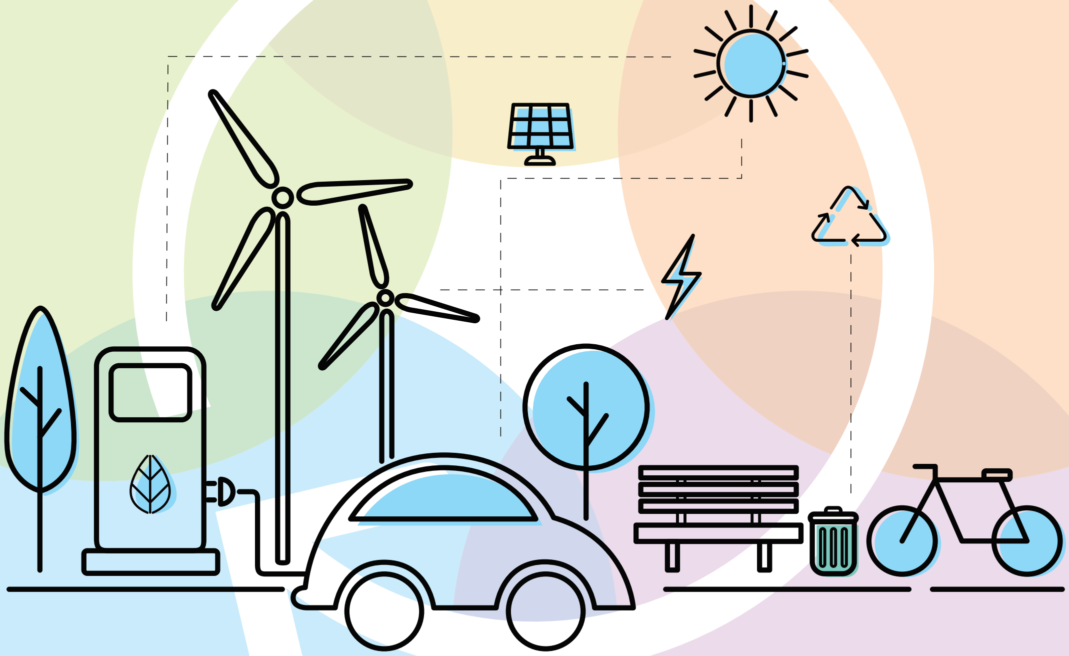
EU-REI
Creating a Resource Efficient India

Towards Resource Efficient Electric Vehicle Sector in India



September 2018

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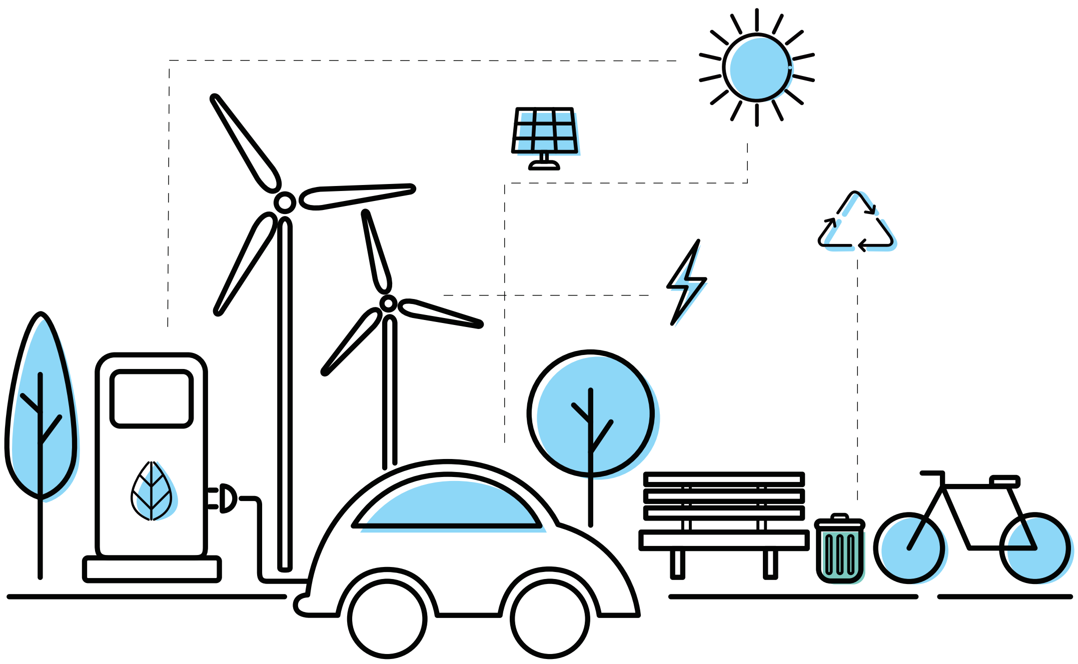

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Project background

Introduction

Economic growth of the 20th and early 21st century has contributed to widespread alleviation of absolute poverty across India. However, the modus operandi of the country's economy is still rested upon a linear "take-make-dispose" logic which extracts resources, transforms them into products and simply discards them at the end of life. Following such linear consumption and production patterns is highly resource intensive and represents a waste of valuable materials. In the light of increasing resource scarcity, promoting resource efficiency (RE) and integrating circular economy thinking becomes imperative and can contribute to the long-term availability of resources for inclusive economic development in India.

Towards an International Resource Efficiency Agenda

Having recognised the urgency of the issue, the Government of Indian (GoI) has actively engaged in international collaboration to implement global RE strategies, such as those in relation to the 2030 Sustainable Development Goals (SDGs) which recognize the potential of resource efficiency in resolving trade-offs between economic growth and environmental degradation. In fact, RE strategies form a key part of Goal 12 (sustainable consumption and production) and Goal 8 (decent work and economic growth), but also links to other goals -sustainable cities and communities (Goal 11), industry, innovation and infrastructure (Goal 9), climate action (Goal 13), and affordable & clean energy (Goal 7).

Other important activities are carried out under the ambit of the G20 Resource Efficiency Dialogue which was launched in July 2017 by G20's Hamburg Declaration. According to the Declaration, the Dialogue has three core objectives- 1) exchange knowledge on policy options to increase resource efficiency; 2) sharing of best practices on resource efficiency along the entire product life-cycle; and 3) spread awareness on solutions and options to strengthen countries' national policies which reduce overall resource consumption. In addition, RE strategies can make substantial contributions to India's efforts towards reaching the 2°C target (on limiting the global warming) and fulfilling countries' Nationally Determined Contributions (NDCs) as part of the Paris Agreement signed in 2015.

At the European level, the transition towards resource efficient economic model is reflected by the European Commission's (EC) Roadmap to a Resource Efficient Europe in 2011. Therein, a key component is the development of policies which encourage management of waste as a resource by means of reuse and recycling. In May 2018, the EC renewed its commitment to aim for more sustainable production and consumption practices by adopting the Circular Economy Package. Mobilising more than six billion EUR in funding under Horizon 2020 and EU structural funds, the Package defines several priority areas to improve the utilisation of critical raw materials which are typically found in packaging and electrical and electronic equipment (EEE), the electric mobility sector (specifically batteries) and renewable energy.

Indo-European Collaboration on Resource Efficiency and Circular Economy

At the national level, the Indian government has given RE substantial priority as is reflected in various policies/programme announcements like Make in India, Zero Effect-Zero Defect Scheme, Smart Cities, Swachh Bharat, and Ganga Rejuvenation Mission, etc. The government also seeks to strategically foster RE on a broader scale, and the country's policy think tank –NITI Aayog has published a national RE strategy paper. In the context of these recent developments, the European Union (EU) is providing support through its Resource Efficiency Initiative in India (EU-REI) which aims to facilitate the implementation of the UN global sustainable consumption and production (SCP) agenda by adapting international standards and best practices to the Indian context. More specifically, the initiative seeks to support the Indian government to identify and implement measures which can foster resource efficiency across four priority areas- waste from plastic packaging and electrical and electronic equipments, buildings and construction sector, electric mobility, and renewable energy (with a focus on solar photo voltaic).

Being implemented over the course of three and a half years (01/2017 to 07/2020), the EU-REI project, using sectoral assessments approach, will focus on assessing the production and consumption trends in selected sectors which are congruent with Indo-European interests and experiences in the above mentioned priority sectors. The project is being implemented on behalf of the EU by a consortium led by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and includes The Energy and Resources Institute (TERI), Confederation of the Indian Industry (CII) and adelphi. TERI analyses the scope and potential for enhancing resource efficiency and integrating circular economy thinking in the electric vehicles sector in India.

Enhancing resourcing efficiency in electric vehicles in India

India's ambition towards an electric mobility economy by 2030 was announced in 2016. Further, in a recent communication by the Ministry of Road Transport and Highways (MoRTH) and NITI Aayog, the government announced its aim of increasing share of electric vehicle (EV) from its current share of less than 1 percent to nearly 30 percent by 2030. This implies that by 2030, the total estimated number of electric two wheelers on Indian roads will be more than 200 million, while for cars and buses, the electric vehicles have been estimated at 34 million and 2.5 million (TERI Estimates). Very soon, the government is expected to announce India's policy on Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles II, at the Global Mobility summit in Delhi towards the latter half of 2018.

It is important to recognize that despite many economic and environmental benefits of EVs and hybrid vehicles, there are challenges with regard to the availability and affordability of material used in manufacturing these vehicles. Going by the current lithium battery chemistry and no further changes in technology in powertrain manufacturing in the four-wheeler hatchback segment, the total demand for materials is estimated to increase from 0.005 million tonnes to nearly 1.6 million tonnes (TERI estimates). Further, many of the resources like copper, lithium, permanent magnets and related materials and components, are heavily imported by India with import costs increasing over the years.

Lithium is considered to be one of the most important resources going into manufacturing batteries in electric vehicles, and the resource availability is largely confined to countries like Chile, China, Argentina and Australia. Cobalt, another material that goes into manufacturing batteries for electric vehicles, is largely mined in Democratic republic of Congo (DRC), and has a very fragile supply chain.

Permanent magnets that are used in manufacturing synchronous motors are largely manufactured from rare earth elements where China has a quasi-monopoly. Absence of appropriate resource use interventions may lead to higher imports of the critical materials that go into manufacturing different EV components including batteries and power trains leading to an increase in our import bill.

There are challenges with regard to introducing break-through technologies in developing products that use recycled materials; in achieving security when it comes to import dependency of raw materials; in formalizing management of end of life vehicles including reverse logistics; in reducing down cycling of secondary raw materials and closed loop management of wastes/scrap at intermediate levels; in tracing mechanism of critical components like batteries, in labelling of resource efficient products and certification of these products and those made from secondary raw materials.

Companies across the world have started adopting innovative practices and resource efficient products, for EVs to address some of the growing concerns of the material availability and improved efficiency. Further, governments have come up with policies and programs that are promoting and facilitating development of a RE ecosystem for the EV sector in their respective countries.

India, too, has the unique potential to create unprecedented opportunities for resource savings along the value chain. Product design and process innovation will reduce primary demand of resources. Further efficient recycling can help in recovering many of the critical materials particularly lithium and permanent magnets among others, thereby enhancing India's material security. Further, formalization of end of life vehicle (ELV) management will also strengthen capacities and skills of untrained people largely engaged in the informal sector thereby making ELV business sustainable and resource efficient.

Before India becomes a leading manufacturing hub of EVs, it is extremely important that an ecosystem is developed that can promote efficiency across the life cycle stages. Apart from research and development for improved product design and process re-engineering and a business model that can promote reverse logistics at the end of life for efficient material recovery, a conducive policy framework, over and above the proposed FAME II, is the need of the hour that will facilitate and support the growth of the sector while promoting a RE ecosystem for the sector.

1. Electric vehicle sector in India

1.1 Background

India's transport sector has predominantly been driven by the growth of Internal Combustion Engine (ICE) based vehicles. The growing middle income class and their rising aspirations, availability of cheaper finances, are some of the key factors that have led to increased demand for personal mobility and proliferation of production and sales of two and four wheelers in recent decades, particularly in major urban centres. As per recent statistics, India's annual vehicle production is over 25 million, and more than 210 million registered vehicles on Indian roads . Around 50 percent of these registered vehicles are in 7 states. With regard to production, two wheelers has the largest share of 79 percent, followed by 14 percent share of passenger vehicles and the remaining 7 percent largely comprising of commercial vehicles that include three wheelers, light commercial vehicles and heavy duty vehicles (SIAM, 2017) . The trend in production of different type of vehicles over the last few years is presented in figure 1.

1.2 Initiatives towards promoting Electric Vehicles in India

The government of India has demonstrated a strong commitment in introducing electric mobility in India and announced a very ambitious plan of making India a primarily electric car driven nation by 2030 (fig 1). The government in this regard launched a scheme for the Faster Adoption and Manufacturing of (hybrid &) Electric Vehicles in India (FAME India) under the National Electric Mobility Mission (NEMM) in 2015. The scheme was successful in increasing the share of hybrid and electric passenger vehicles sales from almost zero percent in 2012 to 1.3 percent by 2016. The government plans to introduce 6–7 million electric vehicles (EVs) /hybrid vehicles on Indian roads by the year 2020.

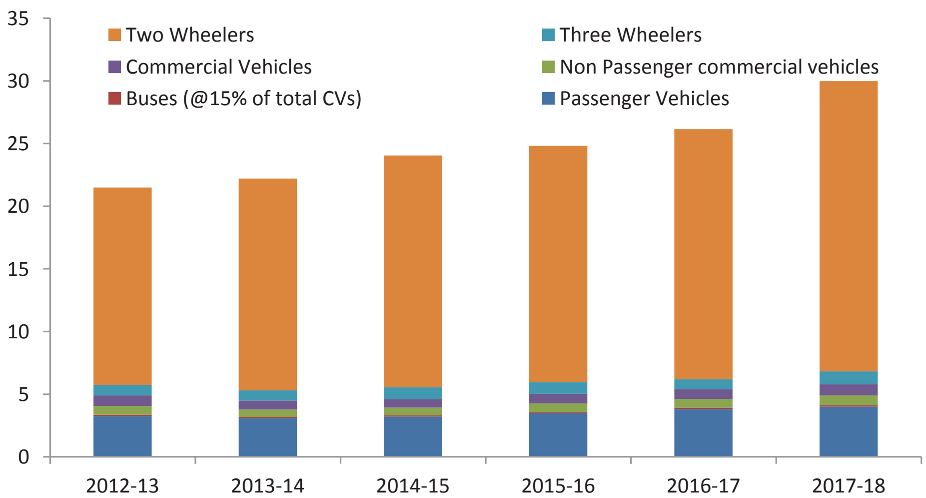

Figure 1: Trend in different type of vehicle production in India (in million)

Source: SIAM, 2018

In order to accelerate penetration of these vehicles, the government had earlier declared certain measures that included placement of battery based electric (BEVs) drive trains in a low Goods & Services Tax (GST) slab of 12 percent, as compared to 28 percent for petrol and diesel cars and hybrid vehicles, and procurement of 10,000 BEVs for its own use. In order to promote domestic production of electric buses, the government is already providing incentives of 60 percent of the cost of a bus or INR 1 million (Euro 12560), whichever is lower, for those products that have localisation content of 35 percent and above. Under the FAME II scheme which is expected to span 5 years with an objective of boosting faster adoption of energy efficiency in the automotive sector in India, a financial support of more than INR 8730 crore (Euro 1100 million) is awaiting final approval from the government.

Given this strong emphasis of the Indian government on EVs, the country has a huge potential of becoming one of the largest electric vehicle markets in the world. This will provide several opportunities for automobile manufacturers, electric vehicle component manufacturers and other players along the electric vehicle value chain, and promote employment generation, greenfield investments, technology development and transfers, amongst others. While it is Mahindra's E2O, the only domestically manufactured battery electric vehicle (BEV) that is sold in Indian market, companies like Maruti Suzuki, Tata Motors, Nissan, Toyota, have expressed their strong willingness to introduce EVs in Indian market. Tata Motors have recently started manufacturing electric vehicles in India. There are other economic and environmental benefits linked to growth of EV sector that include reduction in physical imports of oil and depletion of foreign exchange reserves through reduced import bill, promotion of energy security, creation of better investment opportunity in generation of clean energy, and a lower cost of integrating renewables through "smart charging", etc.

The states too have demonstrated their strong commitments in promoting EVs in their respective geographies. The states of Andhra Pradesh, Karnataka, Maharashtra, Telangana and Uttar Pradesh have already announced policies for deployment of EV and providing charging infrastructure.

Andhra Pradesh for example, will provide reimbursement of road tax and registration fees, on sale of electric vehicles for the next eight years and aims to have 1 million electric vehicles on roads in the next five years[2].

Karnataka came out with its EV and energy storage policy (early this year), that include development of EV manufacturing zones, development of infrastructural capacities, developing charging systems with the help of private investments, exemption of taxes on EVs while subsidising use of charging, and setting up of battery swapping stations. Telengana officially introduced its EV policy in June 2018, by introducing several incentives for EV manufacturers to setting up of charging stations as well as for registration of EVs[3].

The Maharashtra government recently declared its EV policy with an objective of developing an enabling environment for manufacturing nearly 500,000 EVs by 2022. The state government has also proposed eliminating road and registration charges for EVs. Further a 15 percent subsidy has also been proposed to the first 100,000 EVs owners when they are registered in the state. Since charging infrastructure is extremely crucial, the government is proposing for a maximum subsidy of INR 1 million (Euro 12560) per charging station to be awarded to 250 stations in the state[4].

1.3 Electric vehicles evolution in India

Needless to mention, India has emerged as a key global automotive market having strong position across several vehicle segments. The country has also actively been exploring viable solutions to many

2 https://mercomindia.com/states-poised-lead-ev-revolution/

3 IBID

4 IBID

resource use and environmental problems faced by the sector and electric mobility has emerged as one of the potential solutions.

India's journey in electric vehicle started almost two decades ago with the launch of an electric three wheeler Vikram SAFA developed by Scooters India Ltd. The company could sell around 400 vehicles that ran on a 72 V lead acid battery. Mahindra and Mahindra Ltd. launched its first electric-three wheeler in 2001 in the name of 'Bijlee'. Bharat Heavy Electricals Limited (BHEL) also introduced an electric bus using 96 V lead acid battery pack, however the project didn't pick up due to the product quality inconsistency and cost. In 2001, a Bangalore based company 'REVA' entered the Indian EV sector in the four wheel segment and could sell more than 1500 vehicles.

The initial success and failures led to entry of players from the two wheel segment to produce bikes and electric two wheelers. Limited commercial successes achieved by few companies in the three wheel segment attracted many players who manufactured three wheelers largely for use in urban centres. The e-rickshaws, as defined in the recently amended Indian Motor Vehicles Act, are those vehicles that run on battery power of no more than 4 KW and are meant to carry not more than 4 passengers and luggage of 50 kg covering not more than 25 kms per trip. It is estimated that more than 700000 electric three wheelers are operating on India roads and their numbers are steadily increasing. However, most of the e-rickshaws that are plying on India roads run on lead acid batteries; recently some seen on the roads use the lithium ion batteries. However, future electric rickshaws running on lithium batteries can create significant opportunities of exports in newer markets particularly in South Asia and Africa.

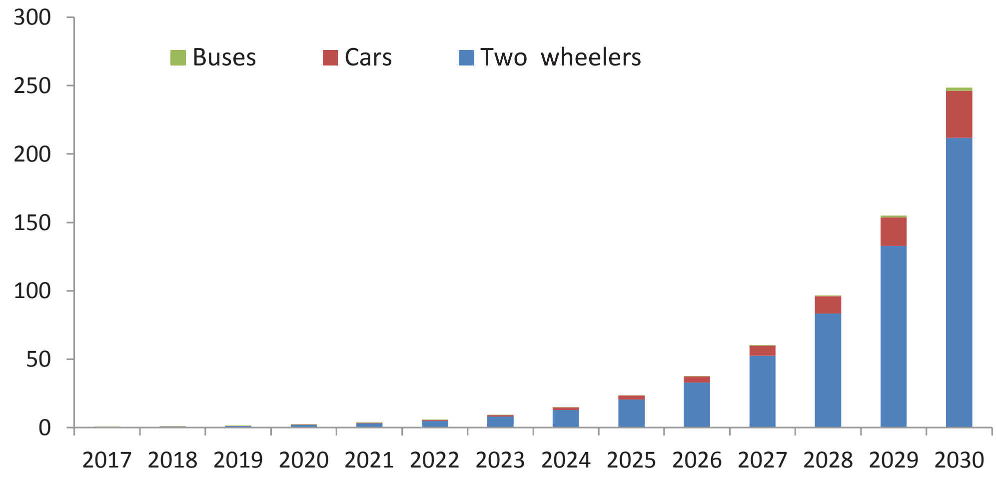

Figure 2: Estimated increase in electric vehicle production in India for selected segments (in million)

Source: TERI calculations

In the 4 wheel segment, Mahindra & Mahindra, launched E2O couple of years ago, with a two battery variants of 48 V and 72 V, and later launched the Mahindra Verito in the sedan segment. Tata Motors also entered in the electric car segment with the introduction of the Tata Tigor with a battery capacity of 72 V and a maximum power of 30 KW.

In the commercial vehicle segment there have been recent introduction of electric buses in existing public transport fleet in selected states. Himachal Pradesh has been the first state in India to operate electric buses on selected routes. Cities like Ahmedabad, Bengaluru, Mumbai, Hyderabad and Kolkata among others have already floated tenders for procurement of buses which would be in operations soon. In recent months, various state governments have demonstrated significant interest in rolling out e-bus tenders. The public procurement of electric vehicles is expected to bring initial scale effect to original equipment manufacturers (OEM) thereby helping them generating volume and reduced prices for consumers. There are projects that are also running at pilot level in the freight segment.

In a recent communication by the Ministry of Road Transport and Highways (MoRTH), Government of India and NITI Aayog, the government targets to increase the share of electric vehicles from its current level of less than 1 percent to nearly 30 percent by 2030[5] while the share of electric buses could be expected to reach as high as 100 percent. This implies that by 2030, the total number of electric two wheelers to be on Indian roads would be 211 million, while for cars and buses it will be around 34 million and 2.5 million respectively. A year wise estimates of the share of electric vehicles across the different category of vehicles on India roads is presented in figure 2.

1.4 Potential challenges related to increased demand for resources in EV sector

There are quite a number of challenges that may impede the growth of electric vehicle sector in India. These include high manufacturing costs and price competition with their ICE counterparts, lack of sufficient charging infrastructure, and low performance and high cost of batteries. Minimal scope for innovations in technology due to limited research and development capabilities is another challenge the electric automotive industry in India is grappling with. The performance standards of electric vehicles are still not comparable with those of conventional vehicles with respect to range, speed, power etc. At the same time India doesn't have a clear policy on electric vehicles and promotion of alternate fuels in the transport sector. Lack of consistency in government policy has made it difficult to predict the future of the electric automotive market.

Further, one of the challenges that have not received enough attention is the growing requirement of different materials for manufacturing EVs and the absence of integrated assessment of resource requirement for EVs. EVs require substantial amount of newer materials (particularly, lithium, rare earths, flame-retardant and thermoplastic materials) which may not be available in abundance or may be geologically concentrated and often experience price volatility. This criticality of raw material may become a major challenge and calls for developing strategies to ensure steady and secured supply of raw materials at affordable prices. The existing studies on availability of raw materials off late have been confined to only assessment of limited resources that find application in manufacturing selected components. Given that EVs, require many newer materials with enhanced performance over their predecessors, particularly for manufacturing batteries and powertrain, it is important to note that assessment of these newer resources is also done in a comprehensive manner and effective sectoral strategies and national policies for resources security are designed to be able to move on our ambitious plans.

If we take the example of lithium which is considered to be one of the most important resources going into manufacturing of the batteries in electric vehicles, the resource availability is largely confined to Chile, China, Argentina and Australia with their share in global reserves of lithium over 95 percent[6]. Cobalt, another material that goes into manufacturing batteries for electric vehicles, is largely mined in Democratic Republic of Congo (DRC), and has a highly fragile supply chain as can be seen from the more than doubling of the global cobalt prices between 2015 and 2017.

Permanent magnets that are used in manufacturing synchronous motors are largely manufactured from rare earth elements. However, China plays the role of a quasi-monopolist in the international rare earth market, accounting for more than 90 percent of the supply. Although China lost the famous case in 2014,

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5 https://www.financialexpress.com/auto/car-news/government-finally-wakes-up-sets-a-realistic-goal-of-30-electric-vehicles-by-2030-from-existing-100-target/1091075/

6 https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2018-lithi.pdf

of export quota that it had imposed on its exports to Japan, the growing demand of rare earths within China itself in the high tech industry and in particular for its target of making 2 million electric vehicles by 2020, may result some reversal in recent trend in prices in the coming years[7]. India being highly import dependent on these resources, their procurement will have significant impact on the exchequer.

Given the complexity and fast evolving scenarios in EV technology across different vehicle categories, it calls for a detailed assessment to address the issues. The European Union supported resource efficiency initiative (REI) study will try to address the following questions and suggest essential elements of a roadmap for creating a resource efficient EV sector in India.

- What are the various materials that will be required for manufacturing electric vehicles in India?
- What materials have the largest potential for achieving material use efficiency in the EV sector?
- How are the Indian OEMs placed to adopt the disruptive changes in the technology adoption?
- What would be the challenges with regard to accessing key materials in the sector?
- What best practices in the form of closed loop resource management of the materials exist in India and abroad?
- How would the issue of circularity and product standards and end of life management be addressed through existing and new policies?
- What would be the essential elements of a resource efficient EV policy roadmap for India?

7 www.mdpi.com/2075-163X/7/11/203/pdf

2. Estimating material requirement for EVs in India

An electric vehicle uses a lot of newer materials compared to their ICE vehicles counterpart. While the body of an electric vehicle is mostly made up of steel, but with an aim to make these vehicles lighter in weight, many light weighting materials are also used that include aluminium, plastics, synthetics and rubber among other materials. The drive motor system is an essential part of EVs as it converts the electrical energy into mechanical energy. This consists of an electric motor, invertor, convertor, power distribution unit (PDU), and charger. The traction batteries are those that are used for the propulsion of any type of electric vehicle are are mostly nickel-metal hydride (NiMH) or Lithium Ion (LIB) type. Since Lithium is the lightest solid element and possesses the highest oxidation potential, it carries higher energy density compared to the standard lead acid and NiMH batteries, thus making it the preferred material among battery manufacturers. The essential components that have been considered for assessing material consumption in an electric four wheeler is presented in figure 3.

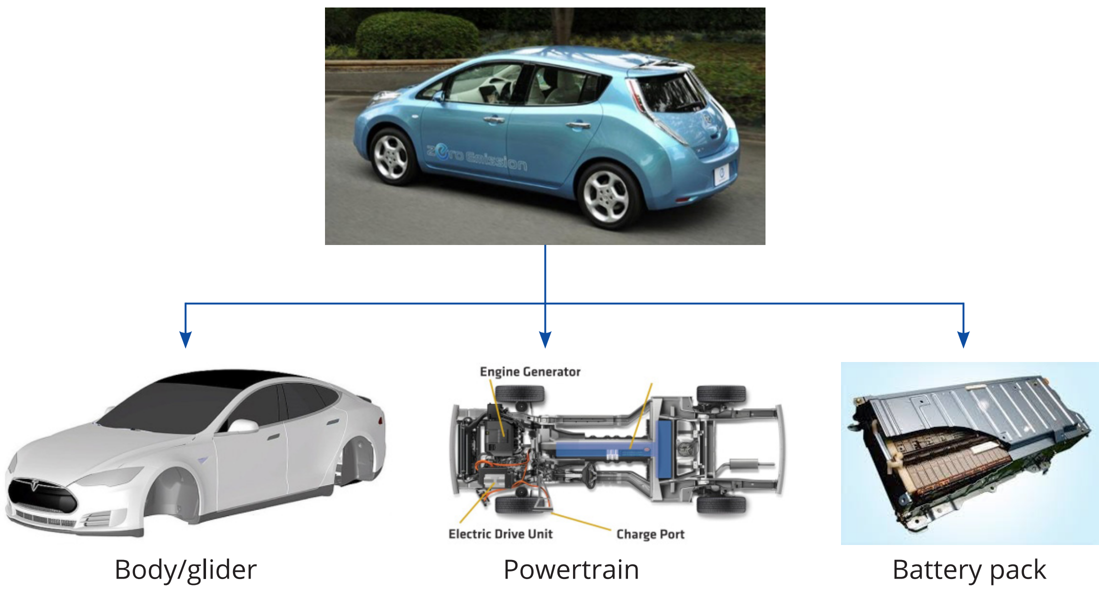

Figure 3: Key components of electric vehicle

The following sections briefly describe the functions of these key components, and the materials that go into manufacturing these components. Due to limited penetration of electric four wheelers in India, manufacturing of these components in India is almost negligible currently and hence, the material requirement for manufacturing these components have been largely based on literature review as well as interactions with selected industry and subject matter experts. With the number of EVs manufactured domestically to rise in the coming decades, the production and hence consumption of materials will peak up significantly in India.

2.1 Traction battery and materials

Battery forms the source of power for electric vehicles. Lithium ion batteries have emerged has the key element for manufacturing batteries. These batteries use metal compound powders coated on aluminium foil as key cathode materials. These may include Lithium cobalt oxide ($LiCoO_2$), Lithium manganese oxide ($LiMn_2O_4$), or Aluminium doped $LiCoO_2$. $LiCoO_2$ has one of the highest energy density and are used in modern electronic devices. The battery consists of a cobalt oxide cathode and a graphite carbon anode. However, these batteries have relatively lower life and low thermal stability and limited load capabilities (specific power)[8].

Li-manganese may have less specific energy than Li-cobalt however design flexibility can help in improved battery life, specific power or high capacity. Further this chemistry is cheaper than some of the other options currently available. Lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or NMC) is a very good cathode material. However, due to high cost of cobalt, manufacturers are moving away from cobalt systems toward nickel cathodes. Nickel-based systems have higher energy density, lower cost, and longer cycle life than the cobalt-based cells but they have a slightly lower voltage. Finally, $LiFePO_4$ (LFP) forms one of the key cathode materials which are commercially available. These types of batteries have good safety with enhanced life, although the specific energy is relatively less compared to other chemistries and self- discharging may be high.

Manufacturers of lithium batteries largely use graphite coated on copper foil as the key anode material. There are however some application of amorphous carbon or lithium titanate as cathode materials. However, the latter is mostly used for stationary applications due to its low specific energy. Newer materials with higher capacities in the form of composites like C/Si, Si alloys, and non-Si alloys are at research phase stages. Lithium hexafluorophosphate ($LiPF_6$) is mostly used as the conducting salt in the battery. Newer salts are being explored to improve electrical conductivity in the batteries.

Finally the battery and thermal management is indeed complex. The system is responsible for continuously monitoring the performance of the battery and accordingly adjusting it to match the usage and the ambient condition. Further there are electronic components of the battery pack that may include switches, contactors and fuses that contain copper, aluminium and other materials. For a four wheeler in the hatchback segment, the battery and associated components on an average weigh in the range of 100 kg to 130 kg.

The share of materials by weight in traction batteries is presented in the figure 4.

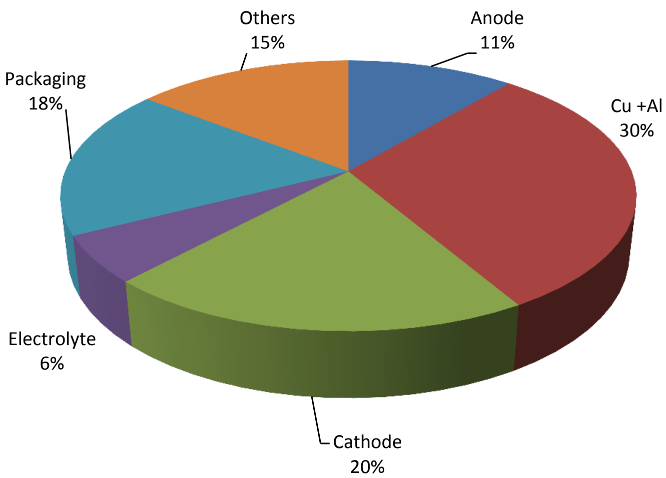

Figure 4: Material composition of traction batteries (by weight percentage)

Source: Elwert, et. al. (2016) and inputs from discussion with subject matter experts

8 http://advances.sciencemag.org/content/3/5/e1602427

2.2 Electric Drive Motors

The electric drive train is another major component in an electric vehicle. It converts the electrical energy into mechanical energy. Challenges and issues associated with its manufacturing include material availability and ensuring of cost competiveness (particularly for rare earth elements). This can be addressed through material selection, product design, optimal functional efficiency, etc. There are continuous efforts in improving electric motors using newer materials that do not compromise with operational efficiency. Some of the alternate technologies that have been tested include reduced NdFeB (Neodyium iron boron) magnet, ferrite permanent magnet, copper rotor induction, wound rotor synchronous, switched reluctance motor. Table 1 presents efficiency parameters of these different types of motors.

Table 1: Electric motor technologies having limited or no use of rare earths.

Motor technology	Reduced NdFeB magnet	Ferrite permanent magnet	Copper rotor induction	Wound rotor synchronous	Switched reluctance Motor
Peak power	80 kW	80 kW	50 kW	50 kW	75 kW
Peak efficiency	98%	96%	96%	96%	97%
Active material cost per kW	$2.78/kW	$1.93/kW	$2.88/kW	$2.88/kW	$1.57/kW
Torque density	15 Nm/kg	11 Nm/kg	10 Nm/kg	10 Nm/kg	15 Nm/kg

Source: Widmer et.al (2015)

However, the real challenge remains in terms of accessing relevant information with regard to material specificity, weights and even sometime performances. Regarding the material composition, electric motors mostly consist of aluminium, cast iron, copper, steel and NdFeB magnets since till date permanent magnet motor is the most common propulsion types in EVs.

NdFeB magnets contain about 30 percent of rare earth elements, mainly neodymium and dysprosium with small amounts of terbium and praseodymium. Magnets applied in synchronous motors often consist of up to 10 percent of dysprosium, which helps in improving coercivety and , temperature tolerance.

Apart from the motor, the other key components (presented in figure 3) include inverter, converter, PDU and charger. The inverter converts the direct current (DC) of the battery to alternating current (AC) for electric motor operation. The DC voltage converter supplies power for on-board electrical system using low voltages. However, certain EV concepts have been developed that provide additional DC converter which converts the battery voltage to a higher voltage before converting it into AC for the electric motor using a downstream inverter. The power electronics also have printed circuit boards with other control electronics equipment. Typically a vehicle with 20 kW of power is estimated to weigh between 40 to 60 kg.

The share of materials by weight in electric drive motors is presented in the figure 5.

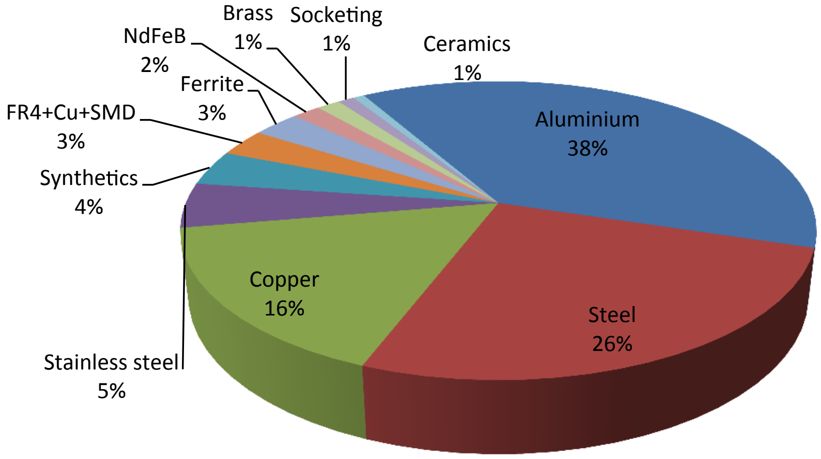

Figure 5: Material composition of electric drive motors (by weight percentage)

Source: Elwert, et. al (2016), discussion with subject matter experts

2.3 Glider

Steel has remained a major material for the body of an automobile because of its structural integrity and ability to maintain dimensional geometry throughout the manufacturing process. In response to increasing demands for more fuel efficient cars, the past ten years have seen changes in the composition of materials used in automobiles. Most of the original equipment manufacturers (OEMs) are developing multi-material strategies for building body in ICE vehicles and the same thinking is applicable for EVs. Companies are using a mix of ferrous and non-ferrous metals and plastics. Uses of iron and steel have come down over the years and have been replaced by plastics and aluminium. The decline in steel used in automobiles is partly due to the use of better and more compact steel components in recent years, particularly the use of high strength steel plate (High-Tensile Steel). Its use is rapidly increasing as a means to reduce car body weight; in some types of automobiles, high tensile steel constitutes more than 50% of the car body weight. Aluminium and plastics are also valuable materials that are used in the body, not only for their lighter weight, but also because of their inherent corrosion resistance (GIZ, 2016). Tesla Model S body and chassis are manufactured mostly using aluminium. Being lightweight material, it helps in maximizing the range of the battery beyond that of other EVs. The total amount of aluminium used in the car is 190 kg that constitutes to somewhere 8 to 10 percent of the vehicle weight.

The share of materials by weight in gliders is presented in figure 6.

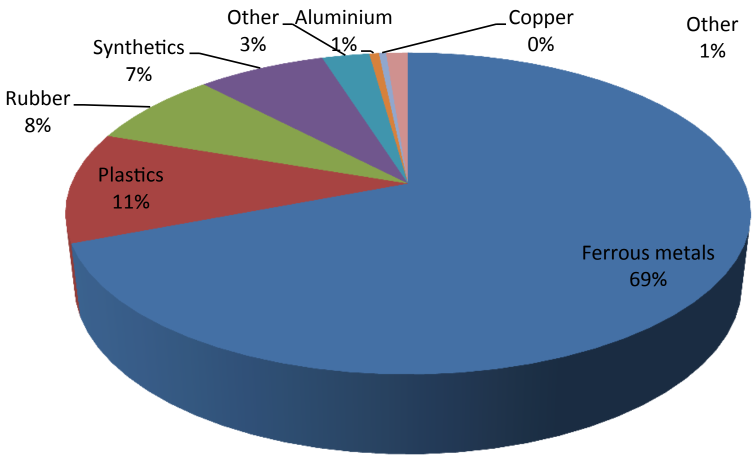

Figure 6: Material composition of glider (by weight percentage)

Source: TERI estimates

2.4 Estimated consumption of materials for manufacturing electric cars in India

The estimated material consumption is based on the projected production of the electric cars in India. For this, we use the estimates on number of registered vehicles in India as presented in chapter 1. Assuming that 70 percent of the vehicles are in the hatchback segment, the annual production of electric cars (hatchback) will increase from its estimated current value of 30000 to almost 10 million by 2030, with a cumulative registration of 24 million by 2030. The reason for considering hatchback is to ensure equivalence with the drive train power and the battery capacity as considered for the exercise and described in above. This big change in manufacturing electric cars will drive up the consumption of different materials.

Since the volume of production of electric vehicles that run on lithium batteries are currently limited, the demand for related materials is currently insignificant. However, consumption of materials by 2030 will increase significantly from its current level of 0.03 million tons to 11 million tons. Ferrous metals will contribute to 53 percent of the total estimated demand, followed by 17.4 percent of plastics and synthetics, 2.5 percent of aluminium and 7.2 percent of copper. Figure 7 presents the materials that will be required to meet the cumulative demand for manufacturing nearly 24 million vehicles (hatchback) by 2030.

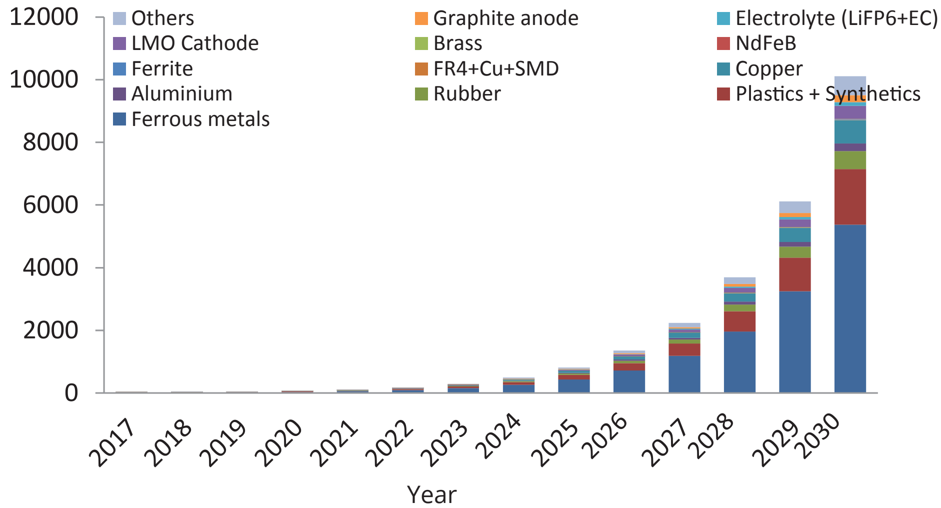

Figure 7: Material requirement for various four wheel electric cars (hatchback) in India till 2030 (thousand tons)

Source: TERI calculations

With no change in material composition in three major components (i.e. glider, drive train and battery pack) of electric vehicles, the estimated demand for ferrous metals would increase from 0.016 million tons to 5.3 million tons. Estimated increase in consumption of plastics and synthetics would be nearly 1.8 million tons, while the increase in copper would be around 0.8 million tons by 2030. Requirement of neodymium, iron, boron fused permanent magnets would increase from 28 tons to almost 9000 tons, while lithium based cathode and electrolyte salts would increase from 2000 tons to 525000 tons.

2.5 Understanding the material availability and need for RE measures for EV sector

2.5.1 Permanent magnet motors

Many critical materials that are used in manufacturing EVs are mostly imported by India. For example rare earth materials for non-defence applications are currently imported to India in finished form. Rare earths are present in different minerals and are recovered as by-products from phosphate rock and from spent uranium leaching[9]. Indian Rare Earths Ltd (IREL), a public sector enterprise, under the administrative control of Department of Atomic Energy (DAE) has been processing monazite and has also recently set up a plant in Odisha for processing 10,000 tonnes of monazite per annum. However, this is largely used for defence application. India mostly imports rare earths as monazite which is the principal source of rare earths in India, contains uranium and thorium which are prescribed substances and controlled under Atomic Energy Act, 1962.

Between 2009 and 2017, India's import of rare earth has increased nearly four times from INR 0.7 billion (Euro 8.5 million) to INR 2.4 billion (Euro 33 million)[10]. In terms of quantity, the average imports in recent years are reported to be around 400 to 500 tons[11]. Absence of adequate recovery and inefficient recycling, combined with lack of use of newer/substitutable materials will lead to increased imports. The estimated demand of rare earth magnets for manufacturing motors in electric cars (hatchback), assuming no change in technology and efficiency of motors, will be approximately 9000 tons by 2030. This is approximately 150 times the current import of the rare earths by India. Further, the estimated import demand will increase further if its application in other forms of electric vehicles (e.g. two-wheelers, buses, etc.) is also taken into consideration. Given that majority of the rare earths are produced in China, recent imposition of mining quota and consolidation in mining operations, it is predicted that there will be lesser supply flexibility and mounting pressure on prices. This development in the international market of rare earths will significantly increase the import cost and has the potential to nullify the anticipated benefit arising from reduced import of crude oil.

Further the environmental footprint of rare earth extraction is quite high. Studies have confirmed that that the extraction and refinement of oxides of rare earth has serious environmental consequences. Research based on life cycle assessments (LCA) in automotive industry conclude that permanent magnets NdFeB may be substantially damaging when compared to other materials commonly used in electrical equipments. NdFeB magnets may be responsible for as high as 25 percent of the material processing related GHG emissions, although there share of weight in motors may be very less.

2.5.2 Materials for battery manufacturing

Lithium has emerged as a key resource that goes into manufacturing batteries in electric vehicles. For lithium batteries in electric vehicles, as presented in the previous sections, cathode materials largely include minerals such as aluminium, cobalt, lithium, manganese, and nickel, with anode made up of graphite. Primary availability of many of the materials, that go into manufacturing batteries, like lithium, cobalt, nickel, copper used in conductors, cables, and busbars is limited. Value of import of lithium (e.g. Lihtium oxide, hydroxide, carbonates and pure metal) has increased from INR 2 billion (Euro 25 million) to nearly INR 15 billion (Euro 188 million) between 2010 and 2017, increasing at a compound annual growth rate of 30 percent. Import of cobalt has also increased in recent years[12]. While import of cobalt ore and concentrates have fallen over the years, India's import of cobalt salts and materials like cobalt oxides and hydroxides, commercial cobalt oxides, and other articles of cobalt has more than doubled between 2010 and 2016. Specifically, India's import of processed cobalt salts and materials increased from INR 0.5 billion (Euro 6.2 million) to INR 1.1 billion (Euro 13.8 million), between 2011 and 2018.[13]

Although certain studies reveal that there are enough lithium resources available globally to meet the growing requirement and in particularly for the energy storage sector, the challenges that remain for India is largely with regard to trade supply chain, availability at affordable prices and its many competing

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9 https://ibm.gov.in/writereaddata/files/12272016154439IMYB2015_Rare%20Earth_27122016_Adv.pdf

10 Based on Exim Import data analysis, Ministry of Commerce, Government of India

11 http://dae.nic.in/writereaddata/parl/budget2015/lsus4616.pdf

12 https://ibm.gov.in/writereaddata/files/12092016171712IMYB2015_Cobalt_09122016_Adv.pdf

13 Based on Exim Import data analysis, Ministry of Commerce, Government of India

applications among others. Further, India, has not made any substantial efforts to ramp up domestic availability of these scarce minerals. There are also investments risks foreseen, possibly due to absence of long-term policies.

Thus India is highly import dependent for these minerals and at times has had to struggle to acquire lithium and cobalt assets abroad, along with other resources, to ensure security of their future supply. China has taken a lead in the race towards acquiring assets of these mineral resources, similar to the way it did through investment abroad in oil and gas sectors.

2.5.3 Material recycling

Currently end of life vehicles in India usually end-up in the informal sector. In the absence of any appropriate strategy, the future EVs will also be dismantled in the informal sector leading to improper recycling and possibly down cycling (use of recovered valuable materials in inferior applications). Given that most of the critical resources are imported, unscientific handling and recycling will lead to economic losses and environmental hazards. In typical vehicle scrapping sites, dismantling (stripping vehicles and scrap metals and recovering all sorts of parts) happens using crude ways, after which the recovered auto components are either refurbished and sold in the second-hand market (directly to end use consumers or traders of second-hand parts) or the material resource is recovered from these components and sent for recycling (in many cases for down cycling). With Original Equipment Manufacturers (OEMs) introducing new fleet of vehicles to meet the new emission norms and design specifications, this implies that lesser number of components can be reused. This would also lead to more focus being on recovery of materials from the used components.

2.6 Conclusion

India's ambition towards an electric mobility economy by 2030 was announced in 2016. Further, in a recent communication by the Ministry of Road Transport and Highways (MoRTH) and NITI Aayog, the government announced its target of increasing share of electric vehicle (EV) from its current share of less than 1 percent to nearly 30 percent by 2030. This implies that by 2030, the estimated number of Plug-in electric two wheelers on Indian roads will be more than 200 million, and the electric cars and buses would be about 34 million and 2.5 million respectively. It is important to recognize that despite many economic and environmental benefits of EVs and hybrid vehicles, there are challenges with regard to material availability and affordability used in its manufacturing. Going by the current lithium battery chemistry and no further changes in technology in powertrain manufacturing in the four-wheeler hatchback segment, the total demand for materials is estimated to increase from 0.005 million tonnes to nearly 1.6 million tonnes. Many of the resources like copper, lithium, permanent magnets and related materials and components, are heavily imported by India and the cost of import has been increasing over the years, which can pose severe resource security concerns for the country.

3. Opportunities and Best Practices across the value chain

The interplay of technology and mobility is expected to bring a paradigm change in our mobility patterns. Considering the strong emphasis that is being laid by the government on EVs, India has a huge potential of becoming one of the largest EV markets. This section discusses some of the best practices across the value chain that may require scaling up for closing the loop for the materials embedded, leading to manufacturing of resource efficient electric vehicles.

Having looked at the material composition of an Electric vehicle, it appears that non-fuel minerals are key inputs to the manufacturing process and are fundamental ingredients in the current and emerging technologies and products. Strong growth in material demand is expected as global penetration of electric vehicles increases. In this section we look at the use of permanent magnets that brought about a step change in electric motor performance and the opportunities for using recycled material[14] for manufacturing EV batteries.

3.1 Neodymium Iron Boron magnets and electric traction motors

Neodymium is a member of the family of materials known as Light Rare Earth Elements (LREE). These magnets offer such high levels of performance owing to their very high Maximum Energy Product compared to other magnetic materials. The key ingredient allowing NdFeB magnets to operate at high ambient temperatures is Dysprosium; a Heavy Rare Earth Element (HRE) which is added to NdFeB in order to increase the high temperature coercivity (ability to withstand demagnetisation) of the magnets above 100 °C. Although the performance benefits of these NdFeB permanent magnets are undisputed, but there are concerns over the availability, supply and the prices of these rare earth materials. However it has been established that the traction motors without NdFeB materials would have significantly lower costs. Figure 8 shows material costs in a 30KW traction motor with and without rare earth magnets (Widmer, J. et.al 2015).

Reducing the use of NdFeB magnets would have significant environmental benefits too as they are responsible for 25 percent of the material related greenhouse gas emissions, despite being less than 5 percent of the motor by mass (ibid). It is therefore worthwhile to consider the alternatives replacing or minimizing the used of rare earth permanent magnets.

Hitachi Metals have developed magnets with reduced Dysprosium content as compared to conventional NdFeB materials, and without a reduction in their high temperature coercivity. These magnets are manufactured using a new process, which involves the diffusion of Dysprosium into the magnet material in place of direct alloying. Other interventions are targeted towards reducing the grain size in the magnets to nanoscale with the expectation that this will significantly increase the Maximum Energy Product of the material (Widmer, J. et.al 2015).

14 Countries have been trying to reduce their dependence on rare earths and to diversify sourcing to cut its reliance on China, which controls more than 90 percent of global supplies and has moved to restrict production and exports.

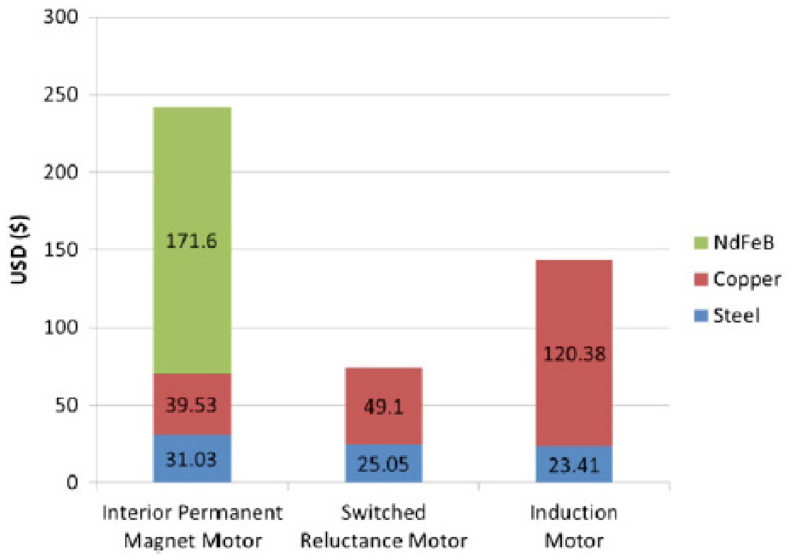

Figure 8: Material costs in a 30KW traction motor with and without rare earth magnets

Source: Widmer. J et.al. 2015

Toyota Motor Corporation had developed a magnet which replaces around 20 percent of the neodymium, a rare earth metal used in the world's most powerful permanent batteries, with more abundant and cheaper lanthanum and cerium, each of which costs around $5-$7 per kilogram. This could tame the cost of producing electric cars and reduce the risk of a supply shortage of materials needed for their production. Automakers including Honda Motor Co. Ltd have also found ways to eliminate dysprosium and terbium, which cost around $400 and $900 per kilogram, respectively, from magnets by increasing the amount of neodymium, which costs around $100 per kilogram (Economic Times, 2018). For use in the drive motors of electric vehicles, neodymium magnets must have high heat resistance properties as they are used in a high temperature environment. Adding heavy rare earth (dysprosium and/or terbium) to the neodymium magnets has been a conventional method to secure such high heat resistance.

Honda Motors has joined hands with Daido Steel for practical application of a hot deformed neodymium magnet containing no heavy rare earth which still has the high heat resistance properties and high magnetic performance required for use in the driving motor of a hybrid vehicle. Daido Electronics has been mass-producing these rare earth free magnet from neodymium using the hot deformation method, which is different from the typical sintering production method for neodymium magnets.

The hot deformation method is a technology that enables nanometer-scale crystal grains to be well-aligned in order to realize a fine crystal grain structure that is approximately ten times smaller than that of a sintered magnet, which makes it possible to produce magnets with greater heat resistance properties. Honda has also developed a new drive motor for hybrid cars that also has a reshaped rotor that helps in optimising the flow of the magnetic flux of this new magnet[15].

In 2018, it is predicted that some 49.8 million metric tons of e-waste will be generated globally (Statista, 2018). Various technologies are currently being investigated for recovering rare earth and its potential usage in permanent magnets.

15 https://www.materialstoday.com/metal-processing/news/daido-steel-and-honda-use-rare-earthfree-magnet/

3.2 Designing for high torque densities with less rare earth magnetic material

It is important to ensure that motors with alternate materials can withstand demagnetizing fields, weakening and under short circuit conditions. 'Salient' rotor structures using smaller amounts of magnetic materials are widely used in hybrid motor technologies. For instance BMW i3 electric vehicle; uses a highly salient rotor topology to produce 250 Nm torque and 125 kW power from just 1 kg of magnet as compared to earlier hybrid motor designs, such as that used in the Nissan Leaf, which achieves 280 Nm and 80 kW with an estimated 2 kg of magnetic materials (Widmer, J. et.al. 2015).

3.2.1 Induction motors with no permanent magnetic materials

Induction motors contain no permanent magnetic materials, instead they operate by inducing electrical currents in conductors in the motor's rotor; these currents in turn give rise to a magnetic field in the rotor and hence produce torque. Further when switched off, these motors are inert, producing no electrical voltage or current, no losses and no cogging torque. However, induction machines incur losses in their rotor conductors, which can result in total rotor losses typically two to three times higher than in a permanent magnet based motor. High rotor losses are not desirable as the rotating rotor is much more difficult to cool than the stationary stator. In practice these high losses mean not just that this type of electrical machine may be less efficient than other options but also that in operation it may quickly become overheated. However, these motors are able to produce high levels of performance using modern and appropriate vector control techniques as was in the case by Tesla motors.

Tesla Motor Corporation uses copper rotor cage in their electric vehicles as opposed to commonly used aluminium. This motor technology had proved to be highly successful for Tesla in recent years (Widmer, J. et.al. 2015). However with Model 3 Tesla has made a significant change to use a permanent-magnet electric motor instead of the AC induction motor it has used so far (Lambert, F. 2018).

3.2.2 Wound rotor motors

Integration, miniaturization and simplification were the three objectives that guided the design of this motor. In place of permanent magnets on the rotor, copper windings are used to set-up a magnetic field, with an electrical current being supplied to these rotating windings from the stationary part of the machine. This requires a mechanism for passing current from the stationary part of the motor to rotating part of the rotor. This often involves use of wireless power transfer based systems, which are similar to the wireless charging systems currently being used to charge consumer electronic devices. However these systems are currently immature (Widmer, J. et.al. 2015).

Car manufacturer Renault uses wound rotor that develops 65 kW and peak torque of 220 Nm (162 lb-ft), and features an integrated Chameleon charger in Renault Fluence and Renault Zoe. The designers have improved the electronic management of the charging process in order to reduce charging times using low-power infrastructure. With this comprehensive redesign of the inverter system, the designers have been able to improve efficiency, thereby reducing the consumption of electric energy (Green Car Congress, 2014).

Apart from the above mentioned technologies, switched reluctance motors and those replacing rare earth magnets with low cost ferrites, may prove less costly and achieve higher performance traction but these technologies are yet to be proven for application in automotive (refer table 1).

3.3 Using recycled material/ secondary resources for manufacturing lithium ion batteries

Tytgat (2013) had carried out a life cycle analysis of Lithium Cobalt Oxide based Lithium ion battery and reveals a 70% reduction in energy consumption (shown in figure 9) when lithium ion cell is produced from recycled cobalt vis-à-vis virgin raw material.

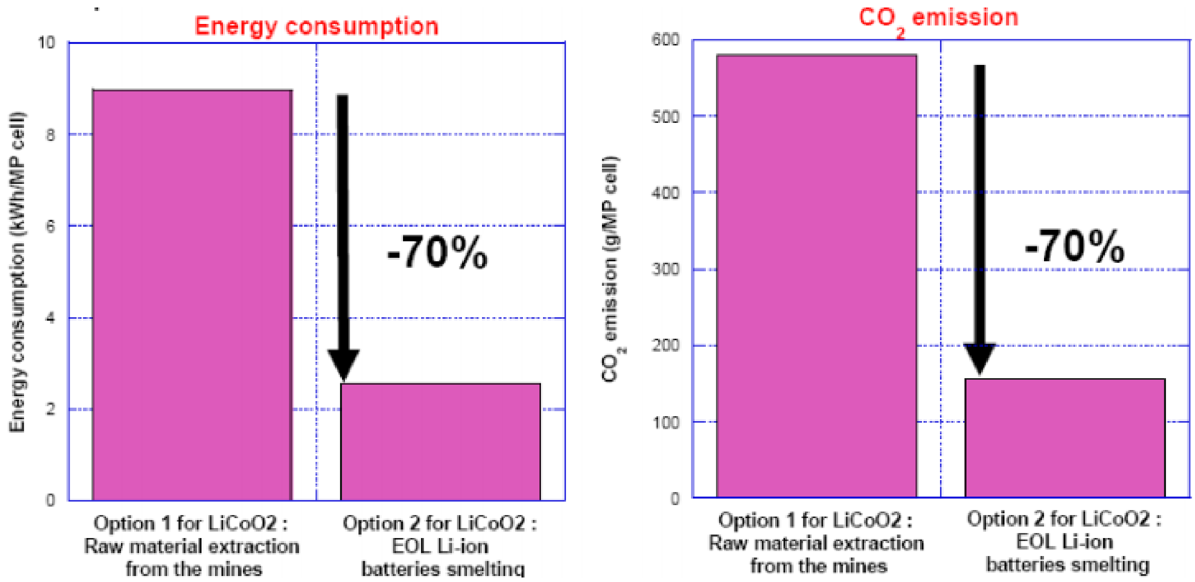

Figure 9: Environmental impact of producing Lithium ion cell from recycled cobalt vis-à-vis virgin raw material

Source: Tytgat (2013) and Umicore (2013)

The recycled lithium is more expensive than extracted lithium and currently it may not be attractive to retrieve lithium from used batteries. However, this will not be the case in the future, when recycled lithium will represent the largest cumulative source[16]. Although experts do not consider a scenario of lithium depletion[17], the question of emancipation from suppliers remains crucial. Miedema and Moll[18] assessed the supply capacity of lithium to the needed demand from the automotive industry. They concluded that undersupply can be expected in the near future, and may call for a large scale recycling of batteries. The challenge in the future is to meet the growing demand without causing price volatility and to implement early enough recycling networks to provide a capital of lithium in countries using it.

3.4 Next Generation Batteries/Innovation in Battery Chemistries

With the aim of returning Japanese manufacturers to the forefront of automotive battery technology, the four heavyweight Japanese companies -Toyota, Nissan, Honda and Panasonic have teamed up for a new research and development program to develop solid-state batteries. The Consortium for Lithium Ion Battery Technology and Evaluation Center, or "Libtec," (figure 10) is being supported by a $14 million support grant from Japan's Ministry of Economy, Trade and Industry (Koga. Y, 2018).

Solid-state battery technology is increasingly seen as the next big development in the EV sector. While lithium-ion batteries use liquid electrolytes, solid-state batteries employ a solid form of this key component, making the new batteries easier to manufacture and safer, as they do not leak. They also have fewer components, cost less, and provide higher energy than the lithium-ion batteries -- the current choice for electrics and hybrids. Libtec consortium's end goal is to jointly develop net battery technology that could support 800-km runs between charges by 2030. The shorter-term goal is to create a 550-km range pack. That's well above the range of most of today's EVs, and is around the capacity of Tesla's Model S 100D, which has a massive, heavy and costly 100-kWh pack.

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16 D. Kushnir et B. A. Sandén, « The time dimension and lithium resource constraints for electric vehicles », Resour. Policy, vol. 37, no 1, p. 93 103 (2012)

17 S. E. Kesler, P. W. Gruber, P. A. Medina, G. A. Keoleian, M. P. Everson, et T. J. Wallington, « Global lithium resources: Relative importance of pegmatite, brine and other deposits », Ore Geol. Rev., vol. 48, no 0, p. 55 69 (2012)

18 J. H. Miedema et H. C. Moll, « Lithium availability in the EU27 for battery-driven vehicles: The impact of recycling and substitution on the confrontation between supply and demand until2050 », Resour. Policy, vol. 38, p. 204- 211 (2013)

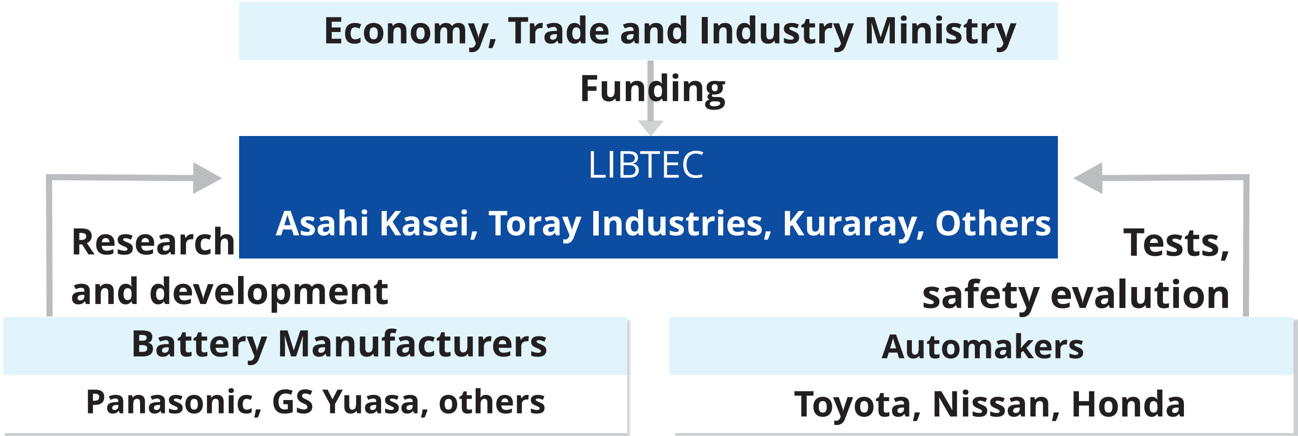

Figure 10: Public Private project to develop next generation battery

Source: Koga. Y (2018)

Solid state lithium ion technology has a real promise but this is clearly a moving target. Meanwhile other companies like BMW have also started investing in developing their own solid state designs. The company claims to have achieved a breakthrough by incorporating a high-capacity lithium metal anode in lithium batteries – creating a solid-state cell with an energy capacity "2-3X higher" than conventional lithium-ion (Lambert, 2017) (Figure 11).

EXISTING BATTERIES (Liquid)		NEXT-GENERATION BATTERIES (solid state)
Voltage limitations	Performance	Higher voltage and output
Much work required in assembly due to large number of components	Manufacturing process	More flexibility in manufacture; easier to assemble
Risk of liquid contents leaking and fire	Safety	Solid-state construction makes it resistant to catching fire
Limited use at battery tempertures of 60 C to 70 C	Operational temperature	Can operate at lower and higher temperatures
Technoligy established; efficiency improvements	Mass production technology	Mass production method not yet established

Figure 11: Next Generation batteries Vs existing batteries

Source: Koga. Y (2018)

3.5 Design of EVs

At the design stages it becomes essential to design for an elongated use phase that not only delays the death of the vehicle but allows the reuse of parts which are in working condition (and do not create any safety issues). Moreover designing for greater dismantling on effective disposal, will enhance the recovery of parts which could be used for remanufacturing of vehicles. In case of any failure to meet the recovery target, manufacturers will have to consider redesigning of the vehicle to enable easier and efficient dismantling. Also having a design of vehicles which is receptive to using recycled/secondary raw material will reduce the chances of downcycling (Arora. N et.al, 2017). This should be accompanied by focusing on high-efficiency engines and lightweight materials which take less energy to accelerate the vehicle.

3.5.1 Build a native and inherently flexible EV

Native EVs because of their architecture and body in white can accommodate a bigger battery pack, which in turn correlates with higher range. This is evidenced by the fact that native EVs have on average a 25% larger battery pack volume (relative to body in white volume, shown in figure 12) compared to non-native EVs. The reason is that the body structure can be fitted around the battery pack and does not have to be integrated in an existing architecture. This additional freedom in design typically resulting in larger batteries also leads to other potential advantages such as higher ranges, more power or faster charging. Moreover since battery technology is evolving at a faster pace, native EVs will be critical for adopting various powertrain options. For example, battery packs can house a varying number of active cells while keeping the same outer shape, and variable drivetrain technologies can allow producing rear-wheel, front-wheel, and all-wheel drive on a single platform (Mckinsey and Company, 2018).

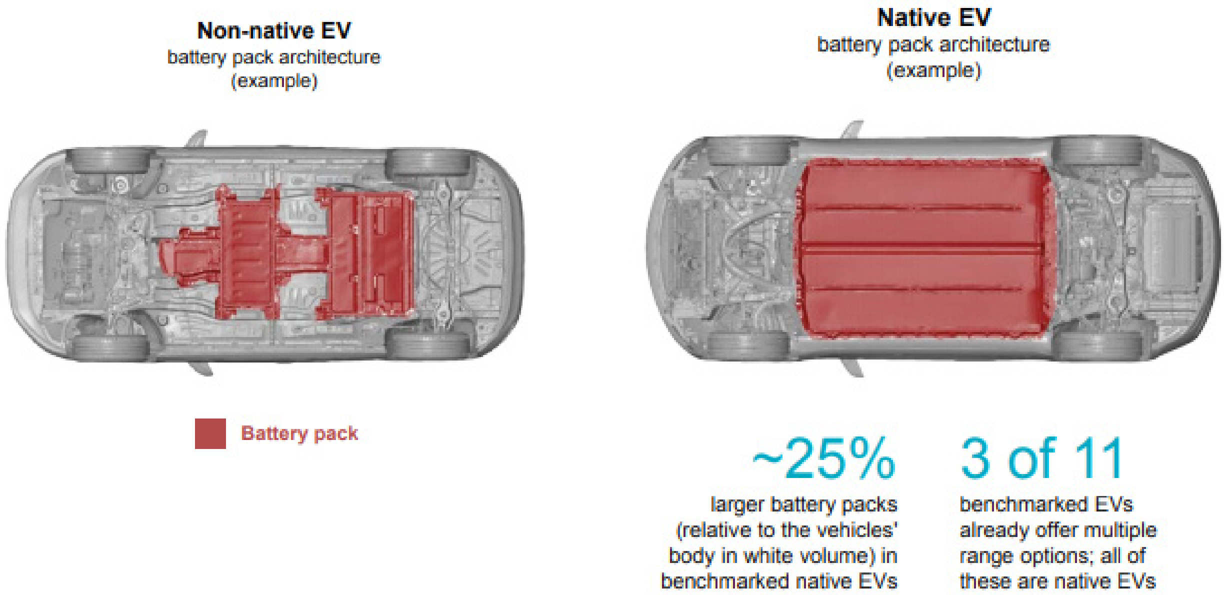

Figure 12: Native vs Non Native battery pack architecture

Source: Mckinsey and Company, 2018

3.5.2 Better EV powertrain integration

Efficient powertrain integration calls for moving many parts of the power electronics closer together and integrating into fewer modules. As OEMs continue their hunt for design efficiency, mainstreaming powertrain integration offers substantial potential in terms of raw material savings and in increasing efficiency. A good indicator for the increased level of integration is the design of the electric cables connecting the main EV powertrain components (i.e., battery, e-motor, power electronics, and thermal management modules). For instance if we look at the weight and total number of parts for these cables across OEMs and their EV models, we observe a decrease in both cable weight and number of parts in the OEMs' latest models compared to the earlier vehicles, reflecting a higher integration of more recent EV powertrain systems (as shown in figure 13).

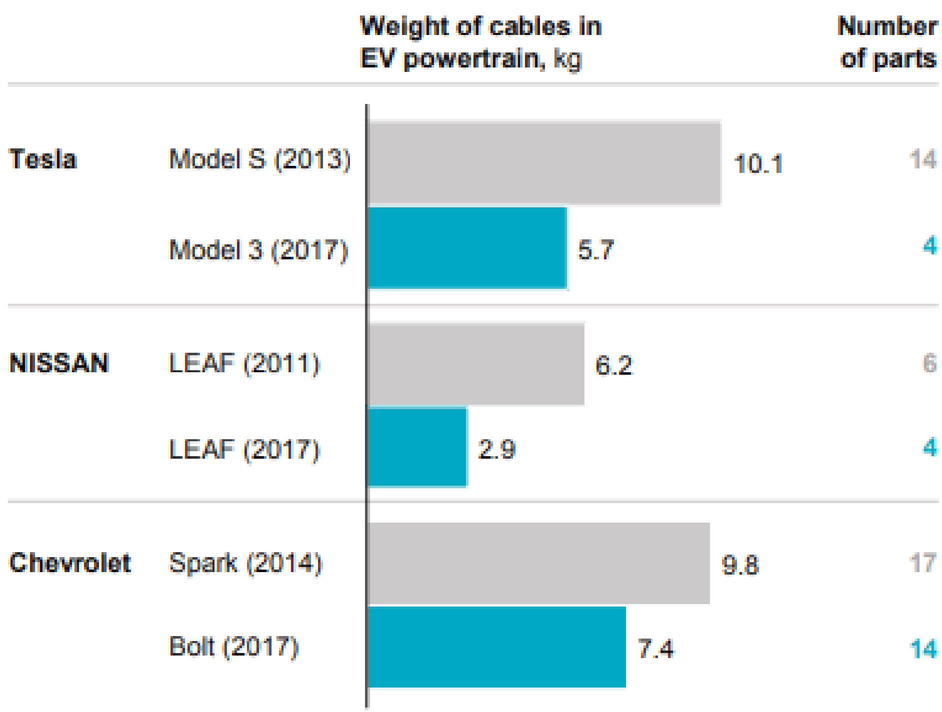

Figure 13: A comparative assessment of EV powertrain integration

Source: Mckinsey and Company, 2018

3.6 End of Life management of EVs

Effective end of life management calls for building robust reverse logistic network and recycling infrastructure. In this section, we look at some of the best practices and recent initiatives for ELV management of EVs.

3.6.1 Recycling and Reusing Worn Cathodes to Make New Lithium Ion Batteries

Less than five percent of used lithium ion batteries are recycled today and with EV sales picking up, it implies that overtime we will face huge stocks of end-of-life batteries and given the finite amount of resource available it becomes essential to invest into technologies aimed at extending the use life of components and recovering the embedded materials. Further with prices of lithium, cobalt and nickel having risen significantly in recent times, recovering these expensive materials could lower battery costs.

As a lithium ion battery wears out, the cathode material loses some of its lithium atoms. The cathode's atomic structure also changes such that it's less capable of moving ions in and out. University of California has developed an energy-efficient recycling process that restores used cathodes from spent lithium ion batteries and making them work sufficiently good enough to restore the storage capacity, charging time and batter lifetime to their original levels. The process involves harvesting the degraded cathode particles from a used battery and then boiling and heat treating them. Efforts are geared towards making new batteries using the regenerated cathodes. The new recycling process uses 5.9 megajoules of energy to restore one kilogram of cathode material whereas several other lithium ion battery cathode recycling processes consumes at least twice that energy. Currently the researchers are working towards refining this process so that it can be used to recycle any type of lithium ion battery cathode material, in addition to lithium cobalt oxide and lithium NMC with the goal to make this a general recycling process for all cathodes (Labios, 2018).

3.6.2 Copper recycling from End-of-life Electric Vehicles

Copper is in high demand for infrastructure development in emerging economies and will be one of the key materials in manufacturing of electric motors for hybrid, PHEV and EV powertrains, given the increase in the proportion of electronics in the next generation of vehicles vis-à-vis conventional ICE based vehicles. Toyota Motor Corporation along with a number of partner firms in Japan, have developed what it claims to be the world's first technology to recycle copper in wiring harnesses. According to the company, the new recycling process is able to produce copper with a purity level of 99.96 percent from the wiring found in automobiles and after stringent quality checks, the retrieved copper was successfully reintroduced into the vehicle production process. Toyota estimates as much as 1000 tons of copper can be produced annually using the new recycling process (Recycling today, 2014).

3.6.3 Reusing or recycling batteries from retired electric vehicles

Lux Research (2016) estimates that around 65 gigawatt hours of second-life battery packs will enter the market in 2035 once the first major wave of electric-car retirements begins. The report asserts that with present technology, recycling old batteries for new materials is the more economical option for creating the most value from existing materials.

Before evaluating the possible ways of recycling different materials of battery it becomes essential to

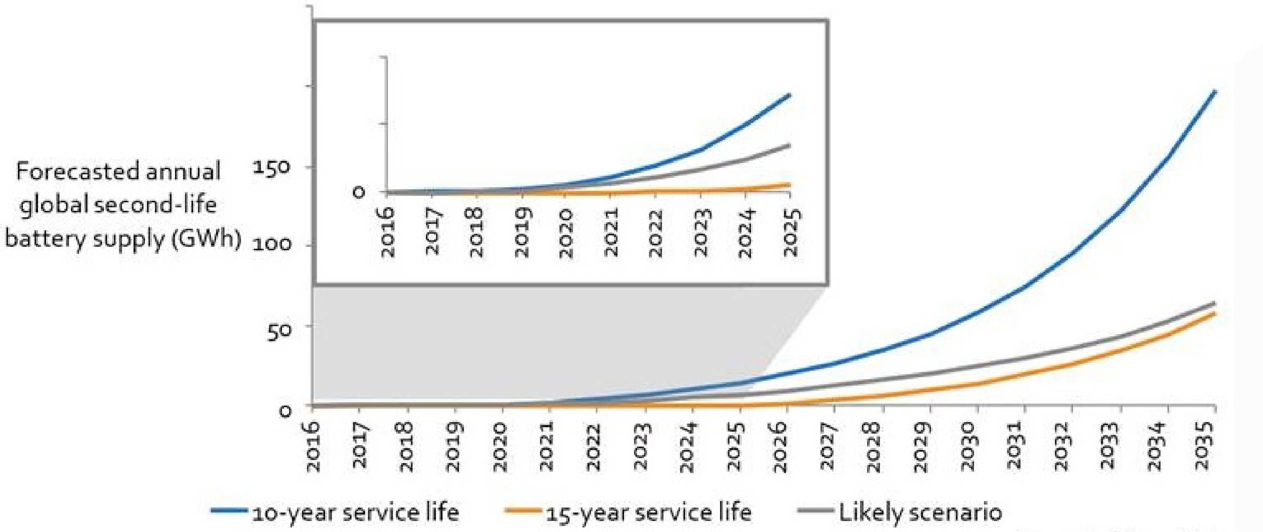

Figure 14: Recovery processes and Li-on cell materials

Source: Friedrrich. B et. al, 2017

have a qualitative look on the possible recycling processes. Figure 15 shows the fractions of assembled Li-on cells and associated recovery process.

Figure 16 shows the four key operations for a resource efficient cell recycling.

Step I involves Pre-treatment that is, methods of deactivation. The possible options at this stage include:

a) Pyrolysis: Thermal treatment of cells and packs, removal of electrolyte, plastics and halogens
b) Discharge: Immersing into conductive (salt) solution, washing with deionized water
c) Cold Vacuum: decomposition of electrolyte
d) Passivation: Immersing into liquid nitrogen

For Lithium recovery new microwave technology and low temperature thermal treatment of Lithium compounds in electrode powder is currently being looked into.

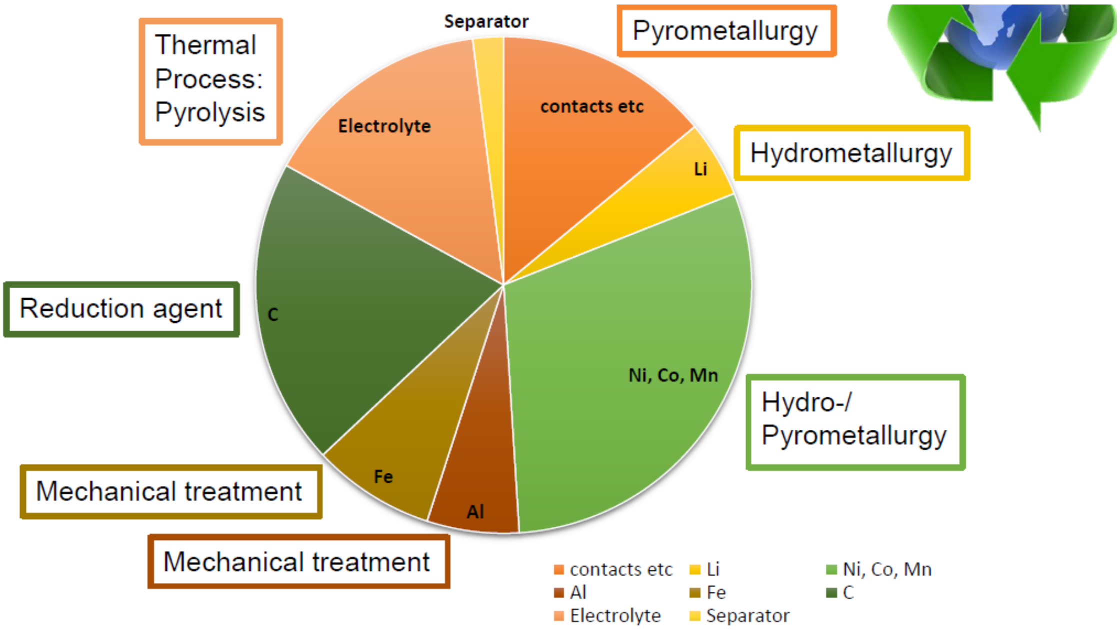

Figure 16: Recovery processes and Li-on cell materials

Source: Friedrrich. B et. al, 2017

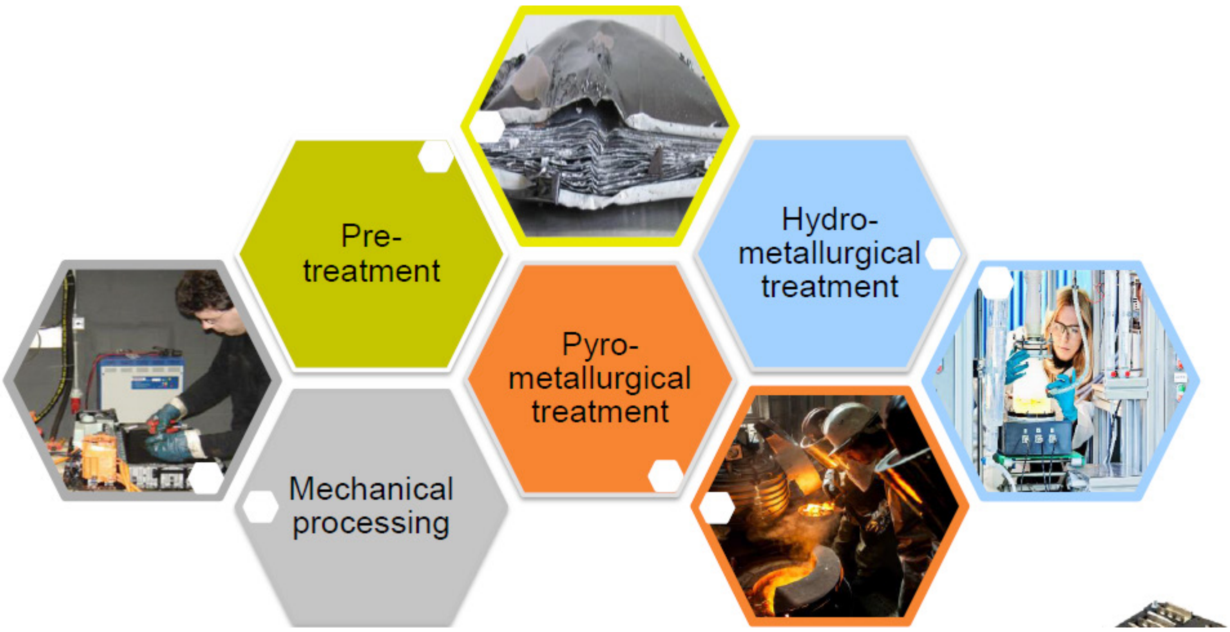

Figure 16: Resource efficient cell recycling

Source: Friedrrich. B et. al, 2017

Step II involves mechanical processing it includes comminution, separation, sorting and classification to extract a Nickel and Cobalt concentrate and directly marketable products.

Step III pyro-metallurgical treatment involves all processes aimed at recovering or refining of metals at elevated temperatures.

Step IV is the Hydrometallurgical treatment which involves extraction of metals at low temperatures by using aquatic media via process of leaching, cementation, purification, solvent extraction or precipitation, hydrothermal reaction. Leaching process when done using bacteria is called Bio-Leaching, it further uses sulphur and ferric ion as energy source.

Lux Research report (2016) evaluated the technology landscape for recycling batteries and identified potential applications for second-life batteries. Their research highlights that among all the available recycling technologies, pyro-metallurgical processing, or smelting, is the most mature and can recover key metallic elements. Mechanical processing can recover valuable cathode materials directly, and hydrometallurgical processing can be lower cost.

For instance recycling processes at Umicore has evolved overtime. It started off with using Pyrolysis and hydrometallurgy recycling processes for effective closed loop recycling of lithium ion batteries (as shown in figure 17 below). Under Pyrolysis batteries are shredded and smelted in a furnace where limestone is added as a slag-forming agent. Pyrolysis is highly effective at recovering Nickel, Cobalt, and Copper in a concentrated and relatively clean alloy, with high efficiency. Other toxic solvents are burned, providing much of the process energy and removing their toxicity. However Lithium and Manganese gets lost in the slag which is a fairly complex material and recovering lithium from the slag is only a theoretical possibility, and even then, would be expensive and inefficient. Hence from a lifecycle perspective, the process seems to provide a sub-optimal solution (Umicore, 2013).

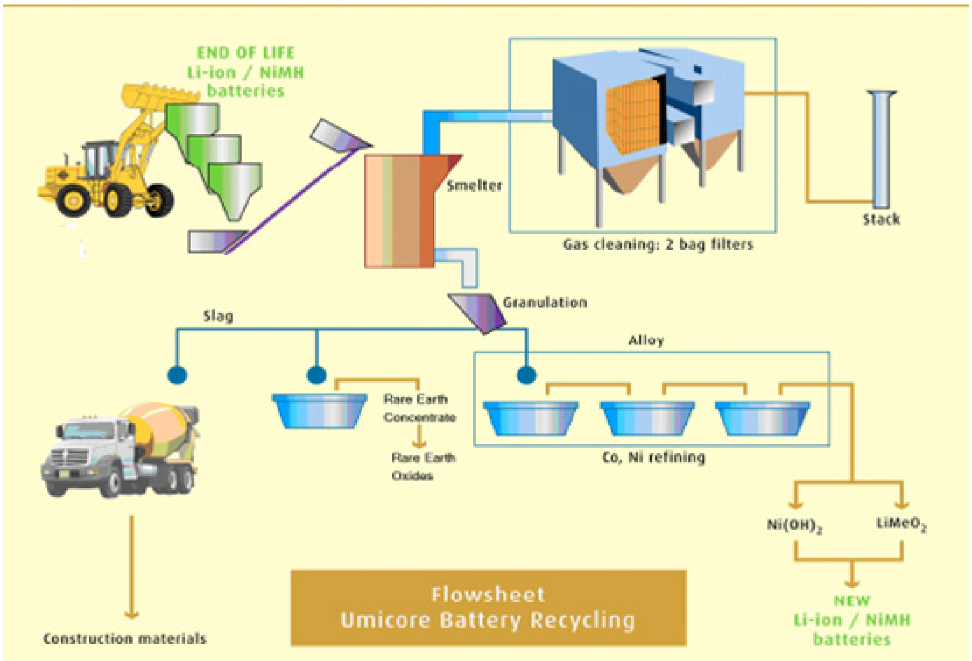

Figure 17: Umicore Process of recycling Li-ion batteries

Source: Tytgat, 2013

For hydrothermal processes, batteries are largely mechanically separated and the cathode materials are crushed after isolating and drying the cathode powder residue, the metals in it can be leached out with an acid, often a strong one such as Nitric acid, but this can also be done with more 'eco-friendly' acids such as citric acid (Li, Dunn et al 2013). The metal can then be precipitated as a pure salt. The potential revenue and costs that make hydrothermal approaches promising are highly dependent on scale.

Improving over the above sub-optimal recycling process Umicore developed a unique process combining pyro-metallurgical treatment and a state-of-the-art hydro-metallurgical process, with this process Umicore is now able to recycle all types and all sizes of Li-ion and NiMH batteries in the most sustainable way. The Umicore pyro-metallurgical phase converts the batteries into 3 fractions:

- An alloy, containing the valuable metals Cobalt, Nickel and Copper designed for the downstream hydro-metallurgical process.

- A slag fraction which can be used in the construction industry or further processed for metal recovery. The slag from Li-ion batteries can be integrated in standard Li recovery flowsheets through a cooperation with external partners. The slag from NiMH batteries can be processed to a Rare Earth Elements concentrate that is then further refined through a cooperation with Solvay.
- Clean air, released from the stack after it has been treated by the UHT's unique gas cleaning process.
- The pyro-metallurgical step deploys Umicore's unique Ultra High Temperature (UHT) technology. It is designed to safely treat large volumes of different types of complex metal based waste streams. It differentiates itself from other recycling technologies, by
- A higher metal recovery compared to existing processes and the output of directly marketable products.
- Direct feeding of the batteries, which avoids the need for any potentially hazardous pre-treatment
- The gas cleaning system, which guarantees that all organic compounds are fully decomposed and that no harmful dioxins or volatile organic compounds (VOC's) are produced. Fluorine is safely captured in the flue dust.
- Reducing energy consumption and CO2 emissions by using the energy present inside the battery components (electrolyte, plastics and metals).
- Generating close to zero waste

Umicore currently operates a pilot plant with a 7,000-tonne capacity that can process some 35,000 electric vehicle batteries a year. By recovering strategic elements like Cobalt and Lithium from end-of-life batteries, Umicore is leading the way towards a circular economy, providing solutions to the growing demand for sustainably sourced materials (Umicore, n.d).

3.6.4 Opportunities in Recycling EV Batteries

If EV growth proceeds as expected, we would have looking at about 11 million metric tons of lithium batteries entering the waste stream by 2030 as projected in figure 18 (World Economic Forum, 2017).

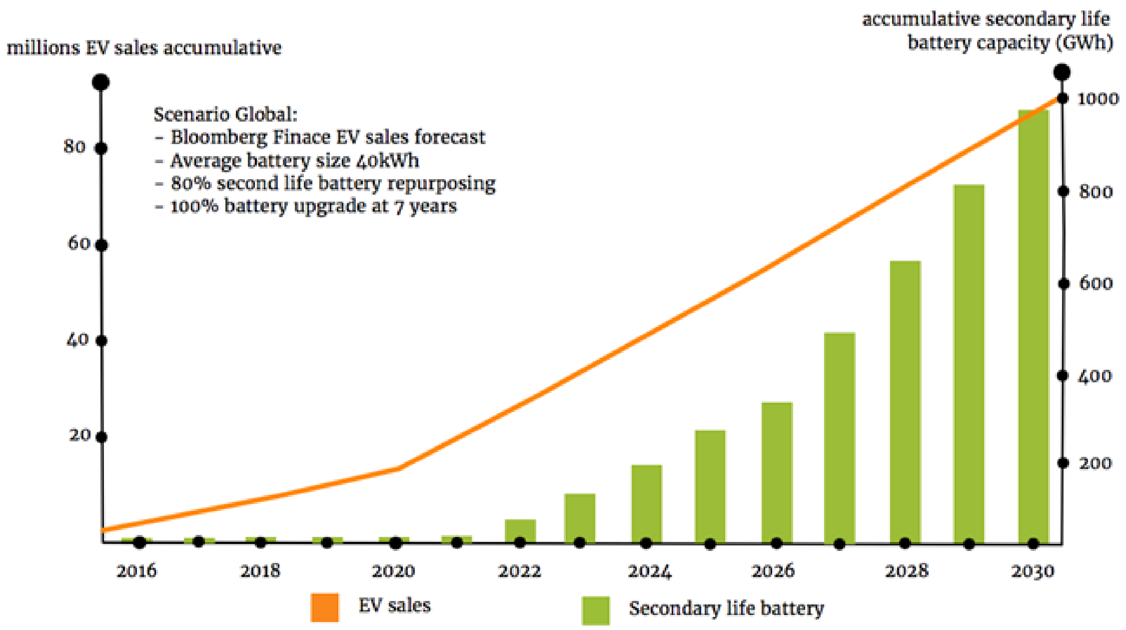

Figure 18: Global accumulative sales of EV and second life batteries

Source: World Economic Forum (2017)

Sustainable Management of End-of-life EV batteries is crucial in order to avoid pollution from toxic waste and secure a strong supply of raw materials at low environmental cost.

Though lithium-ion batteries contain none of the caustic chemicals found in lead-acid batteries, dumping them in landfills would be wasteful and could potentially pollute area groundwater. While lithium is 100 percent recyclable, currently it does not make any economic sense to recycle the batteries. Batteries contain only a small fraction of lithium carbonate as a percent of weight and are inexpensive compared to cobalt or nickel. The average lithium cost associated with Li-ion battery production is less than 3% of the production cost. Intrinsic value for the Li-ion recycling business currently comes from the valuable metals such as cobalt and nickel that are more highly priced than lithium. Due to less demand for lithium and low prices, almost none of the lithium used in consumer batteries is completely recycled. Currently, recycled lithium reports to the slag and is currently used for non-automotive purposes, such as construction, or sold in the open-markets. Recycled lithium is as much as five times the cost of lithium produced from the least costly brine based process. It is not competitive for recycling companies to extract lithium from slag, or competitive for the OEMs to buy at higher price points from recycling companies. However closed loop recycling, where the recycled materials are sold back to OEMs, is likely to help against potential price fluctuation of metals or compounds. EV battery recycling is expected to play a significant part of the value chain by 2016 when large quantities of EV batteries will come through the waste stream for recycling. Projects are currently underway in Europe, United States and Japan to develop effective and feasible recycling technologies with a complete life cycle analysis of recycling. LithoRec, Toxco Inc, Umicore recycling units have been able to extract the lithium with almost 50 percent efficiency and the cobalt with almost 25 percent efficiency. Recycling of Li-Ion batteries become difficult, because unlike NiMH batteries that are all relatively the same, Li-Ion batteries can contain greatly different components from one manufacturer to another (Arora, 2017).

3.6.5 Opportunities for reusing EV Batteries

Given that in general, a battery pack is considered at the end of its life for automotive use when its energy-storage capacity has declined to about 70 percent of the original rating, it becomes essential to evaluate how these batteries can be reused or given a second life in other applications. Lux Research (2016) finds that although there were concerns with respect to giving a second life to EV batteries in stationary energy storage applications on account of reduced round trip efficiency and cycle life, but companies like BMW, Nissan and Tesla are working towards developing residential storage products out of these ELV batteries. Second-life batteries offer only limited cost savings, especially as new cell prices continue to fall. Still, with more efficient testing, sorting, and repackaging, second-life systems could be made more competitive for applications like demand response and backup power.

3.6.6 Giving electric vehicle batteries a second life in solar projects

Electric vehicles and solar are often categorized under the umbrella of green technology and hold the key element for transitioning towards a low carbon future. But what exactly is their relationship? Whether the solar industry should pay attention to what's happening with EVs? Perhaps the most important nexus between solar power and EVs is energy storage. As EVs become popular, they can play a key role in the expansion of the energy storage infrastructure particularly when EV drivers have to replace their batteries about every eight years, once the battery capacity is below 80 percent.

The immediate question that arises is that whether EV batteries can be used for storing solar power. When it comes to assessing batteries for storage four criteria hold the key: Battery's capacity & power ratings, depth of discharge (DoD), round-trip efficiency and warranty. Not every EV battery may be suitable for reuse. For instance each EV battery has been exposed to different charging and discharging cycles, environmental and physical conditions through its lifetime, implying that it will have different degradation trajectories. Thus accurately assessing the ability of each EV battery to be safely repurposed into its new application is critical. Moreover stationery storage is cheapest when its constituent battery cells are most uniform. The more they vary, the more expensive software is required to regulate them. This requires a lot of technical expertise and investments to figure out how to mix and match old EV batteries into consistently performing storage so that EV batteries become a source of grid balancing. What is needed is the process and standards for testing and certifying second-life EV Batteries for creation of market demand (Arora, 2017).

3.7 Selected Initiatives by OEMs

3.7.1 Electric-car battery recycling plant in Japan- Initiative by Nissan and Sumitomo

Nissan and Sumitomo together have set up a joint-venture company called 4R Energy Corporation, to kick-start battery recycling operations especially when the earliest fleet of Nissan Leaf have started reaching their end of lives. Japan has very strict inspection rules for older vehicles that essentially make recycling process economically viable as it is cheaper to scrap cars that are five or seven years old than to keep them on the road. The company has developed a system to measure the performance of the battery as a whole and that of individual modules, letting it assess which components and subassemblies can be reused and which should be recycled. Components with remaining energy capacity can be reused and reassembled into "refabricated" battery packs, some of which will be offered as lower-cost replacement batteries for older electric cars (Voelcker. J, 2018).

3.7.2 Recycling Hybrid Battery Packs Into Rare-Earth Metals for New Ones- Initiative by Honda

Since 2013 Honda has been extracting an oxide containing rare earth metals like nickel from old batteries. Using molten salt electrolysis, Honda can extract rare earth metals with 99 percent purity--the same as ordinary traded, newly mined rare earth metals. Up to 80 percent of the metals found in a battery can be extracted, and it's suitable for re-use on the electrodes of other batteries (Ingram. A, 2013).

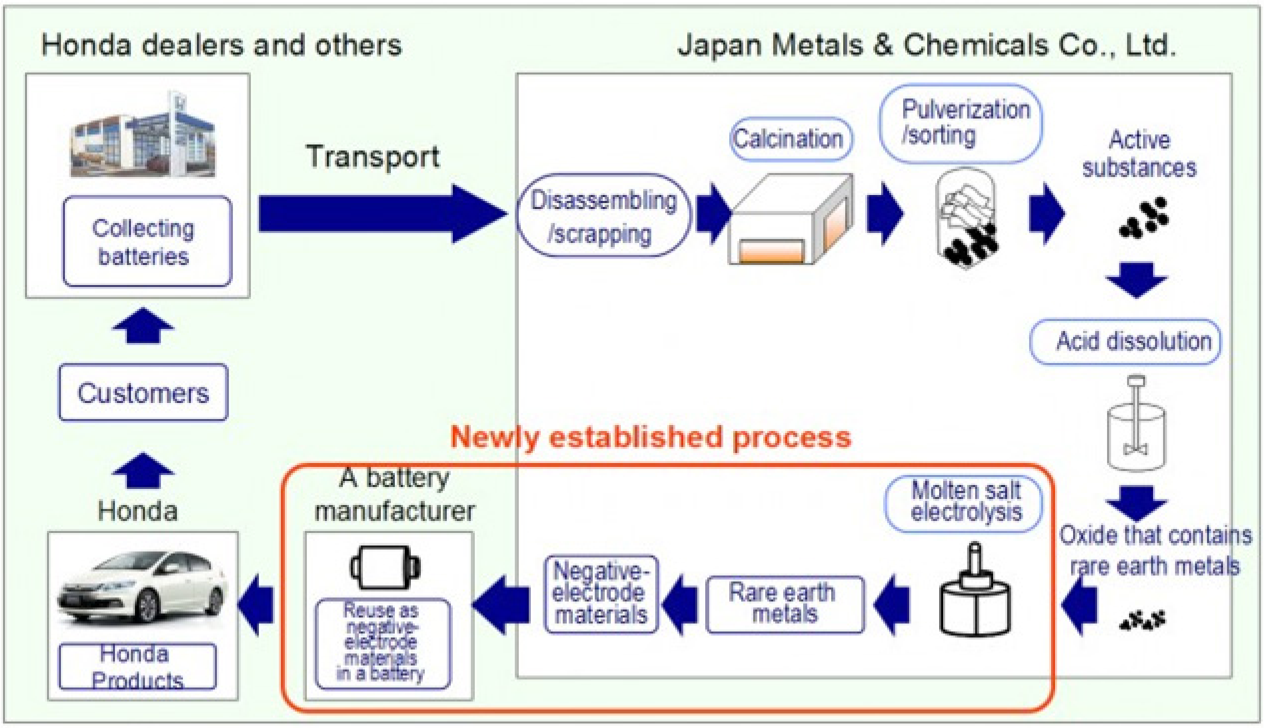

Figure 19: Honda's battery recycling

Source: Ingram. A, 2013

3.7.3 Second life to EV batteries in energy storage applications

BMW and Nissan are commercializing residential storage products, while Daimler has started operating a large 13 MWh system. Tesla, on the other hand, pursues recycling as its NCA cathodes are not suitable for most stationary storage needs (Lux Research, 2016).

i. 'xStorage Home' system from NISSAN and EATON, wherein old batteries from Nissan leaf are provided for home energy storage. Eaton provides the electronic interface that manages all the various functions required to interface the battery with the connected loads, the solar panels, and the grid. 'xStorage Home' stores energy at the most economical times of the day while controlling how and when that energy is put to use, saving you money and bettering the entire energy system. This is because 'xStorage Home' could charge from the grid or discharge to the grid in order to generate the flexibility needed to further increase the penetration of renewable energy. Further the system can store energy from your renewables implying that the battery stocks both grid and renewable energy during the day, allowing you to use that energy for your home when you need it. At times when your renewables are producing more energy than needed to power the load, the 'xStorage Home' system injects the energy back into the grid when the demand is high. The 'xStorage Home' system showcases a holistic approach which optimizes the battery performance, integrates renewable and smooth interaction with the grid (xStorage, 2016)

ii. Similarly BMW has taken a couple of initiatives to give a second life to used battery packs from its electric vehicles. In early 2016 BMW launched a stationary energy storage system solution integrating used electric vehicle batteries. Moreover BMW in association with BOSCH and Vattenfall have built a storage facility consisting of 2,600 battery modules from over 100 electric vehicles for a total power capacity of 2 MW and a storage capacity of 2.8 MWh. The system is used to stabilize the grid and reduce the impact of peak demand. Further these strategies have successfully extended the useful life of the battery for the owner, even beyond its vehicle use (Lambert, 2016).

3.8 Conclusions

Countries across the world are eyeing electrification of the automotive industry in their efforts to decarbonise the transport system. Given that EV industry is still at a very nascent stage in India, this would require policy interventions across the value chain to facilitate greater EV deployment. Some of the global experiences and initiatives discussed in this chapter showcases the need for having policy instruments across the value chain and at all levels for accelerating the transition to EVs as interventions in isolation fails to incentivise the stakeholders.

India still lacks the presence of sufficient technical know-how in lithium battery manufacturing. Recently, the Indian Space Research Organisation has expressed willingness to transfer its in-house technology non–exclusively to qualified production agencies. Further, the Central Electro Chemical Research Institute (Karaikudi, Tamil Nadu) and RAASI Solar Power Pvt. Ltd are expected to jointly start in-house lithium ion battery manufacturing. Other areas that need strengthening of the semiconductor manufacturing facilities and controller design capabilities, as these industries form crucial base for manufacturing electronics for EVs.

So far five Indian states have rolled out EV policy; these include Karnataka, Andhra Pradesh, Maharashtra, Telangana, Uttar Pradesh. With policy framework in place, these states have re-iterated their commitment to transit from combustion vehicles to EV vehicles. The states are giving special incentives and concessions to attract investments in electric vehicles manufacturing, EV battery manufacturing/ assembling and developing charging and swapping infrastructure for EVs for spearheading the electric mobility initiative in the country. Apart from the environmental gains, states are also recognizing the job creation potential of EV ecosystem and the need for skill up-gradation. A detailed look at state specific EV policy reflects efforts in the right direction. In-house manufacturing is key to building technological expertise and providing jobs. For this it may be a good idea to encourage public-private partnerships with clearly defined revenue models backed by a supportive tax structure and policies that could encourage car manufacturers and help bolster India's charging infrastructure.

4. Policy interventions across the EV value chain

Transformation to EVs is inevitable in India and this can create a great opportunity for the growth of the automotive industry in the country. However, the successful tapping of this opportunity and adoption of EVs will need a conducive policy framework that clearly sheds light on the long term vision of the government for electric vehicles and will help consumers have faith in the initiatives.

In this chapter, we map the policies and initiatives in selected countries across the world including in some of the EU member states and then analyse the applicability of these policies and initiatives to the Indian context. Recommendations will be made for building the capacities of OEMs in the upstream value chain and also suggest ways to make EV attractive for end consumers. It is important for the policy framework to not only address the supply side challenges with respect to material availability and high upfront costs, but will also have to look into addressing the demand side challenges of range anxiety of users and lack of charging infrastructure. This would lessen the complexity and unpredictability linked to the EVs.

EV policy is a multi-level policy game, where policy makers continuously have to take into account and operate within frameworks and actions set elsewhere (Steen. M et.al, 2015). The reason country experiences become all the more important is that EV policy critically relies on dynamism, learning and experimentation, lobbyism and implementation experiences at the local level given the disruptive nature that EV technologies are bringing to the automotive industry.

4.1 Understanding and developing policy framework for E-mobility in India

For understanding and developing the policy framework for E-mobility, we can look into three main aspects-the value chain of electric vehicles, the value chain of charging infrastructure and the elements of the surrounding network (as shown in figure 20).

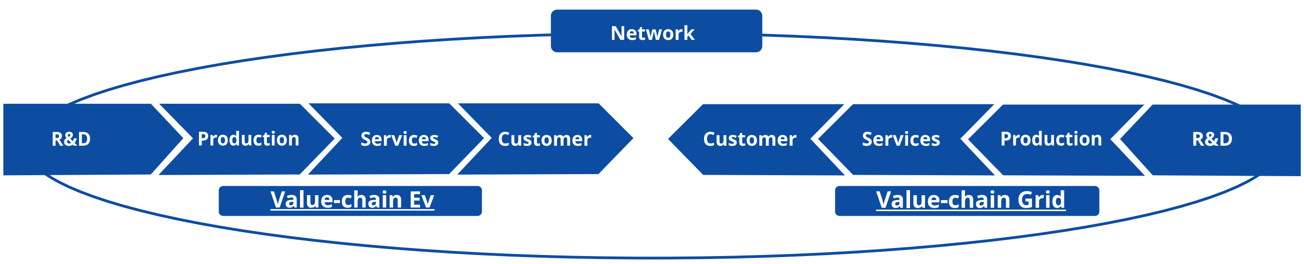

Figure 20: E-mobility value chains

Source: Steen. M et.al, 2015

EV Value chain: Targeting the supply side, the policies along the value chain of EVs can draw upon an instrument that incentivize EV R&D investments and development costs, promotes resource efficient extraction of critical resources and finding substitutes for these critical resources. The design of EVs also needs to be done keeping their end of life management in mind so that efficient and easier extraction of secondary resources can happen later. Incentives such as investment promotion subsidy are needed for encouraging the development of local technology for production of electric vehicles and components such as batteries and other hardware, and the software used in electric vehicles. If India can create components domestically, it will lead to significant reduction in costs of EVs too. Policy framework may initially have to do hand holding of the various service providers in context of EVs that include car dealerships, mechanics, insurance companies, repairs and service centres, and centres for promoting skill development.

Moving to the demand side, combination of fiscal and non-fiscal incentives will be needed. Fiscal incentives could focus on subsidizing the cost of EVs through subsidy or reducing the taxes on these to make it financially attractive in comparison to the traditional ICEs vehicles. Non-fiscal incentives would include special treatment to EVs such as dedicated driving lanes, parking spots (including free spots), convenient availability of charging stations. Public procurement by the central and state governments and PSUs can help create the demand that is needed to make the production financially viable and also act as an example for the other potential customers including individual consumers and fleet owners. Tradable carbon credits to OEMs could also act as incentives to increase the production of EVs

Charging infrastructure value chain: According to a Bloomberg New Energy Finance report, India has only about 350 charging points, compared to China which had about 215,000 installed at the end of 2016. Taking an immediate stock of existing and planned EV charging infrastructure deployment in the country becomes extremely important. For this, different levels of government need to work with the private sector to incentivise infrastructure development through policy instruments of different types. In-fact some of the local businesses can provide the needed innovation in charging infrastructure development and create innovative deployment business models.

Policy instruments focused on influencing the research and design of charging infrastructure including advanced technology based charging stations, and incentives and support for setting up of charging stations will play an extremely important role to create the needed ecosystem for EV deployment and its sustainability. It is also important to harmonise the charging standards before the mass rollout of EV charging infrastructure. In India few initiatives have been taken to set up/strengthen the charging infrastructure. For example, Tata Power Delhi Distribution Limited (Tata Power-DDL) has installed Electric Vehicle Charging centers at five locations spread across in its area of distribution. These charging centers provide access to free of cost charging to owners of Mahindra Reva Electric Cars. In the central Indian city of Nagpur, ACME in May 2017 launched India’s first battery swapping and charging station with lithium batteries. According to the Indian Energy Storage Alliance, there are more than 50 companies waiting on the sidelines to get involved in the Indian EV charging market. Other firms such as Exide Industries Ltd, Amaron Batteries Ltd and Microtek International Inc. are looking to supply batteries and set up repair shops.

Public sector undertakings in the energy sector such as NTPC, Power Grid Corp and Indian Oil Corp are likely to initiate the process to set up charging stations at several locations in identified cities to implement Government of India’s proposal to set up charging stations for electric vehicles every three kilometres in cities with million-plus population and smart cities, and every 50 km on busy national highways.

Regulations will also be needed for EV system components such as the electricity network, energy production, and service providers for charging stations (such as energy suppliers, power plants, renewable energy developers, grid managers, software developers etc.) to ensure a smooth set up and functioning of the charging infrastructure. The new CERC guidelines provide an opportunity for cash-strapped discoms to create new business verticals and revenue streams to utilize there surplus power. An improved charging station network being utilized by a growing fleet of EVs also offers an opportunity to reduce fluctuations on the grid induced by renewable energy integration. Discom Maharashtra Power Company is looking to use its substations in prime Mumbai and Pune locations as EV charging station sites. In a sign of the challenges, the commercial market presents high costs led discom Bangalore Electricity Supply Co to reassess plans to set-up a smart grid to provide an EV charging network in the city.

Further, policy instruments are also required for connecting stakeholders across the EV and infrastructure value chain as well as along the operational phase. These include instruments targeted towards the development of larger e-mobility ecosystem which includes smart grids and smart mobility. In India, the focus of the government within the EV value chain, has primarily been on downstream aspects of providing different kinds of incentives to encourage consumers to buy EVs, and there has been very limited focus in R&D and in upstream segments of the value chain.

Having seen the focus areas that should be targeted via policy instruments, the next section discusses policies from some of the countries across the world for promoting EV deployment in the respective countries and we discuss these along the life cycle stages in the EV sector. The policy instruments can be legal, financial, awareness and communication related, capacity building oriented and those related to rewarding for fostering cleaner environment.

4.2 Raw material Stage

As discussed earlier EV manufacturing requires a number of raw materials ranging from rare earth critical minerals to steel, aluminium, copper, cobalt etc. and given the concerns related to the availability of these resources and the associated price volatility and supply shocks it becomes essential to have an policy framework that promotes resource efficient extraction of virgin resources and secondary resource management. Many countries have taken initiatives in this regard and we discuss them here.

4.2.1 Canada

The Minerals and Metals Policy of the Government of Canada

The policy aims to create greater responsibility towards environmental and resource use impacts associated with exploration metals and minerals. Government has been investing in geoscience to promote efficient exploration and foster the growth of metals and minerals sector. Further, to promote efficient utilization of metals and minerals "Safe Use Principle" has been initiated that takes life cycle-based approach. Recycling of metals and minerals to promote secondary raw material consumption by manufacturing firms, recovery of metals, and advance recycling as a feature of product design are also part of the policy framework. Designing of a comprehensive geoscience information infrastructure is underway to develop value added minerals and metal products.

4.2.2 China

Although China is estimated to have half of the world's total rare earth reserves, yet it has implemented measures to regulate their extraction, control their exports and prices (Morrison and Tang, 2012). Also with a view to close the loop for these critical resources China has drafted a Developmental Plan for Rare Earth Industry and Non-ferrous Metals Industry (2016-2020). The plan's objective is to ensure orderly production of rare earth and non-ferrous metals, technological and scientific innovation required for efficient extraction and ensuring efficient utilization so that these resources can add high values to the development stage. In order to regulate uncontrolled extraction of resources, Ministry of Natural Resources (MNR) and Ministry of Industry and Information Technology (MIIT) have announced mining quotas on rare earth ore. Apart from it, the Plan aims to promote the circulation of these elements back into the economy once they have been utilized before (LexisNexis, 2018).

4.3 Design Stage

With an aim to utilize resources efficiently, it is important to focus on EV designs that allow elongated and efficient utilization of raw materials by supporting a design that allows for component reuse, use of secondary material, easier repairs and refurbishment and ease of dismantling for greater recovery. Standards and labelling becomes a key tool for ensuring design efficiency. Taking the example of China, even though the country has drawn up to 100 technological benchmarks for EVs so far, but one of the major challenges that the sector has been facing is the lack of standardization. Recently, China's Ministry of Industry and Information Technology (MIIT) has announced its focus on the standards for EV battery design and charges especially for power delivery, connector and software protocol for controlling the process. Moreover, the government is planning to promote its own standards overseas with an aim to become a global leader in standardization (Reuters, 2018).

4.4 Production Stage

In order to ensure higher material use efficiency and increase energy density at the production stage, countries have been revisiting their incentive policy in the upstream value chain.

4.4.1 China

Out of the total EV production in the world, an impressive 43% of the production took place in China in 2016 with approximately 375,000 EVs. China has outperformed in EV market as per the Electric Vehicle Index 2016 (EVI) score calculated by McKinsey. EVI is calculated every year since 2010 to analyse the overall state of EV producers on the basis of supply, demand and other dimensions. Supply dimension includes current and projected EV production and production of key components such as batteries and e-motors, demand dimension includes EV share of a given country's market and the number of EVs sold, and other dimensions include government incentives, existing infrastructure and new EV models offered within each country examined. China accounts for 25% of the global supply of lithium-ion battery, has come up with new 25 EV models in 2016 and has recorded a large number of EV sale (Mckinsey, 2017).

With an ambitious target of 5 million New Energy Vehicles (NEVs) on the roads by 2020, Chinese Government is committed in providing substantial subsidies to the manufacturers. Its New Energy Vehicle (NEV) Subsidy policy, was first revised in 2016, and then further for the period 2017-2020. The Policy adjustment details the subsidies for the manufacturers rather than the end-users and will end in 2020 with a phased drop of 20% in the subsidy each year (Dixon, 2018). Reducing subsidy in a phased manner will provide short term cushion to the domestic manufactures and will incentivise them to use this blanket cover to innovate, upgrade and manufacture high performance EVs to ensure that Chinese auto industry continues to be of the global leaders. These subsidies are available for qualified NEVs such as passenger cars, buses/coaches and trucks. The passenger cars vehicles with driving range below 150 km will not receive subsidies, while the vehicles with 300 km of driving range will get the current electric vehicle subsidies, and ranges over 400 km have higher subsidies. This is to encourage automakers to produce longer range vehicles. Secondly, battery power/weight requirements have been increased from 90 wh/kg to 105 wh/kg. They also only apply the full subsidy for vehicles with 140 wh/kg batteries, again pushing for better electric vehicles. Thirdly, power consumption requirements have been increased, pushing for more efficient vehicles, which fit into the government policy to push the development of better electric vehicles and the underlying technology.

For Battery Electric buses, minimum requirements include energy consumption of not more than 0.24 Wh/km•kg (electricity), minimum range at 200 Km with battery mass ratio (battery mass as a percentage of vehicle curb weight) at 20%. Scaling requirements include battery energy density of 85 Wh/Kg and the minimum charging speed. For battery electric trucks, there are two minimum requirements- energy efficiency (no higher than 0.5 Wh/km•kg for trucks) and —battery energy density of at least 90 Wh/Kg. For plug-in hybrid electric trucks, there is only single requirement of battery energy density of at least 90 Wh/Kg. In this category, the cap is CNY 150,000 (EUR 19000) per vehicle (Perkowski, 2018).

4.4.2 Japan

Under the act on promotion and procurement of eco-friendly goods and services, government of Japan has emphasized the procurement of resource efficient low emission vehicles. The evaluation criteria focuses on procuring vehicles that are designed for long-term use by using resources efficiently. Especially, since low emission vehicles includes rare earth elements, then reuse of these components should be taken into consideration while designing the product. This has to be followed by recycling of the vehicle once it reaches its EOL stage. Based on the Standard JIS D 4234, tires used for passenger cars should have rolling resistance coefficient of 9 or less and should not be a spiked tire. Tires have to be designed taking into account the ease of recycling (Ministry of Environment, Japan, 2016).

4.4.3 European Union

One of the core objectives EU member states strategies is the decarbonisation of transport sector through Research and Innovation (R&I) in e-mobility. Member states reiterated their commitment in the “SET-Plan ACTION n°7 –Declaration of Intent “Become competitive in the global battery sector to drive e-mobility forward”. The R&I effort covers materials, cells, packs and systems with a focus on high energy and resource efficiency, modularity and re-configurability, while also taking into account second life and recycling (the later as regulated by Directive 2006/66/EC). In terms of chemistries, the core focus is on Li-ion batteries. Nevertheless post Li-ion technologies should also be considered for strong support, covering e.g. basic technology, materials, manufacturability, LCA, second life and recyclability (European Commission, 2016).

TARGETS		Current (2014/2015)	2020	2030
Manufacturing targets				
1	Automotive (Li-ion and next generation post-lithium) battery cell production in EU [Gwh/year]1 (% supporting EU PHEV+BEV production)	0,15 -0.20	5 (50% of the 0.5 MEVs with 20 kWh)	50 (50% of the 2 MEVs with 50 KWh)
2	*Utility Storage (Li-ion and next generation post-lithium)battery cell production in EU [GWh/year]	0,07 - 0,10	2.2	10
3	Recycling			
	**Battery collection/take back rate	45% (Sept 2016)	70%	85%
	Recycling efficiency (by average weight)	50%	50%	50%
	Economy of recycling	Not economically viable	Break even	Economically Viable
4	Second life	Not developed	Developed	Fully establised

Figure 21: Manufacturing targets for OEMs and battery manufactures

Further European Commission has set manufacturing targets for OEMs and battery manufacturers (Refer figure 21) with the objective of increasing efficiency, reduced use of critical materials, reduced environmental impact and implementation of Eco-design (energy savings and solvent reduction) for advanced battery materials/components manufacturing processes.) It also targets that EU battery manufacturers will supply half of the cells needed for the PHEVs+BEVs produced by EU OEMs (European Commission, 2016).

Within the EU, some countries have also used specific policy instruments/schemes to facilitate newer developments across the value chain of the EV sector. Germany is one of the countries with a strong focus on R&D in EV policy. This could be explained by the presence of major vehicle manufacturers in Germany (which collectively comprise the largest automotive industry in Europe). Sweden also has a strong focus on R&D. Over one third of the policy instruments found in Sweden focuses on stimulating Research and Development. In France, Renault has teamed up with the CEA (French Alternative Energies and Atomic Energy Commission) to work on electric vehicles, new energies and cleaner combustion engines.

Following table lists some of the interventions provided by the countries in the upstream EV value chain

Table 2: Examples of financial incentives by countries in the upstream EV value chain

Countries	Kinds of intervention
Germany	• Research funding for the production of storage batteries, federal government granted 35 million euros for a three period 2009-2012. • Funding for developing new vehicle concepts and technologies for reducing energy consumption and pollution from road transport • Project to increase the energy and performance density of lithium ion batteries and for research in newer battery chemistries
Sweden	• Research funding with aim to become a global leader in vehicle electronics and software and increase expertise in the efficient design of vehicles through continuous cooperation between industry and academia.
California	• Research funding for developing advance cells and design technology for electric vehicle batteries with a aim to reduce battery costs and improve its use life. • Funds for developing advance energy storage technologies and to enhance PEV value through secondary use of EV batteries • Sales tax exclusion for advance manufacturing projects • Incentives for commercialization of advance low emission transportation technologies

Source: Adapted from Steen. M et.al, 2015

4.5 Use phase

In the recent past, majority of the incentives have been targeting the use stage so as to make EV a lucrative option for the buyers. This includes subsidies on high upfront costs, subsidies on use of charging infrastructure and other kinds of incentives like exemption on road taxes, registration, etc. In order to ensure that buyers make an informed choice, EU has made it mandatory for manufacturers to provide a capacity label for the batteries and providing understandable, useful and comparable information for end-users (European Commission, 2013).

In Denmark, one-third of the instruments in the EV value chain are targeted towards making EV purchase lucrative for consumers. Different levels of government implement downstream policies. Although subsidies and tax incentives are usually implemented at national level, but local governments also provide financial incentives, often “in-kind.” These include free or preferential parking, access to toll lanes, free charging, and free access to ferries for EVs. These might look as small incentives however; their impact should not be overlooked. For instance in a survey in California in 2014, 59 % of the respondents indicated that access to the high-occupancy vehicle lane (HOV-lane) was extremely important in their decision to purchase an EV (CCSE 2014).

Table 3: Examples of financial instruments for EVs that focus on downstream aspects in the vehicle value chain (consumer focused)

Countries	Kinds of intervention
Denmark	Tax incentives • In initial years BEVs were exempted from registration tax • BEVs and fuel cell vehicles are also exempted from annual tax Local benefits ('non-fiscal incentives') • Several cities (including Copenhagen) have reduced the parking fee for EVs and in some cities EVs are exempt from paying parking fees • Free use of toll roads for EVs
Germany	Tax incentives • Exemption of annual circulation tax for EVs bought during the period 2011-2015. The Federal government doubled the exemption period from 5 to 10 years • Motor vehicle tax is determined by the amount of CO2 emissions, which is a pro for EVs Rebates/subsidies • Granting of subsidies up to 5.000 Euros for EV buyers • Local benefits ('non-fiscal incentives') • In several cities, EVs have privileges for parking
France	• Residents receive up to 7,000 EUR in form of a one-time bonus for vehicles emitting less than 20 g/km of CO2. There is nonetheless the condition that the total amount of the incentive cannot exceed 30% of the vehicle's purchase price, including the value added tax. For the vehicles producing between 21 and 50 g/km of CO2, the incentive is 5,000 EUR
United Kingdom	• The incentive for purchasing a vehicle that emits less than 75 g CO2/km is25% of the purchase price, however, limited to the maximum of 5.000 GBP (about 5,800 EUR).
Norway	Tax incentives • In initial years EVs were exempted from non-recurring vehicle fees, sales tax and annual road tax. • Registration tax is calculated according to weight, motor power and CO2 emissions. The vehicles are classified by groups per CO2 'tax. EVs are exempt from this tax Reduced tax for leasing EVs thereby incentivising car sharing and rentals Rebates/subsidies • Granting of subsidies (approximately €4.000) to individuals who buy an EV or HEV class N1 or M1 • Granting of subsidies to companies which purchase EVs; the funding is 50 % of vehicles price Local benefits ('non-fiscal incentives') • EVs have free use of domestic ferries • EVs have free access to public areas • EVs can park for free in public parking places. This measure has been in place since the beginning of the 1990s • EVs can use the toll roads for free EVs are permitted in bus and taxi lanes. This measure has been in place since 2003

Source: Adapted from Steen. M et.al, 2015, Mock 2014 End-of-Life Stage

4.6 End-of-Life Stage

With EV sales rapidly picking up it would imply an unprecedented surge in demand of materials, end-of-life strategy presents an important source of secondary raw material and would help in reducing the demand for virgin raw material. Recycling or reuse of secondary raw materials helps to realize some material which can be fed again into the economy closing the loop.

4.6.1 European Union

Directive 2006/66/EC of The European Parliament and of the council on batteries and accumulators and waste batteries and accumulators: It is estimated that 1 million end-of-life EV batteries will be there in EU member states by 2030, which is further expected to increase to approx. 6 million in the year 2040 (Drabik and Rizos, 2018). In EU member states, batteries from electric vehicles are subject to the EC Directive 2006/66/EC (Batteries Directive). The directive enforces battery producers, or third parties acting on their behalf, to finance the net cost of collecting, treating and recycling waste batteries. This Directive regulates the end-of-life management of EV batteries and sets targets on the recycling efficiency. (H)EV batteries are classified as 'industrial' batteries and not automotive batteries. There is a ban on incineration and landfill of industrial batteries. Further the directive sets the Recycling Efficiency target (RE), that is, 50% of battery weight has to be transformed into an output fraction that has ceased to be waste or that will be used for their original purpose or for another purpose (without undergoing further treatment) (European Commission, 2006). However, the Directive needs to consider the specificities of lithium-ion traction batteries in the absence of guidelines on the transfer of ownership and changes to EPR with corresponding identification of responsibilities for a second use option. In addition, the Battery Directive needs to be harmonized with Directive 2000/53/EC on end-of-life vehicles and with Directive 2008/98/EC on waste (European Commission, 2016).

The End-of-Life vehicles Directive- Directive2000/53/EC : Approximately 8-9 million tonnes of End-of-life (ELV) vehicles are generated in the EU every year. The End-Of-Life Vehicle Directive has been successful with 23 member states meeting reuse/recycling targets by 2011 and a significant number exceeding targets. However, the Directive does not yet cater for the first wave of End-of-Life (H)EVs. The problem is that the current ELV recycling practice, which includes shredding, causes random dispersion of the critical metals, especially for metals, which are concentrated within specific process streams but are used in small amounts in the whole vehicle (e.g. neodymium, samarium) (Rowson. N, 2017).

Coming to the policy initiatives across the infrastructure value chain, relatively large number of instruments focus on installation of charging infrastructure. Given that availability of affordable charging options at home is a key to up-take the demand for EVs. In order to offset the upfront costs of purchasing and installing charging points governments across countries are giving subsidies. Table 4 highlights some of these incentives.

Table 4: Incentives given by countries for supporting charging infrastructure

Countries	Incentives
Netherlands	Tax incentive • Through the MIA and VAMIL regulation of the central government, entrepreneurs can receive a subsidy for installing charging infrastructure Rebates/subsidies • Drive4Electric (Province of Friesland) introduced a subsidy on the creation of charging points. Customers and companies that create charging points on private space can get a discount of 500 Euros per charging point • On private property, a charging point is partly subsided

United Kingdom	• Under the Electric Vehicle Home charge scheme, government provides a grant of 75% of total cost of one charging point up to a maximum of 500 Euro per household.
Norway	• EV users can use the public charging infrastructure for free • Grants of 11.9 Million Euro for new recharging stations

Source: Adapted from Steen. M et.al, 2015, Electric Vehicle Home Charge Scheme, 2018w

4.7 Conclusion

EV adoption in India will face common global challenges and can learn from the global policy initiatives and best practices. But the design of the policies in the country and adoption of best practices will need to address the local and India specific challenges. Given the socio-political context of India, complete replication of global experience may not be possible. So the policy makers have to be careful but at the same time should not delay in providing the right environment and help scale up the EV sector. In India, initiatives such as the National Electric Mobility Mission Plan (NEMMP) and Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) are concerted efforts towards building an EV market.

One aspect that needs a policy push is that for enhancing the resource efficiency of the sector. This efficiency will need to be looked at the manufacturing stage for electric vehicles by encouraging resource use efficient domestic manufacturing, at the use stage through the setting up of charging stations to facilitate the charging of these vehicles, and at the end of life stage, particularly the end of life management of batteries which will become an important issue in near future. Design of vehicles and their components with a view to their recoverability and recyclability and encouraging/supporting use of secondary raw materials is also extremely important.

Analysing the raw material, design and production stage, it is seen that the research currently focuses mainly on reducing the rare earth content in electric traction motors using two main approaches: (i) increasing material efficiency in magnet production (e.g. grain boundary diffusion processes), thereby obtaining NdFeB magnets with less rare earth content but with similar performance; and (ii) optimising the motor design, enabling high technical performance while using fewer NdFeB magnets. Overall, current research indicates a possible reduction in the amount of neodymium and praseodymium in permanent magnets by up to 29 percent from 2015 to 2030. However, substitution would only be able to partially mitigate a potential shortage in the supply of rare earths in EV applications. There is a need for a policy to foster integrated security of supply for rare earths that also considers substitution alongside secure access and recycling as potential solutions. Exploration of primary source of Rare Earths has not been given due thrust by Geological Survey of India (GSI) in the past, though the Atomic Minerals Division (AMD) has carried out some exploration for REs in the granite, pegmatite and inland placers limited to their association with radioactive minerals. Recycling of rare earth containing products needs a careful analysis of several factors such as availability of adequate waste material and appropriate technologies for economical recovery. Scale of operation linked with economic aspects is another important factor to be taken into account. Partial substitution of scarce materials is a promising area of research in Materials Science. The Department of Heavy Industry, Bureau of Indian Standards, and the Automotive Research Association of India are working towards establishing various technical standards for design and manufacturing of EVs and electric vehicle supply equipment (EVSE) or charging infrastructure.

In context of the use phase, a number of incentives for EVs can be considered which include exemption from permits, concessional toll, a higher rate of depreciation, lowering of taxes and mandatory rules for having a certain percentage in private and public fleet of vehicles. Government procurement in particular can help drive down prices and scale up the investment and manufacturing capacities within India. It is important to highlight here that the Government of India's first tender for procuring 10000 electric cars has been a success and recently the second tender for an additional 10000 electric cars has also been announced. Public procurement will then be able to support in the form of economic instruments, policy enablers for creation of business models. There is also encouragement to standardization of charging infrastructure. It is important that for an optimal development of charging networks in India, there is analysis of the demand from electric vehicles and electricity supplies, especially after the initial phase when the demand for electric vehicles is predicted to grow. Appropriate codes and standards for recharging power supplies and for smart metering should be established. The roles and responsibilities of various stakeholders (governments, regulators, utilities, vehicle manufacturers and consumers) should be established and there is a clear strategy of collaboration and cooperation between different levels of government, as well as with companies and electric vehicle manufacturers.

At the end of its useful life in the vehicle, the battery must be disposed of, either by applying it to a secondary use (for example, as a back-up power source in a stationary application) or by reusing materials and components that have value and disposing of the remainder as waste. Extending the polluter pay principle, the cost of disposal, less any value in secondary use or of recycled parts and materials, ultimately must be paid by the vehicle owner. There is need to provide policy support for collection and channelization of batteries to the formal sector and for technology penetration to help in remanufacturing, reprocessing and/or recovery of materials. Battery standards are essential for efficient and safe disposal and recycling; designing batteries with recycling in mind reduces the cost of recycling, and standardization of designs simplifies the operation of recycling facilities. Labelling is necessary to ensure that batteries of different composition can be properly sorted for recycling. Design standards also could facilitate secondary uses. Relevant laws and regulations, particularly those with compliance strategies such as financial penalties, may create incentives for people to recycle spent LIBs NITI Aayog's Report on- Approach to Mobility Transformation has recommended incentivizing efficient new vehicles by penalizing inefficient ones and setting up "a manufacturer consortium for batteries, common components, and platforms to develop battery cell technologies and packs and to procure common components for Indian original equipment manufacturers".

5. Outlook and Recommendations for promoting Resource Efficiency in EV sector in India

Electric vehicle industry is still at a very nascent stage in India with less than 1 percent of the total vehicle sales, but has a potential to grow to more than 5 percent in few years. At present there are more than 4 lakh electric two wheelers and few thousand electric cars on Indian roads (SMEV). However India's ambition towards an electric mobility economy by 2030 announced in 2016 can take us to higher growth too. Further, in a recent communication by the Ministry of Road Transport and Highways (MoRTH) and NITI Aayog, the government announced its aim of increasing share of electric vehicle (EV) from its current share of less than 1 percent to nearly 30 percent by 2030. This implies that by 2030, the total estimated number of electric two wheelers on Indian roads will be more than 200 million, while for cars and buses it has been estimated at 34 million and 2.5 million respectively (chapter 1).

It is important to recognize that despite many economic and environmental benefits of EVs and hybrid vehicles, there are challenges with regard to material availability and affordability used in manufacturing EVs as explained in detail in the previous chapters. Going by the current lithium battery chemistry and no further changes in technology in powertrain manufacturing in the four-wheeler hatchback segment, the total demand for materials will increase from 0.03 million tonnes to nearly 11 million tonnes. Many of the resources like copper, lithium, permanent magnets and related materials and components, are heavily imported by India and the cost of import has been increasing over the years.

However, there are challenges with regard to introducing break-through technologies in developing products that use recycled materials, achieving security when it comes to import dependency of raw materials, formalizing management of end of life vehicles including reverse logistics, reducing down cycling, closed loop management of wastes/scrap at intermediate levels, tracing mechanism of critical components like batteries, labelling of resource efficient products, certification of used products etc. These challenges however do not lessen the potential of the EV sector to create unprecedented opportunities for resource savings along the value chain. Product design and process innovation can reduce primary demand of resources and some of the good practices were highlighted in chapter 3. Further efficient recycling can help in recovering many of the critical materials particularly Lithium and permanent magnets among others, thereby lessening India's import dependence and enhancing its material security. Before India becomes a leading manufacturing hub of EVs, it is extremely important that an ecosystem is developed that can promote efficiency across the life cycle stages-- manufacturing stage for electric vehicles by encouraging resource use efficient domestic manufacturing, at the use stage through the setting up of charging stations to facilitate the charging of these vehicles, and at the end of life stage, particularly the end of life management of batteries which will become an important issue in near future. Design of vehicles and their components with a view to their recoverability and recyclability and encouraging/supporting use of secondary raw materials is also extremely important.

Process re-engineering and a business model that can promote reverse logistics of end of life for efficient material recovery, and a conducive policy framework is the need of the hour which will enhance establishment of such an ecosystem thus making India's EV sector most competitive.

Exploring the potential of a resource efficient EV sector for CO2 mitigation, it is important to note that the current carbon intensive power generation mix may not yield environment benefits (CO2 emission reduction) from increased deployment of electric vehicles. EVs may offer limited advantages with respect to their ICE vehicles counterpart and may even result in an increase when a life cycle CO2 emissions inventory assessment is undertaken (IEA, 2018)[19]. The reduction can be achieved by reducing the CO2 intensity of power generation, i.e. moving away from conventional power generation to renewable based system, and reducing the impact associated with battery production and other critical component manufacturing phases. Further, EVs' sustainability will improve with battery technology advancement and as more batteries are re-used for electricity storage or recycled.

5.1 Recommendations for enhancing Resource Efficiency in EV sector in India

The aim of this study was to understand the possible scope of enhancing resource efficiency in electric vehicles sector in India. The study has also illustrated some of the best practices and policies used by other countries that if appropriately adopted can play a key role in fostering RE in the sector and also be an effective means of reducing the environmental burdens and simultaneously strengthening India's economy by helping decouple resource consumption and economic growth. It is important to however note that the policy support should promote competition, be implementable and can be monitored and sustained with minimum fiscal burden and maximum impact. Based on the study, we present here few recommendations for the EV sector keeping in mind our broader objectives pertaining to resource efficiency for the country in Table 5.

Table 5: Action plan towards a resource efficient EV sector in India

Objective	Actions	Outcome	Policy instruments	Timeframe
Enhance raw material security of the country	Encourage material substitution and use of recycled materials (support to research and development on using different battery chemistries, incentivizing technologies and development of vehicles/components that have superior performance in terms of energy density, range anxiety and higher commercial proposition)	• Reduced imports • Recovery of secondary raw material • Substitution of virgin raw material with recycled raw material • Identification of substitutes for critical and scarce resources	• Financial support through subsidies and other incentives to encourage responsible product design • Awareness generation through showcasing of innovation and exploring potential for upscaling of the new technologies	Immediate

19 https://webstore.iea.org/global-ev-outlook-2018

	Component recycling: • Support recycling of components such as electric motors help to recover steel and copper; • Establish a rare earth recycling processes through the industrial implementation of efficient magnetic extraction processes for different technologies • Setting up of recycling channels for battery collection, storage and recycling by the manufacturer. • Creating a "traceability" system to identify the owners of discarded batteries. • Adopt standardised and easily dismantled product designs		• Investment in formal recycling set ups • Arrangements for skill training for managing end of life of EVs , particularly in recovering materials from their composite forms • Define labelling and standards that could be adopted for recycled/ secondary products	Medium to Long term
	Reuse of recycled material • Set up a modest target of use of recycled material in their new products , followed by gradual rise in the target	Reduced pressure on virgin raw materials	Provision of additional incentives during manufacturing (such as through GST reduction) for manufacturers and to consumers (such as through exemption on road tax, registration or insurance) for manufacturing and using such electric vehicles respectively	Medium term

Create demand to generate economies of scale	• Demand creation by the government / public sector both for the final product of EV and the resource intermediate materials/ components; • Bring down prices, create homogeneity and quality of procured materials in context of resource intensive materials/ components	• Increase in availability and affordability of electric vehicles	• Increased public procurement of electric vehicles • Organizations such as Energy Efficiency Services Limited (EESL) can pool demand for different kind of resource efficient cells/ components in the country through imports from global cell manufacturer. • Modifications on import duty on resource intermediate materials/ components	Immediate to Medium term
Resource efficiency standards	• To strengthen and organize the spare parts and used parts industry by recognizing specialized dealer network or manufacturers channel partners • Develop the ecosystem for spare parts of conventional ICE vehicles	• Bring back used, remanufactured, and refurbished parts and sell them through organized channels • Ensure reduction in re-entry of spurious and untested parts.	• Introduction of appropriate functional criteria and labels • Monitoring and supervision by OEMs	Long term

Capacity development	• Support for R&D in EV end-of-life activities • Support for technology innovations • Training of personnel in resource efficient techniques and processes through different vocational training programmes • Industrial cluster cultivation between the automotive and waste sectors as well as cross-cutting R&D programmes • Accessing human talent across different disciplinary fields, including engineering, science, environmental management, finance, business and commerce.	• Improved technological performance and generation of greater value from the recycling output • Creation of high-value recycling processes for rare, valuable and potentially hazardous materials • Additional environmental and socio-economic benefits • Increased quality for recycling technologies and processes	• Grants for organizing training and workshops • Financial support for R&D	Immediate to Long term

5.2 Conclusion

In an era where economies are striving to achieve ambitious and interconnected global development agenda, the role of a new global partnership has become even more relevant and critical. A successful sustainable development agenda requires partnerships between government, private sector and civil society as reflected in SDG 17.

Business to Business partnerships between India and other countries supported by targeted dialogue and action can help mainstream and institutionalize resource efficiency and lifecycle thinking. There is significant scope for collaboration and information exchange for resource efficiency innovation across the life cycle and promote effective use of applied research and analysis to support innovation.

5.2.1 EU-India B2B cooperation –Scope to exchange learning and explore potential business collaborations

The EU India Circular Economy Mission, under the Resource Efficiency Initiative is an ideal platform to establish new partnerships and strengthen existing ones in mobility sector and more so in the electric vehicle segment. In a world with dwindling resources and increased price volatility, the platform will create unprecedented opportunities for businesses from EU and India and learn from each other's experiences on strengthening resource efficiency and circular economy. The Circular Economy Missions are a series of high-level political and business meetings in third countries to communicate and promote sustainable and resource-efficient policies.

The missions are organised by the Directorate-General (DG) for the Environment of the European Commission and aim to build bridges between European institutions, NGOs, civil society organizations, companies and the relevant stakeholders in those developing countries, in pursuit towards promoting and adopting sustainable consumption and production.

EU a resource constrained region have achieved breakthrough technologies and processes in the automotive sector across the different life cycle stages that enhances resource productivity and circularity, while catering to the growing mobility requirement in the region in a sustainable manner. India, on the other hand, an emerging market with high ambition and significant growth potential in the electric mobility sector. This creates opportunities for technology and know-how transfer between India and Europe. While India can leapfrog others towards a sustainable resource efficient electric vehicle sector, at the same time India will provide EU new avenues of collaborative research and development and innovative service delivery to existing and future consumers along the value chain of the EV sector.

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