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(RESEARCH ARTICLE)

Electric vehicle batteries and its effect on the global market

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Abstract

The introduction of autonomous vehicles (AVs) and battery electric vehicles (BEVs) to the global automotive industry has generated ongoing, significant advances. Electric vehicles (EVs) are becoming more and more popular due to a variety of factors, including falling prices and greater environmental and climate awareness. Unique essential criteria, including vehicle range, have been produced because of the BEV powertrain's new features compared to the combustion type, and this has made them a key selling factor. The cost structure of the vehicle is altered by the fact that the electric components are still not optimized, and the required sensors are still expensive. The battery is one of the core elements of EVs, thus the paper provides a full analysis of all available battery technologies, from lead-acid to lithium-ion. Finally, we conclude our work by presenting our projections for this field's near future as well as the study areas that are still accessible to both the academic and industrial groups.

Keywords: Autonomous Vehicles (AVs); Lithium Ion (Li); Battery Electric Vehicle(BEV/s); Sulphur Dioxide (SO2); Particulate Matter (PM)

1. Introduction

The automobile industry has developed to become one of the most important worldwide industries, both monetarily and in terms of research and development. More technological components are being introduced to autos to improve passenger and pedestrian safety. Furthermore, there are more automobiles on the roads, allowing us to travel quickly and comfortably. However, this has resulted in a significant increase in the number of air pollutants in urban areas, such as Sulphur dioxide (SO_2), nitrogen oxides (NOX), carbon monoxide (CO), and particulate matter (PM).

The megatrends of electrification and automation are posing new challenges for manufacturers, creating needs for future cars and paving the way for hitherto uncharted mobility systems. For example, powertrain electrification offers a greener future, whereas autonomous driving will increase safety, availability, and efficiency. These tendencies, however, produce new boundary conditions throughout vehicle development and various cost structures. When compared to internal combustion engine cars, the traction battery increases both the weight and the purchase price of BEVs (ICEVs).

Furthermore, according to a European Union assessment, the transport sector is responsible for about 28 percent of overall carbon dioxide (CO2) emissions, with road transport accounting for more than 70 percent of transport sector emissions. As a result, governments in most industrialized nations are supporting the use of electric vehicles (EVs) to minimize the concentration of air pollutants, CO2, and other greenhouse gases. [1] They especially support sustainable and efficient transportation through various efforts, mostly through tax breaks, purchasing incentives, or other special measures such as free public parking or free use of highways. Compared to regular automobiles, electric vehicles have the following advantages:

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- Zero emissions: These cars produce no tailpipe pollutants (CO2) or nitrogen dioxide (NO2). Furthermore, manufacturing procedures are more environmentally friendly, yet battery manufacturing has a negative impact on carbon footprint.
- Simplicity: The number of engine elements in Electric Vehicles (EVs) is reduced, resulting in substantially lower maintenance.
- Cost: The vehicle's maintenance and power expenses are substantially lower when compared to typical combustion cars' maintenance and fuel expenditures. EVs have much lower energy costs per kilometer than regular automobiles.
- Efficiency: EVs are more fuel efficient than regular automobiles. [2] However, overall well-to-wheel (WTW) efficiency is also affected by power plant efficiency. For example, the overall WTW efficiency of gasoline cars range from 11% to 27%, but diesel vehicles vary from 25% to 37%.

2. Materials and Methods

2.1. Classification of Electric Vehicles

An electric vehicle is a vehicle that is powered totally or partially by electricity from a rechargeable battery. Although prototype electric cars (EVs) were conceived in the 1800s and numerous versions were produced in the 1900s, the EV industry did not take off until the turn of the twenty-first century. [3] However, hundreds of EV vehicles are predicted to be available globally by 2025.

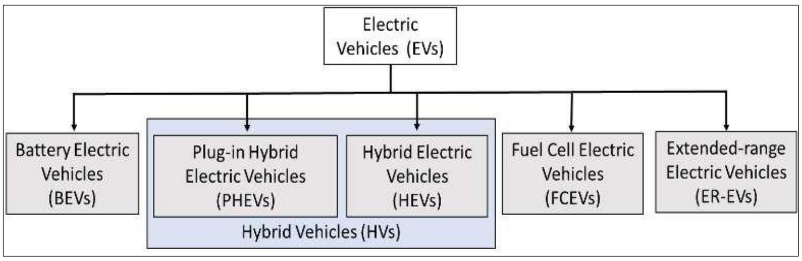

Figure 1 Classification of Electric Vehicle [3]

2.2. Shapes of batteries:

Electric vehicle (EV) batteries come in various shapes, each designed to optimize energy storage, efficiency, and vehicle integration. The main shapes of EV batteries include cylindrical, prismatic, and pouch cells, each with unique characteristics and applications.

2.2.1. Cylindrical Cells

Cylindrical cells are among the oldest and most established battery formats, widely recognized for their robust mechanical structure and ease of manufacturing. These batteries, resembling common household AA cells but larger, are known for their high energy density and durability. Their standardized sizes, such as the 18650 and the larger 21700 cells, make them highly compatible with various manufacturing processes and applications. Tesla, for instance, has popularized the use of cylindrical cells in its electric vehicles, primarily due to their proven performance, efficient cooling, and ability to pack densely within a battery pack. However, the cylindrical shape can lead to less efficient use of space compared to other shapes, as there is inevitable wasted space between the cells.

2.2.2. Prismatic Cells

Prismatic cells have a rectangular shape and are designed to maximize space utilization within the battery pack. They offer a high energy density per volume and are more adaptable to the shape of the battery enclosure in vehicles, allowing for more compact and streamlined battery designs. These cells are often encased in either a hard or soft aluminum shell, which provides structural support while remaining relatively lightweight. Prismatic cells are favored for their efficient space usage and ease of stacking, making them ideal for applications requiring a higher energy density in a confined space. However, they can be more complex to manufacture and typically require a more sophisticated thermal management system to handle the heat generated during operation.

2.2.3. Pouch Cells

Pouch cells are known for their flexible, soft packaging that resembles a flat, rectangular bag. This design allows for significant versatility in terms of shape and size, enabling manufacturers to tailor the battery pack to the specific contours of the vehicle, thereby maximizing space utilization. Pouch cells offer high energy density and are lightweight, making them a popular choice for electric vehicles where weight and space are critical considerations. The flexible design can also help reduce the overall cost and weight of the battery pack. However, pouch cells are more prone to swelling over time, which can lead to safety concerns and requires careful management and containment within the battery pack.

2.2.4. Solid-State Batteries

While not yet widely commercialized, solid-state batteries represent an emerging technology with significant potential to revolutionize EV battery design. These batteries can take various shapes, similar to prismatic and pouch cells, but use solid electrolytes instead of liquid ones. This allows for greater energy density, improved safety, and the potential for longer lifespan and faster charging times. Solid-state batteries can be more efficiently packed and are expected to provide greater flexibility in terms of size and shape, making them an exciting prospect for future EV applications.

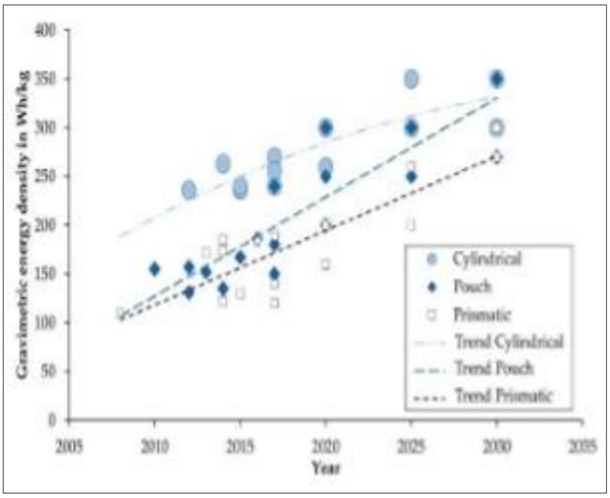

Figure 2 Different Shapes of Batteries w.r.t Life Cycle Vs Energy Density [4]

2.3 Typical battery sizes available with respect to its cost:

- Lead Acid Battery

Batteries made from lead-acid (Pb-PbO2), these are the earliest type of rechargeable battery, having been invented in 1859. Although this type of battery is commonly seen in traditional automobiles, it has also been employed in electric vehicles. [4] Its specific energy and energy density ratios are quite low. A 4. sulfuric acid deposit and a collection of lead plates combine to make the battery. Average cost for Lead Acid Battery: 130-140 USD.

- Nickel-Metal-hydride batteries (Ni-MH)

Instead of cadmium (Cd), negative electrodes in this type of battery are made of an alloy that stores hydrogen. Despite having a greater self-discharge rate than nickel-cadmium batteries, these batteries are utilized in many hybrid automobiles, including the Toyota Prius. Average cost for Nickel metal hydride Batteries: 250-1500 USD.

- Lithium-ion batteries (Li-Ion)

These batteries use a lithium salt as an electrolyte, which supplies the required ions for the reversible electrochemical process that occurs between the cathode and anode. The advantages of lithium-ion batteries are their lightweight components, high loading capacity, low internal resistance, and high loading and unloading cycles. Since 2010, the average price of a lithium-ion (Li-ion) EV battery pack has fallen from $1,200 per kilowatt-hour (kWh) to just $132/kWh in 2021.

2.4 Types of lithium-ion batteries currently used in commercially available vehicles:

- Lithium Manganese oxide

Forms a 3D Spinal Structure improving ion flow on electrode, resulting in low internal resistance and improve current handling. The low internal cell resistance enables fast charging and high current discharging. Li-Mn are used for power tools, medical instruments, hybrid and electric vehicles. Advantages of Spinal Structures is high thermal stability and enhance safety, but cycle and calendar life are limited.

- Lithium Nickel Manganese Cobalt Oxide

It is a cathode combination of MNC (Nickel Manganese and Cobalt). These systems can be tailored to serve as energy or power cells. These is the battery of choice for power tools, electric bikes and electric drivetrains etc. The cathode combination is 1/3rd nickel,1/3rd manganese and 1/3rd cobalt. Also called 1-1-1 configuration. [5] The nickel based systems have high energy density, lower cost, longer cycle life. Whereas sit is wise versa for cobalt systems.

- Lithium Nickel Cobalt Aluminium Oxide (NCA)

Batteries have the highest specific energy while also having a good specific power and a long lifespan. This is why they are highly suited to the electric car industry, despite the fact that they require rigorous safety inspections due to their more unstable nature. Tesla employs NCA batteries in the majority of their vehicles, with the exception of the Model 3, which just began to use the LFP chemistry.

- Lithium Titanate(LTO)

The anode of lithium titanate (LTO) batteries is built of this material rather than graphite, while the cathode is made of either LMO or NMC chemistry. As a result, the battery is exceptionally safe, has a long lifespan, and charges faster than any other form of battery. Although they appear to be excellent, they have a lower energy density and are quite pricey. They are commonly found in military or aerospace equipment, as well as wind and solar energy storage, charging stations, and certain electric cars.

2.5 Why lithium-ion batteries is not optimal for long term usage?

- Protection / battery management system required

As opposed to certain other rechargeable technologies, lithium ion cells and batteries are not as durable. Protection against excessive charging and discharge is necessary for them. Additionally, they must keep the current within safe boundaries. [6] As a result, one drawback of lithium ion batteries is that protection circuitry must be added to make sure they operate within safe parameters.

- Ageing

Lithium ion batteries age prematurely, which is one of its main drawbacks for consumer gadgets. This is based on both time and the calendar, as well as how many charge-discharge cycles the battery has gone through. Frequently, batteries lose capacity after only 500 to 1000 charge-discharge cycles. This number is rising as a result of advances in lithium-ion technology, but if 4. the batteries are built into the machinery, they may need to be replaced eventually.

- Cost

Cost is one of the main drawbacks of lithium ion batteries. The cost of manufacturing them is typically about 40% more than that of nickel-cadmium cells. This is a critical consideration when taking into account their use in mass-produced consumer goods, when any additional expenses are a serious concern.

- Technological Advances

Despite the fact that lithium ion batteries have been around for a while, some may still view them as a developing technology. Given that technology is always evolving, this could be a drawback. But as newer solutions are constantly being created, the constant development of new lithium ion technologies can also be advantageous.

2.6 Technological Advancements in Batteries:

- Nano-Bolt lithium tungsten batteries

The addition of tungsten and carbon multi-layered nanotubes to battery anode materials by researchers at N1 Technologies.Inc created a web-like nanostructure by bonding to the copper anode substrate. [7] During recharge and discharge cycles, that creates a sizable surface on which more ions can attach. The Nano-Bolt lithium tungsten battery can be recharged more quickly as a result, and it can store more energy. Any Lithium Battery design can use nanotubes if they are trimmed to the appropriate size.

- Zinc-manganese oxide batteries

What is the real mechanism of a battery? When examining accepted theories, a team from the DOE's Pacific Northwest National Laboratory discovered an unanticipated chemical conversion process in a zinc-manganese oxide battery. Increasing energy density in traditional batteries without raising costs is possible if that process can be managed. Because of this, lithium-ion and lead-acid batteries may not be the only options available.

- Organosilicon electrolyte batteries

The risk of the electrolyte igniting or exploding is a drawback of lithium batteries. Professors of chemistry at the University of Wisconsin-Madison Robert Hamers and Robert West created organosilicon (OS) based liquid solvents in an effort to find a safer alternative to the carbonate based solvent system used in Li-ion batteries. The resulting electrolytes can be molecularly tailored for the industrial, military, and consumer Li-ion battery sectors.

- Gold nanowire gel electrolyte batteries

Researchers at the University of California, Irvine used gels, which are less flammable than liquids in their pursuit of a better electrolyte for lithium ion batteries. They attempted to apply an electrolyte gel layer after coating gold nanowires with manganese dioxide. Normally too fragile to be used in batteries, nanowires had developed a tough exterior. The resulting electrode could be charged 200,000 times without losing its capacity to store a charge, the researchers found when they tested it. For a typical battery, that equates to 6,000 cycles.

- Tank Two String Cell batteries

The lengthy process of recharging electric vehicles (EVs) is a deterrent to their use. Tank Two considered modularizing a battery as a method to reduce hours to minutes. Their String Cell TM battery is made up of a number of tiny, independent, self-organizing cells. Each string cell is made of a plastic casing that is coated in a conductive substance that enables it to make contacts with other cells fast and readily. [7] The connections in the electrochemical cell are managed by an internal processing unit. The battery's little balls are sucked out and replaced with recharged cells at the service station to enable rapid charging of an EV. The cells can be recharged at the station during off-peak times.

2.7 Analysis of state of the art of lithium-ion battery

Some of the important properties of Li-ion batteries include size (physical and energy density), lifespan (capacity and life cycles), charge and discharge characteristics, cost, performance over a larger temperature range, self-discharge profile, and impact on leakage, gassing, and toxicity. In general, lithium ion batteries have both positive and negative characteristics. Some of their positive traits are their high specific energy (230 Wh/kg) and power density (12 kW/kg), good energy density, outstanding cycle life and extended life, and good charging and discharging efficiency. The cost, the requirement to use an electrical protection system during charging and discharging, and the GHG emissions during manufacture and disposal are common downsides. Good electrical charging and discharging capabilities are displayed by the Li-ion battery. The charging capacity gradually rises as the charge voltage is maintained constant throughout charging. [8] As the voltage rises to its maximum, the current decreases exponentially. Until the cell capacity reaches the minimum acceptable level, which is set by the manufacturer as an end-of-charge voltage, there is a slight increase and decrease in the voltage and current values, respectively. In contrast, the capacity discharge maintains an almost constant voltage and current to the load.

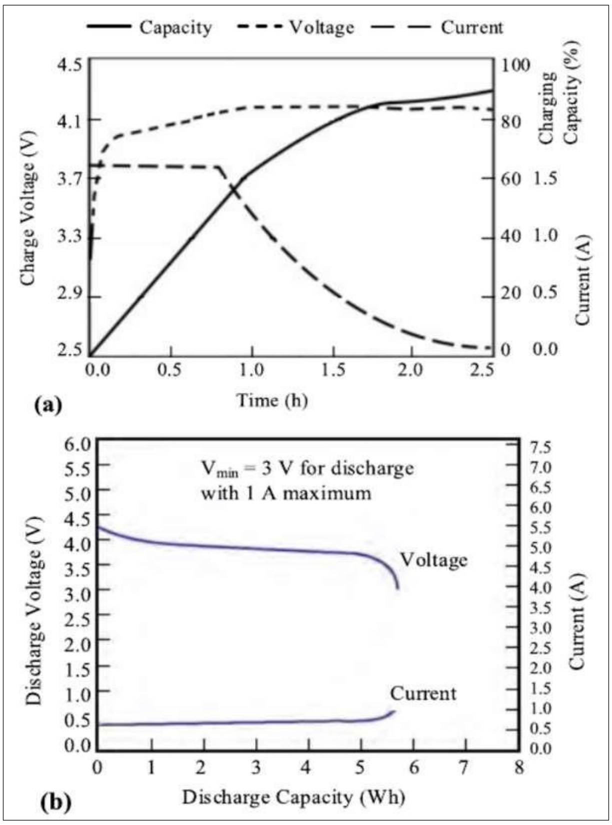

Figure 3 Typical Characteristics of the lithium ion battery (a) Charging, (b) Discharging [9]

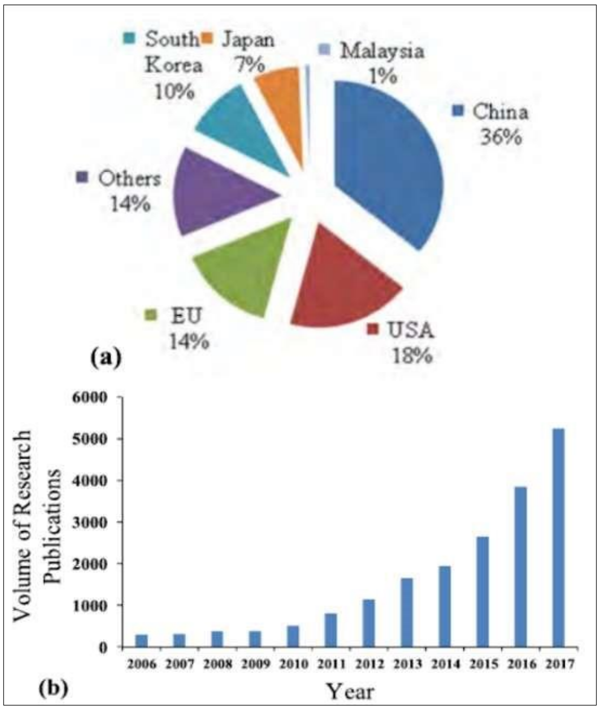

Figure 4 Volume of research publications on Li-ion battery technology and application: (a) country-wise, (b) in each year worldwide. [8]

The challenges for the management of battery charging and discharging within the ideal operating range of SOC have become more important topics for advanced research and technology. Now, the advancement of Li-ion battery production and application is growing beyond expectation. Fig. 2 shows the volume of research publications, specifically in engineering and physics research areas, on Li-ion battery technology. The research has progressed dramatically throughout the world, though it was limited to a few Asian countries such as Japan, South Korea and China. Moreover, the research publications forecasted that the importance of Li-ion battery has been increasing over the years, as shown in Graph. 4(b).

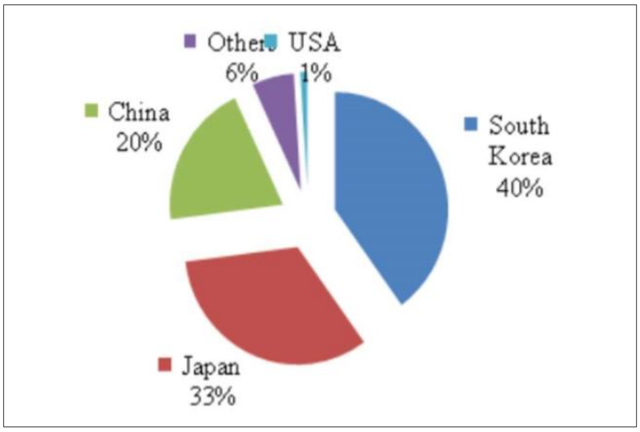

Figure 5 Manufacture of Li-ion batteries for vehicle applications and market share [9]

Conversely, as seen in Graph 5, the manufacturers of Li-ion batteries for vehicle applications is not common everywhere due to the necessary high technical support, management of raw resources and budget constraints.

2.9 Market analysis

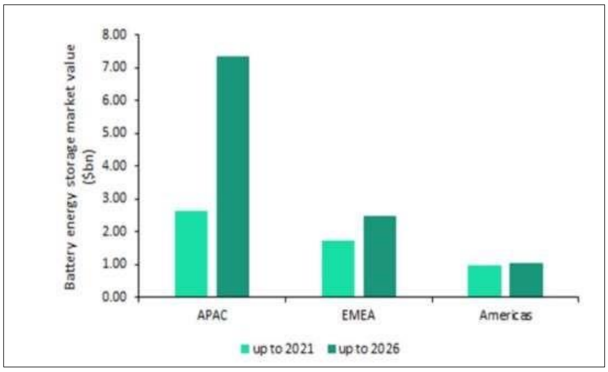

Figure 6 Battery energy storage, regional market value($bn), 2021 and 2026 [10]

Over the last decade, various new digital and smart technologies have been integrated, with countries aggressively promoting the modernization of grids and enhancing the grids' capability to meet the requirements of the present and future. As part of the effort, batteries are being deployed to aid smart grids, integrate renewables, create responsive electricity markets, provide ancillary services, and enhance both system resilience and energy self-sufficiency. Various technologies have disrupted the operational structure of the power grid, altering the market from a linear centralized model to a decentralized model. With improving market conditions, more companies are moving into decentralized generation, leading to an increase in the onsite deployment of renewables and batteries, as with micro grids or mini-grids. Encouraging policies and high electricity charges are also nudging the market closer to renewables and/or storage plus renewables at the end consumer level. As the power sector evolves to accommodate new technologies and adapt to varying market trends, energy storage will play a crucial role in the transition and transformation of the power sector.

3. Conclusion

The progress that the electric vehicle industry has seen in recent years is not only extremely welcomed, but highly necessary in light of the increasing global greenhouse gas levels. As demonstrated within the economic, social, and environmental analysis sections of this webpage, the benefits of electric vehicles far surpass the costs. The biggest obstacle to the widespread adoption of electric-powered transportation is cost related, as gasoline and the vehicles that run on it are readily available, convenient, and less costly. As is demonstrated in our timeline, we hope that over the course of the next decade technological advancements and policy changes will help ease the transition from traditional fuel powered vehicles. Additionally, the realization and success of this industry relies heavily on the global population, and it is our hope that through mass marketing and environmental education programs people will feel incentivized and empowered to drive an electric-powered vehicle. Each person can make a difference, so go electric and help make a difference. [10] Both developed and developing countries have become more active in EV introduction and diffusion. In developed countries, the government has led the promotion of next-generation environment-friendly vehicles. In the industrial world, not only conventional auto manufacturers but also large and small enterprises have joined the EV business as new business opportunities. In accordance with the implementation of many pilot projects and EV related events, public expectation on EVs is high. However, there is no clear indication for full-fledged diffusion. This is because of high prices of EVs, limited models, lack of charging infrastructure, and lack of trust in the market in terms of life span of EVs and safety. On the other hand, big auto manufacturers have become bolder in EV development, which is seen to address the abovementioned problems and accelerate EV diffusion.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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