International Journal of Energy
ISSN: 2957-9473 | Vol. 8, No. 2, 2025

Research on Matrix Analysis and Selection Strategy of Power Battery Recycling Modes

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Abstract: The rapid growth in the number of new energy vehicles has led to a sharp increase in the volume of waste power batteries, and power battery recycling modes drive the development of the power battery recycling industry. Based on a brief introduction to power battery recycling modes, this paper uses the matrix analysis method from the two dimensions of policy and technology to discuss four mainstream power battery recycling modes. Finally, it puts forward corresponding optimization suggestions from the aspects of technology, policy and the selection of waste power battery recycling modes.

Keywords: Power Battery; Recycling Mode; Matrix Analysis.

1. Introduction

With the advancement of technology and the enhancement of people's environmental awareness, electric vehicles have become an increasingly popular means of transportation. According to statistics, by the end of 2024, the number of new energy vehicles in China had reached 31.4 million, and the installed capacity of power batteries has been leading the world for many years [1]. With the rapid growth of the ownership of new energy vehicles, the problem of recycling waste power batteries has become increasingly prominent. According to industry estimates, the decommissioning volume of waste power batteries in China will reach about 2.3 million tons by 2030 [2]. However, a survey by the Development Research Center of the State Council found that as of 2023, the standardized recycling rate of power batteries for new energy vehicles in China was less than 25%, far lower than 95% in the EU and 85% in Japan [3]. Waste power batteries contain a large amount of metal resources such as nickel, cobalt and lithium. Improper disposal will not only cause resource waste, but also trigger environmental pollution and potential safety hazards.

2. Literature Review

The rapid development of new energy vehicles has attracted numerous scholars' attention to power battery recycling behavior. Existing research on power battery recycling mainly focuses on recycling modes, recycling networks and supply chain profits. It mainly builds and optimizes the reverse logistics network and Closed-loop Supply Chain of waste power batteries by establishing mathematical models and considering different influencing factors, so as to provide decision-making basis for reducing the recycling cost and increasing profits of waste power batteries[4][5]. The power battery recycling mode affects the recycling network, and the recycling network affects the recycling efficiency, so it is necessary to pay more attention to the power battery recycling mode. Existing waste power battery recycling modes mainly include four types: automobile manufacturer-led mode, third-party enterprise recycling mode, battery manufacturer-led mode and industrial alliance mode[6]. The research on waste power battery recycling modes, which focuses on the profit analysis at the micro level and the description of each link in the industrial chain, lacks a macro and systematic framework to compare and analyze the applicable conditions and evolution paths of different recycling modes. The matrix analysis method provides a visual tool for complex decision-making through the logic of "dimension extraction - mode classification - strategy matching". In the research on the selection of the last-mile distribution mode of fresh e-commerce, some scholars constructed a matrix based on the level of distribution capacity and distribution strategy by using the matrix analysis model, providing a basis for the selection of the last-mile distribution mode of fresh e-commerce [7]. In view of this, this paper studies the recycling modes of waste power batteries through matrix analysis, providing a reference for the recycling of waste power batteries.

3. Power Battery Recycling Modes

The power battery recycling market has responded positively to the increasing number of waste power batteries, forming a variety of power battery recycling modes. Different recycling modes have different characteristics and adapt to the power battery recycling market in different ways.

(1) Battery Manufacturer-led Mode

The waste power battery recycling mode led by battery manufacturers refers to the mode in which battery manufacturers take the lead in recycling power batteries, and other participating entities assist battery manufacturers in recycling, which is a typical "Extended Producer Responsibility (EPR)" recycling mode. The main participating entities in this recycling mode include battery manufacturers, automobile manufacturers, automobile retailers and third-party recyclers.

After producing batteries, battery manufacturers sell them to new energy vehicle manufacturers or other customers who use batteries. New energy vehicle manufacturers equip the batteries on vehicles and sell the vehicles equipped with power batteries to consumers through automobile retailers. When these batteries are decommissioned, as the core recycling subject, battery manufacturers, on the one hand, directly recycle power batteries from the consumer market through self-built recycling networks, and use their own technical advantages to test and classify the recycled power batteries. Waste power batteries that meet the echelon utilization standards are disassembled and reorganized to

enable them to be safely and reliably applied to other fields. Waste power batteries that do not meet the echelon utilization standards are disassembled, crushed, screened and extracted to recover metals such as nickel, cobalt and lithium, realizing the recycling of resources. On the other hand, battery manufacturers cooperate with automobile manufacturers, automobile retailers and third-party recyclers to indirectly recycle power batteries from the consumer market. New energy vehicle manufacturers use their own sales channels to provide channels for waste power recycling for battery manufacturers, and provide battery usage information and decommissioning status. Third-party recyclers exist as affiliated enterprises of battery manufacturers, giving play to their original channel advantages as third parties, taking the initiative to recycle waste power batteries, and carrying out subsequent operations on the recycled batteries in accordance with the requirements of battery manufacturers (as shown in Figure 1). Representative enterprises such as CATL (Contemporary Amperex Technology Co., Limited) have laid out recycling networks by holding shares in Bangpu Recycling, covering 15 recycling outlets nationwide, forming a closed-loop production system of cathode materials.

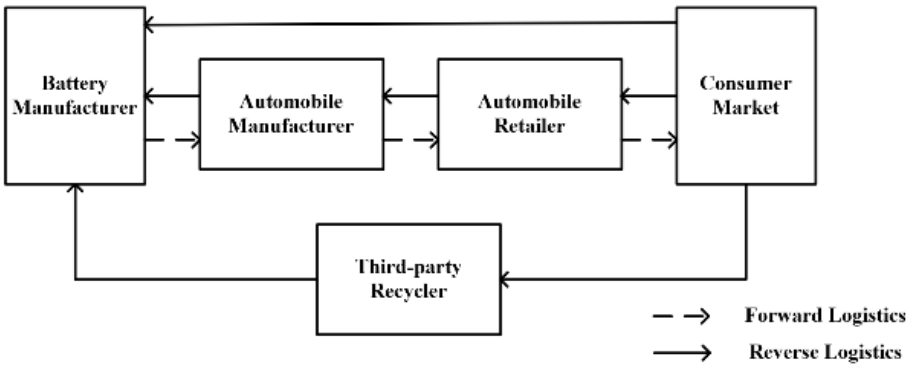

Figure 1. Battery Manufacturer-led Mode

The core competitiveness of this mode is highly dependent on the technical barriers and supply chain integration capabilities of battery manufacturers themselves. Relying on their in-depth understanding of battery material composition and production processes, as well as core patented technologies, battery manufacturers can realize the detection, disassembly and reuse of recycled waste power batteries. Their dependence on external policy environments such as government subsidies and mandatory recycling regulations is relatively low. Even in the stage where the policy system is not yet perfect or the subsidy intensity is weak, they can drive the layout and development of their own recycling networks by virtue of technological advantages and closed-loop economy. Due to its position at the source of the Closed-loop Supply Chain of power batteries, it inherently has the advantage of communicating and coordinating with various entities in the closed loop, thus obtaining timely and accurate battery information.

(2) Automobile Manufacturer-led Mode

The power battery recycling mode led by automobile manufacturers is a business model in which automobile manufacturers take the core position and use their extensive sales networks and after-sales service systems to recycle power batteries. The main participating entities in this recycling mode include battery manufacturers, automobile manufacturers and automobile retailers. Among them, automobile manufacturers assume the main responsibility for recycling waste power batteries, are responsible for establishing power battery recycling channels, and improve the recycling rate through various methods such as repurchase, trade-in and subsidies. Automobile manufacturers establish cooperative relations with channels such as 4S stores and auto repair shops, and use existing logistics systems such as 4S stores and after-sales service networks to transport waste batteries back to recycling centers in a reverse manner. After recycling, automobile manufacturers evaluate and test the waste power batteries and then decide to sell them to battery manufacturers or energy storage markets for echelon utilization and recycling (as shown in Figure 2). Battery manufacturers cooperate with automobile manufacturers, provide relevant technical information and support for batteries, and assist automobile manufacturers in battery recycling and treatment; this mode has significant channel advantages, because automobile manufacturers can efficiently collect waste power batteries through existing channels such as 4S stores, auto repair shops and end-of-life vehicle dismantling enterprises. For example, SAIC Motor Group has established an extensive recycling network through its 4S stores and after-sales service points to efficiently recycle waste power batteries.

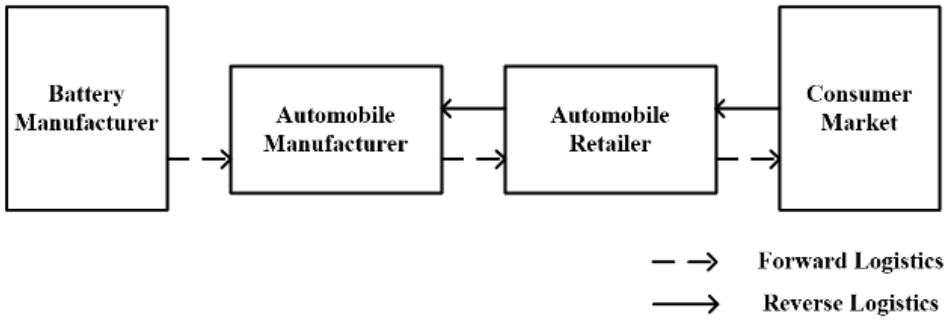

Figure 2. Automobile Manufacturer-led Mode

The core advantage of this mode lies in the breadth and speed of channel coverage, and its development is highly dependent on strong policy environment support, while its own technical capabilities are relatively weak. On the one hand, the core competence of automobile manufacturers lies in whole vehicle manufacturing and sales, and they lack core technologies and professional equipment for in-depth treatment of power batteries. Most of the recycled waste batteries need to be outsourced to professional battery manufacturers or third parties for processing, and automobile manufacturers themselves are mainly engaged in collection, transportation and preliminary screening. Their technical control over the back-end dismantling and recycling links is weak, and the recovery rate and economy of recycled materials are often subject to outsourcing parties. On the other hand, the initial investment in the construction of large-scale recycling networks is huge, the operation cost is high, and the recycling economy is often insufficient in the early market environment, which is highly dependent on government subsidies. Regulatory compulsions are the direct driving force for its large-scale layout of recycling systems, and the intensity of policy support has a great impact on the living space and development scale of this mode.

(3) Third-party Enterprise Recycling Mode

The third-party enterprise recycling mode refers to the mode in which third-party enterprises independent of the battery production and use links and specialized in the collection, transportation, treatment and reuse of waste power batteries carry out recycling. Due to the low threshold of the battery recycling industry and fierce market competition, third-party recycling enterprises are divided into two categories according to their professionalism: one is professional third-party recycling enterprises such as GEM (Greenerity Co., Ltd.); the other is non-professional third-party recycling, such as recycling by informal small workshops.

1) Professional Third-party Recycling Mode

Professional third-party recycling enterprises refer to specialized institutions independent of the battery production, sales and use links, which are engaged in the recycling, testing, dismantling, material recycling and echelon utilization of waste power batteries. Such enterprises usually have professional technical teams and advanced equipment, and can accurately evaluate and classify waste power batteries.

The main participating entities in the professional third-party recycling mode include third-party recyclers, battery manufacturers, automobile manufacturers and automobile retailers. Third-party recycling enterprises are the leading entities in the operation of this mode, undertaking the core responsibility of power battery recycling, including comprehensively collecting waste power batteries through recycling networks and scientifically testing, dismantling, repairing or carrying out echelon utilization and resource recycling on recycled waste batteries through advanced treatment facilities and technologies; battery manufacturers are responsible for reselling a part of waste power batteries that are difficult to handle through their own channels to professional third-party recyclers for treatment; automobile manufacturers and automobile retailers are responsible for reversely recycling waste power batteries through their own forward sales channels and reselling them to third-party recycling enterprises to fulfill the Extended Producer Responsibility (EPR).

In terms of operation mode, as the core enterprise in the industrial chain, third-party recyclers, on the one hand, directly recycle waste power batteries in the consumer market through self-built recycling outlets and channels. On the other hand, they obtain sources of waste power batteries by establishing cooperative relations with new energy vehicle manufacturers, battery manufacturers and other parties (as shown in Figure 3). Existing professional third-party recycling enterprises such as Tinchy Co., Ltd. have built an "Internet + recycling" platform, with service networks covering the whole country.

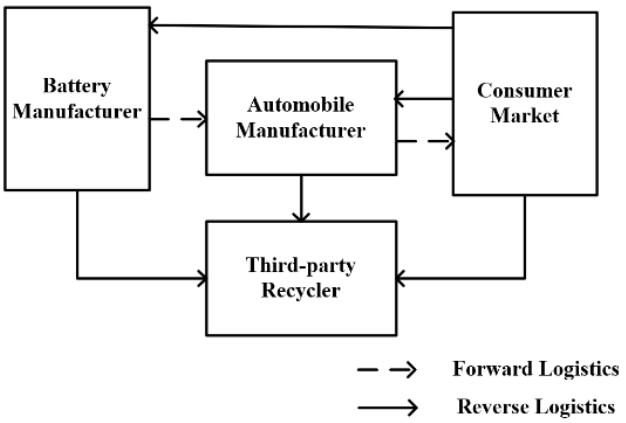

Figure 3. Professional Third-party Recycling Mode

This mode adapts to the scattered waste power battery recycling market with its flexibility and multi-brand compatibility, and its development requires clear policy clarity, and the mastery of core technologies is the foundation of its survival. In terms of technology, the core competitiveness of professional third-party enterprises lies in their mastery of core technologies and large-scale processing capabilities for power battery dismantling, testing, echelon utilization and recycling. Technology is the key for them to gain market share, ensure processing compliance and economy. However, compared with leading battery manufacturers with core material patents, their technical barriers are usually lower. In terms of policy dependence, the standardized, orderly and large-scale development of this mode urgently needs the support of a clear and stable policy environment. The "white list" system, treatment qualification requirements, provisions of environmental protection laws and regulations, market access conditions, etc., will all have a huge impact on it.

2) Non-professional Third-party Recycling Mode

Non-professional third-party recycling enterprises for waste power batteries refer to entities independent of the battery production, sales and use links, which do not have professional qualifications, technical capabilities and standardized processes, and engage in irregular recycling and treatment of waste power batteries for short-term interests. Such entities usually lack systematic environmental protection measures and safety management, and obtain benefits through low-cost irregular dismantling.

The non-professional third-party recycling mode is characterized by extensive and non-standard processes for recycling and treating waste power batteries. The participating entities of this mode show the characteristics of "scattered, small and miscellaneous", mainly including mobile recycling vendors, illegal waste recycling enterprises,

family workshops and illegal dismantling enterprises. Mobile recycling vendors and illegal waste recycling enterprises recover waste power batteries from the consumer market at a price slightly higher than that of compliant power battery recycling enterprises, and sell them to family workshops and illegal dismantling enterprises to obtain operating income. Family workshops and illegal dismantling enterprises carry out simple dismantling of waste power batteries for maximum profit and sell the obtained rare metals to make profits (as shown in Figure 4). Due to the low cost of non-professional recycling and dismantling and high recycling prices, the non-professional third-party recycling mode has been formed and accounted for a large proportion in the early stage of the power battery recycling market.

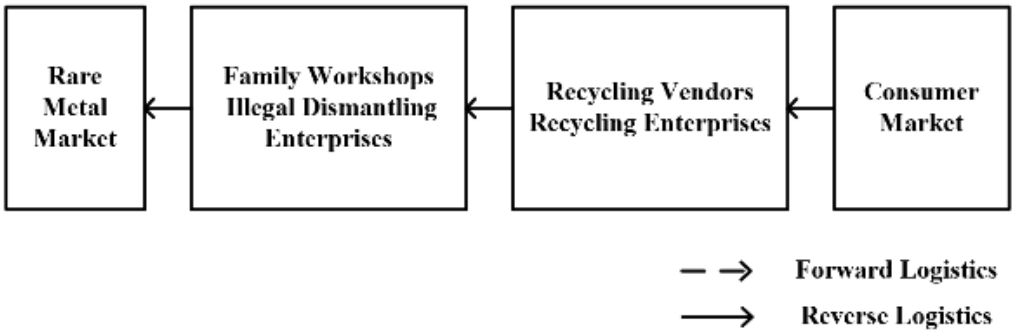

Figure 4. Non-professional Third-party Recycling Mode

(4) Industrial Alliance Mode

The industrial alliance mode for power battery recycling is a business model that integrates resources of various entities such as power battery manufacturers, new energy vehicle manufacturers and third-party recycling enterprises to jointly build a full-life-cycle management and recycling system for power batteries. This mode gives full play to the advantages of all participating parties, realizing the closed-loop management of the whole industrial chain from battery production to use, recycling, echelon utilization and recycling.

Under the industrial alliance mode, the industrial alliance is responsible for formulating norms and standards for power battery recycling and utilization within the alliance, coordinating resources of all parties, promoting the construction of recycling and utilization systems, organizing member enterprises to carry out technical research and development, project cooperation and other activities, and improving the overall competitiveness of the alliance in the field of power battery recycling and utilization. New energy vehicle manufacturers rely on their extensive sales networks and after-sales service systems to layout recycling stations at the front end of recycling, collect and initially screen waste power batteries; power battery manufacturers use their technical advantages and in-depth understanding of battery performance to provide professional technical support and recycling guidance, and recover a part of waste power batteries through their own channels; third-party recycling enterprises focus on the dismantling, recycling and reuse of waste batteries, realizing the efficient recovery and resource utilization of battery materials through professional technologies and equipment (as shown in Figure 5). The industrial alliance mode realizes the full-life-cycle management of power batteries and improves the efficiency of recycling and utilization through information sharing, technical R&D cooperation and resource integration.

Existing industrial alliances such as the Hubei Provincial Industrial Alliance for Recycling and Utilization of Power Batteries of New Energy Vehicles are jointly composed of many members including new energy vehicle manufacturers (Dongfeng Motor Group, etc.), battery manufacturers (Camel Group, etc.), battery recycling and utilization enterprises (GEM (Wuhan) New Energy Vehicle Service Co., Ltd., etc.), scientific research institutions and universities (Wuhan University of Technology, etc.) and relevant industry associations. It has built a Closed-loop Supply Chain of "battery production - automobile enterprise recycling - classification treatment - echelon utilization/raw material recycling - return to production". All participating entities are accurately connected under the alliance framework to complete the full-life-cycle management of waste power batteries.

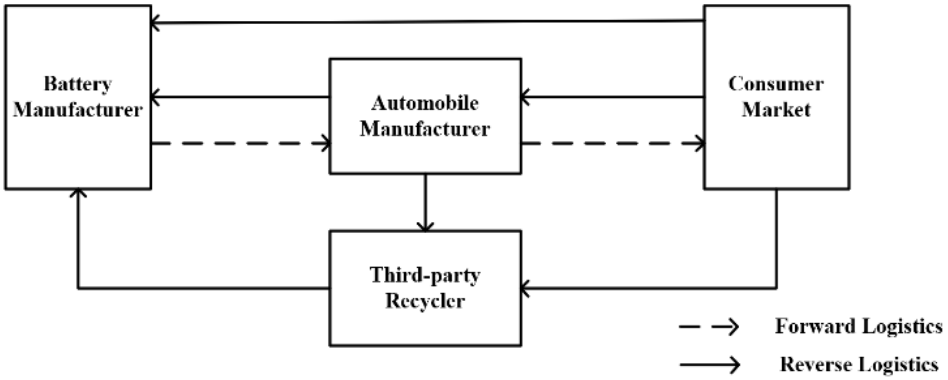

Figure 5. Industrial Alliance Mode

This mode aims to integrate resources of the whole industrial chain, and its successful operation is highly dependent on a strong policy framework as the basis for cooperation, and it is necessary to promote cross-entity

technical coordination and standardization. The technology in the alliance mode does not refer to the technological monopoly of a single member, but is reflected in the shared technical standards, co-constructed technical platforms and collaborative innovation capabilities formed under the promotion of the alliance. For example, jointly researching and promoting standardized dismantling processes, establishing a unified blockchain traceability platform, sharing testing and evaluation methods, etc. The formation, maintenance and effective operation of the alliance fundamentally depend on the strong policy guidance, regulatory constraints and resource coordination of the government, so as to realize the efficient operation of the alliance.

4. Construction of Matrix for Power Battery Recycling

Based on the in-depth analysis of the four mainstream power battery recycling modes mentioned above, it can be clearly observed that different modes have systematic differences in their dependence on the external policy environment and their mastery of core technologies and processes during effective operation and sustainable development. These two dimensions profoundly affect the advantages, disadvantages, applicable conditions and evolution potential of different waste power battery recycling modes. Based on this, this paper constructs an analysis matrix from the two dimensions of "policy dominance" and "technology dominance" (as shown in Figure 6). Policy dominance refers to the degree of dependence of the development, promotion and effective operation of the recycling mode on government policies such as regulatory mandates, subsidy incentives and access lists. The higher the degree of dependence, the stronger the policy dominance. Technology dominance refers to the degree of dependence or mastery of the effective operation and competitiveness improvement of the recycling mode on core patented technologies, advanced dismantling and recycling technologies. The higher the technical barriers and the stronger the independent control, the stronger the technology dominance.

Based on these two dimensions, the existing mainstream power battery recycling modes are divided into different quadrants of the matrix, aiming to systematically reveal the core driving forces, inherent advantages and disadvantages of different modes, as well as their most suitable industrial development stages and market environments.

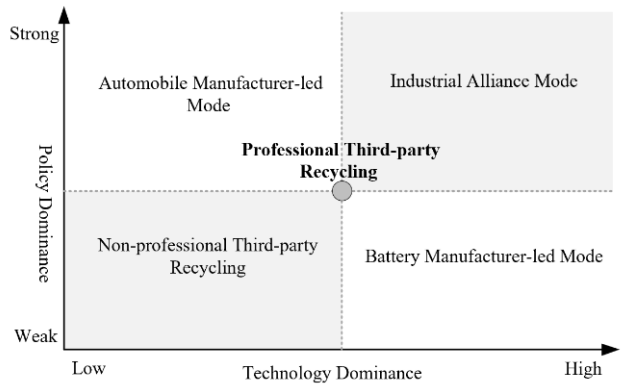

Figure 6. Policy-Technology Two-dimensional Matrix Analysis Chart

(1) Battery Manufacturer-led Mode

The battery manufacturer mode has developed rapidly in a weak policy environment by virtue of its high technical capabilities and strong patent barriers, showing significant technology-led characteristics. The battery manufacturer-led mode achieves high material recovery rate and self-supply of recycled resources through patent control, forming a cost competitive advantage in the Closed-loop Supply Chain. In addition, due to its position at the source of the Closed-loop Supply Chain of power batteries, it inherently has the advantage of communicating and coordinating with various entities in the closed loop, thus obtaining timely and accurate battery information. Its core risks lie in the possible attenuation of technical advantages due to the expiration of concentrated patents and the impact of raw material price fluctuations on recycling economy. Therefore, the battery manufacturer-led mode is more suitable for the middle and late stages of the development of the power battery recycling market. Through continuous technological R&D and renewal, it can expand the technical service market, thereby maintaining its advantages and achieving sustainable development.

(2) Automobile Manufacturer-led Mode

The automobile manufacturer mode quickly lays out recycling outlets based on its own forward channels. It does not have strong technicality, but has significant channel coverage advantages in the early stage of the market with high-intensity policy subsidies. Due to the lack of technical capabilities, most of its waste power battery dismantling relies on outsourcing, and the recovery of recycled materials is lower than the industry average. At the same time, the high dependence on policies has laid systematic risks for subsequent sustainable development. Therefore, the automobile manufacturer recycling mode is more suitable for the early and middle stages of the development of the power battery recycling market, i.e., the period of government subsidies.

(3) Third-party Recycling Mode

Third-party recycling modes can be divided into professional third-party recycling and non-professional third-party recycling according to the difference in professionalism, showing a significant division in the policy-technology matrix.

1) Professional Third-party Recycling Mode

The professional third-party recycling mode is in the quadrant of "medium policy dominance - medium technology dominance". Its core competitiveness lies in the market-oriented service network and multi-brand compatibility capabilities. Technology dominance is reflected in the possession of independently developed dismantling processes, material recycling technologies and intelligent recycling platforms, such as GEM's modular dismantling equipment, but the technical barriers are slightly lower than those of the battery manufacturer-led mode; policy dominance is manifested in the dependence on policy stability, but the degree of dependence is weaker than that of the automobile manufacturer-led mode and the industrial alliance mode. The advantage of this mode is that it can flexibly adapt to multi-brand battery recycling scenarios and reduce unit recycling costs through large-scale recycling; the disadvantage is that the cost of building its own channels is high, and the cross-enterprise data sharing capability is weaker than that of the industrial alliance mode. It is suitable for the middle stage of industry development - when the policy framework is initially

formed, the market decommissioning volume increases but a monopoly pattern has not been formed, it can rely on technological advantages to fill the gaps in the single manufacturer's network, and improve market voice by participating in policy formulation.

2) Non-professional Third-party Recycling Mode

The non-professional third-party recycling mode is in the quadrant of "weak policy dominance - weak technology dominance", and its core feature is to maintain a price advantage by evading environmental protection costs and low technical investment. It has no standardized testing and dismantling capabilities, relies on manual extensive processing, and its technology dominance is almost zero; it is outside the regulatory system and survives by illegal channels, with weak policy dominance. This mode occupied a certain share in the early stage of the market due to flexible recycling prices and extremely low thresholds, but it has serious environmental risks and resource waste. With the tightening of policies and the technological cost reduction of compliant power battery recycling enterprises, its living space will continue to be compressed and will eventually be replaced by professional modes.

(4) Industrial Alliance Mode

Driven by both strong policy constraints and high demand for high-tech sharing, the industrial alliance mode builds a collaborative system covering the full life cycle of batteries by integrating resources of automobile manufacturers, battery manufacturers and professional recyclers. Therefore, the realization of the alliance mode is inseparable from a strong policy framework as the basis for cooperation, and it is necessary to promote cross-entity technical coordination and standardization. The technology in the alliance mode does not refer to the technological monopoly of a single member, but is reflected in the shared technical standards, co-constructed technical platforms and collaborative innovation capabilities formed under the promotion of the alliance. For example, jointly researching and promoting standardized dismantling processes, establishing a unified blockchain traceability platform, sharing testing and evaluation methods, etc. The formation, maintenance and effective operation of the alliance fundamentally depend on the strong policy guidance, regulatory constraints and resource coordination of the government, so as to realize the efficient operation of the alliance.

The industrial alliance mode can evolve following a three-stage development path: the policy support stage - the government leads the establishment of a basic collaboration framework and a patent sharing compensation mechanism; the technology integration stage - focusing on breaking through standardized dismantling processes and the construction of blockchain traceability platforms; the mature operation stage - shifting to market-oriented autonomy and maintaining the sustainability of the alliance through economic leverage such as carbon quota trading.

5. Suggestions for Vehicle Power Battery Recycling

Through the above analysis, the core driving forces, inherent advantages and disadvantages, as well as the applicable conditions of the four mainstream recycling modes are clearer. Based on the analysis of the policy-technology two-dimensional matrix, combined with the current situation and development trend of China's power battery recycling market, the following optimization suggestions are put forward for the recycling of waste power batteries:

(1) Adapt to the Development Stage and Select Appropriate Recycling Modes

The selection of power battery recycling modes is not static, and should be closely aligned with the industry development stage.

In the early stage of industry development, the policy and regulatory system is initially established, mandatory recycling requirements and subsidy incentives are the main driving forces, the market decommissioning volume is limited and scattered, and professional technical capabilities are not yet popularized. At this time, the "automobile manufacturer-led mode" should be prioritized. Make full use of the extensive and mature sales networks of automobile manufacturers to quickly roll out recycling outlets and solve the core pain point of "inability to collect batteries".

With the gradual improvement of the policy framework, significant growth in decommissioned battery volume and continuous improvement of recycling technologies, the "professional third-party recycling mode" is the most dynamic and adaptable at this stage. Its flexible service network, multi-brand compatibility and continuously improving technical level can effectively fill the gaps in the single manufacturer's network and reduce unit recycling costs. At this stage, we should encourage the development of third-party recycling enterprises, and guide them to improve technical standardization and data sharing capabilities through policies. At the same time, the battery manufacturer-led mode, relying on its technical barriers and Closed-loop Supply Chain advantages, can serve as an important supplement for the recycling of self-owned brand batteries of leading battery manufacturers in this stage.

As the industry moves towards maturity in the future, the policy environment is highly mature and stable, the level of technical standardization and intelligence is significantly improved, large-scale decommissioning becomes the norm, the policy system is increasingly sound, the technical level is significantly improved, and the standardization level is continuously raised. We should actively promote the transformation to the "industrial alliance mode". By integrating resources of battery manufacturers, automobile factories, professional recyclers and other parties, gathering technical advantages, and building a collaborative management platform covering the full life cycle of batteries. On this platform, realize information sharing and responsibility sharing, form economies of scale, so as to achieve the goals of maximizing resource utilization and minimizing recycling costs. The battery manufacturer-led mode, relying on its technical advantages and supply chain integration capabilities, can also serve as an important supplementary mode in the later stage of the development of the power battery market.

(2) Strengthen Policy Guidance and Supervision to Build a Fair and Efficient Market Environment

The complexity of power battery recycling has led to disorder in the recycling market. Strengthening the supervision and policy guidance of the power battery recycling market is crucial for promoting the healthy development of the industry.

On the one hand, it is necessary to strengthen the supervision of the power battery recycling market, improve the laws and regulations on the recycling of waste power batteries, and make more clear legal norms for power battery

recycling enterprises and recycling outlets. Crack down on illegal recycling activities in accordance with the law, strengthen joint law enforcement by environmental protection, industry and information technology, market supervision and other departments, focus on cracking down on illegal collection and dismantling chains, compress the living space of the "non-professional third-party mode", and create a fair competitive market environment. At the same time, accelerate the establishment of a qualification certification system for power battery recycling enterprises and treatment facilities, and strengthen the qualification review of power battery recycling enterprises. Explore the promotion of Extended Producer Responsibility (EPR) legislation, clarify the responsibilities of power battery manufacturers, automobile manufacturers, consumers and recycling enterprises, and explore implementing the full-life-cycle management responsibility of relevant recycling entities for power batteries.

On the other hand, strengthen policy support for recycling outlets of compliant power battery recycling enterprises. The government should enhance the authority and influence of the "white list" system, and link it with government financial subsidies, tax incentives, project bidding and tendering, battery production access and new energy vehicle promotion catalogs. Enterprises included in the "white list" can enjoy government subsidies, tax preferential policies, participate in government project bidding and tendering, and even obtain battery production licenses and new energy vehicle promotion qualifications, thus forming an effective market screening and incentive mechanism. At the same time, increase the support for compliant power battery recycling enterprises, including tax incentives and policy support, provide subsidies or loan interest discounts for the layout of standardized recycling networks, effectively reduce the compliance operation costs of enterprises, and enhance their competitiveness.

(3) Strengthen Technological Innovation and Promote Standardization and Intelligent Upgrading

The variety of power batteries, rapid technological iteration and low standardization level are the pain points of the recycling industry, which strengthen the technical requirements for waste power battery recycling. Strengthening technological innovation and promoting standardization and intelligent upgrading are the keys to solving the industry's pain points. The government should strengthen the formulation and implementation of national standards for battery module design, interface specifications, unified coding and basic dismantling processes, solve the problem of recycling compatibility from the source, and lay the foundation for the automated and large-scale treatment and utilization of waste power batteries; enterprises should strengthen innovation in technologies related to the testing and dismantling of waste power batteries, focus on tackling key problems such as efficient intelligent dismantling equipment, high-purity material recycling technologies and rapid battery health assessment systems with policy support, reduce costs and increase efficiency through technology industrialization, enhance their own competitiveness, and promote the development of the waste power battery recycling and treatment industry.

6. Conclusion

This study systematically analyzes four mainstream power battery recycling modes through the policy-technology two-dimensional matrix, clarifying their applicable stages and core characteristics. The selection of recycling modes should dynamically adapt to the industry's development process, with policy guidance, technological innovation and mode matching as the key supports. With the advancement of standardization and intelligent technology and the improvement of the policy system, the power battery recycling industry will gradually move towards efficient and sustainable development, realizing the dual goals of resource recycling and environmental protection.

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