The Development And Future Prospects Of Electric Vehicle Batteries An Overview

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Abstract—As electric vehicles become more popular, an increasing number of people are using it as their mode of transportation. However, the current stage of electric vehicle technology is limited by lithium battery technology, making it difficult for them to be fully accepted by everyone. As solid-state lithium battery technology matures, electric vehicles will also have a broader customer base.

Keywords—Electrical Vehicle, Solid Sate Lithium Battery, Battery Management System, Range anxiety, Pollution, Global warming

I. INTRODUCTION

The Origin of Electric Vehicles.

Since 1832, Robert Anderson develops the first electric vehicle.[5] Electric vehicles appeared in our vision. Over the next decade, technology continuous iterations and upgrades, becoming a favored means of transportation, especially in urban elites. During that period, electric vehicles used disposable dry batteries, limiting their range to short distance, and it makes only urban rich elites the major group that interested this transportation. Improved roads and the discovery of affordable Texas crude oil led to a decrease in electric vehicles by 1935, with gas-powered vehicles becoming more popular.[5] With the increasingly advanced industrialization of humanity and the continuous expansion of people's activity radius, the characteristics of rapid fuel replenishment, resilience to working environments, and the ability to undertake long-distance journeys made gasoline-powered vehicles the world's most mainstream mode of transportation. At that time, the United States, one of the leading automotive manufacturing nations, was once referred to as the "nation on wheels" due to its exceptionally high number of gasoline-powered vehicles.

Global warming causes concern.

However, various issues with gasoline-powered vehicles prompted countries to reconsider and promote electric cars. Firstly, environmental concerns, as vehicles using fossil fuels generate significant amounts of carbon dioxide and other environmentally harmful emissions, with exhaust emissions being a major contributor to global warming. The Paris Agreement, a legally binding treaty in force since November 4, 2016, seeks to significantly cut global greenhouse gas emissions, limiting the temperature increase to below 2°C above pre-industrial levels. Currently, 195 Parties are part of the Agreement.[6] Traditional automotive manufacturing giants in Europe took the lead, with major players such as Volkswagen, Mercedes, and BMW increasing the sales proportion of electric vehicles. BMW said half of its sedans, SUVs and Mini vehicles will be electrified in Europe by 2030.[2] The Paris Agreement led to a noticeable acceleration in the global manufacturing and consumption of electric vehicles. After five years of planning and construction, the development of electric vehicles underwent a radical transformation starting from 2020. The share of electric cars in total sales has more than tripled in three years, from around 4% in 2020 to 14% in 2022. [1] China, the United States, and the European Union together hold 94% of the market sales share, with China alone accounting for 57% of the electric vehicle market sales share.

New power joins the game.

Unlike EU countries transitioning to electric vehicle production to fulfill agreements, developing countries clearly have their own perspectives on the development of electric cars. Due to the early development of Western society, which nearly monopolized most of the patents for internal combustion engines, developing countries can bypass the industrial chains laid out by developed countries a hundred years ago and stand on an equal starting line in the new field of electric vehicle development. The inexpensive labor and rapidly growing economies of emerging nations naturally provide advantages for the development of electric cars. In the first half of 2023, China's car exports reached 2.14 million units, surpassing Japan to become the world's first place, with electrical vehicles accounting for 25%.[7] Additionally, the developed countries' automotive industry such as United State has also benefited from China's rapid development. Tesla, the largest electric car manufacturer in the United States, is one such beneficiary. In 2022, the company delivered 1.31 million vehicles globally, more than half of which were from Shanghai, China.[8] Tesla's goal is to produce 20 million electric vehicles per year by 2030, executives reiterated.[3]

II. ADVANTAGES OF ELECTRIC VEHICLES

It is not possible for the government and enterprises to promote electric vehicles without customer demand. For most consumers, car is an expansive daily use tool that need to be reliable performance and affordable cost of ownership. Therefore, electric vehicles must possess their own unique advantages before they can be chosen by ordinary people and become the preferred option for consumers.

Comfortable and High-Quality Driving experience.

Traditional fuel vehicles produce vibrations when the engine is working while driving, and these vibrations are transmitted to the vehicle interior, felt by the driver and passengers. The noise emitted by the engine and exhaust pipe is also felt by people inside and outside the car. This noise is amplified, especially during traffic jams on city trip. To reduce noise and vibration, traditional luxury car companies usually increase the number of engine cylinders and use a large amount of sound insulation materials. However, those extra material significantly increases the car's price, making it generally reserved for high-end luxury cars. Cheap cars are often considered uncomfortable and provide no driving experience.

Now, electrical vehicle changed this opinion on the cheap model. The motor's smooth operation and quiet operating noise not only make it almost impossible for the driver to feel that the vehicle has started and is on standby but also make the vehicle extremely quiet and smooth when driving.

The torque of an electric motor is significantly higher than that of an internal combustion engine, eliminating the need for a gearbox to shift gears. An ordinary electric car can easily outperform the acceleration of a supercar. This feature is particularly appealing to young people who are highly concerned about the speed and performance of their vehicles compared to others. Combined with intelligent car systems and assisted driving features, an increasing number of young people in urban areas are choosing electric cars as their first vehicles.

Intelligent assistance and driving systems.

Simultaneously, due to electric cars being equipped with large-capacity batteries, this significantly increases the usage of electrical devices in the vehicle. This enhances the overall driving experience in many aspects. Even when the vehicle is not running, high power consumption equipment such as air conditioning can still be utilized. The electric car allows passengers and pets to comfortably wait inside the vehicle while stationary or waiting for someone. This is one of the reasons why many urban households choose electric vehicles. Furthermore, since the power source of electric cars is the electric motor, the system can intelligently adjust the vehicle's driving experience.

One of China's largest electric vehicle manufacturing, BYD, release the "Yang Wang E4 Platform” in 2023, allowing individual control of the power output to all four wheels. By adjusting their different rotation directions and speeds, electric vehicle equipped with the “Yang Wang E4 Platform” can automatically engage the vehicle's computer system when experiencing a tire blowout at speeds of up to 120 kilometers per hour, then it allows vehicle only using the rest of three wheels to maintain the vehicle's continued operation. The “Yang Wang E4 Platform” also enables each tire to rotate in different directions, achieving a full 360-degree turn in place, which proves to be very practical in congested areas. Moreover, as electric cars do not require air intake and exhaust, they inherently possess strong waterproof capabilities. The “Yang Wang E4 Platform” allows electric vehicle to floating in the top of water and using wheel as a propeller to power the vehicle driving in water. These scenes from science fiction movies have become a reality in 2023, with many people purchasing and driving models equipped with the “Yang Wang E4 Platform”.

Figure 1. Floating Yang Wang [15]

III. CHALLENGES

The speed of development in electric vehicles over the past two years has surpassed the expectations. However, electric vehicles also contend with a significant problem, which happens to be the most crucial factor impeding their development—the battery.

Energy density.

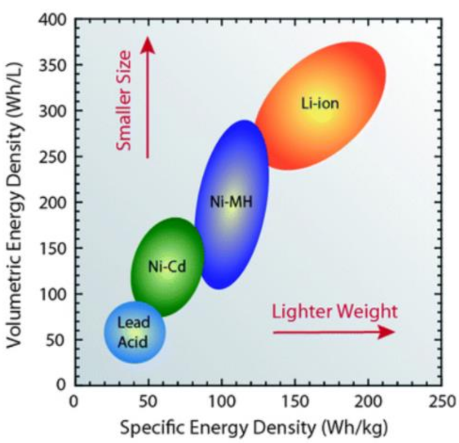

Figure 2. Energy density of different elements [17]

Different batteries have varying energy densities, and the reason lithium-ion batteries are currently highly sought after is due to their significantly greater energy density compared to traditional lead-acid batteries. According to the Figure 2, Li-ion batteries contain almost four-time energy by the same density. That is the main reason that most electric vehicles company like to select lithium-ion batteries.

However, the energy density is still the significant issue for electric vehicles by compare with fuel vehicle that can travel around 600 kilometers on a single tank of gas, the major weight in an electric vehicle is the battery, constituting over half of the total vehicle weight. According to the data, stored energy in fuel is considerable: energy density of gasoline is at 47.5 MJ/kg and 34.6 MJ/liter; A lithium-ion battery pack has about 0.3 MJ/kg and about 0.4 MJ/liter.[16] This difference of nearly a hundred times makes it difficult for electric vehicles to surpass traditional fuel vehicles in terms of energy density.

Instability of lithium batteries.

The biggest hidden danger of lithium batteries is their propensity to catch fire. On June 5th, 2023, a Volkswagen ID.4 Electric Car caught fire after a collision. [9] The fire occurred rapidly within a few seconds after the collision, causing four people, including the driver, to be unable to escape in time and were burned to death in the car. The widely used ternary lithium batteries in electric vehicles, once ruptured or if the temperature control system fails, can lead to the dissolution of the separator at temperatures above 140 degrees Celsius. This causes the rapid mixing of cathode and anode materials and a short circuit, forming high-temperature liquids and gases that then eject from the battery casing, leading to a series of chain reactions. Moreover, as it is a chemical fire, ordinary dry powder extinguishers are ineffective, and a large amount of cool water is needed to cool down the battery to extinguish the fire. The issue of lithium batteries catching fire is not only present during use; often, discarded lithium batteries also pose a fire hazard. One landfill in the Pacific Northwest reported 124 fires between June 2017 and December 2020 due to lithium-ion batteries.[12]

The instability of lithium batteries is also reflected in daily use. Fuel cars are not very sensitive to environmental temperature. Traditional fuel cars move by internal combustion in the cylinder. Apart from the consumption of air conditioning, the mileage of traditional fuel cars in winter and summer, when there are significant temperature differences, is roughly the same. However, electric cars require the battery to discharge electricity to rotate the motor and move the car. In low temperatures, the battery temperature drops, the movement of electrons within the battery slows down, requiring more energy to move inside the battery, thus greatly reducing the range of the electric car in low temperatures.

Lithium battery recycling and pollution.

The pollution from lithium batteries is a problem many people are not aware of. Since the lifecycle of a lithium battery is generally about ten years, and since the rapid growth of EVs began in 2020, the production of lithium batteries has also increased. As of December 2023, the trading price of lithium carbonate in Brazil is about $13,000 per ton.[10] According to an article by professional analysts, as of December 2022, the average cost to recycle and process a ton of used lithium batteries is about $4,500 per ton. Taking the commonly used NCM523 cathode material as an example, which theoretically contains 7.19% lithium, and assuming a recovery rate of 90% (which is relatively high), this would yield about 95.7 kilograms of lithium carbonate. Calculating at today's price ($13,000/ton), the value of this lithium carbonate is about $1,248. This is clearly not cost-effective, because even using the $4,500 for recycling to buy lithium carbonate would yield over 300 kilograms of lithium ore. [11] Therefore, at the current stage, recycling lithium ore cannot generate any profit. According to the author of the article, the price of lithium carbonate must exceed $50,000 per ton for recycling to be cost-effective compared to purchasing. This is clearly unrealistic at present. In the United States, there are only a few companies that cover lithium battery recycling, and these businesses are entirely supported by government subsidies. It costs more to recycle them than to mine more lithium to make new ones. Also, since large scale, cheap ways to recycle Li batteries are lagging, only about 5% of Li batteries are recycled globally, meaning the majority are simply going to waste.[4]

With the high cost of recycling lithium batteries and the extremely low recycling rate, while at the same time the production of electric vehicles is rapidly increasing, manufacturers have no choice but to continuously mine for lithium. Contrary to the clean and green image people have, lithium battery mining comes with a lot of pollution. Mining the various metals needed for Li batteries requires vast resources. It takes 2,273,000 liters of water to mine one ton of lithium. [4] The huge amount of water required for mining brings disastrous consequences for the local people in the water supply areas. In the Salar de Atacama region of Northern Chile, mining activities used an incredible 65% of the region's water supply, putting increased pressure on farmers in the area, and forcing local communities to source their water supply from elsewhere. [13] To meet this huge demand for water, lithium mines often must discharge a large amount of used water into nearby rivers or lakes. This wastewater affects an area of 150 kilometers downstream, causing many fish deaths. The closure of the BYD lithium battery factory in Ganzi, Sichuan, China, was due to the discovery of hundreds of yaks dying from drinking river water nearby.

Not only is there damage to water resources, but contrary to the zero-emission image of electric cars, the production of batteries emits a large amount of carbon dioxide, leading to the greenhouse effect. Producing a battery weighing 1,100 pounds emits over 70% more carbon dioxide than producing a conventional car in Germany, according to research by the automotive consultancy Beryll's Strategy Advisors. [14] Therefore, people only notice the energy-saving and environmental protection of electric cars in daily use, greatly underestimating the damage to the environment caused during the production of electric cars. It can be said that electric cars have completely surpassed traditional fuel cars in other aspects, and the biggest issue limiting electric cars is battery technology. If there is a significant breakthrough in battery technology, then the prospects for electric cars will become much better.

IV. TECHNICAL SOLUTIONS

Electric vehicles are still in the initial stages, so the battery technology suitable for electric vehicles and battery recycling are also in the exploration phase. Governments and enterprises need to invest more to improve battery technology, allowing electric vehicles to truly achieve their original intention of environmental protection and keep customer's safety.

The basic structure of liquid lithium batteries

The current lithium-ion batteries commonly use a liquid form, for example, the ternary lithium battery is a type of liquid battery. Inside the battery case, there are three main parts: the cathode, the anode, and the separator.

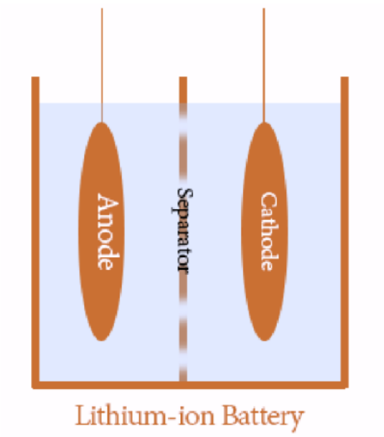

Figure 3. Structure of a conventional lithium battery

The battery's cathode is composed of lithium and other metals. The function of the cathode is to release lithium ions during the discharge process to provide energy to the device being powered. The addition of varying amounts of nickel, manganese, and cobalt achieves a balance between energy density, safety, and lifespan. The anode is typically made of graphite, storing lithium ions when the battery is charged. The movement of ions from the cathode to the anode generates an electric current. The separator is a key component that isolates the cathode from the anode, preventing direct contact and short circuiting. Although the separator isolates the cathode and anode, it allows lithium ions to pass through. It is usually made of a polymer film with many tiny pores. The current batteries have several significant problems; the first is that the anode material limits the energy density. The cathode, anode, and separator can be considered as three parts within a water pipe; if the diameter of any part decreases, it will affect the flow of water through, and the same principle applies to batteries. The commonly used graphite anode has a lower energy density, which leads to a lower overall energy density for the battery. The second problem is the safety of the separator. To ensure lithium ions can pass through smoothly, the separator must be as thin as possible. However, during the charging and discharging process of lithium ions, the liquid electrolyte is prone to forming lithium dendrites, and these small crystals can puncture the separator, causing a short circuit between the cathode and anode, leading to a rapid increase in battery pack temperature and causing fires. The electrolyte is also the main reason for the instability of the battery at low temperatures because when the temperature drops, the lithium battery electrolyte can become thick and increase the internal resistance of the battery, causing the operation rate of lithium iron phosphate to slow down. [19] The third problem is the challenge of recycling. In fact, a large part of the cost of recycling used lithium batteries is spent on separating the cathode, anode, and separator. The internal cathode is metal, the anode is graphite, and the separator is a polymer. This combination of different materials and complex structures significantly increases the difficulty of separation and recycling.

The ideal form of lithium batteries - Solid state lithium battery

Based on the three main shortcomings of liquid batteries, solid-state batteries are the best solution. The biggest difference between solid-state batteries and existing liquid lithium batteries is that the separator in solid-state batteries will be eliminated, and the electrolyte will change from liquid to solid.

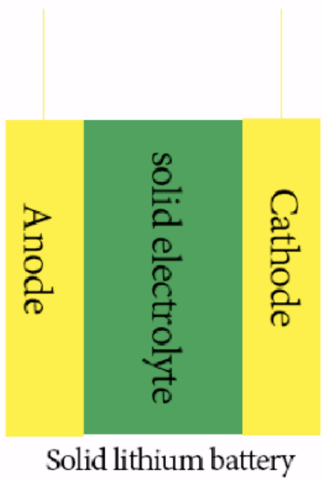

Figure 4. Structure of a solid-state lithium battery

The first advantage is the increase in energy density. After upgrading from graphite to silicon-carbon anodes, the energy density of the battery is expected to exceed 500Wh/kg, which in turn will enable electric vehicles to have a range of over 1000 kilometers. If metallic lithium is used as the anode, the energy density could reach 2600-3500Wh/kg, achieving a qualitative leap. The second advantage is safety. Since there is no separator and the solid electrolyte has overcome the lithium dendrite phenomenon, the risk of spontaneous combustion of liquid electrolytes is eliminated. Ideally, the cycle performance of solid-state batteries can reach about 45,000 times. In addition, solid-state batteries can be fully charged in just a few minutes, and the operating temperature range has expanded to more than three times. The third point is that the more straightforward structure and solid metal materials of solid-state lithium batteries can significantly reduce the processing steps of recycling lithium batteries, which can further reduce the cost of lithium battery recycling. This can allow more companies to see the benefits of recycling lithium batteries and begin to invest in the research and development of lithium battery recycling technology. In addition to the above three main advantages, solid-state batteries also have significant improvements in automobile lightweighting, cycle life, charging speed, and operating temperature range. In terms of vehicle lightweighting, the separator and electrolyte combined account for nearly 40% of the battery's volume and 25% of its weight. After being replaced by a solid electrolyte, the thickness of the battery can be significantly reduced. At the same time, after the safety is improved, the internal temperature control components of the battery can be removed, further improving the volume utilization rate. [19]

The current solution - Hybrid solid electrolyte-liquid electrolyte systems

However, solid-state batteries still have issues such as low ionic conductivity leading to poor performance and high costs, so it will be at least 5-10 years before they can be mass-produced. The rapid growth of the electric vehicle market makes it urgent for companies to find a new battery solution to increase their competitiveness. Therefore, before completely overcoming the challenges of solid-state lithium batteries, the hybrid solid-liquid battery has become a compromise solution currently adopted by car manufacturers.

Unlike pure liquid batteries and pure solid batteries, hybrid solid electrolyte-liquid electrolyte systems combine solid and liquid electrolytes. To solve the problem of poor performance caused by low ionic conductivity, the combination between the solid-state battery electrolyte and electrodes is solid to solid, which is challenging to form as tight and full contact as solid mixed with liquid, therefore not conducive to the transmission of lithium ions between the cathode and anode, affecting battery performance. However, by adding some liquid electrolyte to the interior of the solid-state battery, it is possible to improve the interface contact resistance. The solid electrolyte is safer and has a higher energy density, while the liquid electrolyte provides better ionic conductivity and is easier to manufacture. Compared with traditional liquid electrolyte batteries, hybrid solid-liquid batteries use anodes with greater energy density, which significantly improves the overall energy density of the battery. [18] The semi-solid-state battery has already shown its ability to enhance the performance of electric vehicles in practical applications. On December 17, 2023, William Li, Nio's co-founder, and CEO, personally tested the new 150 kWh semi-solid-state battery (SSB). Driving the Nio ET7 large sedan, Li and his co-driver achieved a range of 1,044 km (650 miles) with 3% battery capacity remaining, which would likely provide an additional 30 km range. This test was conducted in winter, a time when most gasoline vehicles on the market cannot achieve such range. The pure electric sedan, equipped with this new battery system, easily completed a long-distance journey, attracting global attention. Once mass production begins, it will undoubtedly give a significant boost to the electric vehicle market. It is believed that after the complete breakthrough in solid-state battery technology, electric vehicles will have an even larger market.【20】

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