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Progress in Recovery and Utilization Technology of traction batteries for New Energy Vehicles and Analysis on Tendency

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Abstract: The recycling and utilization of retired traction batteries for new energy vehicles has attracted widespread attention in recent years and has developed rapidly. This article reviews the technology routes for the recycling and utilization of retired traction batteries, identifies the technological bottlenecks, and examines the development and promotion of advanced applicable technologies. It also analyzes case studies of traction battery recycling and utilization in the United States and Europe, as well as government-related plans and goals. By comparing the progress and trends of traction battery recycling and utilization technologies domestically and internationally, and focusing on the development and application of these technologies, this article provides reference for the development and planning of related technologies for recycling and utilization of traction batteries for new energy vehicles.

Keywords: New Energy Vehicles; Retired Traction Batteries; Recycling and Utilization; Key Technologies.

1. Introduction

Currently, tackling the challenges of climate change, reducing excessive reliance on traditional fossil energy, and promoting low-carbon development in the transportation sector have become global consensus. The development of new energy vehicles plays a crucial role in achieving carbon-zero emission goals and has become an important direction for the global automotive industry. With the promotion by the government and the drive from market demand, China's new energy vehicle industry has developed rapidly. According to data from the Ministry of Public Security, as of the end of September 2023, China's total number of new energy vehicles reached 18.21 million, accounting for 5.5% of the total number of vehicles. Among them, pure electric vehicles accounted for 14.01 million, which is 76.9% of the total number of new energy vehicles. In the first three quarters, a total of 5.198 million new energy vehicles were registered nationwide, an increase of 40% compared to the previous year, accounting for 28.6% of the total number of new registered vehicles [1]. While new energy vehicles are developing rapidly, the retirement of traction batteries is also gradually increasing, and it is expected to face a wave of retirements during the "14th Five-Year Plan" period. According to public data from the China Association of Battery Recycling and Reutilization for New Energy Vehicles (CABRCA), from January to September 2023, a total of 131,000 tons of retired traction batteries were generated nationwide, a year-on-year increase of 72.8%. It is estimated that in 2023, the total amount of retired traction batteries for new energy vehicles in China will reach 13.6 GWh (121,000 tons), and the number of retirements during the period from 2023 to 2025 will reach 63.8 GWh (530,000 tons).

Given the increasingly tense supply and demand of raw materials such as metals for traction battery production, downstream companies in the industry chain, including automobile and traction battery manufacturers, are accelerating the layout of the recycling and utilization industry, hoping to control resource supply through traction battery recycling and utilization business to alleviate supply pressure. Governments in developed regions such as the United States and Europe are also actively promoting traction battery recycling and utilization through various measures to address environmental and safety pressures and to ensure the sustainable development of the industry.

2. Key Technologies for Recycling and Utilization of Retired traction batteries

2.1. Main Technological Routes

Currently, there are two main directions for the recycling and utilization of retired traction batteries in China: cascaded utilization and regeneration utilization. Before carrying out echelon utilization or regenerated utilization, the retired traction batteries need to undergo pre-treatment. Retired traction batteries suitable for cascaded utilization are dismantled and pre-processed into module or unit structures, and then undergo processes such as testing, sorting, and recombination to form end-use products. Retired traction batteries that are not suitable for cascaded utilization are pre-treated through processes such as dismantling, discharging, and component separation, and then become powder materials. The raw material resources in the powder materials are recovered through dry or wet metallurgical processes. [2] The specific technological processes are shown in Table 1:

2.2. Research and Application Progress of Common Key Technologies in China

Driven by the prospects of traction battery recycling and utilization, industry-related companies, research institutions, and universities have conducted research on key technologies in the process of dismantling, cascaded utilization, and regeneration utilization of retired traction batteries. They mainly focus on solving several aspects: First, breaking through the technological bottleneck of automated dismantling of retired traction batteries, improving the environmental friendliness and efficiency of the dismantling and crushing process, reducing secondary pollution, increasing the variety of recyclable materials, and improving the recycling rate. Second, breaking through the key technologies of cascaded utilization, including identifying safety hazards in retired traction batteries, analyzing the cost of cascaded utilization, studying the performance degradation trend and safety state evolution rules, and developing traction battery state diagnosis methods based on historical data. Third, breaking through the key technologies for efficient recovery of materials such as graphite, separators, and electrolytes, developing repair and regeneration technologies for positive electrode materials of low residual value traction batteries such as lithium iron phosphate and lithium manganese oxide, efficient lithium extraction technologies, and high-value utilization technologies for inexpensive components such as iron and phosphorus.

Table 1. Technical route of recycling retired traction battery

Process	Main technology	Content
Pretreatment technology and process	Dismantling process of traction battery	• Battery pack dismantling, including removing the cover, copper busbar, wiring harness, module, and other materials from the battery pack; • Module dismantling, including removing the module end plate, side plate, aluminum bar support, and separating the battery cells.
	Discharge process of traction battery	• Soaking in a solution method involves using a chemical solution to soak and short-circuit the retired traction battery, releasing the remaining energy in the battery. • Conductor or semiconductor discharge method involves using an external resistor, metal powder, or carbon material to short-circuit for discharging.
	Component decomposition and dissociation process	• Fragmentation and sorting method involves crushing the entire battery and separating different components based on their physical characteristics such as particle size, magnetic properties, density, and electrical conductivity. • Intelligent dissociation method refers to the fine separation and recovery of components such as the battery casing, positive electrode plate, negative electrode plate, and separator to obtain high-purity products such as the casing, positive electrode material, negative electrode material, and copper foil.
Echelon utilization technology and process	Residual energy detection	• The industry mainly characterizes the remaining energy of batteries through actual testing. It is also promoting the application of technologies such as residual value evaluation based on historical data and non-destructive testing.
	Dismantling and recombination	• Battery dismantling using a combination of manual and semi-automatic methods. • Recombination involves capacity and consistency screening and matching of batteries of the same type to produce recombined products that can be used in other fields.
	Coding and labeling	• Coding and labeling of recombined products are done according to the "Automotive traction battery Coding Rules" (GB/T 34014-2017).
	Operation monitoring	• Products are monitored during operation using the BMS (Battery Management System) of the recombined products.
Regenerated utilization technology and process	Dry recovery processes	• Based on temperature differences, dry recovery processes can be classified into low-temperature pyrolysis processes and high-temperature calcination processes. • Low-temperature pyrolysis is mainly used to decompose organic substances in the battery, while high-temperature calcination is used to extract valuable metals.
	Wet recovery process	• Acidic or alkaline solutions are used as leaching agents to leach valuable metals from the positive electrode materials. After removing impurities such as aluminum and iron through chemical precipitation, nickel and cobalt are further separated and purified using extractants. Nickel, cobalt, and other metal salts are then recovered and prepared through electrochemical or crystallization methods.
	Material repair process	• Techniques for repairing and regenerating the recovered positive electrode materials to meet the requirements of traction batteries include solid-phase repair, hydrothermal repair, electrochemical repair, etc.

At the national level, efforts are also being made to strengthen the guidance and promotion of related technological research and development. In 2021, the Ministry of Industry and Information Technology issued the “14th Five-Year Plan for Industrial Green Development,” which proposed the improvement of regulations and systems for traction battery recycling and utilization, exploration and promotion of new business models such as “Internet + recycling,” strengthening traceability management, encouraging upstream and downstream companies in the industry chain to build and share recycling channels, and constructing a number of centralized recycling service centers. It also aims to promote the large-scale cascaded application of waste traction batteries in fields such as energy storage, backup power, and charging and swapping, and establish a relatively complete traction battery recycling and utilization system by 2025. Efforts will be made to develop intelligent dismantling and high-value utilization equipment for retired traction batteries and promote the application of fine automatic dismantling technologies. [3] In 2022, the Ministry of Industry and Information Technology, along with 8 other departments, jointly issued the “Implementation Plan for Accelerating the Promotion of Industrial Resource Comprehensive Utilization,” which proposed to promote the safe cascaded application of waste traction batteries in areas such as backup power and charging and swapping, and to increase efforts in research, development, and promotion of technologies for non-destructive testing, automated dismantling, and efficient extraction of valuable metals from traction batteries. [4] In terms of specific technological process equipment, from 2021 to 2023, the Ministry of Industry and Information Technology selected and published two batches of the “National Catalogue of Advanced Applicable Process Technology Equipment for Industrial Resource Comprehensive Utilization” through industry solicitations, and the number of advanced and applicable process technology equipment related to the recycling and utilization of retired traction batteries has significantly increased. (Table 2)

Table 2. Advanced and applicable technology and equipment for recycling retired traction batteries

NO.	Edition	Name of technology equipment	Brief introduction of process technology and equipment
1	2021	Retired traction battery Pack Flexible Intelligent Disassembly System	The equipment includes material storage and feeding mechanism, loading and unloading mechanism, intelligent transportation system, intelligent disassembly system, visual positioning mechanism, irregular package handling mechanism, cell detection mechanism, module stacking mechanism, human-machine interaction system, electrical control system, and MES system, suitable for intelligent disassembly operations of various retired traction battery packs.
2	2021	Clean and Efficient Recycling Technology and Equipment for Waste Lithium-ion Batteries	Using retired lithium traction batteries that cannot be reused in cascades as raw materials, techniques such as oxygen-free crushing, pyrolysis, and wet stripping are used to achieve compatible crushing and sorting and green recovery of waste phosphate iron lithium batteries, ternary lithium batteries, 3C batteries, and waste electrode material. It can handle more than 20 types of lithium battery solid waste, including square shells, cylinders, soft packs, mobile phone batteries, and electrode sheets.
3	2023	Disassembly and Utilization of Lithium Iron Phosphate Batteries	Through the wet recovery process of phosphate iron lithium batteries/electrode black powder, precise separation of various components in phosphate iron lithium batteries is achieved. The process includes directed impurity removal, lithium carbonate synthesis, and iron phosphate synthesis.
4	2023	Highly Compatible Retired Battery Rapid Non-destructive Testing and Sorting System	This technology establishes a set of retired traction battery status evaluation methods, efficiently arranging batteries through parameter extraction, state prediction, and rapid sorting. Compared to traditional processes, this system achieves more than 5 times higher sorting efficiency and reduces costs by more than 50%.
5	2023	Pre-treatment Technology for Recycling of Power Lithium Batteries	This process technology can handle retired traction battery packs with remaining energy. The battery pack is disassembled to obtain battery modules. After directly crushing the battery modules without discharging, the electrolyte is removed through low-temperature evaporation. Then, the materials are collected and classified according to battery components. All materials except electrolyte can be recycled, with a recycling rate of over 90%.
6	2023	High-quality Utilization Technology and Equipment for the Whole Process of Retired traction batteries	This technology achieves high-quality utilization of "waste monomer batteries to black powder, copper, aluminum, with priority given to lithium extraction in black powder through pyrolysis, sorting, calcination, and complete exhaust gas treatment processes. The exhaust gases generated in each process meet emission standards after treatment by the exhaust gas treatment system.
7	2023	Automated Disassembly of Individual traction battery Packs for New Energy Vehicles and Material Restoration Technology for Cathode and Anode	The process technology integrates techniques such as composite washing, composite intelligent identification and selection integrated separation, controllable bending precise selection integrated stripping, and solid-phase repair to separate and recover the 7 key components of traction batteries and repair positive and negative electrode materials. The repaired products can be directly applied to battery manufacturing and further applied in the new energy industry such as low-speed vehicles and energy storage.
8	2023	Key Technologies and Equipment for Comprehensive Recycling of Retired Lithium Batteries	Using physical separation, wet leaching, short-range extraction, and low-carbon sintering methods, the targeted circulation of retired lithium batteries is achieved. The technology includes pretreatment, leaching, impurity removal, extraction, aging synthesis, material sintering, etc. By using integrated equipment for disassembly, crushing, pyrolysis, and separation, selective priority lithium extraction, coordinated disposal of three wastes, and ultra-long sintering system. Products such as nickel cobalt manganese lithium acid, nickel cobalt manganese hydroxide, battery-grade lithium salt, elemental powders, and regenerated lightweight building materials are produced, achieving resource utilization of retired lithium batteries.

From the listed process technology equipment in the catalog, it already includes key processes such as automated flexible dismantling, various battery crushing and valuable material sorting and extraction, non-destructive testing and sorting, and positive and negative electrode material restoration. This indicates that the industry has made positive progress in the development of technological process equipment in the aforementioned areas. Some key technological bottlenecks have been gradually overcome and reached practicality. In terms of the industry's technological development trends, future technological research and development applications will still focus on new battery recycling and utilization technologies, as well as clean and efficient recycling and utilization technologies compatible with various battery products.

3. Layout of Traction Battery Recycling and Utilization in the United States and Europe

3.1. United States

In recent years, the United States has attached great importance to traction battery recycling and utilization. In February 2019, the U.S. Department of Energy established the first lithium-ion battery recycling center (ReCell Center) to promote the recycling of used traction batteries and form a closed loop of the battery industry chain. U.S. universities and research institutions are also actively conducting research on traction battery cascading and regeneration. Sandia National Laboratories (SNL) conducted research and analysis on the cost of retired battery cascading applications and constructed corresponding economic analysis models. The Electric Power Research Institute (EPRI) compared the application prospects of lead-acid, nickel-hydrogen, lithium-ion, and lithium-polymer batteries in areas such as power systems, communication base stations, and UPS power supplies. In terms of industry development, General Motors and ABB Group of Sweden jointly conducted research on cascading utilization of lithium batteries for vehicles, mainly for smart grids, for storing electricity generated by distributed power generation systems such as solar and wind energy. FreeWire Technologies has developed a portable charging station for new energy vehicles using retired batteries, providing mobile charging services for new energy vehicles in office areas and other working areas. The first recycling and processing factory of Redwood Materials located in Nevada, USA, has started operation and can recover and reuse 95% of nickel, cobalt, aluminum, and graphite in scrap batteries, as well as over 80% of lithium.

In June 2021, the U.S. Department of Energy released the "National Blueprint for Lithium Batteries 2021-2030" developed by the Federal Consortium for Advanced Batteries (FCAB), emphasizing that the recycling and utilization of lithium-ion batteries can not only reduce the constraints caused by material shortages and improve environmental sustainability, but also provide support for a more secure and resilient domestic supply chain with circular properties. By implementing corresponding measures to increase the market penetration of lithium-ion battery recycling and utilization, it helps establish a domestic circular battery economy. The blueprint proposes the following tasks related to battery recycling and utilization.

Table 3. Tasks related to battery recycling and utilization.

Time	Primary mission
Recent goals (**2025**)	• Promote the design of battery pack for secondary use and recycling; • Establish successful methods for collecting, sorting, transporting and treating recycled lithium-ion battery materials, with emphasis on reducing costs; • Improve the recovery rate of key materials such as cobalt, lithium, nickel and graphite; • Develop processing technology and reintroduce these materials into the supply chain; • Develop appropriate classification, testing and balancing methods for secondary use applications; • Formulate a federal recycling policy to promote the collection, reuse and recycling of lithium-ion batteries.
Long-range goals (**2030**)	• Encourage 90% recycling of consumer electronics, electric vehicles and grid batteries; • Formulate a federal policy to require the use of recycled materials in battery manufacturing materials.

3.2. Europe

In 2017, Europe established the Battery Alliance, which developed the Battery Action Plan. The plan aims to strengthen the security and sustainability of the battery industry chain, from pre-product design to post-product recycling, ensuring the safety and reliability of the entire battery process. In terms of industry development, the South German Group has been involved in cascade utilization research projects since 2010 and has established a storage application demonstration project in Berlin, Germany. Mercedes-Benz has collaborated with recycling companies to develop cascade utilization and plans to build a 13 MW·h grid service energy storage facility with an effective cascade utilization rate of over 90%. Renault has carried out more than 20 cascade utilization projects, including home energy storage, wind and solar energy storage, and smart grids, verifying the cost advantages of cascade utilization battery systems. Umicore and Engie have built a 1.2 MW/720 kW·h user-side cascade utilization energy storage system using retired lithium-ion batteries from 48 Renault Kangoo electric vehicles that were used for 7 years and put it into operation. BASF, Eramet;

Table 4. Tasks and objectives of battery recycling

Focus of Recycling Strategy		The key plans for the recycling strategy include the development of breakthrough battery recycling processes, with main research directions including: data collection and analysis through labels, battery management systems, sensors, etc.; modern low carbon footprint logistics concepts, including decentralized processing; automatic disassembly of battery packs to the cell level; exploration of maximum reuse and reutilization; automatic disassembly of batteries to the largest individual components; development of selective powder recycling technologies and "refurbishing" them into battery active materials, or synthesizing active material precursors by adjusting their composition if necessary.
		Specific research and development activities will be conducted: extending battery lifespan as much as possible through design, and considering the applicability of recalibration, refurbishing, and secondary and multiple uses; integrating sensors and self-repairing functions to identify damaged/aged components and prepare them for reuse; developing traceability concepts, especially traceability of key raw materials throughout the battery lifecycle, automatic battery sorting and evaluation, and developing efficient, low-cost, and sustainable one-step recycling processes for valuable key materials; AI technology and sorting equipment will be used in the selective recycling process, while seeking a universal process applicable to all types of batteries to ensure maximum recycling of battery components, even for new types of batteries such as metal-air batteries.
Research and Development Goals	Short-term	Develop systems for data collection and analysis, develop technologies for battery pack/module sorting and reuse/recycling, and develop methods for automated battery disassembly. Develop new testing techniques for rapid characterization of batteries.
	Mid-term	Develop technologies for automatic disassembly of batteries into individual components, sorting and recycling technologies for powders and components, and technologies for "refurbishing" them into advanced new battery active materials. Test recovered materials in batteries. Develop prediction and modeling tools for material reutilization in secondary applications. Significantly improve the recycling rate of key raw materials and significantly reduce energy and resource consumption.
	Long-term	Develop and validate a complete direct recycling system that is economically viable, safe, and environmentally friendly, with a lower carbon footprint compared to current processes.

And Suez, in partnership with the EU's EIT Raw Materials, will jointly invest in the ReLieVe project for the recycling and utilization of lithium-ion batteries from electric vehicles, aiming to develop innovative processes for dismantling and recycling lithium-ion battery materials for the production of new lithium-ion batteries.

In December 2018, the European Commission issued the "Battery 2030+" Declaration and launched the "Battery 2030+" Coordination and Support Action in 2019 to determine the research roadmap for the "Battery 2030+" plan. In December 2020, the European Battery Technology Innovation Platform "Batteries Europe" (ETIP Batteries Europe), under the European Battery Alliance, published the "Battery Strategy Research Agenda", which clearly defined the research and innovation priorities for European battery technology by 2030. Regarding battery recycling and utilization, the agenda sets out the following tasks and objectives.

4. Conclusion and Discussion

From the progress of domestic and international efforts in battery recycling and utilization, it has been regarded as an important aspect for ensuring the development of new energy industries and enhancing technological competitiveness. However, different countries have some differences in formulating implementation roadmaps and goals based on their own circumstances, with different emphases. Currently, China has certain advantages in the research and development of battery recycling and utilization technologies and their industrial applications, but measures taken by other countries and regions also have valuable reference significance. In general, I believe the focus should be on the following aspects:

Firstly, comprehensive planning should be conducted from a full lifecycle perspective. Western countries consider the importance of battery design and development alongside recycling and utilization in their planning. They propose promoting battery design for easier secondary use and recycling, with the European Union particularly emphasizing the "possible extension of battery life in design, considering re-calibration, refurbishment, and applicability for secondary and multiple uses", thus creating conditions for cascade utilization and forming a complete closed-loop of "production-use-recycling-utilization".

Secondly, breakthroughs in key technology nodes should be emphasized and a systematic approach should be established. Both the United States and Europe focus on the battery classification, testing, and balancing technologies involved in cascade utilization. The European Union pays special attention to the integration of technologies such as traceability, big data, and AI with traditional technologies, aiming to achieve technological breakthroughs at each key node and establish a complete and seamless technological system, thereby forming overall competitive advantages.

Thirdly, a universal recycling and utilization process should be constructed. An outstanding issue facing retired battery recycling and utilization is the rapid iteration and progress of battery technology. With the constant emergence of new materials and structures, the future scrap recycling stage will face a wide variety of batteries, making it difficult to ensure the efficiency and cost-effectiveness of recycling and utilization. Therefore, it is necessary to develop universal and standardized recycling and utilization technology paths suitable for various batteries, ensuring safety and environmental protection, reducing and facilitating tracing of carbon footprints, and promoting resource utilization efficiency.

References

[1] The number of new energy vehicles in China reached 18.21 million. https://www.gov. cn/govweb/lianbo/ bumen/ 202310/ content_6908192.htm.

[2] China New Energy Vehicle traction battery Recycling Industry Development Report (2020).

[3] “14th Five-Year Plan for Industrial Green Development” https://www.miit.gov.cn/jgsj/ghs/zlygh/art/2022/art_dd7cf9f916174a8bbb7839ad654a84ce.html.

[4] Notice of Eight Departments on Printing and Distributing the Implementation Plan for Accelerating the Comprehensive Utilization of Industrial Resources https://ythxxfb. miit.gov. cn/ythzxfwpt/hlwmh/tzgg/sbyw/dzxxjsbzhfwpt/art/2022/art_ece63eff27d3477085ea06a933523bd9.html.

[5] The EU “Battery 2030+ Project Working Group Released the Draft Roadmap for Battery Research and Development http://www.casisd.cn/zkcg/ydkb/kjqykb/2020/202001/202003/t20200310_5511418.html.