Classification and Development Status of Battery Types for New Energy Vehicles

Yuleiming Dai [1], Yiming Liu [2], Zihan Shu [3], Jiatong Zou [4, *]

[1] Winland Academy, London, WC2B 5PT, United Kingdom

[2] Agada International Preparatory Ivy League Academy, Guangzhou, 510530, China

[3] DaLian Ocean University, Dalian, 116023, China

[4] Our Lady of Good Counsel High School, Olney, MD 20832, United State

* Corresponding Author Email: Zoux011@olgchs.org

Abstract. This article provides a detailed explanation of the composition and working principles of current mainstream new energy vehicle (NEV) batteries, summarizing the advantages and disadvantages of different types of batteries and analyzing their development prospects. As the core component of NEVs, batteries come in various forms, with their recycling and reuse becoming pressing challenges that need to be addressed. Based on a comparison of the performance indicators of mainstream batteries such as energy storage batteries and fuel cells, the article explores the advantages and bottlenecks of each battery type in market development. The research shows that the future development of NEV batteries will exhibit a trend of diversification. Although the technological advancements of various batteries are significant, the overall recycling rates remain low, especially for lithium-ion batteries and nickel-metal hydride batteries, which face complex technical challenges in recycling. In conclusion, improving overall recycling rates and optimizing regeneration technologies are crucial to promoting the sustainable development of NEV batteries. Future research should focus on the innovation of battery recycling processes and the integration with market applications to drive the long-term development of the new energy vehicle industry.

Keywords: New Energy Vehicle Batteries, Recycling and Reuse, Performance Comparison, Sustainable Development.

1. Introduction

With the continuous development of technology, the extensive use of fuel vehicles has led to excessive carbon emissions, which cause environmental pollution and energy shortages. In order to reduce the pollution caused by fuel vehicles, people began to explore green energy-saving and environmentally friendly energy such as new energy as an alternative. New energy vehicles with low-carbon and environmentally friendly characteristics have become popular [1]. Battery is extremely important as its main core, and it has a great impact on the development process of new energy vehicles. The research on battery is to improve the performance of vehicle endurance, charging efficiency, etc. At present, new energy batteries can be divided into three categories, which is storage batteries, fuel cells and superchargers.

This paper provides a comprehensive analysis of the components and working principles of the current mainstream batteries used in new energy vehicles, including storage batteries, fuel cells, and others. By comparing the performance metrics, this paper summarize the advantages and disadvantages of each battery type. Furthermore, this paper explores the development prospects of these batteries in the context of evolving market demands and technological advancements.

2. Storage battery

2.1. Analysis of Storage Battery

A storage battery, also known as a rechargeable battery, is designed to store electrical energy and release it when needed after being charged. Typically, it comprises positive and negative electrodes immersed in an electrolyte. Based on the materials used for the electrodes, storage batteries can be categorized into several types, including zinc-based, nickel-based, lead-acid, lithium-ion, and metal-air batteries. Each type varies in its chemical composition and performance characteristics. Storage batteries can also be classified into acid storage batteries, alkaline storage batteries, neutral storage batteries and organic electrolyte storage batteries [2].

2.2. Battery Performance Indicators

The performance index of a battery is a critical parameter for evaluating its effectiveness and functionality. By analyzing this index, it is possible to identify the battery's limitations and implement optimizations. Key components of the performance index include capacity, which refers to the amount of electrical energy a battery can store—higher capacity indicates greater energy storage potential. Voltage measures the potential difference between two points within the battery, while internal resistance affects performance by generating heat, leading to energy loss, reduced efficiency, and a shorter lifespan. The charging and discharging time reflect the duration required for a full charge and the period the battery can sustain power output. Specific energy represents the amount of energy stored per unit mass, with higher specific energy allowing the battery to store more energy relative to its mass, thus extending its usage time. Specific power indicates the maximum power output per unit mass, enabling the battery to deliver significant energy quickly, making it capable of rapid energy release. Lastly, safety evaluates the battery's reliability under fault conditions, such as its resistance to explosion and protection against overcharging. By assessing these performance indices, one can gain a comprehensive understanding of a battery's strengths and weaknesses and explore ways to enhance its design and performance.

3. Lead-Acid Batteries

3.1. Composition of Lead-Acid Batteries

Lead-acid batteries have several essential components: positive and negative plates, separators, electrolytes, safety valves, and a protective shell. The positive plates contain lead oxide ($PbO2$) as the active material, while the negative plates consist of spongy lead (Pb). Sulfuric acid ($H2SO4$) acts as the electrolyte, enabling the necessary electrochemical reactions. The separator keeps the positive and negative plates electrically isolated to ensure proper battery function [3]. The composition of a lead-acid battery is shown in Fig.1.

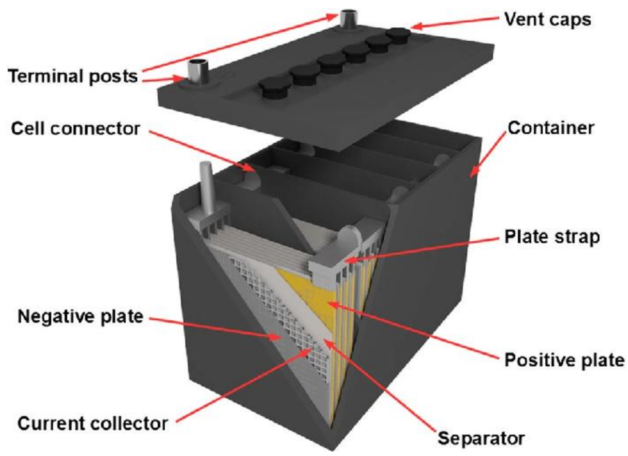

Figure 1. The composition of a lead-acid battery [4]

3.2. Working Principle of Lead-Acid Battery

When a lead-acid battery discharges, the lead oxide (PbO2) on the positive electrode and the spongy lead (Pb) on the negative electrode react with sulfuric acid (H2SO4) in a reduction process. This reaction forms lead sulfate (PbSO4), releases electrons, and produces water (H2O), while the sulfuric acid is gradually depleted. During the charging phase, the process is reversed as external electrical energy is transformed into chemical energy. The lead sulfate (PbSO4) undergoes oxidation, regenerating lead oxide (PbO2) on the positive plate and spongy lead (Pb) on the negative plate. Simultaneously, water in the electrolyte is consumed, leading to the reformation of sulfuric acid molecules.

3.3. Advantages and Disadvantages of Lead-Acid Batteries

Lead-acid batteries are the most commonly used today, with over 50 years of widespread application and mature technology. They are cost-effective to produce and affordably priced [4]. The battery materials such as the board and electrolyte of lead-acid batteries can ensure that the battery is non-corrosive, reduce the possibility of battery self-explosion, and improve safety during use [5]. Lead-acid batteries have the disadvantages of low specific energy and specific power [4]. Secondly, lead oxide is large in size and heavy in weight, which increases the weight of new energy vehicles. In addition, lead is toxic to the human body. From the perspective of recycling, it may be replaced by new environmentally friendly energy [2].

4. Lithium-Ion Battery

4.1. Composition of Lithium-Ion Battery

Lithium-ion batteries are composed of several essential parts, including a positive electrode, a negative electrode, an electrolyte, a separator, a current collector, and a protective casing. The materials chosen for the positive electrode play a crucial role in defining the different types of lithium-ion batteries. For example, batteries that utilize lithium manganese oxide as the main component for the positive electrode are classified as lithium manganese oxide batteries, while those that primarily employ lithium iron phosphate are known as lithium iron phosphate batteries [3]. The most commonly used material for the negative electrode is graphite. The electrolyte, which facilitates the movement of lithium ions between the positive and negative electrodes, typically consists of lithium salts and organic solvents [2]. The current collector is responsible for collecting and transmitting the electric current. The composition of lithium-ion battery is shown in Fig.2.

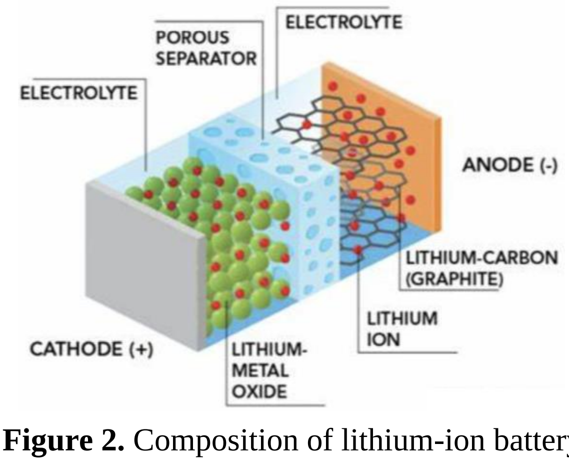

Figure 2. Composition of lithium-ion battery

4.2. Working Principle of Lithium-Ion Battery

The operation of lithium-ion batteries involves the movement of lithium ions between the positive and negative electrodes. For example, in a battery with graphite as the negative electrode and lithium cobalt oxide (LiCoO2) as the positive electrode, charging drives electrons from the positive to the negative electrode. At the positive electrode, lithium ions (Li+) are released, resulting in the formation of cobalt oxide (CoO2). Meanwhile, at the negative electrode, lithium ions (Li+) are intercalated into the graphite, where they combine with the incoming electrons to form lithium atoms. During discharge, the battery supplies electrical energy to the load, causing electrons to flow from the negative electrode to the positive electrode. At the negative electrode, lithium atoms release electrons, becoming lithium ions (Li+) once again. These de-intercalated lithium ions then travel back through the electrolyte to the positive electrode, where they are re-intercalated into the lithium cobalt oxide (LiCoO2) and recombine with the electrons that have reached the positive electrode.

The positive electrode reaction equation for a lithium-ion battery is shown in formula (1).

$$LiCoO_2 \rightleftharpoons Li_{1-x}CoO_2 + xLi^+ + xe^- \tag{1}$$

The negative electrode reaction equation for a lithium-ion battery is shown in formula (2).

$$C_n + xLi^+ + xe^- \rightleftharpoons Li_xC_n \tag{2}$$

4.3. Advantages and Disadvantages

Compared to nickel-metal hydride and lead-acid batteries, lithium-ion batteries offer a higher operating voltage and significantly greater specific energy—up to three times that of nickel-metal hydride batteries [4]. The primary characteristics of lithium-ion batteries are as follows: Firstly, they possess the highest mass specific energy and volume specific energy among current battery technologies, ranging from 120-200Wh/kg and reaching up to 300Wh/L, respectively. Secondly, they have a high discharge voltage, with the discharge voltage platform typically between 3.2V and 4.2V. Thirdly, lithium-ion batteries boast a long cycle life with no memory effect; for example, lithium iron phosphate batteries and those using lithium titanate as the negative electrode can endure over 2,000 and 5,000 charge-discharge cycles, respectively. Additionally, they have high charging efficiency, with energy conversion rates during charge and discharge cycles exceeding 90%. Finally, they operate over a wide temperature range, generally from -20°C to 40°C, and lithium titanate-based batteries can function even in temperatures as low as -40°C [6].

4.4. Lithium-Ion Battery Cathode Materials

The positive electrode material is a critical component of lithium-ion batteries, serving as the primary source of lithium during the charging and discharging cycles. This material must supply the lithium necessary for the battery's operation. Therefore, an ideal positive electrode material must possess several key attributes, including high potential, high specific capacity, high density, excellent safety, good rate performance, and long life. Currently, materials that satisfy these criteria are primarily classified into three categories: 1) layered structure materials like LiMO2 (where M can be Co, Ni, or Mn); 2) spinel-structured lithium manganese oxide (LiMn2O4); and 3) LiMPO4 with an olivine structure (where M can be Fe, Mn, Co, or Ni).

Most commercial lithium-ion batteries use LiCoO2 as the positive electrode material. It offers high working voltage (3.6V), stable discharge, suitability for large current discharge, high specific energy, good cyclability, and a straightforward preparation process. The theoretical discharge capacity of LiCoO2 lithium cobalt oxide is 274mAh/g, and the actual capacity is about 140mAh/g. LiCoO2 lithium cobalt oxide also has shortcomings, such as large battery capacity attenuation, poor overcharge resistance, and poor thermal stability. In order to overcome these problems, doping modification, coating, etc. are generally used to improve its stability [6].

Spinel structure positive electrode material, spinel LiMn2O4 has the advantages of good overcharge resistance, high thermal stability, abundant resources, and environmental friendliness. It is considered to be the most promising lithium-ion battery positive electrode material, but it has the characteristics of poor high-temperature cycle performance. Therefore, the improvement of spinel LiMn2O4 is a research hotspot for this material [6]. The olivine-structured positive electrode material, LiFePO4, is currently a prominent focus in lithium-ion battery research due to its excellent cycle stability, high safety, and environmental friendliness. However, its low electronic and ionic conductivity results in subpar overall electrochemical performance, which significantly hinders its practical application [6].

4.5. Optimization of Safety Aspects of Powered Lithium-Ion Batteries

Lithium-ion power batteries are widely used due to their high energy density and long cycle life, but their poor stability often leads to thermal runaway and spontaneous combustion, posing significant safety hazards. Thermal runaway is typically triggered by factors such as internal short circuits, high temperatures, or overvoltage, which lead to a series of chemical reactions within the battery, generating heat and gas, and potentially causing fires or explosions. To enhance the thermal stability of lithium-ion batteries, scientists have made numerous optimizations, with fluorides showing significant effectiveness.

Fluorides are widely used in various battery components, including electrolytes, separators, binders, and coatings. The introduction of fluorides significantly improves the film-forming ability, antioxidant stability, and flame retardancy of the electrolyte, effectively suppressing interfacial side reactions, extending battery life, and reducing the flammability of the electrolyte, thereby greatly enhancing battery safety. Moreover, fluorinated electrolytes can improve the ionic conductivity of the battery, expand the battery's operating voltage and temperature range, and further enhance the safety performance of lithium-ion batteries.

In terms of thermal management, scientists have conducted three-dimensional simulations of lithium iron phosphate power battery packs to study and optimize the heat dissipation structure of battery modules. Air cooling systems, as the most widely used cooling method, were analyzed by optimizing parameters such as the battery pack layout, wind speed, and ambient temperature. The study found that when the battery pack is arranged in parallel with a spacing of 32mm in the Y direction and 4mm in the X direction, under an ambient temperature of 20°C and wind speed of 5 m/s, the air-cooling effect is optimal [7]. These studies provide important theoretical basis and technical support for improving the safety and reliability of lithium-ion power batteries.

5. Hydrogen Fuel Cells

5.1. Composition Of Hydrogen Fuel Cells

The most important parts of a hydrogen fuel cell are its cell stack and control system, which include bipolar plates, proton exchange membranes, flow field plates, gas diffusion layers, and pressure plates [8]. The composition of hydrogen fuel cells is shown in Fig.3.

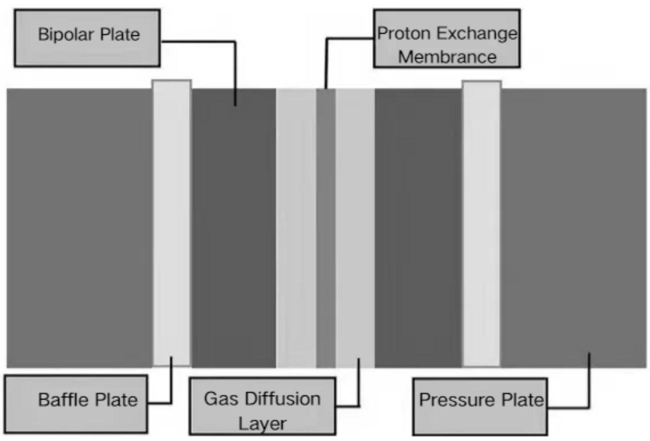

Figure 3. Composition of hydrogen fuel cell

5.2. Working Principle of Hydrogen Fuel Cells

In a hydrogen fuel cell, only hydrogen and oxygen undergo a chemical reaction, which only produces water, achieving zero pollution. The main hydrogen production technologies currently available on the market include electrolysis of water, steam reforming of natural gas, and partial oxidation methods. There are currently three main types of electrolysis of water: alkaline water electrolysis, solid polymer electrolysis, and high-temperature solid oxide electrolysis. Large-scale industrial hydrogen production by water electrolysis mainly adopts alkaline water electrolysis, which is simple in process and easy to operate. The main raw materials are fossil fuels and steam undergoing transformation reactions at high temperatures. Among them, coal gasification for hydrogen production refers to the process of converting coal and steam into gas at certain temperatures and pressures. Partial oxidation of hydrocarbons includes non-catalytic partial oxidation of high carbon hydrocarbons and ATR of natural gas. The former utilizes the reaction of hydrocarbons with O_2 at high temperatures to form COX, H_2, and some coke and ash [9]. Working principal diagram of a hydrogen fuel cell is shown in Fig.4.

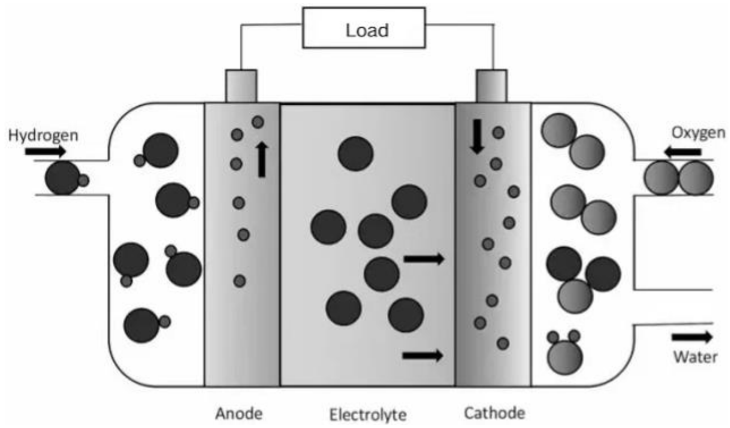

Figure 4. Working principal diagram of a hydrogen fuel cell

The main hydrogen storage technologies commonly used include high-pressure hydrogen storage, cryogenic liquefied hydrogen storage, physical adsorption hydrogen storage, and hydrogen storage using metal materials, among others. High-pressure hydrogen storage has a lower hydrogen volume density, so once the gas cylinder metal experiences fatigue failure or cracks, the danger is unimaginable. Low-temperature liquefied hydrogen storage uses ultra-low temperature technology to preserve liquefied H_2. Therefore, the insulation performance of the container is extremely demanding [9]. Physical adsorption hydrogen storage mainly includes activated carbon adsorption and carbon nanotube adsorption, with low-cost, long cycle life activated carbon having huge application potential. Activated carbon materials with high specific surface area have superior hydrogen storage mass density and volume density. In addition, the adsorption and desorption rates of hydrogen on activated carbon are fast and the conditions are mild, so it has a good application prospect in the hydrogen storage technology of fuel cell vehicles. The release of H_2 in metal hydride hydrogen storage goes through processes such as diffusion, phase change, and combination.

6. The Development of New Energy Vehicle Batteries

VRLA battery as the most widely used lead-acid battery at this stage, compared with conventional lead-acid batteries, it does not need maintenance, the battery is a sealed structure, will not leak acid and will not discharge acid mist, the battery is equipped with a safety valve, when the air pressure rises to a certain value, the gas will be automatically discharged. At present, it is widely used in post and telecommunications, communications, electric power, transportation ships, aerospace, emergency lighting and many other fields. Compared with ordinary lead-acid batteries, VRLA batteries greatly alleviate the loss of electrolyte due to the use of internal oxygen recombination technology.

Lithium-ion batteries have now become the most commonly used type of new energy vehicle batteries, and in the future, with the further improvement of battery technology and the reduction of costs, the mileage and energy density of lithium batteries will also rise significantly. In addition to lithium-ion batteries, more and more clock types of batteries are also being developed and used, such as sodium-ion batteries, zinc-air batteries, manganese batteries, etc. In the future, the use and development of new energy vehicle batteries will also tend to be more diversified.

As an efficient and clean energy conversion technology, hydrogen fuel cells have received extensive attention around the world in recent years. With the transformation of the energy structure and the improvement of environmental awareness, the development of the hydrogen fuel cell industry has shown a steady growth trend. Significant advancements have been achieved in the research, development, and application of hydrogen fuel cells at the technical level, leading to considerable improvements in their power density, durability, and cost-effectiveness. The hydrogen energy industry, with fuel cells as a primary focus, has begun to see initial commercialization. This progress suggests that the industry may experience rapid growth within the next five years. As the global transition to green energy accelerates, hydrogen has emerged as one of the fastest-growing sectors in the energy industry. By 2030, global direct investment in hydrogen energy is projected to reach $320 billion [10].

7. Recycling of New Energy Vehicle Batteries

7.1. Lithium-Ion Batteries

The recycling of lithium batteries is relatively complex, mainly because of its diverse internal materials, including cathode materials, anode materials, electrolyte, etc., the separation and purification of these materials require a high level of technology. With the expansion of the application range of lithium batteries and the increase in the amount of retirement, the lithium battery recycling market is gradually emerging, but there are still challenges in terms of technology maturity and recycling channel construction.

7.2. Lead-Acid Batteries

Compared with lithium batteries, the recycling technology of lead-acid batteries is more mature. Lead-acid batteries are mainly composed of lead grids and electrolytes, and lead and other valuable materials are mainly extracted through methods such as smelting during the recycling process Lead-acid batteries are widely used in energy storage, starting and other fields, and their retirement is relatively large, providing a stable market demand for recycling

7.3. NiMH Batteries

The recycling technology of nickel-metal hydride batteries is relatively complex, mainly because of their diverse internal chemical compositions, including nickel, hydrogen, rare earth elements, etc. The separation and purification of these materials requires a high level of technology. Due to market conditions and technology maturity limitations, the overall recovery rate of nickel-metal hydride batteries is relatively low. However, with the advancement of technology and the expansion of the market, its recycling efficiency is expected to be improved.

8. Conclusion

Based on the four most mainstream new energy vehicle batteries, this paper summarizes and summarizes the components, working principles, advantages and disadvantages of various types of batteries. The development and use of new energy vehicle batteries will tend to be diversified. While the lithium battery market is rapidly emerging, it is also facing the challenges of technology maturity and recycling channel construction. The recycling of nickel-metal hydride batteries is the most complex, and the recycling rate is low, which is expected to increase. The development of hydrogen fuel cells has the greatest potential.

In summary, there are differences in the degree of recycling and recycling efficiency of different new energy batteries. Lithium battery recycling technology is relatively complex but has great potential; Lead-acid battery recycling technology is mature and the market is stable; NiMH battery recycling technology is complex and the market is relatively small. In the future, with the advancement of technology and the expansion of the market, the recycling efficiency and overall recovery rate of various new energy batteries are expected to be further improved.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Su C W, Yuan X, Tao R, et al. Can new energy vehicles help to achieve carbon neutrality targets?. Journal of Environmental Management, 2021, 297: 113348.

[2] Qingfeng L. Agricultural Machinery Use and Maintenance, 2023, (09): 61-63.

[3] Qiyu Y. Discussion on the current situation and development trend of new energy vehicle battery type. Times Auto, 2024, (05): 101-103.

[4] Yonghua S, Yuexi Y, Zechun H. Power System Technology. Energy Strategy Reviews, 2011, 35 (04): 1-7.

[5] Leihua H. Monitoring and control system for battery charging and discharging. Hangzhou Dianzi University, 2014.

[6] Yudhistira R, Khatiwada D, Sanchez F. A comparative life cycle assessment of lithium-ion and lead-acid batteries for grid energy storage. Journal of Cleaner Production, 2022, 358: 131999.

[7] Sharma T, Kalita P. Design and development of a solar powered cold storage system. Doctoral Dissertation, Indian Institute of Technology, Guwahati, 2018.

[8] Tan Lele. Research on hydrogen production technology and hydrogen storage system of hydrogen fuel cell. Transportation Energy Conservation and Environmental Protection, 2018, 14 (06): 7-9.

[9] Kirkpatrick A T. Internal combustion engines: applied thermosciences. John Wiley & Sons, 2020.

[10] McCartney M. The China-Pakistan economic corridor (CPEC): infrastructure, social savings, spillovers, and economic growth in Pakistan. Eurasian Geography and Economics, 2022, 63 (2): 180-211.