The Applications and Challenges of Batteries in New Energy Vehicles

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Abstract: Fossil fuels have historically been crucial for the survival and advancement of human society. However, the excessive exploitation and combustion of fossil fuels to meet increasing demands have severely damaged the ecological environment and, to some extent, hindered further societal development. Electricity, as a widely sourced and fossil fuel-independent cleaner energy, holds significant potential. Given the growing demand for transportation, the electrification of private cars presents an effective strategy to reduce fossil fuel consumption. New energy vehicles, which utilize unconventional fuels and incorporate innovative framework structures suited for these energy sources, are at the forefront of this transition. Predominantly, new energy vehicles include electric vehicles, fuel cell vehicles, and others that rely on electricity as their primary energy source. The battery, being the core component of new energy vehicles, has a crucial impact on how well they perform. This article analyzes advantages and disadvantages of various battery types - nickel-hydrogen batteries, lithium-ion batteries, sodium-ion batteries, and fuel cells - along with their main applications. It explores their current development status and primary challenges, and subsequently predicts the trends of new energy vehicles and their batteries based on market dynamics and policy frameworks.

1 INTRODUCTION

Energy, as the cornerstone of human societal advancement, ensures the continuous survival and development of human civilization. From steam engines to internal combustion engines, fossil fuels have played an indispensable role in energy development. Fossil fuels, as non-renewable energy resources requiring hundreds of millions of years to regenerate, are the most common and easily accessible hydrocarbons in nature. However, current consumption rates have significantly surpassed regeneration and extraction yields. Relevant exploration statistics indicate that there are approximately 894.5 billion tons of coal, 238.2 billion tons of oil, and 186 trillion cubic meters of natural gas left detectable in the world. Based on current average extraction rates, it is estimated that these fossil fuels will be depleted in approximately 113, 53, and 55 years, respectively (Novara et al., 2023). Consequently, the energy issue is a critical challenge facing humanity today, necessitating an urgent reduction in fossil fuel usage and researching and developing renewable energy sources including solar, wind, and tidal energy urgently. These renewable sources possess the cleanliness characteristics absent in traditional fossil fuels. Furthermore, the research, development, and widespread adoption of clean energy can effectively mitigate environmental pollution and damage caused by excessive fossil fuel extraction and use.

Electricity, due to its ease of conversion and wide range of sources, is increasingly recognized as a more economical and cleaner energy alternative to fossil fuels. Various clean energy sources, such as solar and tidal energy, can be converted into electricity through specific technical processes. As the global economy continues to develop, the number of private cars is rising, with individuals increasingly preferring private vehicles for transportation. This trend leads to excessive fossil fuel consumption and continuous environmental pollution and degradation. The electrification of transportation presents an efficient solution to current energy shortages.

Environmental protection, sustainability, low emissions, and energy conservation have become new imperatives for transportation. Among various vehicle types, new energy vehicles best meet these requirements. These vehicles have transitioned from internal combustion engines to batteries as their core power source. Consequently, the performance indicators of batteries, such as energy density, cost, and lifespan, directly or indirectly influence the performance of new energy vehicles, underscoring

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the critical role of batteries. Continuous technological research and development have resulted in various battery types, each with unique performance characteristics, leading to a diverse range of new energy vehicles in the market. However, due to immature technology, new energy vehicles still face challenges related to cost, endurance, and other factors.

Therefore, this article will focus on the various types of batteries used in new energy vehicles, primarily examining the advantages, disadvantages, and applicability of four commonly used batteries: nickel-hydrogen batteries, lithium-ion batteries, sodium-ion batteries, and fuel cells. Additionally, it will analyze their future development trends.

2 CLASSIFICATION AND ADVANTAGES AND DISADVANTAGES OF NEW ENERGY VEHICLE BATTERIES

2.1 Nickel Hydrogen Battery

Nickel hydrogen batteries, characterized by a nickel oxide electrode and a hydrogen storage electrode, function through the hydrogen storage electrode's ability to store and release gases, facilitating ion movement and enabling the charging and discharging process (Figure 1). Widely utilized in hybrid vehicles, nickel hydrogen batteries have reached a mature, large-scale production stage globally. Prominent examples include Toyota and Lexus hybrid electric vehicles such as Toyota's LEVIN Hybrid and Lexus's CT200H and ES300H models (Ying, 2024).

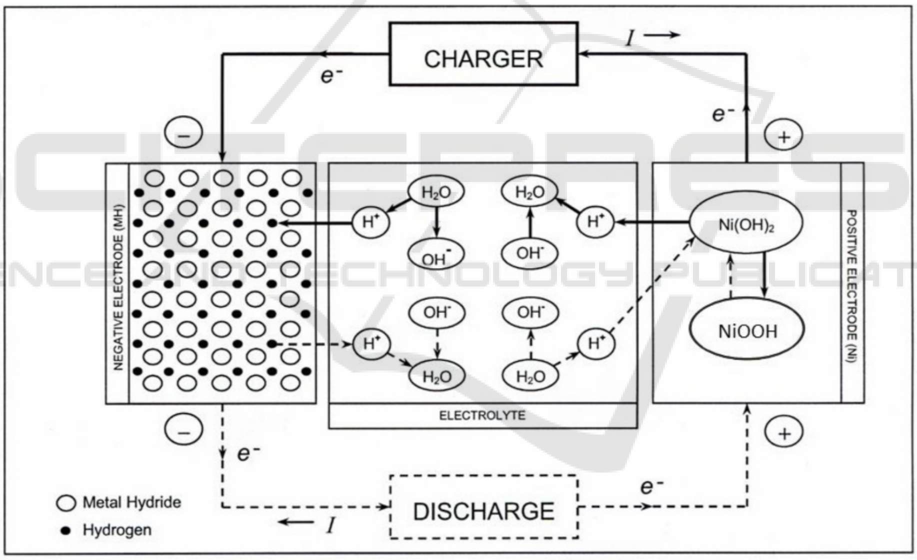

Figure 1: Operating principle of nickel hydrogen battery (Jean and Wang, 2024).

Nickel hydrogen batteries can be classified as single-element batteries, which means that they employ a cathode material containing only one metal element and involve a single electrochemical reaction during charging and discharging (Wei et al., 2024). Other single-element batteries include lead-acid and nickel cadmium batteries. Compared to these, nickel hydrogen batteries can provide with higher energy density, longer cycle life, and greater environmental friendliness due to their recyclability and the absence of heavy metals. However, single-element batteries typically suffer from a memory effect, leading to rapid capacity reduction. Therefore, careful management of charging time is crucial to prevent overcharging, which can result in dangerous battery expansion.

2.2 Lithium-Ion Batteries

Lithium-ion batteries operate by facilitating the flow of lithium ions between the anode and cathode, thereby completing the charging and discharging process (Figure 2). These batteries are the most widely utilized in new energy vehicles, with lithium iron phosphate batteries (binary batteries) and ternary polymer lithium batteries (ternary batteries, such as lithium nickel cobalt manganese oxide batteries) being the most common types. For instance, the entire range of BYD electric vehicles employs lithium iron phosphate batteries, while the rear-wheel-drive version of the Tesla Model 3 also utilizes these batteries, and the all-wheel-drive version uses ternary lithium batteries (Tang, 2023).

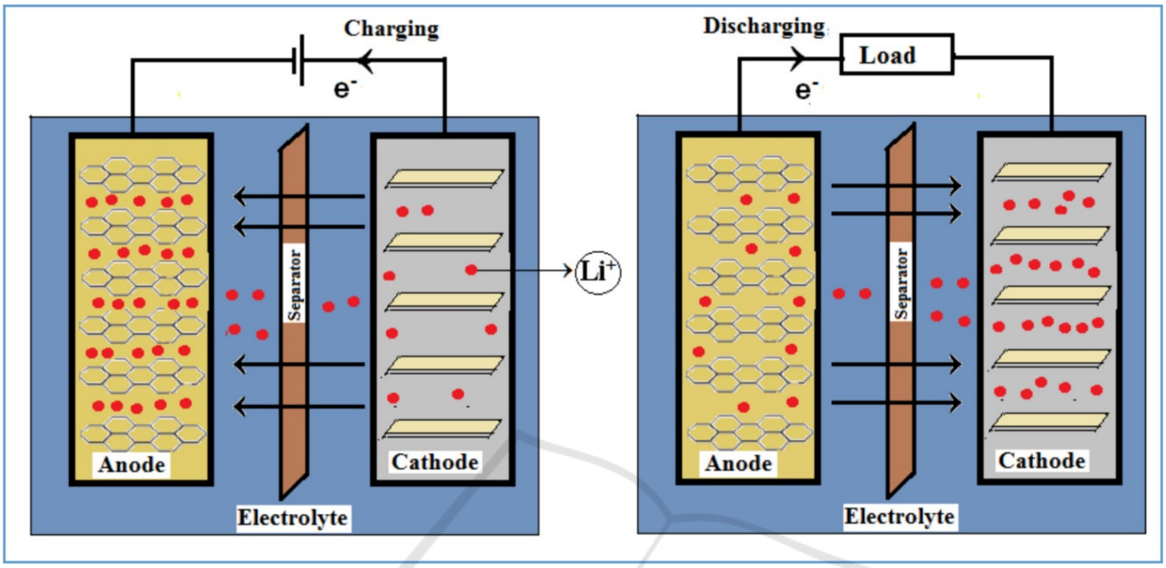

Figure 2: Operating principle of lithium-ion battery (Selvi et al., 2024).

Both types of lithium-ion batteries provide significant merits, such as high energy density, extended cycle life, and environmental friendliness. Ternary lithium batteries, in particular, can enhance their performance by adjusting the proportions of nickel, cobalt, and manganese in the cathode, leading to higher energy density and stability. However, compared to lithium iron phosphate batteries, ternary lithium batteries are more expensive and exhibit poorer performance at high temperatures, limiting their application range. Currently, in the industry, the safety of lithium-ion batteries is often improved through packaging, which, however, results in a decrease in their energy density.

2.3 Sodium Ion Battery

Because both types of batteries store and release energy through the flow of ions between electrodes, sodium-ion batteries and lithium-ion batteries operate on similar principles (Figure 3). Since sodium is more accessible, abundant, widely distributed, and lower in cost than lithium, sodium-ion batteries present a viable substitute for lithium-ion batteries. Studies indicate that the cost of sodium-ion batteries is approximately two-thirds lower than that of lithium-ion batteries. Additionally, sodium ions exhibit faster conduction speed and higher internal resistance, resulting in sodium-ion batteries outperforming in terms of energy density, cycle life, charging speed, safety, and low-temperature performance (Zhang, 2023).

However, sodium-ion battery technology and industrial development are still in their infancy, requiring continuous innovation and advancement. Currently, there is one electric vehicle on the market equipped with a sodium-ion battery: the Jianghuai Automobile Group's Sihao EX10 Huaxianzi short-distance vehicle, which features an energy density of approximately 130 Wh/kg and a range of 252 kilometers (Hanley, 2023).

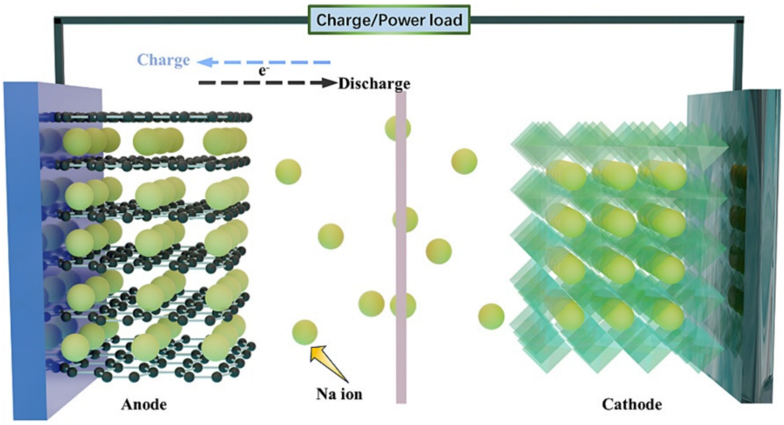

Figure 3: Operating principle of sodium ion battery (Liang et al., 2024).

2.4 Fuel Cell

Through electrochemical processes, a fuel cell is an effective chemical device that directly transforms chemical energy from fuel into electrical energy. It utilizes the directional movement of particles generated by the oxidation-reduction reactions at the positive and negative electrodes to form a circuit, thereby generating an electric current, which is essentially the reverse process of water electrolysis (Figure 4). Fuel cells are characterized by high conversion efficiency and high energy density. Furthermore, they can utilize any hydrogen-containing substance as fuel, although hydrogen fuel cells, which use fuels such as liquid hydrogen and hydrogen storage metals, have the most extensive application prospects (Li et al., 2024). This is primarily because hydrogen fuel cells produce water as a byproduct and do not emit greenhouse gases, thereby offering environmentally friendly and pollution-free operation with high safety and stability. However, due to current technological limitations, the costs of hydrogen fuel cells and the infrastructure required for their deployment are relatively high, impeding their widespread application at present.

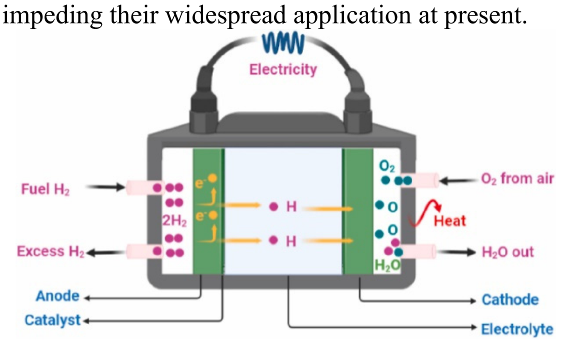

Figure 4: Operating principle of hydrogen fuel cell (Halder et al., 2024).

3 PROSPECTS FOR NEW ENERGY VEHICLE BATTERIES

Currently, the four types of batteries discussed have achieved notable breakthroughs and successes in new energy vehicle applications, with related vehicles performing well or even excellently. However, numerous issues urgently require attention and resolution by researchers. Firstly, energy density, primarily determined by the anode and cathode materials, remains a critical concern. For example, sodium-ion batteries exhibit higher energy density than lithium-ion batteries, which in turn surpass nickel-hydrogen batteries. Additionally, the size and capacity of the battery pack significantly impact energy density and influence material selection and vehicle frame structure. Specifically, increasing the battery pack's capacity and size can extend vehicle range but also increases the overall volume and weight, leading to higher energy consumption to maintain performance, thereby creating a feedback loop of increased weight and energy use. Secondly, the charging efficiency of car batteries presents a significant challenge. To protect battery safety and extend service life, charging methods switch from high-power DC fast charging to low-power AC slow charging after reaching 80% capacity. While the former takes 30 minutes to an hour, the latter can require 5 to 6 hours or more, highlighting the inefficiency in emergency situations (Wang and Li, 2019). Finally, the disposal of scrapped batteries poses a major challenge. Continuous battery use leads to irreversible declines in capacity and performance, rendering batteries unsuitable for vehicle power when capacity falls to 75% of the set value. Recycling and processing methods, such as cascade utilization and regeneration, are essential. Although some countries have achieved success in this area, China's standardized recycling rate through formal channels remains low despite policy support. This results in substandard products on the market, such as mobile phone power banks, posing threats to personal and environmental safety.

As energy and environmental concerns become increasingly pressing, there is an urgent need for breakthroughs in battery and related technologies to address these challenges through technical means. Current research primarily aims to enhance battery performance, environmental sustainability, safety, and cost reduction. One approach involves optimizing electrode materials in existing batteries to improve their energy density, cycle life, and other performance metrics. For example, transitioning from costly chromium and manganese to more economical vanadium in lithium-ion batteries or introducing new elements like silicon into graphite materials can enhance performance while reducing costs. Furthermore, improved performance is promised by the development of new battery types as solid-state and aluminum ion batteries. Another important factor that makes it possible for new energy vehicles to be widely adopted is charging technology. Research efforts focus on accelerating charging speeds, mitigating lifespan degradation, and addressing safety concerns associated with rapid charging-induced heat generation. At the national level, governments recognize the significance of these challenges and have implemented supportive policies to facilitate rapid technological development and promote electric vehicle adoption. For instance, in China, initiatives such as the "Development Plan for the New Energy Vehicle Industry (2021-2035)," "Notice on Organizing Pilot Work for Comprehensive Electrification of Public Sector Vehicles," and "Guiding Opinions on Further Building a High-Quality Charging Infrastructure System" underscore the commitment to advancing the new energy vehicle industry, expanding public electric transportation, and building robust infrastructure (Wang, 2024). Additionally, advantageous support policies, such as subsidies and brand incentives, incentivize consumers to purchase new energy vehicles, promoting enterprise growth and technological innovation in the industry.

The popularization of new energy cars on the road necessitates the expansion of industrial clusters and supply chains. Scaling up not only reduces costs but also fosters the collective advancement of associated industries. Specifically, larger scales ensure efficient and stable supply chain operations, concentrating production processes and reducing cycle times, thereby enhancing production rates and minimizing material waste, leading to decreased production costs. Moreover, scalability facilitates the identification of production process issues, enabling process optimization and fostering mutual growth among industries, ultimately providing robust support for the advancement of batteries and new energy vehicles. Additionally, scale effects ensure consistent and high-quality production, bolstering public acceptance and facilitating the broader adoption of new energy cars.

4 CONCLUSION

In summary, the ongoing development of new energy batteries and the promotion of new energy cars represent highly efficient and feasible approaches to addressing current energy and environmental challenges. This article systematically analyzes several representative new energy batteries, outlining their characteristics, current status, and developmental trajectories. Nickel hydrogen batteries, lithium-ion batteries, and fuel cells, widely utilized and with broad application prospects, have significantly contributed to industry advancement and the resolution of contemporary energy and environmental issues. Additionally, sodium ion batteries, as emerging technologies, exhibit promising performance and represent a highly viable new energy battery option. However, challenges such as cost, charging rates, and cycle life persist and warrant continuous research and development efforts. Furthermore, optimization of battery production supply chains, market expansion for new energy vehicles, and the widespread adoption of such vehicles are crucial endeavors. Alongside scientific exploration, the national government must issue corresponding policies and take action to encourage the growth of the new energy battery sector.

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