Comparative Study of Electric Vehicle Battery Systems with Lithium-Ion and Solid State Batteries

Himanshi Koli, M. P. S. Chawla

***Abstract:** Due to mechanical advancements, a continued emphasis on sustainable power, and the typical decrease of transportation's impact on ecological change and other regular difficulties, EVs are currently seeing a renaissance. Electric automobiles are portrayed by Project Drawdown as one of the top 100 modern solutions for monitoring climate change. Despite the traction battery specialty systems utilized for modern (or wearing) automobiles, an electric-vehicle battery (EVB) is a battery used to control the stimulus plan of an electric vehicle (BEVs). These batteries are typically assistance (battery-controlled) batteries, and they typically include lithium ions. Forklifts, electric golf trucks, riding floor scrubbers, electric bicycles, electric cars, trucks, vans, and other types of vehicles all employ traction batteries, which are categorically arranged with a high ampere-hour limit.*

***Keywords:** Electric Vehicle, Battery System, Renewable Energy, Lithium Ion Battery, Solid State Battery, Cost, Environmental Friendly.*

I. INTRODUCTION

The observable impact of the petroleum-based transportation foundation in the 20th and 21st centuries, together with concern over peak oil, sparked a resurgence in interest in an electric transportation framework. Electric vehicles (EVs) differ from vehicles powered by petroleum derivatives in that the power they use can be produced from a variety of sources, including petroleum products, nuclear power, renewable energy sources like solar and wind power, or any combination of those. Depending on the fuel and technology used for power generation, electric vehicles' carbon footprint and other emissions change. Depending on the vehicle, the power may be stored in a battery, flywheel, or super capacitors. Energy for gasoline-powered vehicles comes from one or more sources, typically non-sustainable petroleum derivatives.

II. HISTORY OF BATTERIES IN ELECTRIC VEHICLE

Inside the flow electric vehicle (EV) development and charge technique towards increasingly green and reasonable vehicle, there are key mechanical obstructions and challenges, which are as often as possible altering according to partners' points of view [1]. 10 years prior, reviews have called attention to this fundamental hindrances of the commercial presentation of EV was rates, existing reach & accessibility of recharging foundation[2]. Nonetheless, the main obstructions had varied radically. Expenses of the battery the most costly part of the EV impetus framework had gone down almost 90% [3,4]. Rate equality will get normal till 2025 most recent. In the times to comes, electric vehicles will be less expensive to purchase contrasted with ordinary vehicles. Realizing going expense & support value are now less expensive presently, but that implies only aggregate value of possession (TCO) would less expensive before long. The driving reach expanded 100-150 km till 400+ km [5-7]. Many nations, accessibility of recharging foundation taken as yet an issue, particularly to individuals in metropolitan regions and who frequently had no personal stopping point. EVs had demonstrated better to the climate [8,9] also permit greater entrance to sustainable power resources in the power network [10].

At the present time, the structure, cell, anode, and material levels of an electric vehicle battery are taken into account. The projected breakdown for 2025 is based on framework level objectives of 225 Wh/kg. The cathode side is hinted at by anode and material properties. By 2030, this can be enhanced even more, reaching 450 Wh/kg. The battery's energy thickness will increase in the same period from 310 Wh/L in 2010 to 580 Wh/L in the present day to 1100 Wh/L in 2030. Battery prices have dropped from 1000 euros per kWh to 130 euros per kWh, and are expected to further decline to under 80 euros per kWh. An increased driving range or reduced vehicle weight will result from a higher explicit energy, and this will happen at a cheaper battery cost. In 2010, batteries were typically 30 kWh in size; currently, 60 kWh is no longer an exceptional circumstance, and by 2030, the battery limit will exceed 80 kWh [11–13].

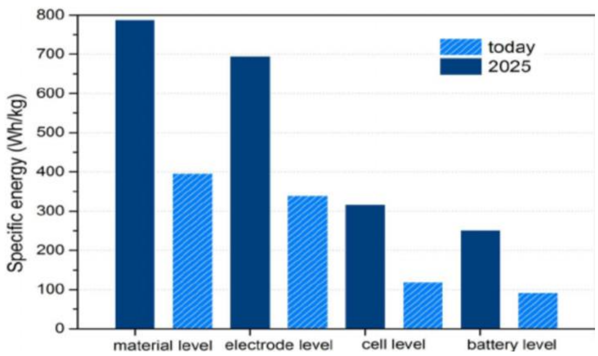

Fig. 1 Specific Energy of Electric Vehicle Battery [1]

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The traction inverter power thickness increases from 10 kW/ L in 2010 to 30 kW/L in 2020 and can further be worked on up to 65 kW/L in 2030 depending on the DCinterface voltag e, which results in a volume reduction of up to 40%. In the s ame period, the peak inverter efficiency increased from 92 p ercent in 2010 to 96 percent in 2022 and can be further impr oved to 98 percent in 2030 by integrating wide bandgap tech nology into the drive system. By doing this, the driving rang e will increase by 8%. Comparatively, the battery charger an d DC/DC converters could achieve efficiencies of up to roug hly 100% by 2030, leading to a 20 percent reduction in char ging costs. Additional efficiency improvements result in decrease in the utilization upto 32% [11].

Ecological effect of EV chiefly relies upon how power delivered. In view of the energy blend the Carbon dioxide discharges was around 300 Carbon dioxide g/kWh in 2010. Normally, through an expanded portion environmentally friendly power resources & taking gradually eliminating thermal energy stations, that by 2030 the CO_2 discharges would lessen underneath no less than 200 CO_2 g/kWh, the EV utilization & emanations that create the power, the carbon dioxide outflows each vehicle would diminish from 66 CO_2 g/km in 2010 to under 30 CO_2 g/km in 2030.

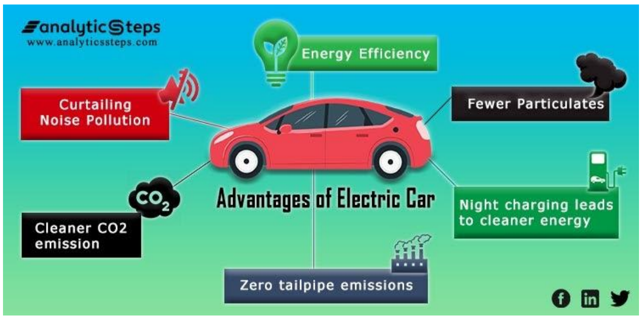

Fig.2 The Environmental Impact of Electric Vehicles [3]

III. LITHIUM-ION BATTERIES WITH LIQUID ELECTROLYTES

Lithium ions flow from the negative electrode via an electrolyte to the positive electrode during discharge and back again during charging in a lithium ion battery, also known asa Liion battery. The positive electrode in lithium ion batteries is made of an intercalated lithium compound, while the negative electrode is commonly made of graphite. With the exception of LFP cells, lithium ion batteries have a high energy density, little memory effect, and a low self-discharge rate. It is possible to construct cells that emphasise power density or energy. However, because they contain flammable electrolytes and can catch fire or explode if damaged, they can pose a safety risk. Alternatives to electrolytes, such the lithium polymer battery, have also been crucial. Polymer electrolytes show promise in reducing lithium dendrite development. The purpose of polymers is to maintain conductivity and prevent short circuits[12].

Because of slight variations in the electrolyte concentration, the ions in the electrolyte disperse. Here, only linear diffusio n is taken into account. As a function of time t and distance x, the concentration change, c, is

$$\frac{\partial c}{\partial t} = \frac{D}{\varepsilon}\frac{\partial^2 c}{\partial x^2}$$

D stands for the lithium ion's diffusion coefficient in this eq uation. Its value in the $LiPF_6$ electrolyte is 7.5 $*10^{-10}$ m^2/s. The porosity of the electrolyte has a value of **0.724**.

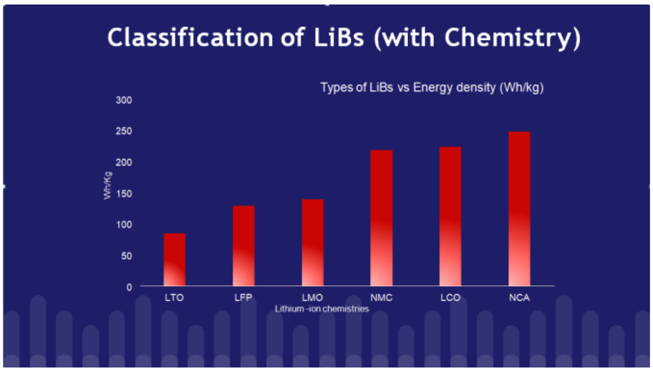

Fig.3 Li-Bs Vs Energy Density Plot[4]

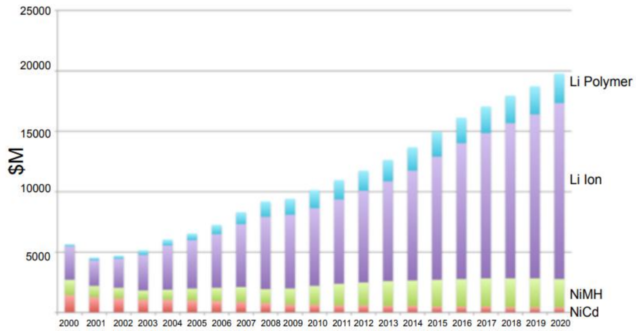

Fig.4 Lithium Battery Market Plot[5]

Table.1 Classification of LiBs (with Geometry) [4]

	CYLINDRICAL CELL	PRISMATIC CELL	PRISMATIC POUCH CELL
MERITS	1. Easily manufactured . 2. Mechanically stable. 3. Holds heavy pressure w/o deformation. 4. Less price(wph) 5. Longer life & recyclable. 6. Greater power density.	1. Lean profile 2. Light weight 3. Allows flexible design 4. Encased in metal or steel for stability	1. Similar to prismatic layer exceptmet allic cast. 2. Efficient space usage 3. Weighing very less.
DEMERITS	1. Noticeable place in cells 2. Heavy 3. Less packaging thickness due to placing area	1. More expensive to manufactur e 2. Less efficient in thermal managemen t 3. Shorter cycle life 4. Thermal managemen t is difficult	1. Provision for swelling must be made 2. Similar to prismatic cell

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	4.	5. Deformation in high pressure situations 6. Higher cost(wph)	
APPLICATIONS	Tools and equipment, medical equipment, laptops, and an electric bicycle	Mobile devices, tablets, and thin computers. Hybrid and electric automobiles, electric buses, electric trucks, and solar/wind storage all employ electric power trains. UPS	Small cells are preferred for portable devices like drones and hobby equipment . The larger cells are used in systems for energy storage (ESS)

IV. DRAWBACKS OF LITHIUM ION BATTERIES

Several drawbacks of Lithium Ion batteries are:

a) Life cycle is upto two to three years after manufacture.
b) Very sensible to high temperatures.
c) If the battery is completely discharged, its very difficult to recharge again.
d) Comparatively expensive.
e) If the "separator" gets damaged, it can burst into flames due to liquids electrolytes.
f) Smaller Lifeline.
g) Rechargeable batteries life gets shorter as the temperature rises.

V. SOLID STATE BATTERY

Solid state batteries are becoming more popular due to its thin size and also they provide high energy density that's why, these solid electrolyte when used in thinner battery helps in reduction of overall size of batteries. Electrolytes and solid electrodes are both used in solid state batteries. They offer a potential substitute for traditional lithium ion batteries, which use liquid or polymer electrolytes as their electrolyte.

As they provide outstanding performance and safety at a reasonable cost, solid state batteries are the current trends for next generation traction batteries. In comparison to liquid electrolyte batteries, they also exhibit superior electrochemical stability, higher potential cathodes, and higher energy density[13].

The question arises that could solid-state batteries meet the technical and energy needs of EVs?

The answer is:

Solid state batteries can be used to overcome a number of barriers to the adoption of electric vehicles because they meet the technological and energy needs of these vehicles [14].

The necessary requirements are: -

i. **Energy density:** rise per kg because solid-state batteries are between 80 and 90 percent thinner than lithium batteries and have a higher decomposition voltage. A vehicle's operating range would rise greatly as a result of improved energy density, eliminating the need for frequent charging and necessitating a huge number of charging stations.

ii. **Precautionary Purpose:** Solid state batteries make it simple to tackle safety-related problems. Since liquid electrolytes are typically flammable, any leaking would raise questions about the safety of batteries and the entire vehicle. Liquid batteries employ safety measures, but solid state batteries do not require them and offer complete safety Solid state batteries have an advantage over lithium ion batteries in that their operational range is greater.

iii. **Speed Charging:** Compared to liquid lithium-ion batteries, solid state batteries offer higher levels of safety since they do not have a liquid electrolyte that can become heated during fast charging. One of the most important elements influencing the increased adoption of electric vehicles powered by solid state batteries in the near future is their ability to charge quickly.

iv. **Less Price:** The present cost of typical liquid lithium ion batteries is about US $220/kWh, and they are very expensive. Over time, this cost is anticipated to decline; however, it is reliant on rare resources like cobalt. Research and development efforts in solid state batteries will help provide cutting edge batteries at a reasonable price. Bringing down the price of batteries for electric vehicles is viewed as a desirable alternative to gasoline-powered automobiles.

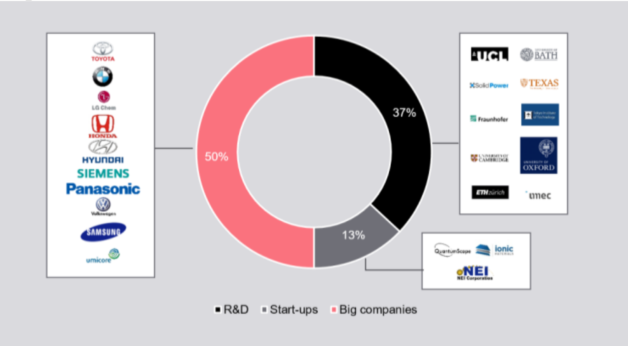

Fig.5 Research & Development Companies in SSB Technology [6]

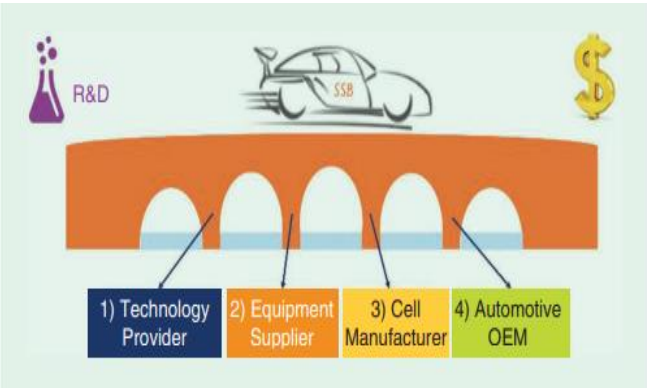

Fig.6 Challenges of SSB Commercialization OEM: Original Equipment Manufacturer [7]

Growing amounts of money are being invested in the research and development of solidstate batteries by OEMs, material firms, and academic institutions. OEMs are working closely with a number of parties involved in the battery production industry to make sure that solidstate batteries are adopted m ore widely.

Table.2 Important investments and collaborations [1]

COMPANY	INVESTOR	TYPE	BATTERY TECHNOLOGY
Quantum Scape solid power	Volkswagen BMW Group Hyundai, Ford Samsung	Investment partnership investment	SS technology
Northvolt Umicore	BMW Group	Partnership	Battery Recycling
Enevate	Nissan Alliance Samsung LG Chemistry	Investment	Lithium-silicon batteries
Sila Nanotechnologies	Siemens Daimler BMW Group	Investment Partnership	Lithium-silicon batteries

Working of Solid State Battery:

Flow of current in solid state battery is same from anode to cathode as of normal battery only the conductive electrolyte material gets differ. One more advantage with solid electrolyte is its life span because solid electrolyte material is very less reactive than liquid electrolytes so these batteries may result in long services.

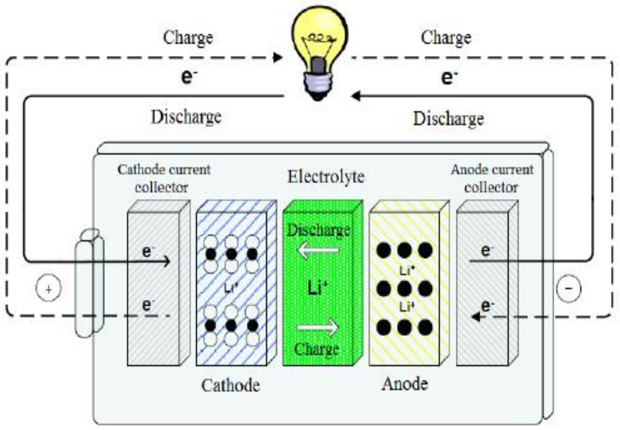

Fig.7 Schematic Diagram of all Solid State Batteries[14]

Despite having all these advantages the solid state batteries are only limited up to small range power applications, more research is going on for finding solid state batteries with high capacity, good conductivity that matches with or near to liquid electrolyte based lithium ion battery performance.
These drawbacks of solid state electrolytes can be overcome by good manufacturing and some advancement in the material development[15]. Even though solid state batteries can be used as a present state in small scale applications like smart phone batteries or in tablets that will be able to provide fast charging in mobile phones and tablets also it will provide very long life to batteries along with very less chances of catching fire or any kind of malfunctioning or failure of battery. The focus area of study is how can we achieve all this functionality for high power high capacity application like Electric Vehicles and various applications which require high energy and charge sustainability.
The mechanical property is the main distinction between sol id electrolytes made of polymers and inorganic/ceramic mat erials. Ceramics with high elastic moduli are more suited for stiff battery systems, whilst polymers with low elastic modu li are better suited for flexible devices[16]. Because polymer s are simpler to work with than ceramics, fabrication costs ar e lower. For extreme climatic conditions, such high temperat ures, ceramics are a better choice.

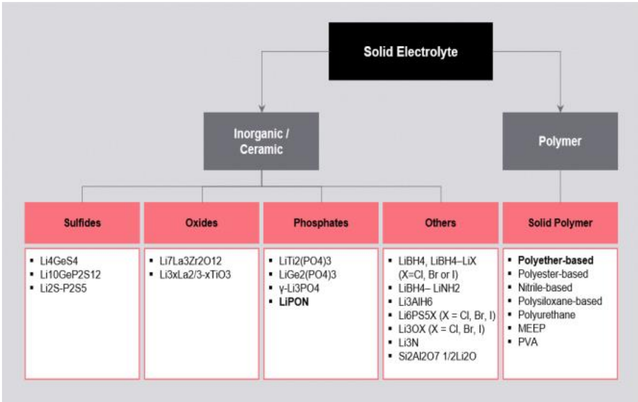

Fig.8 Types of Solid-State Electrolytes [14]

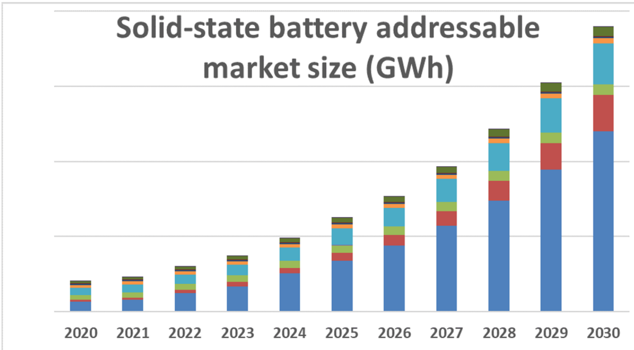

Fig.9 Status & Future of Solid State Battery Business[15]

VI. LITHIUM-ION BATTERIES WITH SOLID ELECTROLYTES

Energy is stored in Electric vehicles in the form of Electro-chemical Energy and at present available batteries which are commonly used in EVs such as Lithium-ion battery, Lead acid battery, nickel incorporated batteries, flow batteries and sodium bromine batteries etc. objective of all this kind of batteries is to provide good performance in terms of battery life cycle, high energy density, compact size, and it should be tested for all safety measures as well.
Battery manufacturing technology is changing day by day and it is very important to know the past development in the field of battery chemistry its characteristics and limitation so that we will have clear idea about the actual challenges and targets that need to be achieved so that we can use Electrical energy as the main energy source for driving the automobiles. Now the trend is moving towards the use of solid electrolyte because it provides wide range of advantages over liquid electrolyte, and efforts to introduce solid state electrolyte material to be used as a current flow medium to batteries is started long back in the period of 1960s, during which time the quick 2D sodium ion phenome non found ($Na_2O.11Al_2O_3$) which was widely being used in sodium sulfur batteries[17]. In later stages ionic chemistry of sodium material is used for development of solid state batteries.

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Hence ionic conductivity is treated as a key factor for solid electrolyte development. Various different types of solid material used as electrolyte are (Oxide, sulfide, Hydride, halide, Borate or phosphate, think film and polymers)

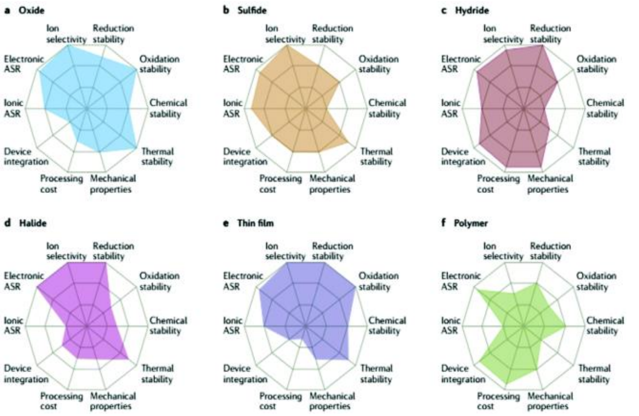

Fig.10 Performance analysis of different solid electrolyte materials[16]

As the Solid state battery having limitation and challenges in manufacturing process while in liquid electrolyte material lithium-ion provides path for electrochemical reaction and for current flow and it is major challenge in building a conductive path for lithium-ion that provides the interfacing between anode cathode electrodes and solid electrolyte. So for resolving this issue to some extent an liquid polymer electrolyte layer was introduced to provide proper interfacing medium in between solid electrolyte and the battery electrodes.

VII. SELECTION CRITERIA FOR SOLID POLYMER ELECTROLYTES

The electrolyte determines how well a battery performs, and there are currently more than 25 different types of solid-state electrolytes available, including oxides, sulphides, phosphates, polyether's, polyesters, nitrile based, polysiloxane, and polyurethane. In solid state batteries, polyether and Lithium Phosphorus Oxynitride (LiPON)based electrolytes are frequently utilized[18].

Table.3 SSB Electrolyte Properties for Selection Criteria

Property	Why?
Dissolution property	Lithium salts must be dissolved in order for polymer salt complexes to form, and this re quires sequential polar groups like -O, C=O, and C=N.
Electrochemical stability	The voltage window and the distance betwe en the onset potentials ought to be substanti al.
High iconic conductivity	For improved performance and to reduce sel f discharge for a longer storage life.
Chemical & thermal stability	Neither a chemical reaction within the batte ry nor between the electrodes, current collec tors, or packaging components should occur when the battery is in use.
Mechanical strength	Positive and negative electrode separation a nd processing viability are both assured by s trong dimensional stability.
Low cost	To help in achieving cost efficiently & commercialization of the concept.
Sustainability & toxicity	Harmful effects on the environment should be minimum.

VIII.ADVANTAGES AND CHALLENGES IN SOLID-STATE BATTERIES

Due to the fact that they don't contain any combustible components, solid state batteries are available in smaller sizes than liquid lithium-ion batteries, improving operating safety. In the case of solid state batteries, Solid Electrolyte Interfacial Layer (SEI) is present, which leads in extremely low self-discharge rates and permits multiyear power storage with little loss. The operational life of the currently available solid-state batteries, which is only three years, presents a problem Research and development efforts will undoubtedly contribute to extending the working life of solid state batteries for electric vehicles to over three years[19].

Table.4 Comparison between Li-ion & SSB Batteries

Liquid Lithium-ion Batteries	Solid-state Lithium-ion Batteries
Low processing cost.	Excellent thermal stability.
Flexible separators can withstand high mechanical stress.	Comparatively less self-discharge.
Only at room temperature does it have a high ionic conductivity.	Temperature variation range over high ionic range.
Life of battery discharge to recycling.	Electrolyte taken is non-volatile.
Combustion cause due to flammable electrolyte.	Electrolytes are non-flammable, and thus safe
Life cycle is affected by SEI degradation.	High energy density.
Material of cathode have limited choices.	High tolerances.
Bad thermal stability.	Ceramic separator used its rigid and it may break with additional stress.
Sensitive to overcharge.	No SEI layer formation, and thus, a longer life cycle.

CHALLENGES ADVANTAGES

IX. UPTAKE OF ELECTRIC VEHICLES

By 2030, electric car sales are anticipated to account for 10 to 12 percent of all auto sales. the product innovations made by significant OEMs like Honda and Volkswagen; and battery technology breakthroughs. By 2025, electric car prices will rise to a point where more people may choose to drive them, predicts Goldman Sachs[20].

The results of an industry poll indicate that lithium ion battery prices will probably continue to be high. New technologies, such metal-air, solid-state batteries, are anticipated to gain substantial market share in the upcoming years in order to address this.

Factors affecting the uptake of electric vehicles:

The adoption of electric vehicles has various restraining factors, which include: [21]

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i. **Long time in charging**: Current lithium batteries need longer charging times to get fully charged.
ii. **Few EV charging stations and short driving range**: As the energy density of the current batteries, including lithium-ion batteries is less, it cannot offer large driving range, which demands for the need for frequent charging and more EV charging stations.
iii. **Expensive**: The cost investment in electric vehicles is higher as compared to the internal combustion engine-based vehicles.
iv. **Safety concerns**: Batteries are the major component in electric vehicles, which are assigned with passive and active safeguards battery structure, but still there is a significant risk in terms of safety, including thermal stability of active materials at high temperature and occurrence of internal short-circuits resulting in thermal runaway.

X. CONCLUSION

According to polls conducted, standard lithium-ion batteries are gradually reaching a technological saturation point. There is a critical need to create an alternate strategy that addresses every obstacle to the adoption of electric automobiles. Solid state batteries are preferable to traditional liquid lithium ion batteries because they have a higher energy density and are safer. It is anticipated that solid state battery technology would lead to better products with lower production costs and better performance.

Major OEMs and MNCs including Toyota, BMW, Honda, and Hyundai are collaborating with R&D organizations, battery material makers, and battery manufacturers to advance technology. Fully marketed solid state battery based electric vehicles are anticipated to go on the market by 2025.

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