Review of Battery Technologies Available for Promoting Electric Mobility in Urban India

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1 Introduction

Urban revolution has transformed the face of Indian cities in the last couple of decades. These cities with an unprecedented population growth and migration have created a surge in the travel demand which have resulted in exponential increase in personal vehicles. Today, India is one of the thriving economies in the world, but its increasing reliance on private vehicles is one of the major concerns for the deteriorating air quality and increased dependency on crude oil leading to higher export bills. While there have been advances in technology to make the country safer and facilitate the lives of everyone, still rising environmental concerns and growing need for sustainable mobility solutions have posed significant economic and social challenges for the country [1]. Therefore, the challenge of technological innovation is growing over time as society continues to build and grow better ways to live and improve lives.

The particular aspect of saving the earth from various environmental threats has led the automotive industry to take various initiatives to prevent environmental degradation, particularly air pollution. Therefore, automobile manufacturers have launched environmentally friendly vehicles to tackle this problem. Other than protecting the environment, sustainable mobility solutions also aim for economic development which requires sound trade-offs and thus calls for green mobility solutions. The recent technological advancement and government policies in the field of automotive industry and pollution control have led to reduction in fuel emissions and thereby enhance the environmental conditions.

Electric vehicles are considered to be one of the best options, triggering the introduction of innovations for electric mobility or e-mobility. The idea of electric mobility is not recent. Reportedly, as early as 15 or so years ago, e-mobility

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innovations began to take root in the automotive industry. In simple terms, e-mobility refers to the development of electric or electronic power trains, cars, bikes or any other vehicle that moves away from the conventional fossil fuel and oil automotive technology. This covers technological alternatives such as battery electric vehicles, hybrid electric vehicles and hydrogen fuel cell vehicles [2].

The key purpose of e-mobility is to manufacture vehicles that are more environmentally sustainable and efficient and thus fulfil current legislative standards imposed by policymakers and other law-setting bodies. The widespread use of electric vehicles (EVs) for personal mobility is likely to make improvements in battery technology possible, as they are seen as one of the solutions for reducing global greenhouse gas (GHG) emissions, improving air quality, reducing reliance on crude oil and increasing energy security [3].

2 Literature Review

Over the decades, progress in production of electric vehicles and innovation in battery technology have been revamped at a rapid pace. This era of limited natural resources such as combustion fuels like oil and coal and also the ongoing environmental concerns have led the society to shift focus onto sustainable mobility. Out of all the options, electric vehicles pose a great power to ameliorate environmental conditions. For production of electric vehicles, batteries play an inextricable role as it stores electricity and provides it to the motor [4]. Further, these batteries used in EVS are known as traction batteries for electric vehicle batteries (EVB). These are usually rechargeable (secondary) batteries, mainly used in road locomotives, trucks and mechanical handling equipment. Examples of major traction batteries are the lead-acid battery, the nickel–cadmium battery (Ni–Cd), the nickel-metal hydride battery (NiMH) and the lithium ion [4]. According to electric vehicle index, countries like China, the United States of America and Germany are in the forefront of transition to electric mobility. India being a developing nation still lags behind in the race to green mobility solutions when compared with developed nations. However, as the battery technology is a crucial part of the electric vehicle industry, different battery technologies for electric vehicles have been elaborated in the further section.

3 Lead-Acid Batteries

The world's first rechargeable traction battery was developed about 160 years ago by Gaston Planté, which was later enhanced and the practical version of the battery came into existence in 1886 [4]. Over the years, the battery's strength and power have been enhanced by better utilization of lead grid lattice for better implementation. These batteries convert chemical energy into electrical energy by employing lead oxide as positive electrode, spongy lead as negative electrode and sulphuric acid as electrolyte; furthermore, it has several types like flooded, sealed and gel type. This technology is primarily used in electric motors, submarines and power generation for sump pumps. Lead-acid batteries provide optimal function at 25 °C as high temperature shortens longevity. Also, due to its wide availability and low cost, it continues to make a huge contribution to the automotive sector. Its ability to supply high surge currents and large power to weight ratio are some of the attractive attributes of the battery. However, the downside is that they have a short life cycle, low power density and heavy weight.

3.1 Lithium-Ion Batteries

Rechargeable lithium-ion batteries came into existence in the 1990s with the substantial advantage over the other battery systems due to its lightweight, high energy density and the ability to recharge. It is one of the most widely recognized innovations in the modern electrochemical industry. Lithium-ion batteries are fast growing, most promising and widely used battery technology in the field of e-mobility. In a conventional Li-ion battery, carbon serves as anode and metal oxide as cathode while electrolyte is a lithium salt in an organic solvent. It shows potential for yet higher capacities and high specific energy. This increases the mileage to three times that of lead-acid battery resulting in coverage of larger travel distance. This technology is primarily applied in the automotive industry on account of its added benefits such as low self-discharge, low maintenance, long-life cycle, high energy capacity and high performance. Other than electric vehicles, Li-ion batteries are also used in portable electronics and aerospace applications. However, the battery exhibits a few drawbacks which include high manufacturing cost, ageing and the requirement for protection circuit. As the output of new technology, inventions and solutions continues to advance, lithium-ion batteries are highly likely to contribute more to established markets and people's lives [2]. There are three main variants of Li-ion batteries, as detailed further.

3.1.1 NMC (Lithium Manganese Cobalt Oxide)

NMC batteries exhibit good overall performance by virtue of its attributes such as high specific energy, high power and low self-heating rate. Graphite is employed as an anode while $LiNiMnCoO_2$ as cathode. Further, the battery is widely used as power tools, e-bikes and other electric power-train because of its relatively low costs and light weight. The downside of the battery is that it requires 6 h of charging time for the regular use of EVs and the restriction on the ambient temperature, which should not be more than 40° for the battery's proper functioning. However, the standard battery discharge rate is 2 h, and it holds up to 80% depth of discharge (DoD) while lasting up to 2500 charging cycles.

3.1.2 LTO (Lithium Titanate)

LTO batteries demonstrate greater prospective than NMC batteries as major drawbacks have been solved by the advancement in the batteries. The reduction in charging time and resistance to ambient temperature (45°) are the most prominent qualities of the battery technology. Also, it can last up to 10,000 life cycles and thus tend to be used for home energy storage, transportation, solar powered lighting, etc. However, the major drawbacks include 3–4 times higher costs than the NMC, low particular energy and high weight.

3.1.3 LFP (Lithium Phosphate)

LFP batteries are one of the safest batteries as it shows great potential to handle high temperature with minimum degradation. Between the NMC and the LTO batteries, the LFP batteries hold an intermediate position as temperature tolerance is higher, but lower than LTO and more effective load and unload ability. Also, it experiences a lower rate of capacity loss with great calendar life.

3.1.4 Nickel-Metal Hydride Battery

Nickel–metal hydride is one of most readily available rechargeable batteries which bear nickel hydroxide as a positive electrode, titanium or nickel as a negative electrode. Electrolyte solutions are alkaline solutions, usually potassium hydroxide. These batteries are immune to a wide temperature range, mild toxins and long life cycles also they are recyclable. However, they suffer from lower self-discharge, lower capacity due to voltage depression and no function in case of devices operating on primary alkaline chemistry, a comparison of the available technologies is as detailed in Fig. 1.

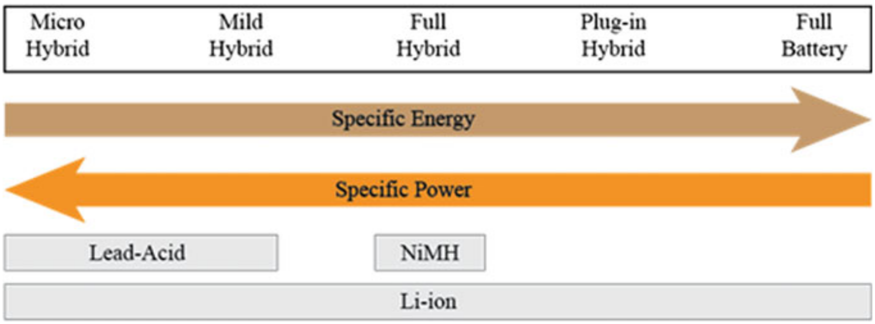

Fig. 1 Battery requirements depending on vehicle class and battery technology

3.2 Nickel–Cadmium Batteries

Nickel–Cadmium batteries consist of nickel and cadmium species which serve as the positive and negative electrodes, as well as alkali solution being the electrolyte. It is a well-established technology which has been in operation since 1950 due to its low maintenance requirement and a long-life cycle of more than 3500. The Ni–Cd battery has low internal resistance, but a high degree of discharge period at a very short time. Its efficiency during service requires a high charging rate at a very fast cycle. A major concern about nickel–cadmium batteries is the toxicity and thus environmental inefficiency of cadmium [5].

3.3 Zebra Battery Technology

The 'ZEBRA' (zero emissions batteries research activity) battery is a limited-volume sodium nickel–chloride battery manufactured in Switzerland for EV applications. The technology was first developed during the 1970s and 1980s in South Africa [6]. It is a well-tested technology available in a variety of EV formats, manifesting maintenance-free operation. Zebra cells deliver 7–8 times higher cycle life than lead-acid and low resistance failure of cells so that sequence of linked strings containing failed cells will continue to function. Also, this technology showcases some other benefits such as robust nature, potentially inexpensive, ambient temperature, no gassing, no self-discharge and easy charge estimation. (Charge Ah in = discharge Ah out). However, it takes 12–15 h for the battery to thaw out after freezing and also shows 90 W energy loss while not in use, which acts as a major disadvantage [7].

3.4 Nickel-Zinc Batteries

Ni-Zn battery technology is one of the alternatives for rechargeable batteries which have shown great potential in high-drain applications and power tools. It is known for its relatively low costs compared to other Ni-based chemistries and high energy to mass ratio. The chemical properties of the battery are quite similar to nickel–metal hydride as zinc and nickel hydroxide serve as negative and positive electrodes, respectively, in the presence of an alkaline electrolyte (potassium hydroxide, KOH). The battery shows very low levels of toxicity and hence do not possess threat to the climate. Other positive characteristics include its non-flammable nature, quick recharge, high discharge rates while preserving thermal stability and easily recyclable while preserving physical and chemical properties [8]. However, commercialization remains problematic due to short-circuit issues, life-cycle issues and gas recombination in a sealed cell.

4 Comparison

The development and revolution of battery technology from old centuries to latest battery technology have been observed all over the world. The parameters such as specific capacity, energy density, particular capacity, weight and size have improved along the evolution based on the transition from lead-acid battery to lithium-ion battery. Therefore, to understand and compare the basic characteristics of various battery typologies, Table 1 has been formulated.

There are various battery technologies present in the current modern world. Out of which, six widely used battery types have been tabulated and compared in Table 1 [9] on the basis of various parameters necessary for the best output in electric vehicles. The most promising candidate amongst the above-mentioned batteries applicable to EVs is lithium-ion battery. It excels mostly in every parameter and hence is considered the best option for the production of new generation EVs. Lithium-ion batteries are superior in terms of high energy efficiency and power density, allowing them to be built lighter and smaller in weight and scale, respectively, when compared to other types of batteries, such as lead-acid batteries, nickel–cadmium (Ni–Cd) batteries and nickel–metal hydride (Ni-MH) batteries. Other advantages of lithium-ion batteries include a wide operating temperature range, fast charging capability, no memory effects, a relatively long-life cycle and a low self-discharge rate. Desired attributes of EV batteries include: high energy density, power density, cycle life, safety and low cost. ZEBRA battery technology also shows great potential, but 90 W of energy loss can be observed when not in use. New cell chemistry is being developed to make batteries smaller, lighter and hold enough energy so that traditional vehicles can compete with EVs. Currently, lithium-ion batteries are the most common and most favourable battery technology that can closely meet the United States Advanced Battery Consortium (USABC) minimum criteria for the commercialization of EVs.

5 Indian Context

In India, the percentage of urbanized areas along with urban population is rising at a faster rate, thereby leading to derived demand for travel for different purposes. Increasing transportation mobility may lead to rise in problems like traffic congestion, air pollution, accidents, etc. Therefore, solution to these problems results in a major transformation of India's transportation system through various government initiatives and schemes at national and state levels. These government initiatives and schemes include National Electric Mobility Mission Plan (NEMMP) 2020, Faster Adoption and Manufacturing of Electrical vehicles (FAME), Smart city mission, etc. These schemes and policies energize elective modular alternatives move to electric vehicles and improvement of public transport, road infrastructure, etc. [10]. The government operates and manages public transit and road networks,

Table1 Specific battery parameters for electric vehicles (rough estimations on cell level)

Battery type	Specific energy (Wh kg^{-1})	Specific power (W kg^{-1})	Cycle life	Efficiency (%)	Self-discharge % per month	Operating temperature	Nominal voltage (V)
Lead–acid	35	150	400	80	3–5%	–20–60 °C	2
Nickel–cadmium	50	400	1500	70	20%	–20–45 °C	1.2
Nickel–Metal–hydride	90	300	1000	75	30%	–20–60 °C	1.25
Nickel–zinc	75	500	500	70	20%	–30–75 °C	1.65
ZEBRA (Na/ $Nicl_2$)	160 cell 90 battery	150	2000	90	Only thermal self-discharge	Internal operating temperature (270–350 °C)	2.67
Lithium-ion	200	400	1500	93	2–3%	–20–60 °C	3.6

while last-mile connectivity is typically managed, controlled and supported by government agencies, while private individuals play a more important role in last-mile connectivity.

Electric vehicles (EVs) are increasingly being taken into consideration because of the maximum logical alternative in the direction of reducing local air pollution. In current instances, EV innovation has sufficiently developed and is being advanced in accordance with zero tailpipe discharge. These forthcoming advances are turning into a brilliant option for customary fuel vehicles in India. The public government programs, plans and policies are the most grounded drive to shift into electric modes [10]. Electric vehicles are estimated to have 35–45% lower emissions compared to traditional IC engines, as predicted by the International Energy Agency. The adoption of electric vehicles could lead to a successful reduction of pollution and health problems. Depending on the specifications and viability of the city, e-rickshaws, e-autos, mini electric buses, etc. For comparison of growth of electric vehicles in India, Fig. 2 depicts the data of automobiles sales against the sale of electric vehicles in Fig. 3 [11].

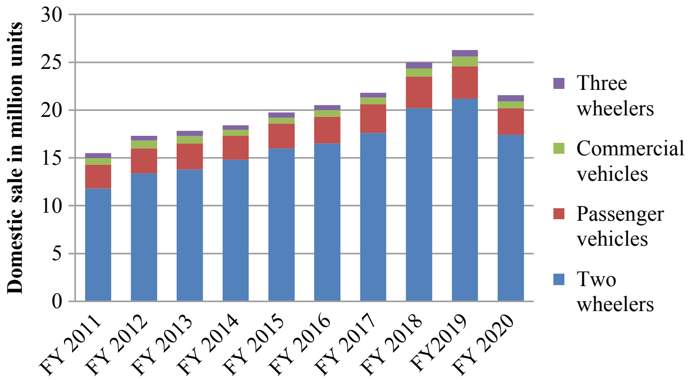

Fig. 2 Sales of automobiles India FY 2011–2020

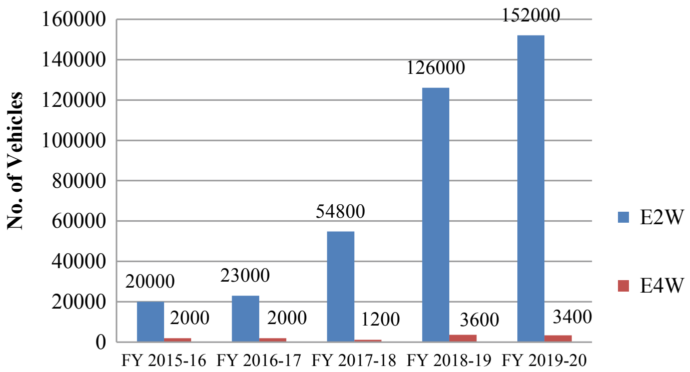

Fig. 3 EVs sale trend in India

The FAME initiative was introduced in 2015 and has resulted in raising the share of electric two-wheelers and four-wheelers in the automobile market in India. In the financial year 2019–20, the EV industry delivered 152,000 electric two-wheelers and 3400 electric four-wheelers. Electric vehicle sales in India rose by 20% in 2019–2020, largely led by rising two-wheeler sales as per the Society of Electric Vehicle Manufactures. In January 2020, the Department of Heavy Industries, under the second phase of the FAME India initiative, approved 2636 electric vehicle charging stations in 62 cities across 24 states and union territories [11].

5.1 Upcoming Energy Technology and Innovation Enables "Make in India"

Research and development on energy can be a good enabler of India's energy policy goals which also leads to wider national agendas such as the 'Make in India' manufacturing initiative. Through this programme, the government is working with multinational companies to produce solar PV, lithium batteries, solar charging facilities and other advanced technologies in India. Innovation and specific policy support for India has been significant in driving the growth of energy technologies. In a wide variety of energy technology fields, including cooling, electric mobility, smart grids and innovative bio-fuels, the government is reinforcing its research efforts [12].

5.2 Battery Cells, Packs and Materials

India needs a minimum of 10 GWh of cells by 2022, which will have to be extended to 50 GWh by 2025. Therefore, in India, manufacturing these cells will be promoted [12]. Therefore, manufacturing of these cells will be encouraged in India. It is necessary for manufacturers to work upon the different parameters such as energy density, efficiency, safety, etc. so that their batteries are the world's best. In order to protect the components used in lithium-ion batteries, including lithium, cobalt, nickel, manganese and graphite, India will need a strategy. Our first job will be to search for these commodities within India while at the same time allowing or promoting strategic investments for these materials in foreign mines. Setting up the lithium-ion battery recycling industry will perhaps be the most critical task. Strict criteria for the recycling of any lithium-ion battery used in electric vehicles, cell phones or laptops should be enforced in India. In order to allow zero emissions at all recycling facilities, it would promote the import of used lithium-ion recycled batteries with stringent environmental criteria [12].

5.3 Last-Mile Connectivity and Rural Transport

Today, some Indian cities have metros as public transportation services while other cities have bus services. Autos/rickshaws provide connectivity in cities which have metro/bus facilities. The early up gradation of cars to electric vehicles by means of lithium-ion batteries would provide a significant sustainable transportation system for countless individuals in cities. Today, three-wheelers are the main transport in towns, for dropping the people to bus stops on motorways or railway stations. It is possible to quickly transform them over to electric, giving pollution-free vehicles in villages. Specifications should ensure that these vehicles are not an annoyance for all users of public roadways. Further, job opportunities in rural areas can be created by operating various battery-charging and swapping outlets in larger villages. Smaller transport vehicles are mostly responsible for the transportation of freight in rural areas and for transport linking agriculture to towns (like tempos, rickshaws, and autos). These vehicles are appropriate for substitution by EVs [12].

6 Conclusion

Electrical mobility is the most feasible approach to accomplish pollution-free environment which is crucial for the sustainable development of the world. EVs have high possibilities of embracing a healthier and eco-friendly transportation system, thereby preventing global warming caused by fossil fuel dependent on the traditional technologies. In EV applications, the battery plays the most important role. This paper gives an overview of various EV battery innovations, impacts and approaching course of progress. Based on the comparison of various batteries, the lithium-ion battery has the best performance amongst different batteries in terms of its efficiency and travel distance. However, there are at present a couple of developing batteries which utilize diverse anode, cathode and electrolyte separator that might upgrade the performance of the batteries by increasing the parameters such as heat capacity, lifecycle sustainability. Therefore, a shift of transportation sector from ICE motors to EVs in India will require a lot of planning, research work and development. Government policies like FAME (faster adoption and manufacturing of electric vehicles) and few other policies which promote the manufacturing of electric and hybrid vehicle technology should be revised and upgraded on a regular basis to keep in pace with the development, while focussing on improving the energy-efficiency of EVs.

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