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Analysis of the Closed-Loop Supply Chain Focusing on Power Batteries in China

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Abstract

The research on waste power batteries in China in the past ten years reveals that the power battery recycling industry is enormous but marred with several challenges. A study of China's current power battery closed-loop supply chain revealed some issues in the power battery recycling industry, such as imperfect supply chain, small recycling scale, asymmetric information, and imperfect profit distribution mechanism. This paper uses the theory of corporate social responsibility and consumer choice to propose a closed-loop network of power batteries based on block chain technology and analyzes the existing closed-loop supply chain of power batteries. Consequently, this study provides a new idea for developing the power battery closed-loop supply chain by proposing the closed-loop network of power batteries based on blockchain technology.

Index Terms: Blockchain, Closed-loop supply chain, Corporate social responsibility theory, Power battery, Recycling

I. INTRODUCTION

The recent rapid development of new energy technologies in China has aided the inflationary growth of new energy vehicles in the past three years. According to the China New Energy Vehicle Development Report, by June 2019, the number of new energy vehicles in China reached 3.34 million, the number of traditional fuel vehicles reached 250 million, and the penetration rate of new energy vehicles was less than 1.4%. Besides, the number of electric bicycles in China will exceed 300 million by 2019. The popularity of new energy equipment and numerous mobile terminals generates a large number of waste power batteries each year.

The "2020 industrial energy conservation and comprehensive utilization of work points" by China's Ministry of Industry and Information Technology focus on "launching new energy power battery recycling system, establishing an echelon product evaluation mechanism." Contextually, sustainable development of new energy green circular economy has essential significance, and this research is aligned with the new pattern of power battery supply-chain for social development, along with advantages of the existing power battery closed-loop supply chain for reducing the damage to the environment caused by waste power batteries and improving the technology for recycling waste power batteries [1].

II. RESEARCH BACKGROUND

With the encouragement for a green, circular, and low-carbon economy in China, new energy equipment has become its path to development due to the advantages of saving energy and reducing emissions. According to the latest data released by the State Internet Information Office at its March 1, 2021 press conference, China leads the world in production and sales of new energy vehicles for six consecutive

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years, totaling more than 5.5 million vehicles. By the end of 2019, there were more than 3.81 million new energy vehicles in the country. According to the average service life of power batteries, which ranges from 5 to 7 years, the cumulative scale of power batteries decommissioned in the Republic of China (ROC) will reach 200,000 tons in this year, with the economic value exceeding 10 billion Chinese yuan renminbi (CNY), implying that the number of waste power batteries will skyrocket soon. A failure to effectively and adequately handle these batteries will cause environmental pollution and a possible energy crisis. The Guiding Opinions on Building a Modern Environmental Governance System, issued by China's State Council in March 2020, set forth more stringent environmental governance requirements by improving the corporate responsibility system, the national action system, the market system, and the credit system for environmental governance. Therefore, reasonable control of power batteries, effective monitoring of its life cycle, reducing the damage of waste power batteries to the environment are all pressing practical problems.

A. Realistic Requirements for the Development of Power Battery Reverse Supply Chain

As shown in Fig. 1, the scale of scrapped power batteries in China will reach 111.7 GWh by 2025, growing exponentially, with severe pressure on recycling. Currently, China's power battery recycling industry has various problems, such as a disorderly recycling system, lack of recycling standards, unclear profit distribution mechanism, backward recycling technology, and low recycling efficiency. There is yet to establish a healthy and effective reverse recycling supply chain system with an urgent need for an efficient and sustainable supply chain recycling system for power batteries.

B. Violations in the Power Battery Recycling Market Have Become the Norm

The power battery recycling market will reach CNY432 million in 2018. With the continuous expansion of new energy automobiles and new energy industries, there is vast scope for the power battery recycling market. As shown in Fig. 2, the power battery recycling market will expand to about CNY20,371 million in 2025, and with the growth of global electrification, the recycling scale will reach CNY120 billion in 2030.

However, it is doubtful that the Ministry of Industry and Information Technology's (MIIT) Standard Conditions for the Comprehensive Utilization of Waste Power Storage Batteries of New Energy Vehicles includes only five enterprises. According to public data, China had more than 3,000 domestic companies operating within the scope of "battery recycling" by May 2020, and above 700 new ones were added in 2019. It shows that illegal operation is a common occurrence in the power battery recycling market, and preventing illegal recycling is vital for the healthy development of the power battery recycling market.

C. Broad Application Prospects of Blockchain

Blockchain has relied on its plasticity, decentralization, openness, transparency, distributed bookkeeping, and other characteristics to gradually change its development in various industries such as finance, education, health care, digital assets, finance, internet, and supply chain logistics. The supply chain will see a typical application of blockchain in the future. Blockchain can help in numerous tasks like tracing the items, decentralizing transactions, and other objectives. It can strengthen the close cooperation between supply chain enterprises and the supervision capacity of the supply chain. Furthermore, it can accelerate the development of an information-based and intelligent power battery closed-loop supply chain.

D. Application and Development Trend of Block Chain Technology and Supply Chain

There are several problems with the power battery closed-loop supply chain management, such as multiple recycling levels, treatment technology, inconsistent recycling stan-

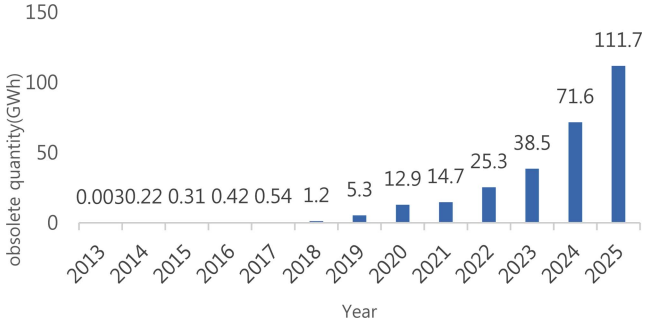

Fig. 1. China's obsolete power battery quantity data from 2013 to 2025.

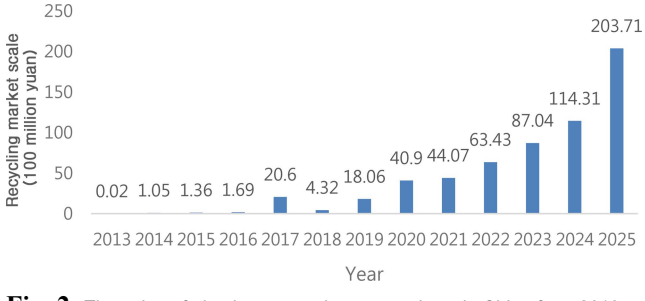

Fig. 2. The value of obsolete power battery products in China from 2013 to 2025.

dards, low recycling efficiency, and normalization of industry irregularities. Currently, China and the world are promoting a low-carbon sustainable development economy, and supply chain development is bound to be an intelligent, information-based digital approach. Thus, this paper introduces blockchain into power battery closed-loop supply chain management, designs a Chinese power battery closed-loop supply chain network based on blockchain, discusses its value advantage in supply chain management, and analyzes the decision of adopting blockchain by supply chain enterprises.

III. Status and Problems of Closed-Loop Supply Chain of Traditional Power Battery in China

A. Status and Problems of Closed-Loop Supply Chain of Traditional Power Battery in China

The power battery supply chain in China currently lacks stable cooperation and effective information exchange. The competitive pressure brings about irregular recycling channels, reducing the operation and efficiency of the power battery supply chain. Besides, some regular power battery recycling enterprises fabricate data to obtain subsidies by taking advantage of the loopholes in the relevant policies of the state on recycling subsidies. Due to the high price of recycling in the black market, some regular enterprises resell the batteries recycled through regular channels, later purchasing the batteries with no utilization value to obtain the national recycling subsidies by cheating at the same time.

Fig. 3 shows the present network structure of the traditional Chinese power battery closed-loop supply chain:

B. Existing problems in China's traditional Closed-Loop Power Battery Supply Chain

1) Asymmetric information and lack of effective communication among all members of the power battery supply chain

Manufacturers estimate the number of waste power batteries in the market based on the existing production data. Due to bullwhip benefits, consumers' power batteries cannot achieve the manufacturer's estimated recovery status. The gamble between the supply and price of waste power batteries, either from production or recovery, shall be carried out through enterprise research. Thus, it requires a lot of time and experience to achieve the best supply chain benefits. Consumers face difficulty in distinguishing between real or fake replaced power batteries.

2) Power battery supply chain is complex, informationization is low, operation cost is high, and profit is difficult

Since the supply chain's demand information does not provide the overall Enterprise Resource Planning (ERP) management, the transmission is still performed by combining telephone calls and documents; the informationization degree is low while there are several levels. There are numerous nodes between each level, causing frequent information faults among the participants. Meanwhile, uncertain factors, long recovery cycle, product quality, recycling places, and other factors like high operation cost and lack of government policy support make it difficult to achieve profitability in the reverse supply chain.

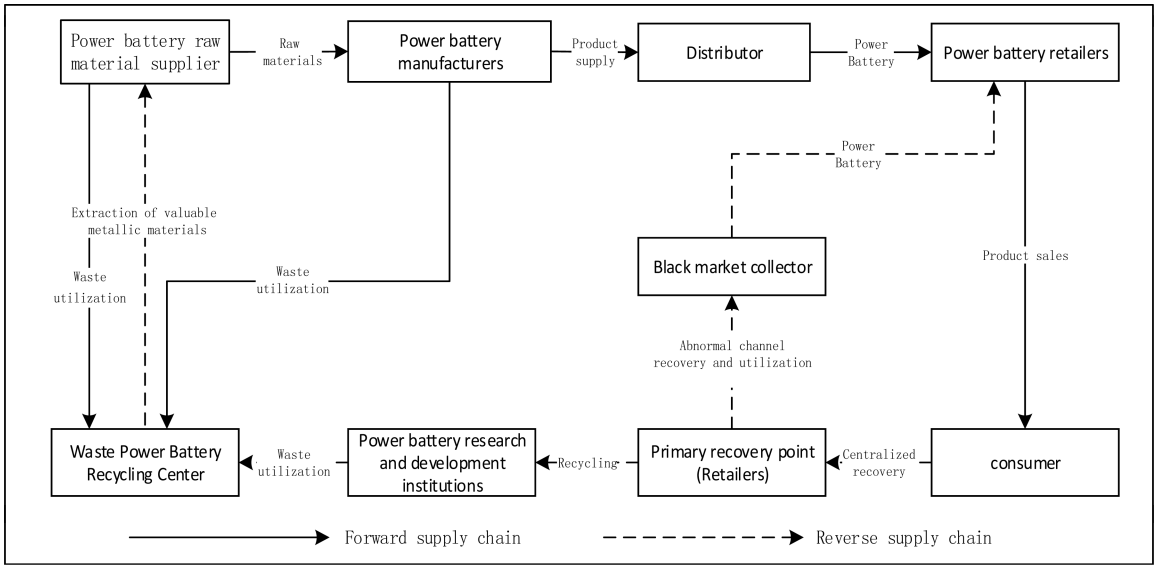

Fig. 3. The basic network structure of the traditional closed-loop power battery supply chain in China

3) The access threshold for the power battery recycling industry is low, and it is difficult for regular recycling enterprises to achieve scale effect

Most waste power batteries in the market currently are recycled through informal channels due to price advantages, making it difficult for regular recycling enterprises to recycle on a large scale. Therefore, it is necessary to increase the access threshold for recycling, restrict recycling channels, and implement the production extension system to enable the flow of waste power batteries into regular recycling enterprises and realize the utilization of waste power batteries.

4) Unsound power battery recycling and supervision system

The breakage of transportation from recycling channels was aggravated by the weak sense of responsibility of the recycling subjects, lack of support from national policies, blindly pursuing profits from recycling, self-processing or recycling of power batteries, and failure to ensure safety. It obstructed formal professional enterprises from having the recycling potential to meet the design needs. The relevant State departments have promulgated several policies and regulations clarifying the recycling subjects and relevant responsibilities of power batteries. However, the profit-seeking mentality of nodes at all levels in the operation process and certain technical obstacles have sabotaged the effective operation and development of the reverse supply chain (logistics) industry for recycling waste power batteries.

5) The traditional power battery supply chain lacks information storage, and some enterprises take advantage of regulatory loopholes by faking data

Currently, there is no significant correlation between the serial number of batteries and the vehicle number in China's new energy industry, leading to the use of battery disassembly loopholes by some enterprises to defraud subsidies. The government is facing challenges in achieving comprehensive management and control concerning regulation. The core reasons are the lack of information storage, data query, and untamable functions in the traditional power battery supply chain.

6) Consumers' willingness to return is not strong, and it is challenging to recycle power batteries from the source

Most consumers will choose to recycle and replace power batteries only after the end of their service life. Then it is not the consumers' responsibility to recycle it. It sets higher requirements for consumers' willingness to recycle and environmental protection. Besides, it is even more challenging to return their waste power batteries through the State's formal channels.

IV. Relevant Concepts and Theoretical Basis

A. Concept and Characteristics of Blockchain

An overview of research on blockchain: Zhai Chaoying (2021) believes that blockchain can be applied to manage capital accounts as they are untamable, traceable, decentralized, and distrustful. Besides, the discussion to further improve the facilitation of capital accounts and the regulatory efficiency is based on aspects; the necessity and feasibility of the application, application framework, and specific application scenarios [2]. Michaúr Kowalskiy et al. (2021) advocated using blockchain technology to address the issue of enduring trust among trading partners in trade finance, and relevant experts investigated how blockchain affects trust among trading partners, demonstrating the possibility of its application [3].

Nakamoto Satoshi first proposed the concept of blockchain in 2008, closely related to Bitcoin. The high value of Bitcoin made people familiar with the concept of blockchain gradually [4]. Until now, there is no unified definition of the concept. According to the China Baidu Encyclopedia, in a narrow sense, a blockchain is a kind of chain data that is arranged in the first position of a time series and can ensure that the data cannot be tampered with or falsified through hash codes. While in a broad sense, blockchain is a new type of distributed architecture and computing mode; it uses chained data structures to store and validate data, distributed node consensus algorithms to generate updated data, cryptography to ensure the security of data transmission and access, and code combinations to control data.

Blockchain technology involves mathematics, cryptography, the Internet, and computer programming to establish a decentralized, distributed chain database that can record events or history comprehensively. All nodes can share the recorded without disturbance and control by any node. It can prevent malicious tampering effectively.

The main features of a blockchain are as follows:

1) Decentralization

Each node of the blockchain system adopts distributed architecture without any mandatory control center in the system, and each node's rights and obligations are equal and non-interfering.

2) Openness

The blockchain system has a completely open interface. The whole network can query information stored on the blockchain and can be related to the application as needed, improving the information symmetry between enterprises.

3) Transparency

Any node in the blockchain can query all data except the

encrypted information of the chain's transaction agents in real-time. Asymmetric encryption technology is used to encrypt the data.

4) Traceability

Blockchain records all the information from each node, and these are tamperproof, unique, and so forth. Any updates to the data are distributed across the network, and the refresher information is recorded.

5) Anonymity

All the nodes that participate in a blockchain exist anonymously in the system. Only the node that receives the private key can decrypt the relevant data, reducing the cost of gaining the trust of the concerned parties.

6) Non-tampering

The chunk chain permanently stores all the verified data. Data modification by a single node is invalid, which increases the cost of data falsification and makes the data in the chunk chain untamable.

B. Corporate Social Responsibility Theory

In 1971, the U. S. Council for Economic Development proposed the idea of integrated corporate responsibility, that is, corporate social responsibility concerning the economic responsibility, legal responsibility, moral responsibility, and charitable responsibility of enterprises to society. The relationship between them is expressed in three concentric circles [5]. The inner circle includes essential economic functions such as products and economic growth. The innermost circle is the fundamental economic responsibility of the enterprise, which mainly involves the issues such as production and personnel employment, which is the root of the enterprise. The second circle is the legal responsibility and moral responsibility. In the process of assuming economic responsibility, we should pay attention to social standards and social values and do not violate customs, ethics, and laws. Finally, the third circle is the social and environmental conditions beyond the moral, legal and environmental conditions that the enterprise must pay attention to in order to improve and develop, and the enterprise has the right to decide freely on the performance of this responsibility, which is generally manifested as charity. Carroll (1979) proposed the Pyramid of Corporate Social Responsibility (CSR) which shows that CSR is the economic, legal, moral, and charitable expectations that society has placed on enterprises in a certain period, forming a pyramid. The base shows the economic responsibilities of enterprises, followed by the legal responsibilities of enterprises [6]. The third contains the moral responsibilities of enterprises, including moral standards and norms reflecting the expectations of shareholders, employees, consumers, and the community concerning fairness, justice, and respect for the moral rights of stakeholders and the protection of those rights. The top displays the charitable responsibilities of enterprises. It includes the enterprises voluntarily promoting the development of people for their welfare, reflecting the society's highest demands or wishes for enterprises.

The social responsibility of supply chain enterprises considered in this study is based on the producer responsibility system, which requires enterprises to assume the responsibility for the whole life cycle of power battery products from sales to recycling. It includes the responsibility for products and services as well as recycling, disposal, and ecological environment protection.

C. Consumer Recall Theory

An overview of research on consumer behavior theory: Chu Jun (2020) believes that human beings' living environment is becoming increasingly critical, and people must pay attention to product recycling. He examines the optimal recycling strategy for enterprises under different circumstances by considering the green behavior of consumers and the recycling strategy of manufacturers. He maintains that enterprises must consider consumers' environmental protection awareness and analyze the government's restraining role on enterprises [7]. Jiang Tian (2019) used Analytic Hierarchy Process (AHP) to examine the weight of the factors influencing the decision-making behavior of consumer channel bias and used it to establish the game model of recycling of waste mobile phones under the consumer channel bias scenario. The analysis of the proportion of consumers and the consumer bias coefficient solved the recycling price, optimal profit, and optimal price in the recycling system of waste mobile phones [8]. Hu Shu (2017) believes that consumers' behavior will significantly affect the supply of waste products, further affecting the decision-making and profits of enterprises. He considers the strategic behavior of consumers and the tricky regulation policy in reverse and closed-loop supply chains, which enriches the basic models of reverse and closed-loop supply chains theoretically, helping enterprises to understand the operation of reverse and closed-loop supply chains better [9, 10].

Consumer recycling is a kind of consumer behavior. Consumer behavior theory is also called utility theory. It studies how consumers distribute their income among various goods and services to maximize the degree of satisfaction. The presuppositions of consumer behavior theory are:

(1) Consumers are entirely rational, having a thorough understanding of the goods they consume and pursue utility maximization consciously.

(2) Consumption sovereignty exists. Consumers decide their consumption and production.

(3) The utility only comes from the consumption of goods.

Consumer behavior theory considers the influence of stimulating and external factors on consumers' purchase intention and reflects the change in their internal activities.

The purpose of this study is to examine how internal and external factors affect consumers' willingness and participation in battery recycling. The expected life of the battery is the primary internal factor. External factors include consumer's awareness of environmental protection, recycling policy, publicity and promotion factors, time cost, etc. Consumer utility behavior is the basis of recycling behavior due to the combined influence of numerous elements.

V. DESIGN OF CLOSED-LOOP POWER BATTERY SUPPLY CHAIN USING BLOCKCHAIN

A. Feasibility of Blockchain Technology Used in the Closed-Loop Supply Chain of Waste Power Batteries

1) The block chain technology has strong traceability

The information about the power battery requires strict control and tracking. Blockchain technology can record all the information about the power battery in circulation across different nodes. It can perfectly achieve the traceability and integrity of data, which helps build pertinent reverse logistics of consumer-to-business (C2B) and business-to-business (B2B).

2) Block chain technology is decentralized, transparent, and untamable

The localized chain of distributed information records of a blockchain can weaken the involvement of a third-party information institution, maintaining the authenticity of power battery flow information and preventing data modification at the source. The authenticity and non-loss can be achieved to enhance the truth and reliability of data further and improve the traceability of power batteries and internal raw materials for the reverse supply chain of waste power batteries. That means that the decentralization and traceability of the blockchain can be utilized to better record and control the flow of data related to obsolete power batteries.

3) Block chain technology can deliver value at a reduced cost

Blockchain technology can record the entire value transfer of power batteries without modification from raw material to cost or even during the sales process. The recording process is distributed to each node. It is to the uniqueness and stability of the record, the recovery and transfer of the waste power battery from the “point to point” of the reverse logistics, indirectly reduce the cost of information collection, and provide the information transfer mode of the reverse supply chain to make it efficient and less expensive.

B. Construction of Closed-Loop Supply Chain Network for Power Battery Based on Blockchain

The closed-loop supply chain of waste power batteries adopts blockchain to address the main problems in the existing supply chain’s operation. It utilizes the unique technical advantages of blockchain to break through the information barrier in the supply chain, speed up the information circulation, and promote the reverse flow of waste power batteries with high efficiency and low cost to improve recycling efficiency [11].

We can use the sales information between direct retailers and consumers to track and bind the battery's information and simultaneously use publicity, consumption incentives, and other means to improve consumers' awareness of recycling waste power batteries. The supply chain could use logistics outsourcing strategy and authorized third-party logistics companies to circulate also process the recycled power batteries. They preliminarily realized cascade utilization, disassembly, recycling, and sending them to the treatment center to disassemble and extract recyclable substances from the waste power batteries. The recyclable waste power batteries can be used for Echelon Use, and the non-recyclable batteries should be disassembled. The recyclable precious metals inside the dismantled used batteries are transported to the material provider through third-party logistics and then returned to the forward supply chain for recycling. All processes will be documented in the blockchain to trace better the origins of used and waste power batteries. Flowchart Shown in Fig. 4 Below:

Consumers will have their power batteries decommissioned for recycling, and regular recycling channels will be available. The traceability of blockchain technology can effectively restrict the illegal operations of retailers, regulating the recycling options for consumers to a certain extent. Consumers can trace the source of newly replaced power batteries to ensure their safety and reliability. While preliminarily recycling waste power batteries, the recycling enterprises shall share the battery-related information by uploading it to the blocks. Thus, manufacturers shall select batteries for testing, dismantling, or remanufacturing through information on blockchains such as type and demand. The use of blockchain reduces the transaction hierarchy and resolves the uncertainty of relevant information such as the quantity, quality, and type of recycled batteries. During the production and remanufacturing of power batteries, relevant information can be integrated to provide information basis for downstream enterprises and consumers of the supply chain.

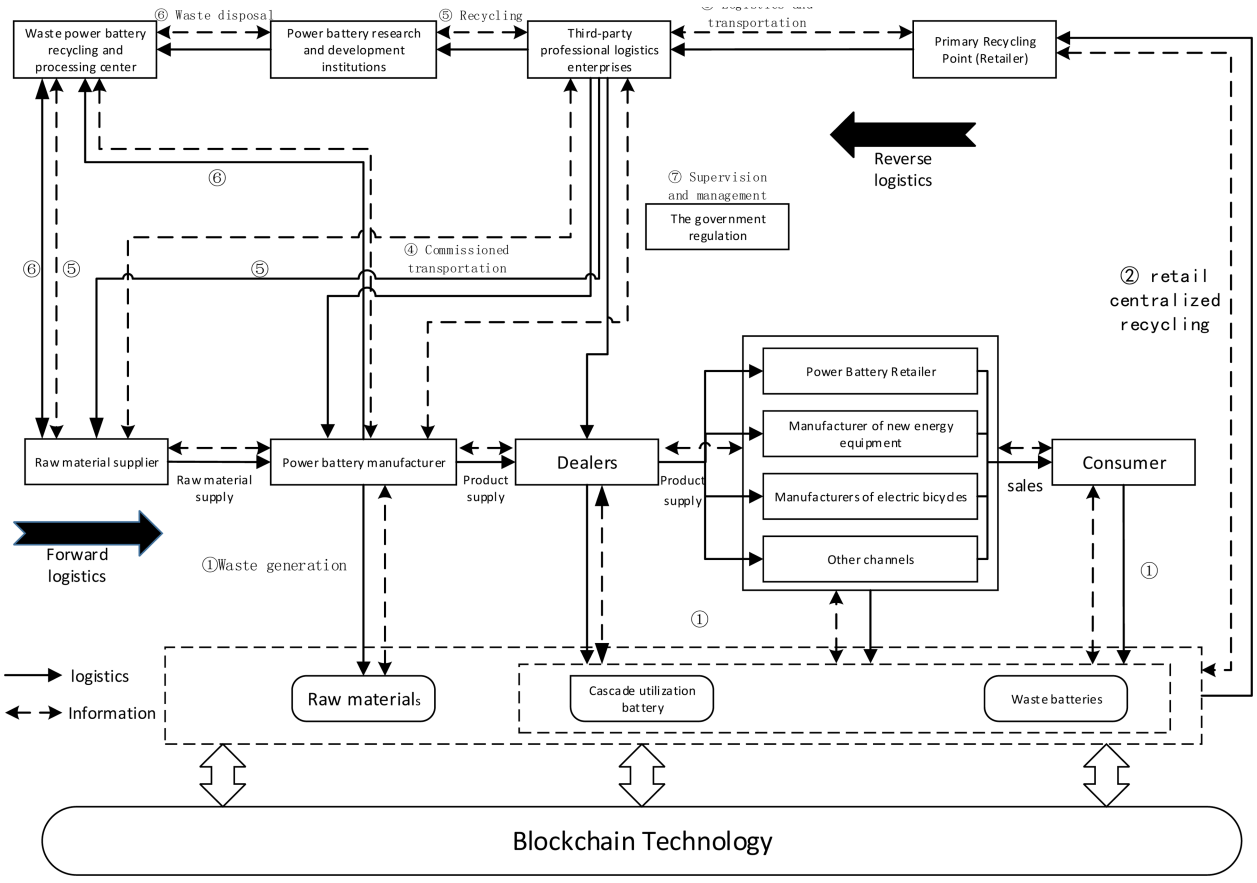

Fig. 4. Blockchain-Based Power Battery Closed-Loop Supply Chain Network Basic Structure Diagram

C. Advantage of the Closed-Loop Supply Chain for Power Batteries Adopting Blockchain

1) Decentralization, reducing the transaction levels of all links and improving supply chains' efficiency

The power battery closed-loop supply chain with blockchain has a decentralized network structure, implying that the data of the whole block is available to all the nodes in the chain, realizing a high degree of autonomy and improving the trust between the nodes. Meanwhile, each block has complete supply chain data, and each transaction will be recorded in each block. If a node has some problem, the remaining nodes can guarantee the integrity and real-time synchronization of data, allowing an increase in the supply chain's fault tolerance and a reduction in maintenance cost. Furthermore, it solves the inefficiency problem caused by the traditional supply chain's centralized autonomy.

2) Improves the reliability of the information in the supply chain and reduce regulatory costs

Every node in the blockchain can record the entire power battery data, and the trading and circulating information stays secure. The node data cannot be tampered with, and the possibility of forgery and destruction by power battery supply chain enterprises is almost nonexistent. Since it is impossible to inquire about power batteries or resell them through formal retailers, casual channel recycling can effectively reduce the cost of government regulation as it has quick investigation and punishment [12].

3) Increases trust between enterprises

The information of exchange is transparent, except that the two parties need their keys to decrypt. Every transaction is irreversible and supervised by all participants, significantly reducing the trust cost and transaction cost between enterprises in the supply chain.

4) Improves the security of supply chain transactions

The power battery closed-loop supply chain that adopts blockchain uses distributed bookkeeping to record all transactions. The use of digital signatures in blockchain ensures that the rights and responsibilities of transactions are transparent data is not manipulated. Besides, problems are found and traced quickly, and the algorithm of asymmetry in blockchain enables open collaboration in the supply chain. It ensures safety and trust in transactions between supply chain

enterprises and meets the actual needs.

5) Realizes the traceability management of the whole life cycle of effective power batteries

Consumers obtain power batteries primarily by purchasing new energy equipment. Blockchain-based power battery closed-loop supply chains are adopted, with information on power batteries related to forward and reverse supply chains available for consumers to identify the authenticity and source of batteries better and establish the trust between enterprises and consumers. The government's traceability of power batteries throughout their life cycle can improve regulatory efficiency, avoid enterprises' fraudulent subsidies, and regulate consumers' recycling behaviors.

VI. Conclusion

The design and adoption of a new management model of a blockchain-based power battery closed-loop supply chain can effectively solve the problems existing in the traditional power battery closed-loop supply chain.

Analyzing the status quo and problems of the traditional power battery closed-loop supply chain in China helps design a closed-loop power battery supply chain. Accordingly, the functional and managerial changes in the supply chain after adopting blockchain are analyzed. Compared to the traditional closed-loop supply network, the blockchain supply chain have characteristics of decentralization. It can reduce the transaction levels of each link and improve the efficiency of the supply chain along with the reliability of supply chain data. Furthermore, it increases the transparency in the supply chain and can trace the power battery source during the whole life cycle, reducing the cost advantage of government supervision and inspiring Chinese power battery supply chain enterprises.

The adoption of blockchain may effectively improve the operation efficiency of the power battery closed-loop supply chain and purify the power battery recycling market. A closed-loop power battery supply chain using blockchain technology can effectively store and track the information of power batteries and alleviate imperfect supply chains and information asymmetry [13].

This paper provides new inspiration and theoretical guidance for the supply chain management of power batteries in China. For the follow-up research, we want to make a more detailed division of the Closed-Loop Supply Chain Network Basic Structure framework: The number of participants and its corresponding relationship is defined by mathematics, and a mathematical model is established to analyze the power battery supply chain, and then the recycle price, recycle rate, recycle amount, income and other related values are further analyzed by mathematics.

Observation of supply chain parameters before and after blockchain adoption is done by considering more complex supply chain networks, three-level supply chains with distributors, and the participation of multiple retailers and manufacturers. A more complex dynamic model is established by applying the derived mathematical model and using system dynamics to solve the complex mathematical model.

This paper introduces blockchain into supply chain management for achieving recycling of power battery closed-loop supply chain, which enriches the content of supply chain management. It has crucial theoretical and practical implications in the development of the power battery supply chain.

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