

A Review of Research on the Cascaded Utilization of Power Batteries for New Energy Vehicles—Multi-Scenario Applications

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ABSTRACT

With the rapid development of the new energy vehicle industry, the scale of retired power batteries continues to grow, making cascade utilization an important path to achieve battery resource recovery and low-carbon development. This paper systematically reviews the policy framework, core technologies, engineering applications, and industrial development status of power battery cascade utilization both domestically and internationally. It compares and analyzes the differences between Europe, the United States, Japan, and my country in research directions, technological focuses, and industrial models. The summary reveals that foreign countries emphasize precision technology R&D, full-cycle benefit assessment, and high-end energy storage applications, while China focuses on engineering implementation and large-scale development across the entire industry chain. However, it faces challenges such as weak basic theoretical foundations, inconsistent standards, and insufficient localization of core equipment. Finally, based on industry hot spots, the paper summarizes future mainstream development directions such as echelon utilization, digital traceability, and new energy storage integration, aiming to provide a reference for subsequent research and standardized development of the power battery cascade utilization field.

Keywords: Retired Power Batteries; Secondary Use; Health Assessment; Energy Storage Applications; Industrial Development

1. INTRODUCTION

Against the backdrop of global energy transition and China's "dual-carbon" goals, the new energy vehicle industry is rapidly expanding, and a large-scale retirement of power batteries has arrived. When the capacity of a power battery decays to below 80% and can no longer meet the requirements of vehicle use, it still possesses stable remaining performance, making its secondary use feasible and economical. The secondary use of retired power batteries can alleviate resource waste and ecological pollution pressure, improve the closed-loop industrial chain of new energy vehicles, and reduce the application costs of energy storage and backup power scenarios. It is a core path to maximizing the value of batteries throughout their entire life cycle and promoting the green development of the industry.

At present, the research and development of technology and application scenarios for the secondary use of power batteries have been continuously deepened at home and abroad. Retired batteries have been applied in engineering in multiple scenarios such as power storage, backup power for communication base stations, backup power for industrial and commercial use, low-speed vehicles, and home energy storage. Related sorting and reorganization, system integration, and safety management technologies have been continuously enriched. However, due to the poor performance consistency of retired batteries, the difficulty in accurately assessing their health status, the imperfect application technology for scenarios, the lack of unified industry standards, and the insufficient economic efficiency of the entire industry chain, there are still many bottlenecks in the large-scale and standardized application of multiple scenarios. Existing research focuses on the optimization of technology or models in a single scenario, and there is a relative lack of systematic sorting, comparative analysis, and overall judgment of applications in multiple scenarios^[1].

Based on this, this paper adopts a literature review paradigm that includes literature summarization, dynamic analysis, comparative review, and trend judgment. Relying on core domestic and international literature, industry standards, and industry survey data from the past five years, it systematically conducts relevant research. The overall research focuses on analyzing the global policy system, core technologies, multi-scenario engineering applications, and existing industry problems related to the cascade utilization of power batteries. It also summarizes innovative research directions based on industry development characteristics: First, it establishes a comprehensive review framework integrating policy, technology, application, and industry to fully present the overall picture of the field's development; second, it conducts a

comparative analysis of domestic and international differences based on the characteristics of the domestic industry, accurately analyzing the shortcomings of the local industry; third, it incorporates the latest research results from 2024 to 2026, focusing on cutting-edge directions such as artificial intelligence assessment and digital traceability; fourth, based on a problem-oriented approach, it identifies four major development pain points: technology, equipment, standards, and business models, predicts industry development trends, and strives to provide theoretical references for the efficient adaptation, technological optimization and upgrading, and standardized development of retired power batteries across multiple scenarios, promoting the deep synergistic development of resource recycling and the new energy industry.

2. CURRENT STATUS AND ANALYSIS OF THE DEVELOPMENT OF CASCADED UTILIZATION OF POWER BATTERIES

2.1 Current Status of Policy System Development

Developed countries such as the US, Europe, and Japan started industrializing their new energy vehicles earlier, and their policies and regulations regarding the cascade utilization of power batteries are many years ahead of China's, forming an integrated policy system encompassing standard setting, division of responsibilities, and full-process supervision. The EU took the lead in issuing specific battery regulations, clearly defining the capacity usage range for cascade-utilized batteries, and legally reinforcing automakers' primary responsibility in battery recycling and reuse, thus defining compliance boundaries for the cascade utilization industry. Germany, relying on existing industrial regulations, has issued supporting detailed rules for battery testing and reuse, ensuring standardized operation of battery health testing and energy storage projects. The US focuses on industry support and evaluation system construction, issuing battery reuse assessment guidelines, continuously increasing financial investment in scientific research, and guiding industry-academia-research collaboration in technological breakthroughs. Japan, based on its local industrial structure, has issued supply chain support policies to guide companies in building a closed-loop power battery recycling and reuse chain, promoting the commercialization of retired batteries in the energy storage field.

China has kept pace with the global energy transition and, combined with the large number of new energy vehicles, has gradually established a multi-level policy management system for the cascade utilization of power batteries, clarified the core development principle of priority recycling of cascade batteries, and promoted the orderly development of the industry from top to bottom. Under the guidance of the policy, the development model of multi-party collaboration between government, enterprises and universities in China has gradually taken shape, and the overall industry has progressed rapidly. However, compared with the mature overseas system, there are still some shortcomings in the implementation of domestic policies: the implementation standards of policies in different regions are not the same, the supporting rules in subdivided fields such as battery circulation, residual value assessment and safety supervision are not perfect, and the unified industry supervision standards have not been fully implemented, which to some extent restricts the standardized and large-scale development of the cascade utilization industry nationwide^[6].

In summary, overseas policies emphasize legislation first, meticulous management, and clear division of powers and responsibilities, relying on sound laws and regulations to protect high-end technology research and development and high-end application scenarios; domestic policies are mainly guided by top-level policies and supported by industries, focusing on promoting project implementation and the layout of the entire industrial chain. The policy implementation efficiency is high, but the standards in specific fields still need to be continuously improved.

2.2 Current Status of Core Technology Research

Technology is the core support for the cascade utilization of power batteries. Currently, global research mainly focuses on six core directions: battery health status assessment, non-destructive testing, intelligent sorting, module reconfiguration, life prediction, and digital traceability. There are significant differences in the focus of domestic and foreign technology research and development.

Foreign countries rely on a strong industrial foundation and scientific research accumulation, and focus on precision, intelligence and theoretical technology routes. Many overseas scholars have applied machine learning and multi-algorithm fusion models to the battery field. Huang et al. (2024) integrated multiple intelligent algorithms to build a battery capacity decay model, which greatly optimized the accuracy of retired battery screening and performance judgment^[4]. At the same time, they combined battery voltage, internal resistance, temperature and other multi-dimensional state parameters to build an intelligent sorting model, which effectively reduced the subsequent operation loss of the cascade battery. In terms of traceability technology, the EU has promoted the battery electronic passport digital traceability technology to realize the

full life cycle information tracking of a single battery from installation, use, retirement to cascade reuse, effectively solving the problems of missing industry data and chaotic battery circulation management. At present, this technology has been piloted in many EU countries and is gradually becoming popular. Overall, overseas technology is biased towards basic theoretical research, high-precision detection and full life cycle benefit calculation, and the level of technology refinement is at the leading level in the world.

Domestic technology research and development is based on the actual needs of the industry, with mass production, engineering and practical application as the core objectives, and focuses on adapting to the processing needs of a large number of retired power batteries in China. In view of the industry characteristics of a large stock of lithium iron phosphate batteries in China, domestic scholars have carried out a large number of special technical research projects: Cai Cheng et al. (2026) sorted out a number of mainstream battery health testing methods and designed a non-destructive testing scheme adapted to mass battery screening to meet the needs of large-scale sorting^[3]; Yan Ning et al. (2025) optimized the clustering sorting algorithm to effectively improve the operational stability of the module after the reorganization of retired batteries^[2]. At the same time, domestic research institutions have made targeted improvements to the cycle life and low-temperature working performance of lithium iron phosphate batteries to alleviate the problem of excessive loss under energy storage conditions.

At present, China has formed a relatively complete testing, sorting and recombination technology system, but its shortcomings are also prominent: basic theoretical research on batteries is relatively weak, and there is still a gap in high-end core technologies such as high-precision testing and intelligent evaluation; the localization of core production and testing equipment for secondary utilization is insufficient, and high-end equipment still relies on imports; the technical standards of different brands and models of batteries are chaotic, which further increases the difficulty of unifying and adapting technologies.

2.3 Current Status of Engineering Application Scenarios

After years of industrial iteration, retired power batteries have formed a diversified secondary utilization system covering energy storage, backup power and transportation sectors. The core application categories include grid energy storage, communication base station backup power, industrial & commercial standby power, low-speed electric vehicles and household distributed energy storage. Distinct gaps exist between China and overseas regions in scenario positioning, battery matching, project scale and economic operation logic, and a quantitative comparative summary is shown in Table 1.

Table 1. Comparison of Second-Life Battery Application Scenarios.

Dimension	Europe, US, Japan	China
Main battery type	Ternary lithium	Lithium iron phosphate
Priority scenarios	MW grid energy storage	Base station backup, PV-storage
Development target	Full-cycle economic & carbon benefits	Mass digestion of retired batteries
Project scale status	Small demo projects, low penetration	Full-scenario large-scale rollout
Core bottlenecks	Insufficient retired battery supply	Missing scenario standards, subsidy reliance

Overseas markets take advantage of ternary lithium batteries' high residual performance and concentrate high-quality retired batteries on high-value large-scale grid energy storage. A batch of megawatt-level cascade energy storage demonstration stations have been constructed across Europe, the United States and Japan, which cooperate with public power grids to undertake peak regulation and renewable energy absorption tasks. Existing research verifies that cascade utilization delivers superior carbon reduction and economic performance versus direct material recycling, so overseas enterprises allocate high-quality retired batteries to high-end energy storage to maximize full-cycle comprehensive income^[5]. Nevertheless, constrained by the limited annual retired battery volume, overseas cascade projects remain at the demonstration stage without large-scale market promotion.

Benefiting from the world's largest retired power battery inventory and complete new energy industrial chain, China has realized batch engineering deployment across all five mainstream scenarios, with far wider coverage than overseas markets. Communication base station standby power and photovoltaic-storage integrated energy storage stations act as domestic core landing scenarios; distributed household energy storage, industrial & commercial backup power and low-speed

vehicles serve as supplementary downstream channels. Domestic enterprises have formed a closed industrial chain covering recycling, classification, recombination and terminal application, and the national cascade utilization market maintained steady growth in 2023 [6].

Notable practical barriers remain in domestic multi-scenario promotion: (1) No targeted technical and safety specifications for different scenarios, leading to inconsistent matching efficiency between batteries and load conditions; (2) Monotonous profit modes heavily dependent on policy subsidies, with incomplete residual value evaluation systems restricting independent market profitability; (3) Weak safety operation management of small and medium-sized projects, carrying long-term hidden safety risks.

2.4 Comprehensive Comparative Analysis of Domestic and International Perspectives

From the perspectives of policy, technology, and application, developed countries such as Europe, the United States, and Japan started earlier and have a strong industrial base. Their overall characteristics include a focus on theory, sophisticated technology, high-end development, and high efficiency: a sound policy and regulatory system with clear division of responsibilities; high levels of refinement and intelligence in core technologies; solid basic theoretical research; and engineering applications focused on high-end energy storage scenarios, emphasizing the assessment of carbon and economic benefits throughout the entire life cycle. However, their market size is relatively small, and the pace of industrial scaling is slow.

Leveraging its advantages in the new energy vehicle industry, my country's secondary battery utilization industry has experienced rapid growth, characterized by strong practicality, large-scale operation, a complete industrial chain, and high applicability. This is evidenced by effective policy guidance, a comprehensive industrial layout, technological research and development focused on practical needs such as large-scale battery processing and lithium iron phosphate reuse, demonstrating outstanding engineering implementation capabilities, and comprehensive application scenarios, making it the world's largest industry. However, it also faces numerous bottlenecks: lagging basic theoretical research, reliance on imports for high-end core technologies and equipment, a lack of unified industry standards, and imperfect residual value assessment and profit models, which have become major obstacles hindering the industry's progress towards a high-quality development stage.

From a global development perspective, the development directions of domestic and international industries are gradually converging. In the future, they will jointly focus on three major directions: AI-enabled intelligent battery evaluation, modular battery design and full-process digital traceability, and the integration of cascaded batteries with new energy storage systems, so as to promote the development of the power battery cascade utilization industry towards standardization, intelligence, and low carbon emissions.

3. SUMMARY AND OUTLOOK

3.1 Summary

This article systematically reviews the current development status of the global new energy vehicle power battery cascade utilization from three dimensions: policy system, core technology, and engineering application, and conducts a comparative analysis of the development models in China and abroad. Currently, a relatively mature battery testing, sorting, recombination, and reuse technology system has been formed globally, and cascaded batteries have been commercialized in various scenarios. Foreign countries rely on comprehensive regulations and advanced technologies to cultivate high-value-added application fields; China relies on its industrial scale advantages to achieve a full-industry chain layout and multi-scenario engineering implementation.

At the same time, the shortcomings of my country's power battery cascade utilization industry are also very obvious: a unified industry standard system has not yet been established, and regulatory rules for subdivided fields are lacking; the localization of high-end testing and production core equipment is insufficient; the battery residual value assessment system is vague; the industry's overall profit model is singular; and the market-oriented development momentum is insufficient. All of these problems restrict the long-term high-quality development of the industry.

3.2 Outlook

Based on current industry research hotspots and development pain points, the future development of the cascade utilization of power batteries will continue to move towards four major directions: intelligence, standardization, decarbonization, and integration. Firstly, relying on artificial intelligence and big data technologies, a smart management platform for the entire

battery lifecycle will be built to achieve accurate assessment of battery health status, lifespan prediction, and intelligent sorting, comprehensively improving the level of technological intelligence. Secondly, unified technical standards, safety standards, and regulatory systems will be improved across the industry, and digital traceability technologies such as battery electronic passports will be promoted to achieve full-process traceability and supervision of batteries. Thirdly, the deep integration of cascaded power batteries with new energy storage systems such as photovoltaics and wind power will be promoted to broaden application scenarios and improve resource utilization efficiency. Fourthly, the residual value pricing and business models of batteries will be optimized to enhance the industry's market profitability.

Through technological upgrades, standard improvements, and model innovation, the efficient recycling of power battery resources throughout its entire life cycle can be achieved, promoting the coordinated and sustainable development of new energy vehicles and the secondary utilization industry ^{[1][6]}.

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