

Blockchain in the Power Battery Supply Chain: Reshaping the Future of Energy Storage

Yue Wang

School of Economics and Management, Chongqing Jiaotong University, Chongqing 400000, China

Abstract: Against the backdrop of the global pursuit of energy transformation and the commitment to achieving carbon neutrality, the new energy industry has ushered in unprecedented development opportunities. Among them, electric vehicles, with their advantages of low emissions and high efficiency, have become a key force in the green transformation of the transportation sector. This paper mainly discusses the issue of blockchain enabling power battery supply chain, focuses on the application of technology in each link of power battery supply chain, introduces 2 successful cases, and gets some management enlightenment.

Keywords: Power Battery Supply Chain; Blockchain Technology; Application Cases.

1. Introduction

Against the backdrop of the global pursuit of energy transformation and the commitment to achieving carbon neutrality, the new energy industry has ushered in unprecedented development opportunities[1]. Among them, electric vehicles, with their advantages of low emissions and high efficiency, have become a key force in the green transformation of the transportation sector. According to the International Energy Agency (IEA), the global stock of electric vehicles has surged from less than 1 million a decade ago to over 130 million today, and is expected to exceed 500 million by 2030. As the "heart" of electric vehicles, the market demand for power batteries has also witnessed explosive growth. However, the traditional power battery supply chain system has many drawbacks. In the raw material procurement link, due to the involvement of various rare metals with extensive and complex sources, it is difficult to effectively integrate and track information, leading to frequent risks of supply disruptions and uncertainties in price fluctuations. For example, cobalt, a key raw material for power batteries, is mainly produced in some regions of Africa[2]. Geopolitical instability and too many intermediate links in the supply chain make the raw material supply information ambiguous, and it is difficult for car manufacturers to accurately control costs and supply stability. During the manufacturing stage, the lack of an efficient information - sharing mechanism between different production links leads to a disconnection between production plans and actual output, frequent occurrences of inventory backlogs or shortages, and seriously affects production efficiency and cost control. In the logistics and transportation process, due to the lack of real - time monitoring and information sharing, it is difficult to accurately grasp the cargo transportation status, increasing the risks of cargo damage and loss, and also resulting in high transportation costs. In the sales and recycling links[3] [4], consumers have insufficient trust in the quality and origin of batteries, and the recycling channels are scattered and irregular, resulting in the battery recycling rate being far lower than expected. These problems have seriously restricted the healthy development of the power battery industry and urgently require innovative solutions. The emergence of blockchain technology provides a new opportunity to break

through the dilemma of the power battery supply chain. Its characteristics of decentralization, immutability, and traceability can effectively solve problems such as information asymmetry and lack of trust[5], and provide solid technical support for the collaborative operation of all links in the supply chain.

To better understand and solve problems, this paper aims to explore the application of blockchain technology in the power battery supply chain. The main research issues in this paper are: 1. How can blockchain technology be specifically applied to various links of the power battery supply chain? 2. Successful cases and experiences in the application of blockchain technology in the power battery supply chain. 3. How to address the challenges faced in the application of blockchain technology in the power battery supply chain to achieve its maximum value? By optimizing the supply chain process, improving information transparency and security, and enhancing trust among various participants, it can reduce costs and enhance the efficiency and competitiveness of the entire supply chain. This not only contributes to the sustainable development of the electric vehicle industry but also provides reference for supply chain management in other industries.

2. Applications of Blockchain in the Power Battery Supply Chain

2.1. Structure and Key Links of the Power Battery Supply Chain

The power battery supply chain is a complex ecosystem, covering the entire process from upstream raw material mining, to mid - stream battery manufacturing, and then to downstream electric vehicle manufacturing and battery recycling. As shown in Figure 1, the upstream mainly involves the mining and supply of key raw materials such as lithium, cobalt, and nickel. The quality and supply stability of these raw materials directly affect battery performance and cost. The mid - stream is the battery manufacturing process, including cell manufacturing, battery module assembly, and the development of battery management systems, which requires a high level of technology and craftsmanship. The downstream focuses on the production and sales of electric vehicles, as well as the recycling and reuse of batteries at the

end of their service life, which is crucial for resource recycling and environmental protection. Key links include raw material procurement to ensure a stable and high - quality raw material supply; manufacturing to guarantee high -

performance and consistent batteries; logistics and transportation to ensure the safe and timely delivery of products; and battery recycling to achieve sustainable resource utilization.

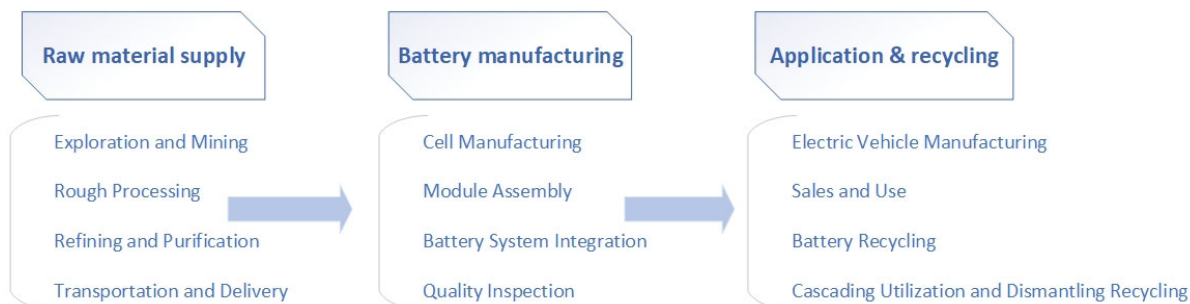


Figure 1. Power battery supply chain flowchart

2.2. Characteristics of Blockchain Technology

Blockchain technology is essentially a distributed ledger that records and validates transactions through a decentralized network of nodes. Its principle is based on cryptographic algorithms. Each transaction is packaged into a block, and blocks are linked in a chain in chronological order, forming an immutable transaction record. Blockchain has characteristics such as decentralization, immutability, traceability, and a consensus mechanism. Decentralization means there is no single control center[6], and all nodes jointly maintain the ledger; immutability ensures the authenticity and integrity of data, making it difficult to be tampered with once recorded; traceability enables any transaction to be traced back to its source; and the consensus

mechanism ensures that nodes reach a consistent recognition of transactions. Common blockchain platforms include Ethereum, which supports smart contracts and provides a rich application development environment for developers; Hyperledger, which focuses on enterprise - level applications and offers highly customizable blockchain solutions; and EOS, which is attracting attention for its high - efficiency processing capabilities and low transaction costs.

2.3. Applications of Blockchain in the Power Battery Supply Chain

As shown in Figure 2, the application of blockchain in the power battery supply chain is roughly divided into four stages, each stage can be subdivided into more subsections.

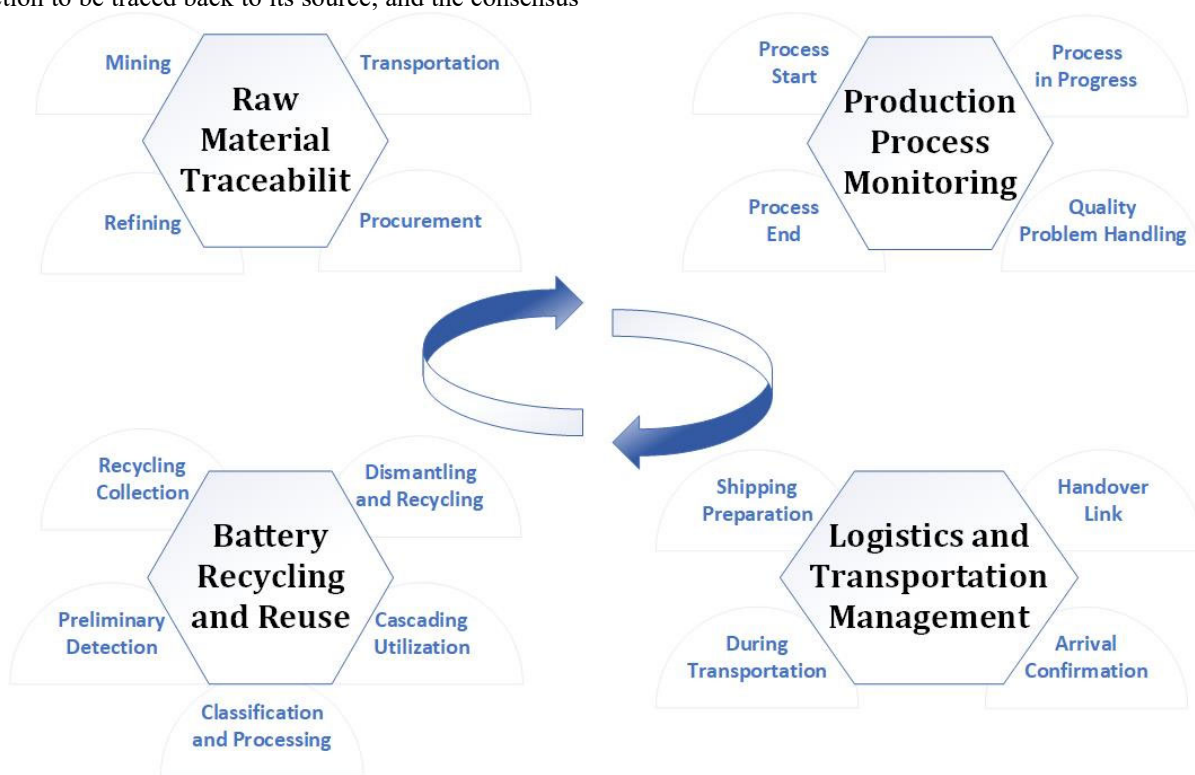


Figure 2. The application of blockchain technology in the power battery supply chain

2.3.1. Raw Material Traceability

In the supply of power battery raw materials, the origin and quality of key raw materials such as lithium and cobalt are of vital importance. Taking cobalt ore as an example, through blockchain technology, starting from the information recording of the cobalt ore mining site, such as the mining

area location, mining license number, mining time, etc., to the logistics information during the transportation process, including the transportation company, transportation route, batch number, etc., and then to the processing data of the refinery, such as purity inspection reports, processing technology, etc., all are recorded on the blockchain one by one.

For example, a well - known battery enterprise cooperated with a cobalt ore supplier to build a blockchain traceability system[7]. When purchasing cobalt raw materials, it can easily query the source of each batch of cobalt ore through the blockchain, confirm whether it comes from a compliant mining area, and effectively avoid the supply chain risks and social responsibility issues that may be brought about by using cobalt ore of unknown origin. This not only ensures the quality of raw materials but also enhances the corporate social responsibility and improves the brand image.

2.3.2. Production Process Monitoring

During the battery production process, the parameters and quality data of each process have an impact on the final product quality. Taking the cell manufacturing process as an example, blockchain can record in real - time the thickness of the electrode coating, the proportion of slurry components, the winding process parameters, etc., as well as the operator, equipment number, and operation time. Once quality problems such as rapid capacity attenuation or short - circuit occur in the cells, through the blockchain traceability system, it is possible to quickly locate the specific parameter anomalies and responsible persons in the production process. For example, after a battery production enterprise introduced a blockchain monitoring system, when a batch of cells did not meet the capacity standards, the blockchain records quickly identified that the parameter deviation of a certain coating equipment during a specific period was the cause. The equipment parameters were adjusted in a timely manner, and the relevant responsible persons were trained, avoiding the production of more defective products and effectively improving production efficiency and product quality.

2.3.3. Logistics and Transportation Management

During the transportation of power batteries from the production factory to the vehicle factory, blockchain technology can be used to monitor the cargo status in real - time. For example, by installing sensors on transportation vehicles and connecting them to the blockchain platform, the vehicle's driving route, speed, stop - over points, environmental parameters such as temperature and humidity are all recorded on the blockchain in real - time. An electric vehicle manufacturer cooperated with a logistics supplier to adopt a blockchain - based logistics management system. During a battery transportation, the system detected an abnormal increase in vehicle temperature. Logistics personnel and the battery production enterprise obtained the information in a timely manner through the blockchain platform and quickly took measures to avoid damage to the batteries due to high temperatures, ensuring the safe and punctual delivery of the goods and reducing the risk of production delays caused by logistics problems[8].

2.3.4. Battery Recycling and Reuse

When the power battery reaches the end of its service life in an electric vehicle, recycling and reuse become key links[9]. Through blockchain, the battery's usage history, including the number of charge - discharge cycles, remaining capacity, usage environment, etc., as well as recycling channel information, such as the qualifications of recycling enterprises, recycling processes, storage conditions, etc., are recorded. For example, a battery recycling enterprise uses blockchain technology to track the recycled batteries throughout the process. Based on the battery usage history recorded on the blockchain, it accurately assesses the remaining value of the batteries and reasonably allocates

batteries in different states to different reuse channels, such as cascading utilization in energy storage power stations or dismantling and recycling metals. This not only improves the recycling efficiency but also realizes the maximized utilization of resources and reduces environmental pollution.

3. Case Study Analysis

This article focuses on case studies from two companies, Tesla and BMW, to illustrate how blockchain technology has brought significant benefits.

3.1. Successful Application Cases

Tesla has collaborated with major raw material suppliers of lithium, cobalt, etc. to build a blockchain - based traceability platform. Through this platform, Tesla can track the entire process of raw materials from mining to battery production in real - time. For example, in lithium ore procurement, Tesla can obtain detailed data such as the mining location, mining time, transportation trajectory of lithium ore, and the purity inspection report of each batch of lithium ore. Before the introduction of blockchain technology, the acquisition of raw material supply chain information was delayed and its accuracy was difficult to guarantee. It took an average of 3 - 5 days to obtain complete raw material batch information. After the application of blockchain technology, the information acquisition time has been shortened to real - time, greatly improving the transparency and response speed of the supply chain. In its battery production plants, Tesla uses blockchain technology to record the detailed parameters of each battery production process. During the cell manufacturing process, key parameters such as electrode coating thickness and winding speed are recorded on the blockchain in real - time. Once there are battery quality problems, through the blockchain's traceability function, the specific production process and equipment can be located within a few minutes, and the root cause of the problem can be accurately identified. According to statistics, after the introduction of blockchain monitoring, the battery defective rate has decreased from 5% to 2%, effectively improving production efficiency and product quality. Tesla has established a blockchain - driven battery recycling system that records the usage history and remaining capacity of recycled batteries. These data help Tesla allocate recycled batteries reasonably to different reuse scenarios, such as energy storage systems or metal recycling through dismantling. Through this system, Tesla's battery recycling rate has reached over 95%, significantly improving resource utilization and reducing the impact on the environment.

BMW has jointly constructed a blockchain network with multiple raw material suppliers to ensure the sustainability and compliance of raw material sources. Taking cobalt ore as an example, through blockchain, BMW can clearly understand the origin, mining method of each batch of cobalt ore, and whether it meets environmental protection and social responsibility standards. During the procurement decision - making process, this information provides strong support for BMW, enabling it to give priority to suppliers that meet the company's sustainable development concept. Through blockchain technology, BMW's due - diligence investigation time for raw materials has been shortened from several weeks to a few days, improving procurement efficiency. During the transportation of power batteries, BMW uses blockchain technology to monitor the cargo status in real - time. By installing sensors on transportation vehicles and connecting

them to the blockchain platform, BMW can obtain real - time information such as the vehicle's driving route, temperature, and humidity. Once during transportation, the sensors detected an abnormal increase in the temperature inside the carriage, and the blockchain platform immediately issued an alarm. The logistics team took timely measures to avoid damage to the batteries due to high temperatures and ensured the safe delivery of the goods. This application has effectively reduced logistics risks, and the logistics accident rate has decreased by 30%.

Table 1. Specific indicators of success cases

Company	Indicator	Before Application	After Application
Tesla	Raw Material Traceability Information Acquisition Time	3 - 5 days	Real - time
	Battery Defective Rate	5%	2%
	Battery Recycling Rate	/	Over 95%
BMW	Raw Material Due Diligence Investigation Time	Several weeks	A few days
	Logistics Accident Incidence Rate	/	Decreased by 30%

3.2. Case Experience Summary and Enlightenment

It is not difficult to draw some lessons from success stories:

1. Technology Integration is Key. Successful cases show that the deep integration of blockchain technology with the Internet of Things, big data, and other technologies can achieve more efficient supply chain management. For example, in production process monitoring and logistics transportation management, data is collected through Internet of Things sensors, and blockchain is used to ensure the authenticity and immutability of the data. Combined with big data analysis technology, more accurate decision - making support can be provided for enterprises.
2. Win - Win Cooperation is the Foundation[10]. Enterprises need to cooperate closely with upstream and downstream partners in the supply chain to jointly build a blockchain ecosystem. Whether it is raw material suppliers, production enterprises, or logistics service providers, the active participation and data sharing of all parties are the prerequisite for the blockchain technology to play its role. Only by establishing a mutually - trusting and mutually - beneficial cooperative relationship can the coordinated development of the supply chain be achieved.
3. Data Security and Privacy Protection Need to be Emphasized. With the wide application of blockchain technology in the supply chain, data security and privacy protection have become crucial. Enterprises need to adopt effective encryption technologies and access control measures to ensure the security of data during transmission and storage, and at the same time protect the business secrets and privacy information of all parties.

4. Conclusion

This paper deeply explores the application of blockchain technology in the power battery supply chain. Firstly, it clarifies the complex structure and key links of the power battery supply chain, and reveals the problems faced by the traditional supply chain, such as information opacity, lack of

trust, and cumbersome processes. Secondly, it elaborates on the principles, characteristics, and common platforms of blockchain technology, demonstrating the potential of blockchain technology to solve supply chain problems. Furthermore, through the analysis of specific application scenarios, such as raw material traceability, production process monitoring, logistics and transportation management, and battery recycling and reuse, it shows how blockchain technology optimizes the supply chain process, improves information transparency and security, enhances trust among various participants, thereby reducing costs and enhancing the efficiency and competitiveness of the entire supply chain. Finally, through the analysis of successful cases such as Tesla and BMW, the feasibility and effectiveness of the application of blockchain technology in the power battery supply chain are verified.

Although blockchain technology is constantly evolving, its current processing speed and scalability still need to be improved, and the application of blockchain in the power battery supply chain lacks unified standards and specifications, and liability definition currently lack clear laws and regulations to regulate and guarantee. It is believed that in the future, with the continuous development of technology, the performance of blockchain will continue to improve, industry associations and relevant institutions will strengthen cooperation, formulate unified blockchain application standards and norms, promote the interconnection and data sharing between different enterprises and platforms, and even blockchain technology will be further integrated with emerging technologies such as the Internet of Things, artificial intelligence, and big data. Form a more intelligent and efficient supply chain management system.

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