would indeed have a business case and could proliferate like a STD-PCO.

A DHI committee standardised Bharat Charger DC-001. The input would be three-phase AC input that is presently widely used in India. The output would have 48V or 72V with maximum current as 200A (implying 15 kW output). All existing Indian EVs will therefore be supported. As mentioned earlier, the EVSE to CMS protocol used is OCPP. For EV-EVSE communication protocol and the choice of connector, the committee noted that all the existing vehicles (EV or vehicles with IC engine) in India use CAN protocol internally for communications. The 2-wheeler and 3-wheeler industry, by and large, refused to use PLCC. Since CCS was wedded to PLCC links, it was ruled out. CHAdeMO protocol did not have enough richness to support Indian requirements. Also, the cost of the connector was high. India already has the protocol software, and therefore the DHI standardisation committee decided that "Bharat charger specs for DC-001" will start with GB/T-27930 with additional requirements embedded into it. Therefore, commands were added which make the standard used as Bharat Charger DC-001 specs and not GB/T-27930 specs. The connector recommended was also GB/T-20234.3 standard. It was however noted that future electric vehicles (larger cars, cargo-vehicles, buses and trucks) may need higher power and would be operating at higher voltage. The DHI Committee therefore recommended that DC-002 charger be evolved for DC power-levels from 30 kW to 100 kW or more, and voltage levels from 300V to 800V or even more. It recommended that data about the required power and voltage levels be collected from the industry. These chargers would be more expensive. If the high-end Indian vehicles use PLCC, CCS could potentially be used to evolve Bharat charging protocol for DC-002. This charger would need further consideration to make business sense.

ANNEXURE 11

BUSINESS MODELS FOR THE ELECTRIC MOBILITY ECOSYSTEM

Economics of a battery swapping facility for 4-wheelers at a petrol station

In battery swapping, a discharged battery is replaced with a charged one. In such cases, the battery is not owned by the vehicle owner but by an energy operator (EO) who stocks charged batteries for consumers to swap with their discharged ones. In this section we present the economics of a swapping facility for 4-wheelers at an existing petrol station.

An EO would broadly incur two types of costs:

- **Capital costs** - This includes the cost of batteries and the infrastructure costs (building, air conditioning, electrical connection, IT, safety equipment etc.)
- **Operational costs** – This is the cost of electricity and other variable costs in charging and swapping a battery.

Capital costs and operational costs are added to determine the charges for leasing a battery.

Assumptions and Analysis[8]

Battery cost

We assume that a typical swapping station invests in 800 batteries for 4-wheelers. Each battery can be swapped 1.3 times per day. This is known as the swap factor. Thus, the petrol station (or swapping station) will have the capacity to serve 1040 (800 X 1.3) vehicles per day.

We assume the battery-size to be 14 kWh, with effective usage during a trip limited to 85% of the size, or 11.9 kWh. Further, we assume that the driver brings the car to the petrol station (or swapping station) when the battery has 10% of the charge remaining (in other words it is 90% discharged) of the allowed 11.9 kWh capacity. This implies that 10.71 kWh of energy has been used up when the battery is brought for swapping. At INR 14,000/ kWh without taxes, one battery with 2000 effective cycles will cost INR 1.96 lakhs (= ₹ 14,000/kWh × 14 kWh). The total investment for 800 batteries at a petrol station thus works out to be INR15.68 Crores.

As the battery is charged-discharged 1.3 times a day, 2000 cycles battery will last 4.21 years. Assuming 10% finance cost, the battery depreciation and interest cost per day works out to be INR 162.3 per battery. The effective cost of the battery per km, then works out to be INR 1.156/km, assuming vehicle efficiency to be 10km/ kWh.

Infrastructure cost

In a similar manner, the other infrastructure costs at a swapping station are estimated. Battery charger costs approximately INR 62.40 lakhs and swapper costs about INR 17.50 lakhs without taxes. Thus, the battery charger and swapper together cost approximately INR 79.90 lakhs per station. It is assumed here that a vehicle will be served in 4 minutes, based on which the number of swappers required has been computed.

There are other infrastructural requirements like building, air-conditioning, IT, safety, electrical connection etc. These are assumed to cost approximately the same as the battery charger plus swapper, giving the total charging-cum-swapping infra cost. This cost is depreciated over a period of more than 8 years. Assuming a finance cost of 10%, the contribution of the infrastructure cost comes to around INR 0.07/km. The battery and infra costs thus add up to INR 1.24/km.

Operating cost

Electricity costs, air-conditioning costs and manpower costs adds up to approximately INR 93,500 per day or INR 0.84/km of vehicle travel. Thus, cost per km for battery swapping works out to be INR 2.08/km. Assuming a 25% margin over costs, the swappable battery can be provided at close to INR 2.60/km. This is about half of today's fuel cost per km for a petrol vehicle. Please note that taxes have not been included in these computations.

[8] *These assumptions and cost computations first appeared in (Jhunjhunwala, 2017).*

Table 29 below provides a snapshot of the economics of a battery swapping facility for 4-wheelers at a petrol station.

Table 29: Cost computations for setting up battery swapping facility for 4-wheelers at an existing petrol station

Parameter	Unit	Value
Battery Cost (INR or ₹)		
Number of Batteries	-	800
Number of vehicles served	-	1,040
Battery size	kWh	14.00
Battery cost	₹/kWh	14,000.00
Battery investment	₹ Lakhs	1,568.00
Battery lifetime	cycles	2,000.00
Battery life	years	4.21
Interest cost	%	10.00
Battery depreciation + interest cost per day	₹	162.31
Vehicle efficiency	km/kWh	10.00
Battery cost per km	₹/km	1.17
Infrastructure Cost		
Charger infra cost	₹	30,000.00
Time taken for charging	Hours	2.00
Number of chargers	-	208
Total battery charger cost	₹ Lakhs	62.40
Number of swappers	-	7
Swapper cost per unit	₹ Lakhs	2.50
Total swapper cost	₹ Lakhs	17.50
Other infra cost factor	-	2.00
Infra cost per day	₹	8,206.45
Infrastructure cost per km	₹/km	0.07
Operational Cost		
Units of electricity used in a day for charging	kWh	11,138.40
Units of electricity used for air-conditioning	kWh	1,113.84
Electricity cost per unit	₹/kWh	6.00
Total cost of electricity in a day	₹	73,513.44
Manpower costs per day	₹	20,000.00
Total operation costs per day	₹	93,513.44
Operational cost per km	₹/km	0.84
Total cost per km (battery+infrastructure+operation)	₹/km	2.08

Conclusion

For the petrol station capable of handling about 1000 vehicles in a day, the investment in batteries would be approximately INR 15.7 crores. Other investments approximate INR 1.6 crores. The revenue per year, assuming a price of INR 2.60 per km charged for a charged battery, would be close to INR 10.6 crores and the operating costs would be INR 3.4 crores. The depreciation and finance costs on the capital costs come to about INR 5 crores. Thus, there is a comfortable profit before tax of INR 2.1 crores per year.

The investment will need to be made in most petrol stations in a region as swapping will work only when a user finds a wide availability of swapping stations in the region. A petrol station may start small and can grow as the demand grows.

As the cost of the lithium battery goes down, the swappable battery would cost less and the margin for energy operators could improve. It is worth noting that the most sensitive element impacting charge per km is vehicle efficiency (km/kWh). The swap factor, battery size, percentage of battery used in a cycle, finance cost and infra-costs have relatively less influence. The battery costs per kWh, battery life cycles, air-conditioning costs and electricity costs matter.

Economics of battery swapping for electric 3-wheelers at a petrol station

As in the case of a battery swapping station for 4-wheelers, the energy operator would incur capital and operational costs for a 3-wheeler (mostly, e-autos) battery swapping station at an existing petrol station. It is assumed e-autos have an energy consumption of 52 Wh/km. Based on the costs and margins assumed, the charges for battery-leasing is determined.

Assumptions and Analysis[9]

Battery cost

We assume that a typical swapping station invests in 800 batteries for e-autos and these batteries can be swapped 1.6 times (swap-factor) per day. Thus, the petrol station (or swapping station) will have the capacity to serve 1280 (800X1.6) e-autos per day.

We assume the battery size to be 3kWh, with effective usage during a trip limited to 85% of the size, or 2.55 kWh. Further, let us assume that under typical circumstances the driver brings the auto to the swapping station when the battery is 90% discharged. This means that when the 3-wheeler reaches the swapping station, 2.3 kWh of energy in its battery has been used up. At INR 14,000/kWh without taxes, one battery with 2000 effective cycles will cost INR 0.42 lakhs (= INR 14,000/kWh X 3kWh). The total investment for batteries at one swapping station thus works out to be INR 3.36 crores.

As the battery is charged-discharged 1.6 times a day, 2000 cycles battery will last 3.42 years. Assuming 10% finance cost, the battery depreciation and interest cost per day works out to INR 41.32 per battery. The effective cost of the battery per km, then works out to be INR 0.59 per km, assuming vehicle efficiency to be 19.23 km/kWh (derived from 52 Wh/km).

Infrastructure cost

In a similar manner, the other infrastructure costs at a swapping station are estimated. Battery charger contributes to approximately INR 15.36 lakhs without taxes. There shall be other infrastructural requirements like building, air-conditioning, IT, safety, electrical connection etc., which are additional costs being approximately double that of a charger, giving the total charging-cum-swapping infrastructure cost. This cost is depreciated over a period of more than 8 years. Assuming the same finance cost of 10%, the contribution of the infrastructure cost comes to around INR 0.04/km. The battery and infrastructure costs thus add up to a total of INR 0.63/km.

Operating cost

Electricity costs, air-conditioning costs and manpower costs adds up to about INR 27,000 per day or INR 0.48/km of the vehicle travel. Thus, cost per km for battery swapping works out to be INR 1.10/km. Assuming 20% margins

[9] *These assumptions and cost computations first appeared in (Jhunjhunwala, 2017).*

over costs, the swappable battery can be provided at close to INR 1.32/km. This is about the same as the fuel cost per km for a diesel auto. Please note that taxes have not been included in computations. As the cost of the lithium battery goes down, the swappable battery could cost lesser and the margins for EOs could improve.

Table 30 below provides the cost computations for a swapping station for 3-wheelers (e-autos) at a petrol station.

Table 30: Cost computations for battery swapping facility for three-wheelers at an existing petrol station

Parameter	Unit	Value
Battery Cost (INR or ₹)		
Number of Batteries	-	800
Number of vehicles served	-	1,280
Battery size	kWh	3.00
Battery cost	₹/kWh	14,000.00
Battery investment	₹ Lakhs	336.00
Battery lifetime	Cycles	2,000
Battery life	years	3.42
Interest cost	%	10.00
Battery depreciation + interest cost per day	₹	41.32
Vehicle efficiency	km/kWh	19.23
Battery cost per km	₹/km	0.59
Infrastructure Cost		
Charger infra cost	₹	6,000.00
Time taken for charging	Hours	2.00
Number of chargers	-	256
Total charger cost	₹ Lakhs	15.36
Other infra cost factor	-	3
Infra cost (including chargers) per day	₹	2,366.42
Infrastructure cost per km	₹/km	0.04
Operational Cost		
Units of electricity used in a day for charg-ing	kWh	2,937.60
Units of electricity used for air-condition-ing	kWh	293.76
Electricity cost per unit	₹/kWh	6.00
Total cost of electricity in a day	₹	19,388.16
Manpower costs per day	₹	7,500.00
Total operation costs per day	₹	26,888.16
Operation cost per km	₹/km	0.48
Total cost per km (battery+infrastruc-ture+operation)	₹/km	1.10
margins at 20% of cost	₹/km	0.22
Charge per km	₹/km	1.32

Conclusion

For the swapping station capable of handling about 1280 vehicles in a day, the investment in batteries would be approximately INR 3.36 crores, with additional investments around INR 0.46 crores. The revenue per year would be close to INR 2.73 crores and the operation costs would be INR 0.98 crores, giving a good gross-margin. The depreciation and finance costs would be about INR 1.3 crores and the profit before tax would be INR 0.45 crores.

Economics of a battery swapping facility for electric buses at a bus depot

Battery swapping could be an option for e-buses as well. Such battery swapping stations could be installed and operated at the bus depot. Usually, the capital cost of e-buses plays a critical role in integrating electric vehicles into public transport system; however, vehicles without batteries would bring down the capital cost significantly. This would make a business opportunity for energy operators in this segment of vehicle apart from 3-wheelers (e-autos) and 4-wheeler vehicle segment. In this section, we take a look into the business model for energy operator providing services to the e-buses. We have considered a 12-meter non-air-conditioned bus for the purpose of the computation. For e-buses of other varieties (e.g. 9 meter and 12-meter e-buses – air-conditioned and non-air-conditioned both), the numbers would change but the conclusion will be similar.

Box 2: How battery swapping model for e-buses would work?

We propose that swapping be carried out for electric buses by the energy operator. This approach implies batteries will be charged only by the energy operator. They could charge the battery in controlled conditions, i.e. at 25 °C, and at a rate not more than 0.5C (two-hour charging). This would maximise the life of the batteries. The buses will be purchased without batteries bringing down the cost which could now be similar to that of a diesel bus in volumes. The objective of the battery-swappable electric buses is to make the capital costs and operational costs of the electric buses close to that of diesel buses.

In case of intra-city buses, its usually the State Transport Utility (STU) that manages all the city buses. Each bus runs over 200kms every day between some 6-9 round trips, with average of about 30 kms or less per trip. The bus schedule is pre-decided and there is an average of 10 minutes wait time between two trips, which allows driver to take some rest. Usually all buses start and terminate their trip from one bus depot, and a city has a limited number of such depots. This trip length of 30 kms or less and about 10 minutes or more of turn-around time between trips makes the public intra-city bus a good candidate for the battery swapping model. The bus depots can have bulk charging and swapping stations and the batteries can be swapped each time a bus comes to a depot.

This approach would allow the swap battery to be of small size and capable of enabling the bus to travel 50 kms or less on a charged battery. A smaller battery has many advantages. The capital costs associated with the battery are now lower. The smaller battery has lower weight and therefore helps the buses consume less energy per km. As the bus does 6-9 trips a day, the same number of battery swaps would be carried out at its designated bus depot.

If the bus travels 30 km on a trip, and the swapped-out battery is to be charged at 0.5C, the battery (capable of 50 km) would be charged and ready to be swapped again in about 70 minutes. Assuming that each trip of about 30 kms takes 90 minutes in a city (typical bus travel time in a city is 20 kmph), a charged battery could be loaded in bus, taken out and got ready again for the next trip in 160 minutes. Let us add 20 minutes for swapping and some wait-time, a battery can be reused every 3 hours. One can therefore use the same battery 3 or 4 times in a day. As buses run for long hours, it may be possible, in some cases, to use a battery even five times.

Assumptions and Analysis[10]

It is assumed that the buses have an energy consumption of 1000 Wh/km. Based on the costs and margins assumed, the charges for battery-leasing per km is determined.

Battery cost

We assume that an energy operator invests in 200 batteries in one bus depot. These batteries are turned around by 3 times (swap-factor) a day. Thus, this depot would support 600 battery swaps and therefore 600 trips out of the depot. If we assume 600 trips in 10 hours, it would imply 60 trips in an hour.

We assume a battery capacity of 55 kWh, with effective usage during a trip limited to 85% of the size, or 46.75 kWh. Further, we assume that the trip ends at the bus depot when battery has discharged by 70% of the capacity, under typical circumstances; thus the effective battery capacity used in a trip is 32.73 kWh. The battery with 5000 effective cycles would cost about INR 18,000/kWh. The 55kWh battery would thus cost about INR 9.90 lakhs. The total investment for 200 batteries will work out to be INR 19.80 crores. Assuming that the battery is used only 3 times a day, 5000 cycles battery will last 4.57 years. Considering 10% finance cost, the battery depreciation and interest cost per day works out to be INR 768.65 per battery. The effective cost of the battery then works out to be INR 7.83 per km - assuming vehicle efficiency to be 1.0 km/kWh (derived from 1000 Wh/km).

Infrastructure Cost

Infrastructure costs required for battery swapping at the depot is estimated in similar fashion. Charger constitutes some INR 36 lakhs while robotic swapper handling mechanism will cost some INR 150.00 lakhs without taxes. There will be other infra requirements like building, air-conditioning, IT, safety, electrical connection etc., which shall cost an additional INR 186.00 lakhs approximately. This total swapping infrastructure cost (excluding the batteries) when depreciated over the period of 8 years and keeping same finance cost of 10%, the effective contribution of the infrastructure cost comes around INR 0.97/km. The battery and infra costs thus adds up to total INR 8.80 per km.

Operating cost

Electricity costs, air-conditioning costs and manpower costs add up to about INR 1.35 lakhs per day or INR 6.91/km of bus travels. Thus, cost for battery swapping works out to be INR 15.71/km. Assuming 20% margins over costs, the swappable battery can be provided at a rate close to INR 18.85/km. This is about the same as the fuel cost per km for a diesel bus. Taxes have not been included in computations.

Table 31 below provides the cost computation for a battery swapping facility for e-buses at a bus depot.

Table 31: Cost computation for a battery swapping facility for e-buses at an existing bus depot

Parameter	Unit	Value
Battery cost (INR or ₹)		
Number of Batteries	-	200
Swap-factor per battery	-	3.00
Number of e-buses served	-	600
Battery size	kWh	55.00
Battery capacity (DOD of 0.85)	kWh	46.75
Battery capacity used per trip	kWh	32.73
Battery cost per kWh	₹ thousand	18.00
Cost per battery	₹ Lakhs	9.90
Battery investment	₹ Lakhs	1,980.00
Battery lifetime	Cycles	5,000

[10] *These assumptions and cost computations first appeared in (Jhunjhunwala, 2017).*

Battery life	Years	4.57
Interest cost	%	10.00
Battery depreciation + interest cost per day	₹	768.65
Battery cost per kWh	₹/kWh	7.83
Vehicle efficiency	km/kWh	1.00
Battery cost per km	₹/km	7.83
Infrastructure Cost		
Charger infra cost	₹	40,000.00
Time taken for charging	Hours	1.50
Number of chargers	-	90
Total charger cost	₹ Lakhs	36.00
Number of swappers	-	10
Swapper cost per unit	₹ Lakhs	15.00
Total swapper cost	₹ Lakhs	150.00
Other infra cost factor	-	2.0
Infra cost (including chargers) per day	₹	19,103.88
Infra cost per km	₹/km	0.97
Operational Cost		
Units of electricity used in a day for charging	kWh	19,635.00
Units of electricity used for air-conditioning	kWh	1,963.50
Electricity cost per unit	₹/kWh	6.00
Total cost of electricity in a day	₹	1,29,591.00
Manpower costs per day	₹	6,000.00
Total operation costs per day	₹	1,35,591.00
Operation cost per km	₹/km	6.91
Total cost per km (battery+infrastructure+operational)	₹/km	15.71
Margins at 20% of cost	₹/km	3.14
Charge per km in ₹	₹/km	18.85

Economics of different charging systems

The AC charger AC001

AC001 would be the most commonly used charger, providing a simple 230V AC supply to the vehicle and having a meter and communications to CMS to enable time of the day metering. In volumes, this would cost about INR 5000. If we assume that an energy operator serves only one vehicle per day for a fee of INR 10 for using an AC001 charger, s/he will get a revenue of INR 3650 per year, excluding the cost of electricity. The actual revenue will be even greater. It is assumed that this will be used in parking lots, where the charges of parking would be a separate viable business. The investment on chargers could then easily be recovered in less than two years if not sooner.

The DC fast charger DC001

The cost of the charger would be less than INR 150,000. This would enable vehicles to charge in an hour (Jhunjhunwala, 2018). The DC charger could be expected to charge at least five vehicles in a day and collect about INR 50 as charging service for each vehicle, over and above the electricity charges. The yearly revenue would then be close to INR 90,000 per year. Once again, parking infrastructure being expected to pay for itself, addition of DC001 could return the investment in less than two years.

IEC-CCS2 chargers for premium cars

This charger, providing up to 75kW DC charging, could cost as much as INR 1.5 million. Besides, there will be costs involved in providing electricity as one may have to use 11 KVA power line. Assuming fast charging of premium vehicles could fetch INR 100 per vehicle, other than the cost of electricity and parking charges, and assuming five vehicles are charged per day on an average, the yearly income will be only INR 180,000. Furthermore, being at much higher voltage and power, it may be desirable that a person is employed to oversee the operation. Such a person could potentially oversee four such chargers. The cost of the person could be merely INR 15000 per month or INR 180,000 per year. To make this operate 24 hours a day, one may have to hire at least three people. Since they would operate four such chargers, manpower cost for each charger would amount to about INR 135,000. While the energy operator may be able to become cash-positive, one could never recover the capital cost of the fast chargers. Even charging INR 200 per vehicle as charging fees, would not make the business economically viable. One will have to drastically reduce the capital costs of the charger and increase the number of vehicles to be charged per day to make any business sense out of this.

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