



ZERO EMISSION VEHICLES (ZEVs): TOWARDS A POLICY FRAMEWORK



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I. THE GLOBAL CONTEXT

Historically, mobility and fossil fuels have been inextricably linked with electric vehicles being successful only in a few niche markets. However, over the last decade, a collection of circumstances have conspired to create an opening for electric mobility to enter the mass market. Those forces include:

1. Climatic change: The prospect of rapid global temperature increase has created the need for a reduction in the use of fossil fuels and the associated emissions. India has committed to cutting its GHG emissions intensity by 33% to 35% percent below 2005 levels by 2030.
2. Advances in renewable energy: Over the last decade, advances in wind and solar electricity generation technologies have drastically reduced their cost and introduced the possibility of clean, low-carbon and inexpensive grids. India proposes to add 175 GW of renewable energy capacity by 2020 and to achieve 40 percent of its electricity generation from non-fossil sources by the same year.
3. Rapid urbanization: Economic development, especially in emerging economies, is creating a wave of urbanization as rural populations move to cities in search of employment. While urbanization is an important component of the process of economic development, it also stresses upon the energy and transport infrastructure leading to congestion and pollution. According to a recent study by WHO, India is home to 14 out of 20 most polluted cities in the world. Electric vehicles (EVs) can improve that scenario by reducing local concentrations of pollutants in cities.
4. Data capture and analysis: With the rise of GPS enabled smartphones and the associated universe of mobility applications, mobility has undergone a digital revolution. That digital revolution has created possibility of a greater utilization of existing transportation assets and infrastructure. For EVs, which rely on lower variable costs to offset relatively high fixed costs, this enhanced utilization is a critical element of achieving total costs of ownership compared to internal combustion vehicles.
5. Battery chemistry: Advances in battery technology have led to higher energy densities, faster charging and reduced battery degradation from charging. Combined with the development of motors with higher rating and reliability, these improvements in battery chemistry have reduced costs and improved the performance and efficiency of electric vehicles.
6. Energy security: The petrol, diesel and CNG needed to fuel an internal combustion engine (ICE) based mobility system requires an extensive costly supply chain that is prone to disruption from weather, geopolitical events and other factors. India needs to import oil to cover over 80 percent of its transport fuel. That ratio is set to grow as a rapidly urbanizing population demands greater intra-city and inter-city mobility.

As a result, developed economies such as EU, the USA and Japan as well as developing economies such as China and India have all included EVs in their policies to lower their carbon emissions while providing convenient and cost-effective mobility.

II. THE INDIAN CONTEXT

While many countries have included EVs as an element of transportation policy, their responses have varied according to their stage of economic development, energy resource endowments, technological capabilities, and political prioritization of responses to climate change. In India, a particular set of circumstances which are conducive to a sustainable mobility paradigm have created an opportunity for accelerated adoption of EVs over ICE

vehicles. These are:

1. A relative abundance of exploitable renewable energy resources.
2. High availability of skilled manpower and technology in manufacturing and IT software.
3. An infrastructure and consumer transition that affords opportunities to apply technologies to leapfrog stages of development.
4. A universal culture that accepts and promotes sharing of assets and resources for the overall common good.

These circumstances position India to pursue an EV policy which systematically ensures that India's EV program keeps pace with the global scale since large economies seem to take significant steps towards electrification of vehicles. India's growth prospects create potential for developing leadership in EV in certain segments. In that sense, the policy will encourage a path which starts with India-specific characteristics and initiatives for its auto sector, building towards global relevance and applications. The key objectives of the EV policy are:

1. Reduce primary oil consumption in transportation.
2. Facilitate customer adoption of electric and clean energy vehicles.
3. Encourage cutting edge technology in India through adoption, adaptation, and research and development.
4. Improve transportation used by the common man for personal and goods transportation.
5. Reduce pollution in cities.
6. Create EV manufacturing capacity that is of global scale and competitiveness.
7. Facilitate employment growth in a sun-rise sector.

III. CUSTOMIZING INDIA'S EV POLICY TO THE INDIAN AUTO-INDUSTRY TODAY

While India is operating in the same global context as other countries who have adopted an EV policy, it has a unique mobility pattern which other countries do not share. An EV policy for India must be tailor made to India's particular needs. While vehicle growth in India is rapid, ownership per 1000 population has increased from 53 in 2001 to 167 in 2015,^[1] a key difference between India and other countries and the types of vehicles being used. India uses a large variety of motorized transport on roads and its auto-segments are quite different from that of most of the world. Based on the last six years of sales data, the vehicles on Indian roads are estimated to consist of:

1. Two-wheelers: 79% of the total number of vehicles.
2. Three-wheelers (passenger and goods), including tempos: 4% of the total number of vehicles.
3. Buses and large goods vehicles like trucks: 3% of the total number of vehicles.
4. Economy four-wheelers (cars costing less than ₹1 million): 12% of the total number of vehicles.
5. Premium four-wheelers (cars costing higher than ₹1 million): 2% of the total number of vehicles.

In India, premium four wheelers (cars) are only 2% of the total sales. However, most advanced technologies are available in this category in global markets. In the near term, India

should foster early adoption of vehicles by premium customers which will pave the way for consumer comfort with electrification, raise aspirations for indigenous products and make advanced technology available in the market. The presence of world-class technology will help India build a world-class ecosystem for high-quality component and subsystems usable for all kinds of vehicles.

In the longer term, India should establish technological and manufacturing leadership in the economy segment of the market. The prevalence in India of small vehicles such as two-wheelers, three-wheelers, economy four-wheelers and small goods vehicles is unique among large countries. These small vehicles require a unique set of technological and industrial capabilities. Here, India has an opportunity to take a leadership role in the electrification of small vehicles. India's potential volumes for these vehicles as the nation grows, lays the foundation for transformational manufacturing and industrial policy. That focusses on the development of technological expertise and industrial capabilities in the production of small electric vehicles which can not only meet domestic demand but can also place India in a position of global leadership. As other countries begin to look at smaller vehicles with appropriate specifications, India can establish a position of leadership based on domestic demand.

Beyond significant domestic demand for smaller vehicles, another aspect of the Indian mobility market is supportive of electrification: its high level of sharing. Shared mobility in India has exploded, changing the way India travels. Taxi aggregators such as Ola and Uber increases from 130 million rides in 2015 to 500 million rides in 2016^[2], leading radio taxis to account for 72% of the overall market. This high penetration of shared mobility in India increases both vehicle utilisation, which plays to the economic advantages of EVs, and also creates natural and large-scale purchases of EVs.

IV. MAKING EVS ECONOMICALLY VIABLE

The limiting factor of batteries on driving range may be addressed by developing an ecosystem of fast-charging or swapping of batteries. This can be achieved by creating requisite infrastructure, possibly even every kilometer, in dense areas. As a result an important question arises as to what kind of strategy can make EVs, especially small vehicles, economically viable. The general strategy should address two key variables affecting the costs of EVs: battery costs and any fiscal policies that either increase the costs of an ICE vehicle or decrease the costs of an EV.

Broadly speaking, approaches exist to reduce battery costs – reducing the number of batteries that an electric vehicle needs and making batteries cheaper on a per kilowatt-hour basis. For the first approach, reducing the batteries needed for a given EV, there are two key pathways:

- 1. Providing charging infrastructure:** The limiting factor of batteries on driving range may be addressed by developing an ecosystem of fast-charging or swapping of batteries, by creating an infrastructure, maybe even every kilometre, in dense areas. A smaller battery will lower costs by reducing the total weight of the vehicle, resulting in higher energy-efficiency and improved ability to upgrade as the technology evolves. Charging infrastructure can be rolled out on a city by city basis with select cities and regions leading the transition. This would be consistent with global experience where 33 percent of all EV sales take place in only 14 cities where charging infrastructure is widespread and convenient to use. Approaches for creating effective charging infrastructure are outlined below.
- 2. Increasing efficiency of vehicles:** Incentivising developments to increase vehicle

efficiency, thereby reducing energy consumption, can enable to a vehicle to travel the same distance on a smaller battery pack. Energy efficiency can be enhanced by using more efficient electric motors [see Appendix II] using better tyres, enhancing the aerodynamics of the vehicles and reducing its weight. This would reduce battery size needed for a certain range.

For the second approach, reducing the unit costs of each battery, India can explore several pathways:

- a. **Selecting appropriate battery chemistries** [See Appendix I]: As batteries dominate costs of electric vehicles, the strategy would be to use battery chemistry with optimized cost and performance at Indian temperatures. India should encourage manufacturing of such battery cells in India. India is already making battery packs (cell to pack).
- b. **Exploring new battery chemistries:** Focussing on materials like lithium, manganese, nickel, cobalt and graphite that are used in batteries and determine its costs. While it is important to secure mines which produce these materials, India must also obtain these battery materials through recycling of used batteries and should aim to become the capital of “urban mining” of used batteries.

Beyond reducing battery costs, India can explore potential avenues of fiscal support for EVs to accelerate adoption. The standard approach in other countries to providing fiscal support to EVs has been direct subsidization. For example, EVs in USA, Europe and China have up to^[3] 40% “all-in” subsidies. Those subsidies include direct federal or state subsidy to buyers, mandates to manufacturers, utility subsidies or subsidy in the form of fee bates where vehicles are taxed based on their CO₂ emissions, whereas EV receives support. As costs decline and the share of EVs in total vehicles increases, most nations plan to taper off such subsidies.

For India, however, those paths are not viable; the elimination of direct subsidy will be the policy basis. Therefore India has to be creative to make electric vehicles and its infrastructure economically viable from the very beginning. Its policy and strategy have to be fundamentally set up to enable EVs to make business sense. Direct financial demand-incentives / subsidies could be replaced by Tradable Auto-Emission Coupons or credits based on CO₂ emissions per km as well as on a sliding scale for vehicle efficiency. This will encourage the market to build efficient vehicles with lower emissions per km. Thus, while vehicle manufacturers exceeding CO₂ emissions targets would have to purchase coupons or credits, the manufacturers meeting the targets would be rewarded with coupons. Market will decide the prices of these coupons. This will incentivize EVs and low-emission vehicles as well as energy-efficient vehicles at the expense of the vehicles with high emissions and lower-efficiency.

Accelerating the availability of necessary electricity network infrastructure as well as domestically produced technologically superior EVs, chargers and components will bring down costs and increase the options available for transportation electrification in India. This could bring total cost of ownership (TCO) of EVs to parity with ICEs by as early as 2025.

V. “MAKE IN INDIA” - IMPORT DUTY AND TAXES

IMPORT DUTY AND MAKE IN INDIA

1. Keeping in mind the stage of EVs in the country, India needs a new approach to import duty while keeping “Make in India” as a goal. The principle of establishing custom duties will be to give specific preference to value chains manufactured in India. Goods contributing to the lowest value-add chain (like finished goods) would have the highest import duty; one

contributing higher value-add (like components) would have lower import duty and the one contributing to highest value-add would have the lowest or zero duty. Thus, finished electric cars and chargers should have highest import duty; sub-systems like batteries, air-conditioners, power-modules and drive-trains will have lower than this highest import duty; and subsystems like battery-cells, motors, controllers, ICs, magnets, and connectors will have zero duty.

PROPOSAL FOR GST

2. GST should favor commercial vehicles that have higher utilization and drive more KMs, to maximize electric Vehicle Kilometre (VKM). The GST benefit should incentivize higher utilisation and replacement of equipment, thereby increasing climate mitigation and congestion reduction.

VI. POLICY FOR CHARGING / SWAPPING INFRASTRUCTURE

EV charging and battery swapping are two means for providing energy to a vehicle. EVs will proliferate as charging/swapping infrastructure is set up. India would recognize battery swapping and battery charging as addressing different segments of vehicles and two equally valid options that industry may choose to use. Businesses that provide charging/swapping would be referred to as Energy Operators (EO). They would deploy slow and fast chargers at suitable locations for EVs. Similarly, they would purchase batteries, setup charging and swapping service and provide the charged batteries on lease for EVs. Both the charging as well as swapping service would require that EVs have standard charging protocols to connect to a charger of swappable batteries and have a standardized connector.

Government of India would consider providing long-term and short-term tax-incentives and faster depreciation as incentives to EOs for deploying slow/fast chargers and carrying out battery swapping. GST for all these chargers and swappers should be the same as that for the vehicles. Swappable vehicle batteries and vehicles without batteries (which receive swappable batteries) should also be treated the same under GST.

Further, installation of chargers would be allowed (and over time, mandated) on street parking, parking lots and any public charging space.

STANDARDS FOR CHARGERS

An EV uses electricity as fuel which is stored in a battery in the vehicle. The charging can be done at home using what is called as home-chargers (also referred to as private-chargers) or public chargers, installed on streets, parking lots, petrol pumps, or any other public charging space. The chargers are referred to as EV Supply Equipment (EVSE). Public-charging infrastructure is an important complement to home-chargers. The main EVSE characteristics that differentiate chargers include,

- Power and voltage levels: the output power range and voltage range supported by an EVSE.
- AC or DC: whether the output of EVSE is AC or DC; if it is AC, the vehicle needs to have an on-board charger.
- Type: the output socket and connect or used by an EVSE.
- Mode: the communication protocol between the vehicle and the charger.

An EVSE standard thus defines power level, voltage level, AC or DC output, type and mode.

Besides, all EVSEs need a communication protocol between EVSE and a Central Management System (CMS). The standard would include safety measures and operational procedures and specifications including packaging, thermal and humidity levels and possibly payment mechanism. In this regard, Department for Science and Technology (DST) will develop indigenous standards through the grand challenge method through active participation of industry, academia and other stakeholders. In the interim, until indigenous standards are developed, subsidy would be provided for setting up of public charging standards adhering to globally acceptable standards.

Today the ratio of public slow chargers and fast chargers deployed is about 5:1. EV industry, on getting cross-subsidy through coupons/credits (as discussed in section IV), could support initial roll-out of the chargers. An attempt should be made to make all these deployed chargers self-sustainable in the financial sense at the earliest possible.

VII. BATTERY CELLS, PACKS, AND MATERIALS

- a. Lithium-ion battery manufacturing consists of three parts. First is cell to battery-pack manufacturing involving a value-add of 30 to 40%. The second is cell manufacturing with a value add of 25 to 30%. The third involves battery-chemicals with a value of 35 to 40% of the total cost of battery pack. While cell to pack manufacturing plants have started functioning, the others need to be encouraged. India would provide MSIPS incentives and tax incentives for such manufacturing.
- b. India needs a minimum of 10 GWh of cells by 2022, which would need to be expanded to about 50 GWh by 2025. Therefore, manufacturing these cells in India would be encouraged. It is imperative that India gets the cell-cost and parameters like energy-density (size and weight), life-cycles, safety, temperature tolerance right, so that its batteries are best in the world. Early plants can be set-up either by international manufacturers or as joint ventures between Indian companies and international manufacturers. MSIPS incentives and tax incentives need to be provided to these companies. This needs to be coupled with strong support to R&D in the new battery chemistry and manufacturing process to those organizations who have the capability of translating R&D to commercialization.
- c. At the same time, India would need a policy to secure materials used in Lithium-ion batteries, including lithium, cobalt, nickel, manganese, and graphite. Our first task will be to scan for these resources within India and at the same time make or incentivize strategic investments in international mines for these materials. Perhaps the most important task would be setting up of Lithium-ion battery recycling industry (what is referred to as urban mining). India would need to introduce strict norms for recycling every Lithium-ion battery used in an EV, mobile phone or a laptop. It could allow import of used Lithium-ion batteries for recycling, with tight environment norms, so that all recycling plants have zero-emission. Finally, MSIPS incentives and tax incentives could be provided for Lithium-ion battery recycling plants as well as for chemical industries, which would convert battery materials into chemicals.

To incentivise longer life batteries to be developed and produced, India would enable battery systems, both within vehicles and in “second life” to avail potential revenue in supporting load balancing, time-of-day charging, energy banking and other uses after their useful life in the automobile is exhausted.

VIII. FOCUS ON SMALL AND PUBLIC VEHICLES TO MAKE EARLY IMPACT

While encouraging the sale of private EVs, India's focus, at least in the first few years, should be on small, public and rural transportation. It is possible for India to have a unique impact and scale early with two-wheelers and three-wheelers, including three-wheeler goods vehicles. Special attention is needed to get these vehicles to become economically viable and flourish.

Simultaneously, India needs to ensure that electric buses become viable. With the credits/coupons as discussed in section IV, buses would become economically viable very quickly with the rationalized customs duties. Cars used in the government and taxi fleets need to be available early. They should be economically viable with credits/coupons discussed in section IV. India could use both charging and swapping to get these vehicles scale early.

IX. RESEARCH AND DEVELOPMENT AND TECHNOLOGY WATCH

It is imperative that India quickly develops strong Research and Development (R&D) capacity leading to commercialization in EV subsystems. The Government will aid R&D grants through grand challenge, for product-development which could commercialize within one or two or at the most, three years. Short-term R&D would be required for electric motors and controllers, DC-DC converters, EV chargers, electric power-steering, electric power-brakes, electrical air-conditioners, vehicle control and management and communication protocols. All such R&D proposals would ab-initio figure out target volume costs of EV subsystems in India. Another area that will require R&D is to understand the impact of large scale charging on the electric grid.

Besides, India would need to watch out for new approaches and technologies and promote long-term R&D in all aspects of EV technologies. These include hydrogen fuel-cells, new battery-chemistries (with higher specific energy and energy densities), battery materials and chemicals, distributed motors, batteries withstanding higher temperatures, motors without permanent magnets, heavy trucks, and two-way power transfer between grid and EV chargers. A model that brings together IITs, private manufacturing and CSR would be put in place.

X. TRANSFORMING AUTO-ANCILLARIES: A FOCUS ON POWER-ELECTRONICS INDUSTRY AND ELECTRICITY DISTRIBUTION SYSTEM / IMPACT ON THE GRID

1. Finally, EVs use power-electronics extensively. India had an early start of its power-electronics industry. However, the industry has not kept pace with new developments that have seen digitization of power-electronics over the last decade. India would need a new power-electronics industry which can help develop and produce high-efficiency sub-systems for EV industries. A special thrust is needed to promote such industries.

2. Indian power industry needs to be prepared for the EV roll-out. The network must be

geared to minimizing impacts. Some key actions to prepare for greater EV penetration are demand-side management, dynamic electricity pricing, and vehicle-to-grid technology for use of EVs as active loads and generators for power demand shaping. Global experience suggests that the distribution systems are generally quite loaded and enough spare capacity is not available to support charging infrastructure required for EVs. A similar situation exists in Indian cities where adding banks of chargers is possible only with upgrading of distribution networks. Managing distribution transformer upgrades may be less expensive and easier. More difficult would be managing overloaded cables which can be significantly more expensive, especially for underground networks. Similarly, harmonic distortions due to EV charging may impact grid stability. The EV chargers must be carefully certified to meet the harmonic-distortion specifications, using active filters if required^{[4],[5]}.

XI. IMPACT OF EVs ON ECONOMIC GROWTH AND EMPLOYMENT

Shifting modes of mobility could launch new business opportunities. These would emerge in areas such as charging and swapping infrastructure, service, or integrated transport. In India, energy players have entered the mobility industry, while some traditional power companies are exploring possibilities in charging infrastructure, and infrastructure companies are seen entering the battery business. An important task that needs attention is transforming and up-scaling small and medium sub-system and auto-component industries. A large number of such mini-micro industries are auto-ancillary companies for diesel/petrol vehicles. They provide large number of jobs. Many of them will not survive as EV replaces petrol/diesel vehicles. A careful plan to hand-hold such industries and help them during the transition to EV components manufacturing is required.

Expansion of transport fleets based on IC engines negatively impact the economy considerably, apart from their negative health contributions. Crude oil price volatility adds uncertainty to an already burgeoning import bill, while also needing huge investments in oil refineries and related distribution infrastructure. There are several studies that suggest overall positive impact on GDP on introduction of EVs in fuel importing service dominated economies. One study has estimated that driving the shift to electric vehicles would lead to a 1% increase in EU GDP^[6]. In another study, net private and social benefits are estimated between \$300 and \$400 per EV^[7]. Coupled with generation of renewable power, the battery manufacturing industry in India can become bigger than the total amount spent on import of crude oil. This would provide a huge boost to the Indian economy. The revenue loss for governments from the taxes on the oil sector is expected to be replaced by higher tax revenues in other economic sectors.

IMPACT ON EMPLOYMENT

European Climate Foundation has estimated that through reducing oil demand by more efficient electric cars, employment will increase by 5,00,000 to 8,50,000 by 2030. Another report estimates that about 2 million additional jobs will be created by EVs by 2050. The report further adds that oil production and distribution has very low employment intensity of just four jobs per million Euros value added compared to 24 jobs per million Euros in the general economy. Therefore, any shift in expenditure from buying imported oil to other expenditure choices would generate additional employment. Further, as imported oil is replaced by electricity and batteries, large employment is possible in enhancing power-generation and distribution, and in battery manufacturing, including battery-recycling.

As far as the automotive sector is concerned, a large part of the supply chain will get transformed in the power train segment. Traditional suppliers will move from supplying parts

such as exhaust pipes and ICEs to perhaps battery materials, electric motors, and regenerative braking systems. EVs will create opportunities in durable and lightweight thermoplastics, higher demand for electricity, storage and many others. The net impact on employment would perhaps be balanced out. In addition, EV battery charging and swapping would create a large number of jobs throughout the country.

IMPACT ON ENVIRONMENT AND HEALTH

ICEs are one of the main sources of air pollution globally. They negatively affect both human health and ecology. Emissions from ICE powered motor vehicles are responsible for about two-thirds of air pollution in urban areas. The current ban on older fuel cars in some Indian cities already shows a positive influence on air quality, and this can only further improve with the large scale introduction of EVs.

LAST-MILE CONNECTIVITY AND RURAL TRANSPORT

Some Indian cities today have metros as public transport and others have bus services. Many other cities and most towns do not have either. The last-mile connectivity in cities which have metros/buses is provided by rickshaws/autos. In cities and towns which do not have metros or buses, the only public transport available are rickshaws and autos. Early conversion of these vehicles to electric vehicles using Lithium-ion batteries will provide clean transport to a large number of people.

Today the primary transport for villages, taking people to bus-stops on the highways or train-stations, is ICE three-wheelers. It is possible to quickly convert them to electric, providing clean transport in villages. Further, battery-charging and swapping outlets may be operated in larger villages, creating jobs in rural areas. Specifications must ensure that these vehicles do not pose an inconvenience to other users of public roads and highways.

Freight movement in the rural areas, and for transport connecting farms to cities, are primarily handled by smaller transport vehicles (like rickshaws, autos and tempos). These vehicles are eminently suited for replacement by EVs. Sustainable mobility would require that small freight vehicles are enabled by aggregators to be made available on request, just as Uber or Ola cabs for city commuters. This would cut farm to market costs for the farmers, and also result in better fleet utilisation. The electronic platforms to enable such operations need to be developed.

XII. CONCLUSION

India has a lot to gain by converting its ICE vehicles to EVs at the earliest. Its oil-import bill would considerably reduce. ICE vehicles are a major contributor to pollution in cities and their replacement with EVs will definitely improve air quality. There is a considerable possibility that we can become leaders in small and public electric vehicles. India has over 170 million two-wheelers. If we assume that each of these vehicles uses a little more than half a litre of petrol per day or about 200 litres per year, the total amount of petrol used by such vehicles is about 34 billion litres. At ₹70 per litre, this would cost about ₹2.4 lakh crores. Even if we assume that 50% of this is the cost of imported crude (as tax and other may be 50%), one may save ₹1.2 lakh crores worth of imported oil. There is a real possibility of getting this done in the next five to seven years. This would however require innovations, a policy regime that encourages access to latest technologies and a concerted effort by the Indian industry to achieve global competition through acquiring the necessary scale and using cutting edge technology.

APPENDIX I: BATTERY SPECIFICS

Battery costs, which are the single largest driver of TCO (Total Cost of Ownership) for EVs, have seen enormous technological advancement in recent years, in both improving battery performance and reducing cost. Most of that progress has come in advances in Lithium-ion batteries which have become the batteries of choice for electric vehicles, largely because of high specific-energy, the ability to charge rapidly and their long cycle-lives which is considered over after a battery degrades to between 75-80% of original capacity. Lithium-ion batteries used in EVs have different chemistries and with specific characteristics. The most common ones are as below:

- 1. NMC-Graphite battery cells:** These battery-cells use Nickel-Manganese-Cobalt (NMC) chemistry as cathode and Graphite as anode. They are most commonly used EV batteries today as they provide specific-energy of 200 Wh/kg or more and the cell-costs are in between \$150 to \$200 per kWh. They are typically charged at 1C or 1.5C and are used with a discharge depth of about 80%. When charged and discharged at 25°C, they would typically give 2500 life-cycles. The cell-chemistry, however, has safety issues at high-temperatures and generally not recommended to be used as cell-temperatures, touches 55°C to 60°C. When charged or discharged at 45°C or at 3-C rate, the life-cycle may reduce to as low as 500 cycles. Thermal design incorporating heat-dissipation is therefore an important element of battery-packs. There are other battery chemistries like Nickel-Cobalt-Aluminum-Graphite (NCA-Graphite), Lithium-Manganese-Oxide-Graphite (LMO-Graphite) and Lithium-Cobalt-Oxide-Graphite (LCO-Graphite) with similar properties. Sometime, LMO-Graphite is mixed with NMC-Graphite.
- 2. NMC-LTO:** These cells use Lithium-Titanium-Oxide (LTO) as anode instead of graphite. They are powerful cells which can be charged and discharged at 10C, have life-cycles upward of 10,000 and can withstand 60°C temperatures, without impacting life cycles. However, their specific energy hovers around 80 Wh/kg to 100 Wh/kg and the current cost exceeds \$450 per kWh. They are therefore, used only in specialized vehicles, where smaller batteries are used with charging and discharging very frequently (like a bus with a small LTO battery being charged at every city bus stop for about a minute).
- 3. LFP-Graphite:** Batteries with Lithium-Ferrous-Phosphate-Graphite (LFP-Graphite) have characteristics in between that of NMC-Graphite and NMC-LTO. They have slightly higher life cycles than NMC-Graphite and can better withstand higher temperature and are therefore, safer. However, their specific energy is about 140 Wh/kg and has a theoretical limit of about 160 Wh/kg. They would therefore not compete with NMC-Graphite in terms of weight or costs and are thus, being fast discontinued.

In addition to currently available Lithium-ion chemistries, future developments in battery chemistry may yield a new generation of batteries which will include 'solid state' batteries that promise a storage capacity of about 1000 Wh/kg and 80 percent charge in about 10 minutes. These batteries, however, are still at laboratory scale and would take time to be commercially available. Ultra-capacitors, an alternative to batteries, are also upcoming potential energy storage systems.

IMPACT OF BATTERY ON VEHICLE PERFORMANCE

Other major concerns are weight of the battery in the vehicle, range that the battery provides and the costs of the battery. A battery pack will need cooling depending upon the usage and the ambient temperature. This adds to the weight of the battery. As mentioned earlier, NMC-Graphite cells today have about 200 Wh/kg or 5 kg per kWh. The weight of the battery pack may be in between 1.3 to 1.5 times that of cells, depending upon the packaging and

the cooling. Higher weight increases the overall weight of the vehicle and results into higher energy-consumption per km of travel.

BATTERY COOLING

When a battery is charged or discharged at 1C, typical heat generation may be only 1% to 3% of the energy used. But at 2C, the heat generation can be 4% to 9% of the energy used and at 3C it can rise to 9% to 27%. First, this would be considerable energy loss for the vehicle. But more important is that the cell-temperature will shoot-up rapidly and the cells would require significant cooling. Problem gets compounded in Indian conditions where the ambient temperature is of the higher range.

RANGE ANXIETY AND CHARGING / SWAPPING

The battery-size, cooling-requirements, weight of the vehicle (including battery and passengers) and energy-efficiency of the vehicle (amount of energy required per km), all goes on to contribute to the range that a vehicle can travel, before it requires recharging or battery-swapping. Addressing range issues is critical to the ecosystem development.

APPENDIX II: DRIVE TRAINS

Drive-trains along with battery are the most important components of an electric vehicle. The drive train consists of electric motor, the controller, and other sub-systems like DC-DC converters. Some key attributes in selecting appropriate drive trains include:

- **Vehicle weight and use patterns:** The power requirement of the motor depends upon the weight of the vehicle along with its payload, the speed-range at which the vehicle has to be driven, gradeability that it has to handle and the acceleration that the vehicle needs. Smaller vehicles like two-wheelers and three-wheelers will use motors with small kilowatt rating, cars will use higher-power motors. The buses and trucks may use even higher power motors.
- **The efficiency of the motor:** Higher the energy efficiency, lower is the electric power consumed and lower is the battery-size required for a specific range.
- **Energy losses outside the drive train:** While many kind of losses in motors and controllers exist and need to be minimized, energy lost to braking is a particularly large and addressable loss. Motors should provide regenerative energy to the maximum extent, such that braking-energy is converted to electricity and recharges the batteries.

¹ <https://community.data.gov.in/registered-motor-vehicles-per-1000-population-from-2001-to-2015/>

² <https://www.livemint.com/Companies/bjNzZDHCO25e0OZhj3oklJ/Ola-Uber-see-rides-rise-fourfold-in-2016-report.html>

³ Derived from https://www.acea.be/uploads/publications/EV_incentives_overview_2018.pdf and RMI analysis

⁴ <https://www.ieee-pes.org/presentations/gm2014/PESGM2014P-002765.pdf>

⁵ Vehicle-Grid Integration A global overview of opportunities and issues - NREL

⁶ How Will EVs Impact Jobs – Eu: Transport & Environment

⁷ PEV Economic impacts and employment growth (2017) Energy and Environmental Research Associates

⁸ IFO Economic Institute

