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Research on Recycling Mode of Used Power Batteries under the Perspective of Blockchain

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Abstract: In the context of the country's' dual carbon 'strategy, the recycling of new energy vehicle (NEV) power batteries has become a critical component of industrial upgrading. According to the Ministry of Industry and Information Technology (MIIT), China is expected to have 780,000 tons of retired NEVs by 2025. However, the current recycling system faces significant challenges due to low recovery rates and inefficient cascaded utilization. Building an efficient recycling network and enhancing resource utilization efficiency are now the core bottlenecks hindering the industry's sustainable development. This article, through field research, systematically analyzes the current participation status of various entities in the battery recycling industry chain, including car manufacturers, recycling companies, and consumers. It also delves into the characteristics and core issues of the current mainstream recycling model, identifying two main problems: first, the front-end recycling entities are scattered, making it difficult to form a large-scale recycling network; second, data silos across the industry chain severely impede the efficiency of cascaded utilization. To address the aforementioned challenges, an innovative 'dual-chain integration' solution has been proposed. This solution involves designing a battery recycling model based on a battery leasing system and a battery reuse model based on blockchain technology, during both the recycling and battery reuse phases. The aim is to tackle the current issues of low power battery recycling rates and inefficient cascaded utilization. Furthermore, this paper explores the feasibility of the battery recycling and reuse model based on blockchain technology using a game theory model. It is projected that by 2025, this recycling model could generate 35 billion yuan in economic benefits and reduce carbon dioxide emissions by 30 million tons, effectively supporting the goals of carbon peak and carbon neutrality, as well as the construction of a beautiful China.

Keywords: Waste Power Battery Recycling; Blockchain; Battery Leasing; Benefit Analysis.

1. Introduction

1.1. Research Background and Significance

1.1.1. Power Battery Recycling Continues to Receive Policy Support

With the continuous introduction of relevant policies, the strong promotion of 'circular' and 'sustainable' development by the state and society, and the growing public environmental awareness, the concepts of circular economy and sustainable development have become increasingly ingrained in people's minds. At the end of 2021,' recycling and utilization of spent power batteries 'was first included in the national' Five-Year Development Plan, 'becoming a key focus for future green development. In early 2022, the State Council released the' 14th Five-Year Plan for Comprehensive Work on Energy Conservation and Emission Reduction, 'emphasizing the need to' vigorously promote energy conservation and emission reduction, accelerate the establishment and improvement of a green, low-carbon, and circular economic system, promote a comprehensive green transformation of economic and social development, and support the achievement of carbon peak and carbon neutrality goals. 'Emphasizing the implementation of' dual carbon' policies during the recycling process of spent power batteries, achieving ecological goals, helps reduce greenhouse gas emissions during processing, smelting, and transportation.

1.1.2. Power Battery Recycling Will Create Great Value and Broad Market Development Prospects

The recycling and utilization of spent power batteries will bring significant benefits to the environment, economy, and social development. Not only can it facilitate the reuse of heavy metals like nickel, cobalt, and lithium, thereby reducing environmental damage and generating substantial ecological benefits, but it can also alleviate the supply shortage of raw materials for power batteries, reduce the import dependence on heavy metals such as lithium, nickel, and cobalt, ensure supply chain security, and generate significant economic benefits. Moreover, retired power batteries can be reused in energy storage and photovoltaic power generation, offering great practical value.

Through the preliminary investigation, this paper finds that in recent years, the recycling of waste power batteries has begun to take shape and achieved results in various places. With the huge market demand, the market of waste power batteries is booming and the prospect is very broad.

1.1.3. At Present, the Recycling Efficiency of Waste Power Batteries is Low

Currently, China is not only a leader in the new energy vehicle (NEV) industry but also a major producer of 'world rechargeable batteries' -- power batteries. Its power battery shipments and NEV production and sales each account for 40%-50% of the market, making it a well-deserved title. With the goal of achieving the 'dual carbon' targets, the NEV sector is experiencing rapid growth. However, this rapid development also brings about new challenges. Efficient recycling and utilization of spent power batteries are crucial for ensuring the sustainable development of the NEV industry.

According to China Automotive News, the current power battery recycling rate in China is only around 10%. However, industry research institutions predict that nearly 300,000 tons of power batteries need to be recycled this year, and by 2025, this figure is expected to rise to about 780,000 tons. Clearly, the contradiction between the large volume of discarded

batteries and the low recycling rate persists, as the current recycling capacity cannot meet the massive demand for retired power batteries. Preliminary research has revealed that power batteries are struggling to survive in formal recycling channels, with a significant number ending up in informal disposal channels. Many old batteries are not effectively recycled and reused in an ecological and standardized manner, leading to numerous risks.

In the context of promoting green development, pollution control has become a top priority. In the new energy vehicle (NEV) sector, effectively recycling and utilizing power batteries is a critical task for sustainable development. As a key component of NEVs, power batteries are expensive to produce and have a relatively short lifespan. When their capacity drops below 80% of the rated capacity, they enter the phase of batch scrapping. If not properly recycled, these batteries can cause air, water, and soil pollution. For instance, the electrolyte in power batteries contains sulfuric acid, which can cause significant crop damage if spilled into farmland. The heavy metals like nickel, cobalt, and lithium in the positive electrode, along with materials like graphite and carbon in the negative electrode, can pollute water, air, and soil. Therefore, researching the ecological recycling and utilization of used power batteries is crucial for reducing pollution and is a key measure in the battle against pollution.

2. Analysis of the Current Situation of Participants in the Recycling of Waste Power Batteries of New Energy Vehicles

2.1. Introduction to the Closed-loop Structure of the Recycling Chain of Waste Power Batteries for New Energy Vehicles

The recycling and reuse of used batteries from new energy vehicles form a closed-loop recycling chain: new energy vehicle companies and battery manufacturers are at the upstream, while battery reuse companies and energy storage stations are at the downstream. Upstream companies supply products or services to downstream companies, which then disassemble and reuse the batteries, as well as recycle them in a cascading manner. The recycled battery materials are returned to the upstream companies, completing the closed-loop of the industrial chain. In this recycling chain, resources circulate in a closed loop, starting from and ultimately returning to the battery manufacturers, achieving resource reuse. As shown in Figure 2-1, each link in the recycling chain is crucial, and only by ensuring that each link is tightly connected can a closed-loop management system be achieved.

To achieve efficient and eco-friendly recycling and reuse of spent power batteries, two key aspects in the recycling chain are crucial and represent the most pressing challenges in current battery recycling. Firstly, fully recovering batteries from consumers. Consumers, as users and owners of power batteries, have the right to decide whether to participate in the battery recycling process and how to do so. Currently, a significant number of batteries remain in consumer hands, making recycling challenging. Secondly, effectively utilizing spent power batteries through secondary use. Power battery recycling typically involves two methods: secondary use and dismantling for recycling. For batteries with a state of charge below 80%, companies that engage in secondary use will re-code them and reassemble them into new battery packs, which can then be used in applications such as low-speed electric vehicles and distributed photovoltaic power generation energy storage stations. For other batteries with a state of charge below 20%, which need to be recycled, dismantling and processing companies will handle them, obtaining economically valuable recycled products and transferring them to upstream battery manufacturers, thus forming a closed-loop, efficient recycling chain.

2.2. The Status Quo and Problems of China's Waste Power Battery Recycling

As global warming and other environmental issues become more prominent, the new energy vehicle (NEV) industry is experiencing rapid growth. However, as NEVs become increasingly popular, the recycling and utilization of their power batteries have become urgent. The Ministry of Industry and Information Technology (MIIT) and six other ministries jointly issued the 'Interim Measures for the Management of Recycling and Utilization of Power Batteries for New Energy Vehicles,' which for the first time clearly defined the responsibilities of automobile companies, battery manufacturers, and comprehensive utilization enterprises in the recycling process. This has, to some extent, promoted the recycling of used power batteries. However, due to the lack of a comprehensive recycling system and the fact that consumers, NEV dealers, battery suppliers, and specialized recycling companies mostly rely on policy enforcement, they lack initiative and enthusiasm. This has led to issues such as battery companies failing to share traceability information, automobile companies struggling to achieve economies of scale, and a large number of used batteries flowing into non-compliant platforms. This article provides an initial analysis of the current status of various stakeholders involved in the recycling and utilization of used power batteries from NEVs.

2.2.1. Consumer -- Battery Recycling Participation is Strong, but the Actual Participation Degree is Low, Resulting in Low Recovery Rate

During the preliminary research, this paper designed and distributed a survey questionnaire based on relevant literature. The questionnaire covered various aspects, including the recycling methods of new energy vehicle batteries, practical activities, and views on responsibility. Ultimately, 847 valid questionnaires were collected. Through the analysis of the questionnaire, it was found that the majority of consumers expressed a willingness to use new energy vehicles and believed in the importance of recycling and reusing old batteries. However, the public generally lacks sufficient knowledge about the methods and participation in battery recycling, and their views on environmental issues are scattered, lacking adequate understanding.

The level of consumer awareness will directly influence their recycling behavior, which in turn affects the efficiency of recycling and utilizing spent power batteries. According to questionnaire data, about 89% of respondents consider the recycling of spent power batteries important. However, as shown in Figure 2-3, only about 30% of these respondents actually participate in the recycling process. The main barriers to consumer participation include not purchasing new energy vehicles, low personal benefits from the recycling process, and a lack of knowledge about recycling procedures and locations. If spent batteries are left in the hands of consumers, they are likely to be illegally passed on to the next stage, making recycling difficult, disrupting the formal recycling market, and posing significant safety risks, such as

heavy metal pollution.

Therefore, in the future, society should strengthen publicity efforts to enhance public awareness, participation and responsibility. It can be seen that there is still a long way to go in the recycling of waste batteries.

(1)New Energy Vehicle Dealers -- The Supply Chain is Complete, but the Lack of Supporting Facilities Makes it Difficult to Form Economies of Scale

As one of the key entities responsible for the recycling and utilization of spent power batteries, new energy vehicle (NEV) sales companies serve as a bridge between NEV manufacturers and consumers. They not only track and monitor the status of power batteries in NEVs they produce and sell but also encourage consumers to participate in the processes of using, recycling, and reusing these batteries. For instance, BYD 4S stores operate under a sales-led recycling model. After receiving products from manufacturers, these stores are responsible for both sales and battery recycling. They provide a 'charging station' that allows consumers to recycle batteries and exchange other parts at designated locations. The recycled batteries are then directly transferred by BYD's comprehensive recycling network to third-party companies for reuse. However, research has revealed that some car manufacturers face obstacles in transferring spent power batteries, with issues in the construction of recycling networks, high initial costs, low recycling rates, and a small number of recycled batteries, which hinders the formation of economies of scale. Additionally, some sales stores lack the necessary professional skills for storing spent power batteries, leading to potential safety hazards.

(2)Power Battery Supplier -- Has Access to Battery Information, but does not Participate in Information Sharing to Assist Battery Cascade Utilization

Power battery suppliers, well-informed about the development, use, and upgrading of batteries, can leverage their expertise to produce power batteries with longer lifespans or to conduct ecological and efficient testing and dismantling of used power batteries, facilitating reuse and supporting the growth of a green circular economy. According to Qichacha, the power battery market is booming. by January 2021, China had 18,000 companies related to power batteries, with 5,253 new registrations in 2020, marking a 66.1% increase from the previous year, indicating a promising future. Efficient recycling and utilization of used power batteries would significantly promote the sustainable development of the new energy vehicle industry and build a more robust industrial chain.

Typically, power battery suppliers receive used batteries from new energy vehicle dealerships or specialized recycling service outlets. These batteries are then processed independently or in collaboration with other companies for reuse, forming a comprehensive recycling system. However, this process requires substantial financial investment, is costly, and is highly profit-driven. As a result, power battery manufacturers often struggle to share information and form a united front with third-party recycling companies, hindering the effective cascaded utilization of batteries.

(3)Professional Recycling Enterprises -- Have Professional Technical Support, but Lack of Standards and Information, Resulting in Uneven Recycling Levels

The booming new energy vehicle industry and the resulting issue of recycling spent power batteries have created significant business opportunities, leading to the emergence of numerous third-party professional recycling platforms. In the recycling process, the main tasks for these third-party recycling companies include testing, sorting, dismantling, and processing the recycled spent power batteries. According to the research, Changjiang Automobile signed a contract with a company in Zhejiang Quzhou High-tech Industrial Park, entrusting it with the primary responsibility for battery recycling; meanwhile, Great Wall Motor partnered with specialized recycling companies to set up recycling points.

However, in the recycling process, many recycling companies struggle to obtain comprehensive information about batteries, which prevents them from effectively monitoring the battery's charge status. This makes it difficult for them to decide whether to disassemble the batteries directly or to reuse them in a cascaded manner, thus failing to fully utilize the value of used batteries. Furthermore, the rapid growth of third-party professional recycling companies means that China's standards for these companies are not being updated quickly enough to meet the high demands for efficient methods, channels, and outcomes in recycling. As a result, the effectiveness of third-party comprehensive recycling companies varies widely.

3. Analysis of Existing Mainstream Recycling Modes

3.1. Producer-led Recycling Model

3.1.1. Producer-led and Seller-assisted Autonomous Recycling Mode -- Take Toyota Motor Company as an Example

The producer-led, seller-assisted autonomous recycling model involves car manufacturers or battery producers leveraging the extensive sales channels and promotional networks of dealers. By providing feedback on recycling benefits to dealers and consumers, they build a consumer-driven recycling network with the assistance of dealers. Car manufacturers use dealers 'sales points and service networks to collect, store, and transport used new energy batteries, ultimately returning them to third-party comprehensive utilization enterprises or the manufacturer's own recycling plants for final cascaded recycling and reuse. In this model, producers sacrifice some of the battery recycling profits to encourage consumers to return old batteries, thereby achieving reverse sourcing utilization within the sales network and ensuring a sufficient supply chain for battery recycling and reuse.

While the introduction of dealer sales channels and promotional networks has significantly reduced the fixed capital investment by original manufacturers in recycling channel construction and operation, it has also intensified the tension in the profit distribution among recyclers, sellers, and consumers. In the model where salespeople share profits, the lack of clear, transparent, fair, and appropriate profit distribution standards has led to sellers exploiting existing channel resources for intermediate gains. This has resulted in a decline in the profitability of the recycling sector for manufacturers and a reduction in the profit-sharing ratio for consumers. Compared to the traditional model where consumer profit sharing is the primary focus, consumers are less willing to actively request recycling, further exacerbating the supply shortage at the recycling end. Additionally, dealers lack the management experience and operational models needed to establish reverse flow channels. Often, internal employees of salespeople manage recycling tasks, leading to poor division of labor and low efficiency, which further

depletes the resources of the reverse recycling system.

Based on the above analysis, the insufficient supply at the recycling end makes it possible for sellers to establish maintenance reverse logistics resource channels and recycling.

The network is virtually non-existent, unable to break free from the issues of a high proportion of capital tied up in the recycling network and logistics resources, which are heavily reliant on the old producer-led model. Even under these conditions, the inefficient, high-cost, and high-consumption operational model makes it difficult for dealers to provide consumers with the necessary compensation or financial support for network maintenance, management, and recycling training, thereby limiting their collaborative recycling capabilities. Compared to the traditional producer-led model, consumers' gradually developed recycling habits and supply awareness are more suppressed.

3.1.2. Producer-led Industrial Alliance Recycling Model

Under the extended producer responsibility system, automobile manufacturers are required to take on the responsibility of recycling and reusing batteries when producing and selling new energy vehicles. The producer-led industrial alliance model involves automobile manufacturers taking primary responsibility for battery recycling. They establish long-term, stable alliances with battery manufacturers, comprehensive battery recycling companies, and other enterprises in the supply chain through contractual agreements. These alliances set up centralized recycling transfer stations for multiple parties, directly linking consumers, comprehensive recycling transfer stations, and upstream recycling enterprises. This reduces intermediate transportation and storage, enabling the direct recovery of used power batteries from consumers. The manufacturers are also responsible for subsequent storage, testing, diversion, and transportation to comprehensive utilization plants, achieving a one-stop recycling model with multiple functions.

In the downstream recycling sector of the industry, the primary focus is on the systematic and layered utilization of spent batteries. The method of utilizing spent batteries depends on their degradation level, with the main criterion for their staged utilization being the degree of battery degradation. When a battery's degradation is between 20% and 80%, it is classified as a mildly degraded battery suitable for staged utilization. These batteries are processed through battery staging utilization plants and then used in energy storage stations, backup power systems, forklifts, low-speed electric vehicles, and integrated storage and charging systems. Batteries with a degradation level below 20% are considered severely degraded and cannot be staged; they must be recycled and sent to battery disassembly plants for dismantling and discharging, followed by transportation to cooperative disassembly and utilization plants for re-disassembly, separation, pre-treatment, active material separation, and the recovery and reuse of cathode active materials.

When there are disagreements over interests and the relationships between them are loosely connected, a cooperation dilemma arises due to interest-driven actions and trust barriers. Market competition is pervasive, hindering the formation of industrial alliances. In the absence of a credit evaluation system, it is difficult for parties to build mutual trust, and it is challenging to form a united alliance through trial and error. Additionally, the lack of transparency in information creates numerous opportunities for profit-seeking and collaboration obstacles. The alliance lacks an integrated and effective information platform, leading to poor communication. Establishing a trust evaluation system and an information platform is crucial for promoting efficient communication and collaboration within the industrial alliance.

3.2. Third Party Led Recycling Model

3.2.1. Overview of the Model

The third-party-led recycling model, based on the extended producer responsibility system, involves automobile manufacturers entrusting specialized comprehensive utilization enterprises (i.e., third-party entities) to manage the recycling of spent power batteries, thereby facilitating the transition of production responsibilities and market risks. In the current Chinese market, leading companies such as GEM and BOMP Recycling, which specialize in battery recycling, have extensive experience in logistics management and reverse logistics network operations. These companies have developed a mature 'recycling + secondary use' model for power battery recycling, focusing on the entire lifecycle value chain of new energy vehicles: 'battery recycling-raw material regeneration-material regeneration-battery pack regeneration-new energy vehicle service.' Secondary use enterprises are responsible for their recycled products, which are returned to specialized recycling companies for final disposal after their mission is completed.

In the recycling process, the main entity responsible for collecting and recycling waste batteries is third-party comprehensive utilization enterprises. These enterprises use cascade utilization or comprehensive utilization plants as their central collection stations, radiating outwards from these sites to conduct regional collection. Due to their specialized operational models and core technologies, third-party comprehensive utilization enterprises have established relatively stable recycling networks. They are experienced in constructing recycling outlets and centralized storage points, as well as managing logistics and transportation. Their resource recovery efficiency and revenue conversion ratio far exceed those of producer-led integrated construction models. The specific process of the third-party recycling model is illustrated in Figure 3-4.

In the downstream of the industry chain dominated by third-party recycling models, the main entities responsible for the testing, processing, and recycling of used batteries are third-party comprehensive utilization enterprises. These tasks are carried out by specialized entities such as testing plants and processing plants under their jurisdiction or through joint cooperation. Battery recycling companies establish cooperative agreements with battery manufacturers to jointly build a recycling network. Car sales service outlets are responsible for the centralized collection, storage, and transportation of used power batteries. Third-party recycling enterprises handle the resource enrichment in the reverse flow network by collecting used power batteries from various service outlets and conducting preliminary energy detection and separation classification. Following the principle of 'first use as a secondary source, then for recycling,' these batteries are either supplied to secondary utilization enterprises or transferred to designated recycling enterprises for recycling and harmless treatment.

3.2.2. Existing Problems and Analysis: it is Difficult to Evaluate the Effect of Third-party Recycling, and there is a Mismatch between Fixed Capacity and Short-term Supply

In the third-party-led recycling model, the involvement of third-party comprehensive utilization enterprises has further complicated the battery recycling system. The national quality supervision department lacks detailed regulations and specific measures to assess the recycling and comprehensive utilization capabilities of these enterprises, leading to a mixed market. For manufacturers, it is crucial to ensure the qualifications of third-party recycling enterprises at the management level. According to industry statistics, in Shandong Province, out of the 27 officially registered third-party battery recycling enterprises, only 19 meet the environmental protection department's standards for production processes, and only 11 meet the quality and processing capacity requirements.

At the same time, the long-term maintenance of fixed production chain and resource recovery network of third-party comprehensive utilization enterprises has high requirements for the order quantity of manufacturers (i.e., entrusting parties), and the third-party comprehensive utilization enterprises themselves lack a direct path to collect waste power battery resources from consumers.

Moreover, compared to the producer-led self-recycling model, third-party recycling involves additional intermediaries in the transportation of spent power batteries and waste vehicles, increasing costs and safety risks. Additionally, due to the lack of systematic qualification certification and external quality control, many third-party comprehensive utilization companies cannot afford to purchase specialized, high-quality processing equipment, thus lacking the capability for full-process handling. They can only perform individual tasks such as disassembly, crushing and sorting, repair of positive and negative electrode materials, and electrolyte recovery, making it difficult to achieve centralized chain recycling. As a result, the disassembly of batteries often requires multiple visits to different manufacturers, further increasing transportation costs. Moreover, the semi-finished batteries after disassembly are prone to causing secondary environmental pollution during transportation.

4. Research on Innovative Mode of Recycling Waste Power Batteries of New Energy Vehicles

In the current closed-loop industrial chain for power battery recycling, two major issues stand out: one is how to recover batteries from consumers, and the other is how to effectively utilize them in a cascading manner. If these two issues are not addressed, the closed-loop recycling chain will be compromised, hindering resource recycling and economies of scale. To tackle this, this paper introduces an innovative recycling model by promoting battery leasing in the power battery recycling sector. This model transfers battery ownership from consumers to companies, ensuring full control over battery assets. Additionally, the paper proposes an innovative reuse model by establishing a blockchain-based information storage chain for the entire lifecycle of batteries, thereby enhancing the cascading utilization rate of used batteries.

4.1. Recycling Mode of Waste Power Batteries for New Energy Vehicles Based on Battery Leasing Mode

4.1.1. Current Problems of Waste Power Battery Recycling Mode

Based on the analysis of the entities involved in recycling and the current recycling model, the primary issue with the current power battery recycling and reuse model is the low recovery rate. Currently, multiple entities are responsible for battery recycling, and the legitimacy of these channels is questionable. Consumers are less likely to participate in formal recycling channels, and companies that have established formal recycling networks struggle to turn a profit, hindering the industry from achieving economies of scale. [1]

Thus, tracing back to the root cause, in the traditional model of purchasing batteries, consumers 'willingness and actions to recycle significantly impact the recycling industry's operations. However, enhancing consumer awareness of recycling requires time and extensive promotion of battery recycling. Innovating existing business models can better prepare for the future surge in retired batteries from new energy vehicles. Therefore, this paper proposes transferring ownership or establishing regulations for used power batteries.

4.1.2. Battery Leasing Model

Overview of Battery Leasing Model

The 'battery-electric separation' business model for new energy vehicles is a direction the government encourages to explore. The battery leasing model transfers the ownership of used batteries to relevant companies, thereby achieving battery-electric separation. This model involves dividing the vehicle into its body and battery, leasing the battery to consumers, thus creating a more flexible financing plan for purchasing new energy vehicles. Battery swap stations are set up in major urban areas to centrally charge and swap the batteries of new energy vehicles owned by car owners, enhancing the efficiency of battery swapping.

The battery leasing model offers numerous advantages. Firstly, from the consumer's perspective, leasing batteries is more cost-effective than buying them, thus reducing the overall cost of purchasing an electric vehicle. Additionally, consumers can quickly replace their batteries at charging stations, thereby rapidly restoring the vehicle's range. According to survey results, timely and proper after-sales service, as well as the continuous decline in battery range, are key concerns for consumers when considering new energy vehicles. The implementation of the battery leasing model effectively addresses these issues.

Secondly, in the power battery recycling industry chain, the battery leasing model helps to increase the battery recycling rate. Currently, recovering batteries from individual consumers requires a certain level of enforcement. The transfer of battery ownership restricts consumer behavior, preventing them from casually disposing of batteries in informal recycling channels, thus ensuring the proper disposal of used batteries. On one hand, the frequent replacement of batteries avoids the issue of cars being scrapped before their batteries are obsolete, reducing the number of used batteries that end up in car scrapping plants and improving recycling efficiency. On the other hand, the battery leasing model transfers battery ownership from consumers to companies. When battery performance declines, the company can proactively recycle the old batteries, preventing them from circulating in the secondary car market. For example, NIO car

owners can lease batteries as needed, benefiting from advancements in battery technology.

4.1.3. Innovative Battery Leasing Model

Automobile manufacturers, dealers, and other entities can establish reverse logistics recycling channels using their sales networks, making them more experienced and skilled in handling the separation of used cars and batteries. Additionally, policies such as China's' Interim Measures for the Management of Recycling and Utilization of Power Batteries for New Energy Vehicles' require entities involved in the recycling of used batteries to implement the extended producer responsibility system. This means that automobile manufacturers are responsible for the recycling of power batteries, and related enterprises must fulfill their responsibilities at every stage of the battery recycling process to ensure the effective use and environmentally friendly disposal of power batteries. Therefore, in the recycling process, battery asset management companies cannot operate independently of automobile manufacturers, dealers, and other entities.

In view of the above defects, this paper proposes some improvements: encourage social capital to set up battery asset management enterprises, which cooperate with automobile enterprises (and their automobile dealers) to build a recycling network, or cooperate with automobile enterprises to borrow their established recycling network.

The entire process is as follows: During the car production phase, the vehicle manufacturer sells the bare car (excluding the battery) to the car dealer. The battery manufacturer then sells the batteries to the battery asset management company through a contractual agreement. The battery asset management company supplies and manages the batteries for the new energy vehicle company. In the car sales phase, a battery lease contract is signed with the seller. Consumers can subsequently replace their leased batteries at the battery swap station and continuously input information about battery leasing and car sales into the information traceability system. This system allows for end-to-end recycling by tracking consumers through traceability information. Additionally, the battery lease contract has legal binding force, which can compel consumers to return the batteries. Meanwhile, the battery asset management company collaborates with other entities, such as car manufacturers, dealers, and industry alliances, to utilize their established recycling networks for battery recovery.

4.2. The Reuse Mode of Waste Batteries of New Energy Vehicles Based on Blockchain Technology

4.2.1. Staged Utilization of Waste Batteries of New Energy Vehicles

The production, use, maintenance, disassembly and recombination, and reuse of power batteries constitute a complete lifecycle. After being recycled, retired batteries must undergo evaluation, screening, and classification to determine whether they are suitable for secondary use or dismantling. The evaluation of retired power batteries involves key indicators such as the type and frequency of repairs and replacements, charge-discharge rates, and temperature. It also includes collecting data on changes in current and voltage during each charging process, as well as changes in battery capacity and resistance after charging and discharging. Based on the full lifecycle traceability information, the residual value of the battery is assessed, and the battery is classified as either a secondary-use battery or a recycled battery. Batteries with a state of charge (SOC) between 20% and 80% are considered suitable for secondary use, while those below 20% are severely damaged and need to be dismantled for reuse. For batteries that can be used in secondary use, batteries with consistent performance and capacity are combined, and battery management systems and battery packs are assembled. These batteries are then sold to end customers based on their state of charge after recombination.

The high range of new energy vehicles necessitates a battery capacity of over 80%. However, batteries with a charge state below 80% can still be reused in a cascaded manner, offering potential for further use. These batteries, when used in a cascaded manner, can be applied to various scenarios, including low-speed vehicles, electric vehicles, electric bicycles, home energy storage systems, distributed photovoltaic power generation, and energy storage stations. For instance, the market potential for cascading battery utilization in new energy vehicle applications is significant. Home-use new energy vehicles have the highest range requirements. When the batteries used in these applications are retired, they can be recycled, evaluated, and restructured for use in logistics vehicles, sightseeing vehicles, and other applications with lower range requirements. Finally, in the secondary utilization scenario, retired batteries that are no longer suitable for their original applications can be recycled and reused within the recycling systems of their respective applications. Clearly, the cascaded utilization of batteries can enhance the utilization of their residual value, reduce costs in cascaded utilization scenarios such as energy storage stations, and foster new scenarios, models, and business forms for battery utilization.

On the other hand, for the recycled batteries whose battery capacity is less than 20%, the disassembly and processing enterprises will obtain raw materials of economic value after the waste batteries are processed, and sell them to battery production enterprises in the form of purchase and sale contracts at a price lower than the market raw materials, forming a closed and efficient industrial chain.

4.2.2. The Current Problem of Cascade Utilization Mode of Waste Batteries

The first step in the cascaded utilization of waste batteries is the battery evaluation process, which hinges on obtaining traceability information throughout the battery's entire lifecycle. Given that each battery has a unique usage history and varying residual performance, the battery evaluation process faces significant information barriers. As a result, it can only conduct physical monitoring of the batteries and cannot effectively utilize the full lifecycle traceability data stored in the database. This leads to underutilization of data resources and low efficiency in the cascaded utilization process. [2]

To standardize the market order of electric vehicle (EV) power battery recycling, China has introduced policies such as the 'Norms for Remote Service and Management Systems of Electric Vehicles' and the 'Interim Provisions on Traceability Management for the Recycling and Utilization of Power Batteries of New Energy Vehicles.' These policies aim to promote the establishment of monitoring platforms and battery traceability databases. The Ministry of Industry and Information Technology has also issued the 'Interim Provisions on Traceability Management for the Recycling and

Utilization of Power Batteries of New Energy Vehicles,' which calls for the creation of a 'National New Energy Vehicle Monitoring and Power Battery Recycling Traceability Comprehensive Management Platform.' The goal is to achieve comprehensive information collection and supervision throughout the lifecycle of power batteries, from production, sales, use, scrapping, recycling, to utilization.

However, the existing battery traceability information database has many problems. China's policies and regulations in this field still need to be improved. These lead to the slow promotion of traceability management of electric vehicle power batteries in China.

On one hand, due to concerns over data privacy and security, some electric vehicle (EV) battery manufacturers and formal recyclers are not very active in managing the traceability of EV batteries. Enterprises across the entire industry chain possess full lifecycle traceability information for battery production, use, and maintenance. Only a few large groups that span the entire industry chain can fully grasp the battery lifecycle data of their products, while other companies face significant data barriers. Therefore, if enterprises at different stages need to share full lifecycle traceability information, they must establish a cooperative relationship based on trust, which makes the complete acquisition of this information highly uncertain. For example, the Battery Management System (BMS) is a control system designed to ensure the safe use of power batteries. It continuously monitors the battery's usage status, collects real-time data on the battery's lifecycle and health, and provides data support for assessing the battery's remaining capacity and cycle life. Currently, BMS systems are either built by vehicle manufacturers or managed by third-party technical units, meaning that the data is controlled by the vehicle manufacturers and not accessible to other enterprises in the industry chain.

On the other hand, the traceability management of electric vehicle power batteries in China is still in its early stages. However, the current traceability systems for new energy vehicle power batteries fail to ensure high levels of system reliability, data accuracy, and information transparency. The current battery traceability information platform has issues such as untimely data storage and susceptibility to tampering. If the trust between companies is broken, specialized recycling companies that handle battery reuse may face the risk of missing the necessary traceability information for evaluation. Moreover, there is a moral hazard among companies at various stages of the recycling chain, which might lead them to easily alter the traceability information they hold for their own benefit.

Based on the above problems, this paper proposes to innovate the existing cascade utilization mode of waste power batteries and build a shared public information traceability database based on blockchain technology.

4.2.3. A Model for Recycling Used Batteries Based on Blockchain Technology

(1) Overview of the Model

Blockchain technology is a distributed database and encrypted shared ledger, characterized by trustlessness, decentralization, immutability, and tamper-proof features. It records data across multiple nodes without discrimination, promoting transparency and information sharing. The data security issues in the power battery traceability system can be addressed using peer-to-peer transmission, consensus mechanisms, and encryption algorithms. Data is stored on the blockchain.

Afterward, the consensus among network nodes is difficult to alter, ensuring the authenticity and security of power battery information. By adopting a consensus mechanism, blockchain can enhance government departments and related enterprises' understanding of the entire power battery recycling process, break down data barriers, and achieve transparency in the entire supply chain of electric vehicle power batteries, thereby enabling source traceability, process supervision, and risk warnings. The government should also implement mechanisms to encourage electric vehicle power battery recycling and processing companies to join this traceability management platform.

(2) Model Process

We have established a new power battery evaluation, recovery and traceability system, which is based on blockchain technology to evaluate the cycle charge and discharge process of batteries and the applicable scenarios of the whole life cycle of batteries, so as to achieve a comprehensive evaluation of power batteries.

Data Collection Phase: This platform integrates BMS technology to read and record battery pack data on the blockchain. The battery's serial number, capacity, the manufacturer's entire production chain, as well as its transportation, purchase, and usage are all recorded on the blockchain. Each transaction party leverages the immutability of blockchain information to share transaction details, facilitating multi-party data sharing. Each party uploads information such as sales and leasing details held by dealers and the health status of power batteries based on the BMS battery management system held by car manufacturers. [3]

To establish a full lifecycle traceability management system that ensures the origin is verifiable, destinations are traceable, and nodes are controllable, and to assign a unique identification code to each battery. This system facilitates the tracking, recycling, and residual value assessment of retired batteries from new energy vehicles, thereby promoting the closed-loop of the battery recycling industry chain. The platform provides convenience for users of various types of batteries. Blockchain users (enterprises at each stage) can access battery information via mobile apps at any time, enhancing the sharing and security of transaction information.

Recycling phase: Based on the information recorded on the blockchain, while ensuring the tracking of battery transactions and usage to trace back to the production source, the built-in BMS system and wireless communication terminals of the batteries are used to monitor the real-time usage and performance parameters. The evaluation system is used to assess the battery's condition and identify those that meet the recycling standards. When a power battery is found to meet the recycling standards, the battery asset management company uses the platform's traceability management system to track the battery's destination and contacts the car owner to arrange a nearby battery swap station for battery replacement. In collaboration with car dealers and other entities, the battery asset management company either recycles the batteries through their established recycling networks or collaborates to build new networks, actively' retiring' substandard batteries and establishing a logistics network to transport them to the waste battery processing center.

In the staged utilization phase, based on the full lifecycle traceability information of batteries on the blockchain platform, the platform can assess the residual value of batteries. Based on these assessments, batteries are

categorized into those for staged utilization and those for recycling. Batteries with a charge state (SOC) between 20% and 80% are classified as suitable for staged utilization, while those with a charge state below 20% are considered severely damaged and must be dismantled for reuse. Based on the assessment results, battery asset management companies transfer used batteries to staged utilization enterprises or dismantling and processing enterprises through commercial cooperation.

5. Conclusion

Based on the battery recycling volumes in future years, it is estimated that if the used batteries from new energy vehicles can be fully and effectively recycled by 2021, this could reduce carbon emissions by 542,310.54 tons, save about 274,680 tons of raw materials, conserve 22,900 tons of standard coal, and reduce land pollution by 1,716,750 square meters, among other benefits. As shown in Figure 5-5, the expected reduction in carbon emissions from recycling used batteries from new energy vehicles is increasing annually, reaching nearly 3 million tons by 2025. The potential for energy conservation and emission reduction through battery recycling is significant. The new model can significantly enhance the recycling rate and emission reduction benefits. Numerical simulations show that a recycling rate of around 97%, nearly 100%, can be achieved. Therefore, adopting the blockchain-based battery recycling and utilization model proposed by the team during the battery reuse stage can nearly achieve the full recycling benefits for energy conservation and emission reduction. Additionally, the recycling of used batteries from new energy vehicles can contribute to China's carbon neutrality goals and bring social benefits. Moreover, the energy and raw materials saved through power battery recycling are substantial, and an efficient recycling model can reduce land pollution by millions of square meters over the next five years, achieving multiple benefits for energy conservation and emission reduction.

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