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Research on the Current Status of Power Battery Recycling for New Energy Vehicles

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ABSTRACT

The rapid growth of China's new energy vehicle industry has led to a surge in decommissioned power batteries, making their recycling crucial for environmental protection and resource sustainability. This study examines China's power battery recycling status, identifying three main models and key challenges: inconsistent standards, unregulated channels, and inadequate infrastructure, which hinder efficiency and increase environmental risks. Proposed solutions include establishing unified standards, enhancing regulations and incentives, and optimizing a three-tier recycling network. These measures aim to improve recycling efficiency and support China's "double carbon" goals and circular economy development.

KEYWORDS

Power battery recycling; Laddering utilization; Recycling model; Reverse logistics

1. INTRODUCTION

1.1. Background and Significance of the Study

With the enhancement of people's awareness of environmental protection and the trend of energy transition, especially under the leadership of the "dual-carbon" goal, China's new energy vehicle industry is booming, and the demand for power batteries is growing explosively. As the "heart" of new energy vehicles, the performance and service life of power batteries directly affect the range of vehicles and the overall economy. However, the service life of the power battery is usually 5-8 years, when the battery capacity declines to a certain extent, the power battery has not met the requirements for continued use, will be decommissioned and recycled.

Firstly, power battery recycling is an urgent need for environmental protection. Retired batteries contain nickel, cobalt, manganese, lithium and other heavy metals, as well as electrolyte, organic solvents and other hazardous substances, if landfill or incineration, may lead to soil, groundwater pollution, and even endanger human health. Improper handling of decommissioned batteries will lead to serious environmental, resource and economic problems. Through professional recycling treatment, we can effectively avoid the leakage of toxic substances and reduce environmental pollution.

At the same time, battery recycling is an important way to alleviate the shortage of resources. The core materials of power batteries are scarce mineral resources, with limited global reserves and uneven distribution. The abundant lithium, nickel, cobalt and other rare metals, as well as copper, aluminium and other commonly used metals, have significant resource recovery potential. Nickel and cobalt, as important cathode materials for lithium batteries, have high prices and limited reserves. Taking cobalt as an example, the global proven reserves are only about 7.1 million tonnes, while 80%

of China's cobalt relies on imports. Effective recovery of cathode materials can be achieved by recycling decommissioned batteries, which not only effectively reduces the demand for mining of new resources and lowers the cost of importing raw materials, but also helps to alleviate the tension between supply and demand of related metals in the market, and realizes the sustainable management of resources and maximization of economic benefits.

On the other hand, although decommissioned power batteries can't meet the normal operation of the car, they can be used in other scenarios such as home energy storage, solar street lights, tower base stations, etc. to extend the service life of the battery and save the cost of new battery manufacturing and procurement.

According to industry research institutes, the total amount of decommissioned power batteries in China will exceed 800,000 tonnes in 2024, a year-on-year increase of about 38%. This rapid growth mainly stems from the fact that the first batch of power batteries for new energy vehicles installed on a large scale in 2016-2018 have been concentrated in the decommissioning period. With the continued expansion of the new energy vehicle market, the future scale of decommissioned batteries will show accelerated growth, it is expected that by 2025 the decommissioning volume is expected to reach 1.2 million tonnes, and in 2030 it may exceed 3.5 million tonnes. In the face of such a huge scale of retired batteries, exploring the current situation of China's power battery recycling industry and the problems it faces, as well as putting forward suggestions for improvement, will contribute to the recycling of used power batteries and provide an effective aid to environmental protection and sustainable use of resources.

1.2. Literature Review

With the rapid development of the global new energy vehicle industry, the wave of power battery decommissioning is coming. Battery reverse logistics, as a key link in resource recycling and environmental protection, has become a focus of attention in academia and industry. In this section, we systematically review the relevant studies at home and abroad. In the 1970s, Guiltinan (1975) 5 used the academic term "reverse flow", and the emergence of the terminology laid the grassroots foundation of reverse logistics. By the 1980s, the concept of reverse logistics appeared in academic writings, put forward by the American scholar Stock (1992) [2] in his work, he defined the concept of reverse logistics as a logistics activity opposite to the flow of ordinary goods. Regarding the recycling of power batteries for new energy vehicles, Lin (2023) [3] pointed out that if the large-scale retired power batteries are not scientifically recycled and managed, it will not only result in the loss of valuable metal resources, but also may lead to the leakage of electrolyte, heavy metal pollution and other environmental risks. Therefore, it is crucial to build an efficient reverse logistics recycling network, which can not only guarantee the stable supply of key raw materials, but also promote the sustainable development of circular economy.

Sun Xingxing (2016) [4] Based on the empirical analysis of China's power battery recycling system, it is pointed out that reference can be made to the EU's "Extended Producer Responsibility System" and other international experiences to build a new recycling management model in line with China's national conditions. After entering the 21st century, China began to gradually implement the extended producer responsibility system, which has been promoted in the field of electric vehicle batteries, and has effectively promoted the construction and development of the reverse logistics system of used batteries by clarifying the recycling responsibility of producers. Yao Hailin (2015) [5] et al. based on the extended producer responsibility system, constructed a battery recycling model that takes into account both economic benefits and environmental sustainability, and provided both innovative and operable solutions for theoretical research and enterprise practice by comparing and analyzing the operational efficiency of different modes, such as manufacturer-led, seller-led and professional recycling enterprise-led.

For the research on recycling channels, some scholars have further constructed a dual-channel recycling competition model on the basis of the traditional single recycling channel.Liu (2017) [6] et al.'s study shows that when there is market competition between the recycling channels of the manufacturer and the retailer, the model of collaborative recycling between the manufacturer and the retailer is always the optimal choice for the manufacturer, regardless of the intensity of competition. In the study by Hao Shoushuo et al. (2021) [7], a whole life cycle costing model for used power batteries was established based on a comparative analysis of four types of recycling entities including vehicle enterprises, battery manufacturers, third-party comprehensive utilization enterprises and industrial alliances. The research results show that the recycling system led by new energy vehicle manufacturers can achieve network coverage more efficiently. For the research on the deficiencies in the recycling of power batteries, Lai Yuke (2012) [8] et al. pointed out in their study that there are still many deficiencies in China's power battery recycling system, such as the dispersion of recycling channels and the lack of management standards. For this reason, they suggested the establishment of a more scientific and efficient recycling mechanism and emphasized the necessity of a clear institutional framework and standardized recycling process to improve the recycling rate.

2. CURRENT SITUATION OF VEHICLE POWER BATTERY RECYCLING

2.1. Analysis of Power Battery Recycling Process for New Energy Vehicles

Power battery recycling includes recycling and transport, testing and classification, laddering, discharge and dismantling, and material regeneration.

The recycled decommissioned batteries mainly come from new energy vehicles, energy storage systems and consumer electronics. When recycling, it is necessary to carry out condition testing to determine whether it is suitable for laddering or direct dismantling for regeneration. Batteries for step-down utilisation are subject to capacity testing, consistency screening and restructuring, while end-of-life batteries enter the dismantling process to extract valuable metals such as lithium, cobalt and nickel through crushing, sorting and other technologies. In terms of transport management, since power batteries contain flammable electrolyte and high-voltage cores, the transport process needs to strictly follow the "Rules for the Transport of Dangerous Goods" to prevent short-circuit, leakage or thermal runaway. Safe packaging, professional means of transport and compliant storage should be adopted for transport.

Decommissioned power batteries need to undergo strict testing and classification to determine whether they are suitable for subsequent step-by-step utilisation or recycling. The testing process mainly includes appearance inspection, electrical performance testing, safety assessment and health status analysis. Appearance inspection of the battery shell for deformation, liquid leakage or corrosion, to exclude batteries with potential safety hazards. Measure the capacity, internal resistance, voltage consistency and other parameters of the battery through the charging and discharging experiments to conduct electrical performance tests to assess the actual usable capacity and the degree of degradation. Then safety assessments such as thermal stability and short circuit testing are conducted to ensure that the battery will not experience thermal runaway or explosion in subsequent use. Health status analysis combines the number of cycles, historical usage data, etc. to comprehensively judge the remaining life of the battery. Classification standards are usually based on the capacity decay rate, consistency, safety and other indicators of the battery, and the retired battery is divided into three categories. Capacity decay ≤ 20%, can be laddered to energy storage, low-speed electric vehicles and other high-demand scenarios; capacity decay 20%-40%, applicable to standby power supply, communications base stations and other low-load scenarios: capacity decay > 40% or the existence of safety hazards, direct dismantling of regeneration, recovery of valuable metals. Scientific detection and classification is a key link in power battery recycling, which directly affects the safety of ladder utilization and the recycling efficiency of renewable resources. At present, automated detection technology and artificial intelligence algorithms are gradually being applied to this field to improve sorting precision and efficiency.

Power battery step-down utilization refers to the retired power batteries of new energy vehicles undergoing strict electrical performance testing, safety testing and consistency matching, eliminating damaged or severely degraded performance cores, and re-integrating standard-compliant battery modules to form an energy storage system suitable for new scenarios. Apply them to energy storage or power supply scenarios with lower performance requirements, thereby extending the service life of the battery and improving resource utilization. Common applications of gradient utilization include: grid-side energy storage such as peak shaving and valley filling, frequency and voltage regulation, distributed energy storage such as light storage integrated system, backup power for communication base stations, power supply for low-speed electric vehicles, and home energy storage. Compared with the new battery, the cost of the battery can be reduced by 30% -50%, which has significant economic advantages in the field of energy storage. The use of laddering faces many technical challenges, such as battery consistency management, life prediction, safety monitoring and so on. In addition, the imperfect standard system and immature business model also restrict its large-scale promotion. In the future, with the improvement of battery big data analysis, battery management system and standardised recycling system, the laddering use will become an important part of the power battery circular economy, helping to achieve the carbon neutral goal.

The discharge and disassembly of power batteries is a key part of recycling. The discharge process aims to eliminate the residual battery power and avoid the risk of short-circuit, combustion or explosion during dismantling. Resistance discharging, salt water immersion or professional discharging equipment are usually used to reduce the battery voltage to a safe range. Among them, salt water immersion is low cost but may corrode the electrodes, while constant current discharge is more accurate but time consuming. The disassembly stage requires different methods depending on the type of battery. Firstly, the casing and high-voltage connections are removed, and then the cells are separated by mechanical cutting or automated dismantling equipment. The dismantling process requires strict environmental control to prevent electrolyte evaporation or thermal runaway. The core is further decomposed into positive and negative electrode sheets, diaphragm and collector, of which the positive electrode materials containing lithium, cobalt, nickel, etc. are the core targets of regeneration and recycling. Currently researched high-efficiency dismantling technologies such as robotic sorting and low-temperature crushing can enhance the metal recovery rate, while environmentally friendly treatment reduces pollution. In the future, intelligent dismantling production lines will further improve the economy and safety of power battery recycling.

Material regeneration of power batteries refers to the process of dismantling, crushing, sorting and metallurgical treatment of decommissioned power batteries, from which valuable metal materials are recovered and reused in the production of new batteries or related industries. Recovered metals can be reused in the production of cathode materials for new batteries, such as recycled lithium carbonate can be used to synthesise new lithium iron phosphate or ternary materials. In addition, recycled copper, aluminium and other metals can be applied to electronics, construction and other industries. Achieve resource recycling power batteries contain a large number of high-value metals, such as lithium, cobalt, nickel, manganese, etc. in ternary lithium batteries, lithium iron phosphate batteries are rich in lithium and iron. The mining cost of these metals is high, energy consumption is high, and some of the resources have limited global reserves, so the supply risk is high. Through material regeneration, it can reduce the dependence on primary minerals and lower the cost of battery production, while avoiding the risk of heavy metal pollution and electrolyte leakage caused by improper disposal of used batteries. With the rapid development of the new energy vehicle industry, the power battery scrap volume surge, material regeneration has become a key technology to solve the resource shortage, reduce environmental pollution and realise circular economy.

2.2. Analysis of New Energy Vehicle Power Battery Recycling Mode

The recovery mode of new energy vehicle power battery is mainly divided into three types: autonomous recovery, third-party recovery and joint recovery.

Autonomous recycling mode refers to the closed-loop recycling system established by automobile manufacturers or battery producers, which completes the whole process of collecting, transporting, testing, laddering, and ultimately dismantling and recycling of decommissioned batteries through self-built channels. The core advantage of this model lies in its complete quality control system. Battery manufacturers hold the core technology and raw data of batteries, and can accurately assess the health status of decommissioned batteries, so as to make optimal disposal decisions. Battery manufacturers can feed back their recycling experience into product design, promoting standardisation and easy disassembly of batteries. However, the autonomous recycling model also faces big challenges. The establishment of a complete recycling network requires huge investment, including the construction of recycling outlets, logistics systems and dismantling plants. Secondly, it is difficult to realise economy when the recycling scale is small, which is also the reason why it is mainly limited to large enterprises. In addition, the difference in battery specifications of different brands also brings technical difficulties in recycling and processing. The model transforms waste batteries into new production factors through resource recycling, which is an innovative practice of practicing the concept of green and low-carbon development, and provides a replicable demonstration sample for promoting the high-quality development of the new energy automobile industry.

The third-party power battery recycling model refers to the power battery recycling system led by professional recycling enterprises, which is an important part of the current power battery recycling market in China. Under this model, professional recycling enterprises such as Greenmax and Bump Recycling build a nationwide power battery recycling network through market-based operation to provide professional decommissioned battery recycling and treatment services for the new energy automobile industry. This model has significant scale advantages. Third-party recycling enterprises have built a relatively complete recycling network through the establishment of diversified recycling channels, including co-operation with 4S shops, setting up recycling outlets, and docking with end-of-life automobile dismantling enterprises. Professional recycling enterprises can realize economies of scale by building large-scale centralized treatment bases. Advanced processing technology enables efficient recovery of valuable metals such as nickel, cobalt and manganese, and the metal recovery rate generally reaches more than 95 per cent, which is much higher than the industry average. The third-party recycling model is developing in the direction of specialization and standardization.

Power battery joint recycling refers to vehicle enterprises, battery manufacturers, recycling enterprises and third-party institutions to build a standardized recycling network through strategic cooperation, so as to achieve the full life cycle management of batteries. Specific processes include: information sharing platform construction, intensive recycling network, ladder utilization and recycling treatment. The construction of the information sharing platform is the key link to realize the full life cycle management of batteries. By integrating data from car companies, battery manufacturers, recycling companies and regulatory agencies, the platform builds a unified battery coding and traceability system to track the production, use, decommissioning and recycling status of batteries in real time. The intensive recycling network is an efficient system built by integrating upstream and downstream resources and optimizing the recycling process. The network takes the regionalied recycling centre as the hub, unites vehicle enterprises, battery factories, third-party recycling enterprises and logistics service providers, and realizes large-scale processing of battery testing, classification and transportation through unified standards. Graduated utilization targets the remaining capacity of decommissioned batteries, which are tested and reorganized for use in low load scenarios such as energy storage and communication base stations to extend the life cycle of batteries. Regeneration treatment dismantles completely failed batteries and recovers precious metals through hydro metallurgy, metallurgy and other technologies. The two synergies to form a closed-loop model of "laddering and then regeneration", which not only reduces the cost of the energy storage system, but also eases the pressure on mineral resources. The joint recycling mode has become the mainstream development direction of the industry by integrating industrial chain resources and building a collaborative and large-scale recycling system.

3. PROBLEMS OF POWER BATTERY RECYCLING FOR NEW ENERGY VEHICLES

3.1. Recycling Standards Are Not Uniform

Power battery recycling is a systematic project involving multiple links and subjects, but a unified and perfect standard system has not yet been established at home and abroad, and this lack has become a key bottleneck restricting the healthy development of the industry. From the industry chain point of view, the complete recycling process includes decommissioned battery assessment, transport and storage, dismantling and processing, laddering and material regeneration and other key links, each of which requires the corresponding standards to ensure operational safety and resource utilization efficiency.

In terms of technical standards, vehicle and battery manufacturers have adopted differentiated design routes, which has brought huge challenges to subsequent recycling. Firstly, the structural design of battery packs varies greatly, with some adopting modular design and others adopting integrated design, and the dismantling methods are very different. Secondly, the choice of cathode material system is different, lithium ternary batteries and lithium iron phosphate batteries in the recycling process there are significant differences. Furthermore, the battery connection methods are different, some use laser welding, some use bolts to fix, the lack of standardized dismantling solutions. This design status quo makes recycling companies have to develop a special dismantling process for each battery model, which significantly increases recycling costs.

In terms of testing and evaluation standards, there is a lack of uniform norms for the state evaluation of retired batteries. At present, the industry has a variety of testing methods for key indicators such as residual battery capacity and health status, and different organisations have adopted different testing protocols and judging standards. This situation has led to three prominent problems: first, it is difficult to accurately assess the residual value of batteries in a gradual utilization scenario, which affects transaction pricing; second, there are safety hazards, and poor-quality batteries may flow into the secondary use segment; and third, it is difficult to establish a supportive service system, such as insurance and finance, which restricts the innovation of business models. Although some of the head enterprises have developed internal standards, but the lack of industry-recognized authoritative testing system.

3.2. Recycling Channels Are Not Standardized

The current power battery recycling market in China is facing serious channel standardization problems. According to the latest statistics, as of June 2024, the number of enterprises engaged in power battery recycling business has exceeded 180,000, but about 65% of them are small-scale, poorly equipped "small workshop" recycling sites. These informal recycling bodies generally have weak technical capabilities, non-standardized processes, immature business models and other problems. A large number of private recycling sites outside the regulatory system constitute a grey industry chain. These informal recycling bodies usually adopt the following operation modes: no qualification certification, no environmental protection facilities, and no traceability management. The main reason for this phenomenon is that: informal recycling enterprises by simplifying the configuration of the production line, reduce environmental protection inputs, tax evasion and other ways to significantly reduce costs, so as to be able to attract the source of used batteries at a higher purchase price. This "bad money expelling good money" market disorder, on the one hand, resulting in valuable lithium, cobalt, nickel and other strategic resources can not be recycled efficiently; on the other hand, simple dismantling process causes serious environmental pollution; more importantly, the lack of professional treatment of batteries there are major safety hazards.

As new energy vehicle ownership continues to climb, the amount of power battery scrapping has shown explosive growth. In this context, the standardization of recycling channels has become a matter of urgency. This is not only related to the sustainable use of resources, but also an important guarantee of ecological environmental protection and production safety.

3.3. Insufficient Recycling Network Construction

Power battery recycling network as the primary link of the reverse logistics system, in the industrial chain has a double strategic value, on the one hand, as a direct contact with the end consumer service nodes, its layout density and reasonableness directly determines the overall recycling system operating efficiency; on the other hand, as a connection between the upstream and downstream of the information hub, assuming the key function of data collection and sharing.

At present, from the point of view of spatial distribution, the recycling network presents insufficient characteristics: First, the regional coverage is unbalanced, economically developed areas are over-concentrated and underdeveloped areas are seriously underdeveloped; second, the service radius is unreasonable, failing to form an effective grid layout; third, the functional positioning is unclear, specialized recycling sites and integrated outlets with a dislocation of the ratios. This non-equilibrium layout directly leads to inefficient resource allocation, part of the region's formal network facing idle capacity, while a large number of retired batteries due to the lack of recycling channels and stranded in the market.

Power battery processing centre as the terminal processing node of the reverse logistics system, bearing the core function of the resource utilization of end-of-life batteries. There is a significant gap between the construction status of China's power battery processing centre and the industry's development needs. On the one hand, the number of existing treatment centre is seriously insufficient to absorb the rapidly growing demand for retired battery treatment, and the capacity gap continues to expand. On the other hand, the completed processing centre lacks upstream and downstream connection: in vertical synergy, the logistics connection with the upstream recycling outlets, transit warehousing is not smooth, and the transport efficiency is low; in horizontal connection, the information sharing mechanism between the links is missing, resulting in product traceability, material scheduling and other key data circulation is blocked. This fragmented industrial ecology seriously restricts the improvement of resource recovery efficiency.

4. POWER BATTERY RECYCLING SYSTEM OPTIMIZATION SUGGESTIONS

Aiming at the three core problems of the current power battery recycling industry in China, namely, inconsistent standards, unregulated channels and insufficient network construction, a systematic solution is constructed to promote the healthy and sustainable development of the industry.

First of all, we should speed up the development of a unified industry technical standard system. It is recommended that the Ministry of Industry and Information Technology take the lead, unite industry associations, leading enterprises and scientific research institutions to jointly develop technical specifications covering the whole process of battery design, recycling and testing. Promote the standardized design of batteries, unify the structure of battery packs, connection methods and other key parameters; establish an authoritative battery health assessment system, develop unified testing methods and judging standards; improve the quality standards of the battery for gradual use, and clarify the technical requirements of different application scenarios. At the same time, a dynamic update mechanism should be established to ensure that the standard system keeps pace with technological progress. Through standardization, recycling costs can be significantly reduced and resource utilization efficiency can be enhanced.

In view of the chaotic recycling channels, it is recommended to adopt the governance strategy of "combining plugging and sparing". On the one hand, we should increase supervision, ecological environment, market supervision and other departments should jointly carry out special rectification, crack down on illegal recycling behaviour; on the other hand, we should improve the incentive mechanism, through tax incentives, subsidies and other ways to reduce the operating costs of formal enterprises. Meanwhile, relevant measures can be taken to strictly implement the extended producer responsibility system, requiring battery manufacturers to establish a comprehensive recycling network; the implementation of the battery recycling qualification system to improve the threshold of entry into the industry; and the establishment of a unified national traceability management platform, to achieve the full life cycle of battery tracking.

It is recommended to build a "three-tier recycling network" system, with the front-end recycling outlets focusing on strengthening coverage in counties and rural areas; the middle-end construction of regional recycling transit centre to undertake battery testing, classification and temporary storage; and the back-end rational planning of the layout of the processing centre to ensure effective connection with the front-end network. Encourage battery manufacturers to build and share recycling networks with recycling enterprises, promote intelligent transformation of processing centre and improve processing capacity. At the same time, an efficient information sharing mechanism should be established to achieve chain-wide data interconnection.

By establishing a unified standard system, standardizing the recycling channels and optimizing the network layout will effectively improve the efficiency of resource recovery, reduce environmental risks and promote the development of circular economy. In the future, with technological progress and system improvement, the power battery recycling industry will surely become a new growth point of the green economy, and make an important contribution to the realization of the "double carbon" goal.

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