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Key technology and application analysis of quick coding for recovery of retired energy vehicle battery

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ABSTRACT

With the increasing production and marketing of new energy vehicles (NEVs) in China, a large number of electric vehicles (EVs) batteries produced by the scrapped NEVs pose a great threat to environmental regulations and social security. Due to the influence of battery type, model, material, battery status, vehicle information and other factors, the scrapped new energy vehicle battery failed to achieve efficient and convenient recycling. Considering the requirements of some recently published government documents and the characteristics of electric vehicle battery, an integrated vehicle identification number (VIN) code is proposed. Based on the analysis of the current national standards GB 16735–2019 road vehicle-VIN identification number and GB/T 34,014–2017 code rules for vehicle power battery, the standard of combining battery code and tracking code is proposed. Finally, the possible coordination code is applied to a case study. The research results of this paper have been implanted into China's national standards.

1. Introduction

China launched the national strategy of new energy vehicles (NEVs) in 2003 because of the shortage of fossil energy, the need of environmental protection and the adjustment and benefit of automobile industry. It has become the world's largest producer and applicator of NEVs after ten years of development. However, with the increase of charging times, the performance of electric NEVs power battery gradually decreases. When the battery capacity drops below 80% of the rated capacity, the normal operation of new energy NEVs cannot be guaranteed [1]. Considering the fixed average service life of the power battery for 5–8 years [2], it is generally believed that the first power battery in China will be retired in 2020 [3], and the number of retired batteries will increase rapidly in the next 3–5 years, according to the annual new energy vehicle listing report released by the Chinese automobile industry authorities. According to the prediction of China Automotive Technology Research Center, the total scrap volume of electric vehicle power battery in China will reach an amazing 120,000–170,000 tons in 2020 [4]. Especially the lithium iron phosphate battery, which is widely used in China, is very cheap. As a result, no institution is willing to recycle them. If these batteries can not be effectively recycled, it will cause a huge potential threat to the environment and human health [5]. For example, some waste batteries contain acid, alkali and electrolyte, which can make soil and water acid and alkali [6]. The heavy metal elements in the battery will also pollute the soil and groundwater [7], and may accumulate in the human body after the biological chain, posing a threat to human health [8]. Therefore, due to the influence of heavy metals and harmful electrolytes, incineration will not only cause heavy metal pollution, but also produce harmful gases, such as HF, Cl_2, etc. [9]. Most notably, composting can cause heavy metal pollution and may affect the quality of compost products [10]. Based on these important demands and benefits, scientific layout in advance can be traced back to the source of the recycling system, which will be an important measure to effectively control safety and environmental risks

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and meet the coming “retirement tide".

Because of the high threshold and the high demand of recovery technology for transportation cost, but its profit is very low, leading to some enterprises only recycling valuable parts, low-value harmful substances are discarded. Most commonly, batteries are used for refurbishment in areas such as rechargeable batteries. This way of recycling and flowing will not realize the recycling of batteries. In addition, there is no effective cooperation mechanism in the vicious competition of ‘pricing’ of aircraft in the auction mode among enterprises, resulting in a series of problems, resulting in a large number of discarded batteries cannot be recycled correctly, and a small number of retired batteries enter the regular recycling companies for recycling. It is difficult for recycling activities to grasp the real flow direction of used batteries. It can be assumed that this will cause huge security risks and environmental problems [11]. In foreign countries, battery management is the key factor to improve the recovery rate [12]. In terms of vehicle power battery recovery, Europe, America, Japan, Germany and other developed countries continue to use lead-acid battery recovery experience for lithium battery recovery [13], known as the main responsibility mechanism of battery recovery of power battery manufacturers.

The European Union forces battery manufacturers to establish a recycling system for automotive used batteries, including a set of manufacturers, importers, distributors and consumers in the battery industry chain, in which clear legal obligations are put forward. Therefore, with regard to the “deposit system” to encourage consumers to voluntarily hand over retired batteries [14], The United States has contributed a “deposit system” to encourage consumers to voluntarily hand over retired batteries. Most of its states follow a regulatory system designed by the (international battery Institute) which also forces battery retailers to recycle used batteries and requires battery manufacturers to use recyclable designs and labels in their manufacturing processes. For other participants in the industrial chain, the battery companies should be guided to participate through the price mechanism [15]. Since 2000, Japan has put battery manufacturers in charge of recycling nickel metal hydride and lithium-ion batteries, and requires the design of battery products to facilitate recycling activities. However, the government will give subsidies to battery manufacturers to improve the enthusiasm of enterprises in recycling [16]. Switzerland has 14,300 waste battery recycling bins [17]. German batteries can only be sold on the market if they are marked with “recyclable” and scrap date [18]. All electrical and electronic retailers in France shall not reject the same kind of waste electrical and electronic products returned by customers when selling new products, and manufacturers shall be responsible for the proper disposal of such retired electrical and electronic products [19]. In the Netherlands, as early as January 1995, the revised manufacturers and importers of mobile phone batteries were fully responsible for collecting and processing retired products [20]. Denmark and Sweden require all battery retailers to recycle used batteries and impose a special sales tax on battery sales [21]. In the UK, consumers are required to wrap the discarded cell phone batteries in impermeable plastic to prevent accidental leakage of toxic substances before they are sent for recycling [22]. In terms of popularizing environmental education and raising awareness, consumers and other subjects mainly participate in battery recycling on a voluntary basis, and battery manufacturers can recycle batteries free of charge to consumers through relevant channels [7]. Both the European Union and the United States have established battery recycling channels, mainly through industry associations or alliances, such as the portable rechargeable battery association (PRBA) in the United States [23] and the GRS foundation in Germany [24]. In Japan, battery companies mainly build recycling channels through reverse logistics [25].

Compared with the developed countries, the recycling of small batteries in China started late, lacking systematic laws and standards. The national recycling awareness is not active enough, and the whole social recycling system is not sound enough. It was not until 2018 that China began to promote waste classification measures in Shanghai, Beijing and other cities. However, the experience of small battery recycling abroad cannot be directly copied to the decommissioning market of power battery in China. Therefore, in order to establish a management mechanism for power battery recycling and utilization nationwide as soon as possible, the Ministry of Industry and Information Technology of the People’s Republic of China and other seven departments jointly issued the *interim measures for the management of power battery recycling and utilization of new energy vehicles* (hereinafter referred to as the “interim measures”) [26] on February 26, 2018. On July 2, 2018, the Ministry of Industry and Information Technology of the People’s Republic of China issued the *interim provisions on the management of traceability for recovery and utilization of new energy vehicle power batteries* [27]. The regulation required the collection of information on the whole process of the production, sale, use, scrapping, recycling and utilization of power batteries, and the monitoring of the fulfillment of the recycling responsibilities of the main body of each link. The article 6 of the battery production, pilot use enterprise should according to *about open auto motive battery code registration system notice* (machine letter [2018] no. 73) in the request, the vendor code application and coding rules for the record, power battery or arrangement in this enterprise production using battery product coding logo [28]. Since China’s power battery recycling system did not really cover the full life cycle of the power battery pipeline, the battery listing announcement-vehicle scrap recycling-bodywork coding logout-battery is cancelled and so on each link belong to the Ministry of Commerce, the Ministry of Public Security management, environmental protection and other departments respectively, and each link for the present data fragmentation, not sharing between system platform, to produce inevitable information island, it is very inconvenient to recycling back.

It can be seen from the literature review that the main difficulties of waste battery recovery in China can be included as following; firstly, the industry of waste battery recovery in China started late, especially the automotive power battery; then, the relevant laws and standards of waste power batteries in China are not perfect; the third is the high technical requirements and high cost of waste power battery recovery; finally, the information of the recycling process of the power battery of the end-of-life vehicle is complex and scattered. By analyzing the current national standard and combining the characteristics of power battery’s own circulation, the technical feasibility and application scheme of three-code integration of vehicle identification code, power battery code and battery recovery code are analyzed and discussed in this paper. Based on the contribution of this study, the recycling of power batteries should ensure orderly and sustainable development. The premise is three-code integration, that is, the integration of battery code, vehicle VIN code and recycling code information, and the sharing of these input information into the battery management platform, so as to ensure that the flow of the battery from the installed to the scrapped life cycle is controllable. Through technical means, the information sharing channels of relevant departments are opened to ensure that the power supply of the power battery is checked, the trace is tracked and the nodes are controlled.

2. Outlook of China’s new energy vehicles

2.1. China’s new energy vehicle trends in the next five years

2.1.1. Trend of production and sales and ownership

Cumulatively, in January–November 2019, China’s NEVs production and sales completed 1.093 million and 1.043 million units respectively [29], a year-on-year increase of 3.6% and 1.3% [30]. Among them, the production and sales of pure electric vehicles reached 891,000 and 832, 000 respectively [31], a year-on-year increase of 10.3% and 5.2% [32]; as of June 2019, China’s NEVs ownership was approximately 3.44 million, and The number of traditional fuel vehicles has reached 250 million [33], and the penetration rate of NEVs is less than 1.4% [34], which has broad growth space. On December 3, the Department of

Equipment Industry of the Ministry of Industry and Information Technology issued the *Development Plan for New Energy Vehicle Industry (2021–2035)* (draft for comments) [35], which was open to the public for comments. The consultation draft states that after fifteen years of continuous efforts, the core technology of China's new energy vehicles has reached the international leading level. By 2025, the sales of new energy vehicles will account for about 25%.

2.1.2. Development trends under the new policy

For NEVs, China's latest subsidy policy proposes that new energy vehicles are exempt from purchase tax [36]. The amount of subsidies for pure electric vehicles is calculated based on cruising range, battery system energy density, and vehicle energy consumption adjustment factors [37]. The subsidy for plug-in hybrid vehicles is 10,000 per vehicle, and the pure electric range is required to be no less than 50 km. The subsidy multiple is determined based on whether the pure electric range is greater than 80 km [38]. This means that the development trend of NEVs will develop in the direction of high cruising mileage, high energy density, and lightweight vehicles.

2.2. Forecast of China's retirement battery scale in the next 10 years

2.2.1. Development status and trends of power battery technology

At present, everyone has high requirements for batteries, hoping to reach the level of competition with fuel vehicles, such as battery energy density, power density, safety, cycle life, fast charging, temperature range of use, and cost can meet market expectations Objective [39]. Through everyone's efforts, some requirements have been met, but there is still a long way to go to complete all the requirements. Lithium-ion battery technology is a research hotspot. Whether it is from materials or battery system integration, safety is still an important aspect [40]. However, the energy density, power density, and life and cost control of lithium-ion batteries have been greatly improved, and they have become upgraded or alternative products of lead-acid batteries. Previously, with the support of the China's three five-year plans, the technology of power batteries has been rapidly improved [41]. In fact, the technical improvement of power batteries is closely related to the China's overall strategic orientation, because China takes pure electric drive as the main guide. From this perspective, lithium-ion batteries should be researched and developed in the direction of high quality, and the whole battery material system should be relatively transformed [42]. At present, the state has made some arrangements in the field of solid-state batteries, and some universities and scientific research institutions have done a lot of research work and made considerable progress [43]. Driven by the national subsidy policy, the industrialization of China's power battery is progressing rapidly. The subsidy is mainly based on the energy density of the battery [5]. The energy density of lithium iron phosphate has now reached 150 Wh/kg. The indicator can get 1.2% subsidy [44]. The density of lithium iron phosphate was increased through subsidies. In 2018, the energy density of lithium iron phosphate will reach 160 Wh/kg or even 170 Wh/kg, and by 2019 it will reach 180 Wh/kg [45]. The energy density of ternary materials is approximately 120–250 Wh/kg [11], and 120 Wh/kg can be used in fast-charge buses [46]. In the field of passenger vehicles, the energy density of ternary materials is 230 plus or minus 20 W per kilogram. Through the improvement of energy density, especially under the promotion of subsidies, the whole battery technology can be promoted, which will indirectly promote the progress of vehicle technology.

2.2.2. China's automotive power battery scrap explosion and growth

With the promotion and application of NEVs, the production and sales of NEVs have increased rapidly, and power batteries have been applied on a large scale (see Table 1). The life of power batteries is generally 3–5 years [40]. After a long period of installed operation, NEVs will be explosively promoted and applied. In the foreseeable future, it will bring large-scale retirement of power batteries [47]. Guo et al. [48] used the Stanford model to predict the retirement of new energy vehicle power batteries in China in the next few years, shown in Table 2. In 2025, China's power battery scrap will reach 46.78 GWh/year, shown in Table 3. According to the sales data of China's new energy vehicle models and the average weight of each model's battery pack, which is equivalent to an annual scrap scale of 420,900 tons, the disposal of new energy vehicle retired power batteries is imminent. In addition, since the scale promotion and application in 2015, the National and Local Joint Engineering Research Center for New Energy Vehicle Power Battery Recycling has made a 10-year forecast for the power battery consumption from 2015 to 2025, in which lithium iron phosphate-based power batteries account for an average of more than 62%, which will mean that China will face at least 300,000 tons of lithium iron phosphate power batteries in the next 10 years. Based on the sampling analysis of different dimensions such as sales volume, time to market, vehicle model, installed capacity of battery, material system and user unit, this information is obtained by consulting the listing announcement list of new energy vehicles issued by the Ministry of industry and information technology of the people's Republic of China, as well as the working conditions. If these large-scale waste batteries cannot be traced back to a standard, effective, safe and controllable recycling source, it will undoubtedly bring huge security risks and environmental risks to this society.

3. Key factors affecting power battery recycling

3.1. Recycling process

At present, the irregular and unprofessional behavior of the recycling process is the first factor of affecting the traceability for controlled recycling. Power battery products are mainly lithium-ion batteries and belong to the class IX dangerous goods. Their number is UN3480 [49]. Before packaging and transportation, they need to undergo professional assessment and diagnosis to effectively classify and safely dispose of batteries. Lithium-ion batteries are packaged in accordance with different safety levels and packaging requirements for dangerous goods. The packaging during the transportation of lithium-ion batteries needs to use class II packaging, temperature control and smoke detectors. The transportation of them needs to use class IX dangerous goods transportation vehicles and the special transportation lines. The recycling process usually involves two possibilities: the first is the recycling during normal decommissioning, and the second is after the end of the life of the step utilization. The flow diagram of the recovery process is shown in Fig. 1.

As mentioned earlier, the recycling process involves multiple transports and the cost of the recycling process is high. After consumers repair the power battery in the 4 S shop, recycling a small amount of retired power batteries is an unsolved problem. Generally, 4 S stores do not have the right to store dangerous goods, and cannot store a large amount of replaced power batteries for a long time. However, 4 S stores are scattered throughout the country. According to statistics from China Automobile Dealers Association and National Bureau of Statistics, China authorized 4 S stores with total number of 29,664 ranged in Chinese cities 672 in 2018. A large number of scattered 4 S stores are not conducive to the recovery of power batteries. Whether it is the docking and processing unit directly docking with the 4 S shop or the docking station with a recycling network, it is necessary to solve the problem of the last mile of high-cost dangerous goods transportation.

3.2. Reverse product

So far, the recycling of retired power batteries mainly includes four reverse product positioning designs: the product, the electrode material of black powder (high purity impurity ratio substrate) product, the metal chemical salt product and the battery precursor or cathode material products. Different reverse product positioning designs determine

Table 1
China new energy vehicle sales volume, 2009–2018.

year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
BEV sales/10,000 units	0.49	0.57	0.56	1.14	2.15	2.62	24.75	40.9	65.2	98.4
PHEV sales/10,000 units	0.02	0.02	0.26	0.14	0.34	4.85	8.36	9.8	12.5	27.1
Total/10,000	0.51	0.59	0.82	1.28	2.49	7.47	33.11	50.7	77.7	125.5

Table 2
Power battery scrap quantity from 2011 to 2019 (unit: GWh).

year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Passenger car	0.01	0.07	0.2	0.27	0.39	0.39	0.75	3.24	4.61
Commercial vehicle	0	0.01	0.04	0.06	0.15	0.17	0.32	0.89	1.27

Table 3
Estimated power battery scrap in 2020–2025 (unit: GWh).

year	2020	2021	2022	2023	2024	2025
Passenger car	9.56	11.4	19.69	23.12	34.05	32.43
Commercial vehicle	1.69	4.01	4.57	4.58	6.87	14.35

the input scale and output category of recyclers, which affects the traceability of controllable recycling to a certain extent. For example, the raw materials can be retired batteries or raw ore or other chemical raw materials to produce this product for the third and fourth recyclers.

In China, such recyclers mainly use nickel cobalt lithium manganate (NCM) and nickel cobalt lithium aluminate (NCA) batteries containing metals such as nickel (Ni), cobalt (Co), and lithium (Li) to recover $NiSO_4$, $CoSO_4$, $MnSO_4$, $NiCl_2$, $CoCl_2$, $MnCl_2$, nickel cobalt manganese hydroxide, nickel cobalt manganese lithium acid, spherical nickel hydroxide, spherical cobalt hydroxide, LiOH, Li_2CO_3 and other products [50]. However, due to the large investment of such enterprises and the complicated structure of raw materials, it is difficult to determine whether the products originate from retired batteries or other waste materials. In addition, such companies highly appreciate the large-scale waste of battery plants, so their investment in the terminal recycling traceability system is extremely small. Although this traceable source of chemical smelting is included in the supervision of the Chinese government, the actual recovery rate data does not match content of retired battery. The second type of recycler wants to produce this product whose raw materials may come from non-tiered NCM retired batteries, graded end-of-life NCM batteries, battery factory NCM process waste, and consumer 18,650 batteries. Because of the difference of the shape for raw material sources, this greatly increases the difficulty of identifying the source of retired power batteries. In addition, the effect of stepwise use products on recyclable traceability is more obvious. Since the batteries used in stepwise use may come from batteries pack (P), module (M) and cell (C), which leads to many combinations' new batteries flow to the market. The application scenarios of these batteries may be in many fields such as charging treasures, electric bicycles, electric motorcycles, express trolleys, AGV trolleys, solar street lights, energy storage cabinets, etc. The secondary operating conditions and life of these batteries cannot be predicted. The huge changes in property rights will make forecasting more difficult, which will cause great difficulty to the flow direction, and will inevitably lead to a high probability that the source cannot be recovered again.

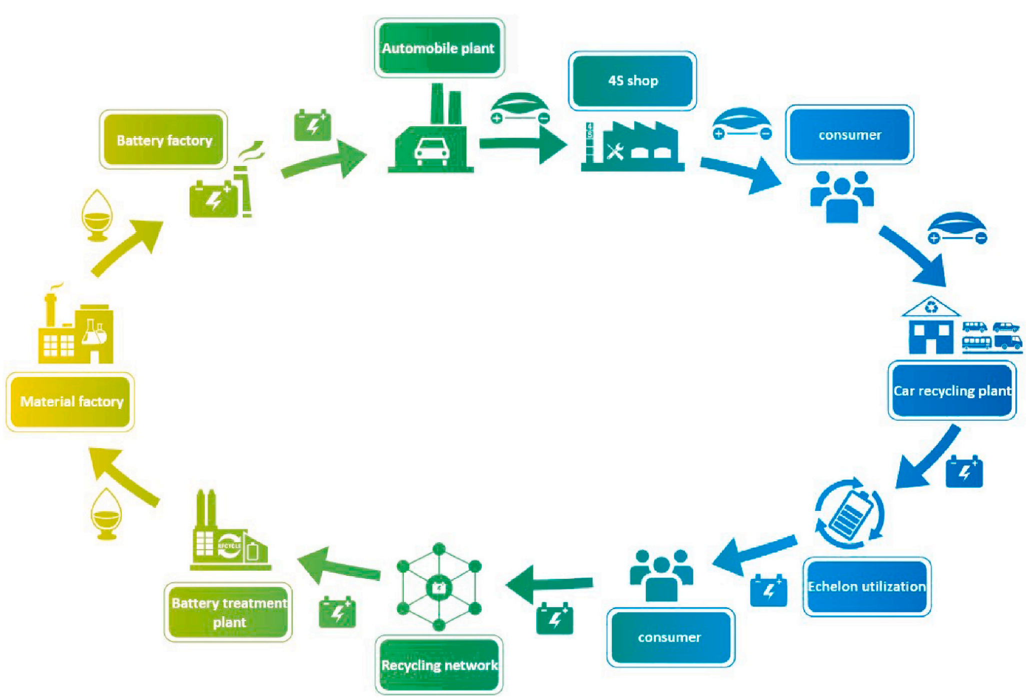


Fig. 1. Recycling process of retired power battery.

3.3. Residual value assessment

Nowadays, the detection of battery capacity requires the determination of the charge and discharge cycle by the device in a step-by-step manner, and the internal resistance needs to be tested separately for each battery. The traditional detection method has reliable results, but the longer detection cycle and the higher energy consumption. By using the training sample for training the BP neural network model Zhang et al. [51] constructed a BP neural network model to predict the remaining energy of retired lithium batteries. The estimated capacity or internal resistance results in poor reliability and no commercial application. The traditional method of testing the battery life requires a long charge and discharge cycle of batteries [52], and the detection is destructive. When the battery reaches the end of its life, the battery is irreversibly damaged. However, any product must meet reliability requirements, when batteries are sold as products with step-by-step. Zhu [53] analyzed the appearance characteristics of the battery and tested the battery for the first charge and discharge, and sorted according to the test results. By establishing a prediction model, the remaining life of the lithium ion battery was predicted. In addition, the estimation of cascade utilization life is still in the laboratory stage.

Wu et al. [54] explored the idea of building a power battery life cycle database. Based on the data of the power battery life cycle, the big data analysis was used to select the four parameters of health degree: SOH, safety reliability, consistency, and remaining life as indicators of residual value assessment. Hu and Yang [55] performed discharge detection on retired batteries to form a standard discharge curve, discharge the batteries installed at the upper station, detect and obtain the discharge current and discharge duration during the discharge process. Ma and Qiu [56] calculated the current battery capacity of the battery corresponding to the first-time interval according to the discharge current and discharge duration, and obtained the residual value evaluation result of the battery based on the calibrated capacity and the current battery capacity corresponding to the first time interval. The residual value evaluation model is not only based on the measurement and analysis of the internal components of the battery, but also mainly depends on the attributes of the recycler, its own reverse product positioning design investment, professional investment in the recycling process, and depth of the internal electrical energy life prediction technology of retired batteries, and even a comprehensive judgment of the trend of non-ferrous metal futures, etc. [57].

$$\text{Model formula design}: V = a_0 \times (\beta_0 \times b_0 + \gamma_0 \times c_0) \times (1 - d_0) + \sum_{i=1}^{3} (p_i \times \rho_i)$$

where.

$a_0$denotes the attribute of the recycler, according to the relevant equipment and technical route of the recycler, the value of the research direction and the degree of fit of the recycled product are taken, and the value range is 0.8–1.2;β_0 expresses the weight of reverse product positioning design, and the proportion of reverse product positioning design for the recycled product in the total reverse product positioning design, with a value ranging from 0 to 1; b_0 is the design input for reverse product positioning; γ_0 is the weight of the specialization input in the recovery process, and is the proportion of the specialization input in the total recovery process for the recovery process of the recovered product, and the value range is 0–1; c_0 is the professional input of the recycling process; d_0 is the depth of the battery life prediction technology, and the value range is calculated based on the enterprise battery life prediction technology depth capability calculation; p_i is the non-ferrous metal futures price of Ni, Co, Li metal respectively; ρ_i is the metal content of the internal components Ni, Co, and Li in the battery material safety data sheet.

It is not difficult to see from the logical structure of the model formula that, except for the absolute value of the internal substance composition of the battery, any slight change in any of the other variables will affect the result of this residual value assessment. The method and result of the residual value assessment directly determine the flow direction and channel of the retired battery, and further determine and influence the recyclable source of the power battery [58]. This is why in Chinese power battery recycling market, buyers and sellers are unwilling to implement the green traceable recycling in accordance with the international contract spirit of the extended producer responsibility system. The seller always feels that the price given by the buyer is not high enough, which has promoted battery companies, car companies and other battery property owners who are enthusiastic about the “highest bidder” auction model, hoping to bid for the highest residual value through auctions; and buyers know that profit Increasingly meager circumstances, have to find various ways to find a quick monetization channel to make money, reduce costs as much as possible, and the safety and environmental responsibility of the whole life cycle traceability is ignored. This malformed value model and business concept is also one of the important factors that seriously affect the traceability of recyclable batteries.

3.4. Processing cost

Retired battery treatment costs and residual value assessments have similarities and differences. Retired power battery processing cost model is related to the recycler attributes, own reverse product positioning design investment, professional investment in recycling process, and comprehensive operation capabilities, etc.

$$\text{model formula design}: V = a_1 \times (\beta_1 \times b_1 + \gamma_1 \times c_1) / e_1^2$$

where.

a_1 is the property of the recycler, according to the relevant equipment, technical route, research direction of the recycler and the degree of fit of the recovered product, the value range is 0.8–1.2; β_1 is the weight of reverse product positioning design, the proportion of reverse product positioning design for the recycled product in the total reverse product positioning design, and the value range is 0–1; b_1 is the investment in reverse product positioning design; γ_1 is the weight of the specialized input in the recycling process, and the proportion of the specialized input in the recycling process to the total recycling process input, and the value range is 0–1; c_1 is the professional input for the recycling process; e_1 is the comprehensive operating capability, which is determined based on the information related to the production cost of the company’s products, such as the completeness of the product line equipment and the efficiency of the company’s work, and the value range is 0.8–1.2.

Through the logical structure of the model formula, we can know that the attributes of different recyclers determine the one-time investment in fixed assets, the annual depreciation value, the design and development cost value of different reverse products, the comprehensive operation input, and the variable value of the rapid realization ability. For example, from the perspective of the variable value of fixed asset investment alone, the cascade utilization is the smallest, followed by the electrode material black powder (high purity impurity ratio substrate) recyclers, and the largest is the metal smelting chemical salt and battery material companies. From the analysis of smelting and material processing, pure electric vehicles mainly use lithium-ion batteries. The commonly used materials are lithium iron phosphate, nickel-cobalt manganate (commonly known as ternary materials), lithium manganate, etc; Hybrid vehicles mainly use nickel-metal hydride batteries. Different processing technologies are used according to the different battery materials, and different processing technologies have their own inherent processing costs. There are usually wet smelting and pyrometallurgical smelting for ternary materials. Chinese companies generally use wet smelting. Representative companies include Brunp, GEM, Haopeng, Huayou, Changyou, Jintaige, Fangyuan. Fire smelting has applications in Belgium and represents Umicore [59]. Pyrometallurgical technology uses high-temperature reduction smelting technology to obtain nickel-cobalt alloys. The nickel-cobalt alloys obtained usually require further recycling through wet smelting technology to obtain higher purity metal salts or battery materials [60]. Wet smelting can recover metal salts with higher purity from electrode materials by leaching, solvent extraction, chemical precipitation, and electrochemical methods. The metal recovery efficiency is high, but the recovery process is long and the consumption of chemical reagents is large [61].

Wet smelting technology usually uses inorganic acid (such as sulfuric acid) as the leaching agent. After removing aluminum, iron, calcium, and magnesium impurities in the leaching solution by chemical precipitation, it uses P204 and P507 and other extraction agents to further separate and purify valuable Metal nickel and cobalt. Subsequently, it is recovered by electrochemical or crystallization methods to prepare metal salts such as nickel and cobalt. The recovery rate of nickel and cobalt in the recovery process can reach 98% [62]. The wet smelting recycling process is long, the recycling cost is high, and the value of recycled products is high. However, for the recycling of low-value power batteries such as lithium iron phosphate, the number of recycled products is low and the value is low, which cannot achieve profitability [63]. Pyrometallurgical technology is to place the battery in a high-temperature furnace for reduction and melting. Organic matter and graphite in the battery provide heat as a carbon source, and valuable metal components are reduced to obtain a nickel-cobalt alloy. Lithium and aluminum enter the slag to obtain the nickel-cobalt. The alloy also needs to be further processed through the wet smelting process to recover chemical raw materials [64]. As low-value power batteries such as lithium iron phosphate do not contain metals such as nickel-cobalt, most of the metals enter the slag resulting in cannot be effectively recovered. The pyrometallurgical smelting technology is not suitable for processing lithium iron phosphate batteries. The pyrometallurgical smelting technology has a short process flow, lower processing costs, and lower value of recycled products [65]. In addition, different recyclers use different recycling processes, different recycling processes produce different secondary products and comprehensive costs so under the premise of the same raw material substance, the processes and results are diverse. With this ever-changing business logic and market, it is difficult to find an objective standard cost. This led to a unilateral negotiation mechanism which is one project one discussion. Under such a mechanism, disorderly or vicious competition is unavoidable, and the inevitable result will affect the recyclable source of power batteries.

3.5. National policy

Because most local governments and enterprises believe that the selected pilot projects promoted by the Ministry of Industry and Information Technology can enjoy state funding and have a favorable impact on local industries and the economy, the national pilot is basically equivalent to the full implementation of all provinces and cities in China. Because of the introduction of this policy, various capitals have poured into the industry, and recycling companies have been quickly established in various cities in China. Local governments have also actively established territorialized traceability management systems, which has led to the rapid recovery of high-priced auctions in the recycling industry across the country, and retired power batteries quickly flow to various places throughout the country, and the recycling traceability information between local governments cannot be shared. Recycling companies are facing repeated entry of battery information in producing and processing cities. And other departments to enter recycling information. Therefore, the existence of such information islands and the repeated construction of the supervision system are also one of the important reasons affecting the traceability of the entire recycling industry.

3.6. Outlet mode

The system requires the establishment of recycling outlets, but there is no policy for the recovery mode of power batteries. Tao and Jia [66] analyzed the recycling mode under the producer responsibility system, the recycling mode with the vehicle company as the main body, and the mandatory recycling policy mode, and proposed the implementation of new energy based on the premise of binding power batteries and electric vehicles based on coding. Regarding the registration and use system in automobiles, consumers will take the initiative to hand over retired power batteries to power battery processing units. Zhu and Chen [67] took the retired power batteries generated by electric vehicles sold by SAIC as the research object, established an evaluation index system, and studied the selection of the reverse logistics mode of decommissioned power batteries using fuzzy comprehensive evaluation method. Regardless of the outlet mode, the first condition is to ensure that the power battery can be effectively, traceably, cost-effectively, and sustainably recycled. The author believes that new energy vehicles should be scrapped, and power batteries should be encouraged to be sent to the dual-qualified factories with qualifications for recycling and disassembly of power batteries and scrap cars for recycling and disassembly. The scrapped cars and power batteries should be disassembled and recycled in the same plant area. Utilization can reduce the number of packaging and transportation as much as possible. If the power battery pack (P) is scrapped, it should be diagnosed and evaluated at the first-level outlets, and the unit module safety stock. If it is module (M) and cell (C) scrapped, it should be shortened the transport radius for reducing safety risks. However, it is regrettable that at present, Chinese recyclers do not scan the product manufacturing code (PMC) to collect information at the recycling outlets, which is also one of the factors affecting the traceability of recyclables.

3.7. Coding problem

It is safe to say that the coding problem is at the core of all factors that affect recoverable traceability. Regardless of the implementation of funds, deposits, subsidies or penalties, or what kind of business model or power materials to recycle, all batteries need to be accurately identified and uniquely matched, otherwise repeated subsidies or fraudulent payments are likely to occur. In order to increase the residual value of the battery, the life of the battery needs to be accurately predicted, and the historical operating data must be used to match the life estimation model when predicting the life. At this time, each battery must also be accurately labeled. However, there are currently battery codes, car VIN codes, and recycling codes. The three-code coding rules are different and cannot be interoperable. Battery coding is the coding of battery packs/modules/cells individually by battery manufacturers in accordance with national coding rules [68] when power batteries are produced. The car VIN code is a code that each automobile is coded by an automobile manufacturer in accordance with the coding rules [69] stipulated by the state during the production of electric vehicles. Recycling code is a code for each battery pack/module/cell individually by the recycling company according to the internal rules of the enterprise when recycling the power battery.

Except for different coding rules, each code has a different application purpose and has no uniform attributes. For example, the battery code itself should be a one-dimensional code or two-dimensional code compiled for the purpose of managing information collection in the process of production, sales, use, scrapping, recycling, and utilization (to the comprehensive utilization enterprise) of power batteries. However, in fact, the purpose of the battery code is mainly for filing on the market. As long as the filing on the market is completed, it means that the identity issue given to the battery has been resolved. The car VIN code itself is a series of numbers and letters combined with codes to manage information collection in the process of production, sales, use, scrap, recycling, and utilization (to the scrap car dismantling enterprise). But in fact, the car VIN code is mainly used for vehicle registration. As long as this action is completed, it means that the historical mission of the vehicle code has ended. The battery recovery code itself is a series of numbers and letters combined with codes for managing power battery information collection during the collection, disassembly, classification, step utilization, metal recycling, resource regeneration, and waste disposal processes [70]. However, the recovery code is mainly used for general statistical management of the internal goods of the recycler. Some companies have not established a recovery code and can also recycle batteries.

In addition, the Ministry of Public Security has established a complete vehicle management system based on the VIN code, the Ministry of Industry and Information Technology has established a battery traceability system based on battery codes, and each recycling company has established a comprehensive battery processing system based on recycling codes. The three-code encoding rules are different, and the docking platforms are different. In particular, the current recycling code has no national standard and is applied based on the information management system independently developed by each enterprise. Each enterprise has different encoding rules and cannot be interconnected and interoperable. The management systems are also different, and the management links and objects of traceability are also different. Each character in the code has a different meaning. It is not easy to bind electric vehicles and power batteries, and it is difficult to accurately trace the source of power batteries in the entire process of production, sales, use, scrap, recycling and utilization. Therefore, in order to open up the information islands that cover the entire life cycle of retired power batteries, it is very important to establish a three-code in one traceability system.

4. Theory and method of three codes in one

At present, all stages of the whole life cycle of retired power batteries are respectively in the charge of relevant departments. For example, the information platform of the Ministry of industry and information technology is managed by the Ministry of industry and information technology, the information platform of the Ministry of Commerce and the information platform of the Ministry of public security are jointly managed by the Ministry of Commerce and the Ministry of public security. The information in three platforms are not shared, communicative, and accurate, and it is difficult to coordinate battery life cycle information. This paper starts from the recycling end, analyzing the embedding rule of the three codes, revealing the source code coupling relationship, checking the internal logic of the three codes, and establishing the three codes in one sharing information platform. Based on the battery recycling information, the battery production information, vehicle circulation information and battery retired information are gathered, the three kinds information back-end are integrated, and the information for government agencies such as the Ministry of industry and information technology, the Ministry of Commerce, the Ministry of public security, as well as the enterprise units of battery production enterprises and battery recycling enterprises is provided, so as to make the battery product information truly traceable in source, controllable in node, traceable in destination and accountability. The logic schematic diagram of three code in one is shown in Fig. 2.

4.1. Analysis of automobile coding structure

The VIN number is the vehicle's identity card, and its meaning and function are similar to the person's identity card. China's current standard GB 16735–2019 *road vehicle identification code (VIN)* stipulates that the vehicle identification code is composed of three parts: the world manufacturer's identification code (WMI), the vehicle description part (VDS) and the vehicle indicator part (VIS), with a total of 17 characters [71], the world manufacturer identification code is used to identify the manufacturer of the vehicle; the vehicle description part is used to describe the general characteristics of the vehicle, and the vehicle indication part is a set of codes developed by the vehicle manufacturer to distinguish different vehicles. Because the number of manufacturers with large capacity is less, but the number of vehicles manufactured by them is more, more digits are needed to distinguish the vehicles manufactured by these manufacturers; the number of manufacturers with small capacity is more, but the output is not high, so more digits are needed to distinguish different vehicle manufacturers for these. Therefore, when the basic content and number of components are specified, the standard divides the vehicle identification code into two formats based on the capacity of the vehicle manufacturer: for the vehicle

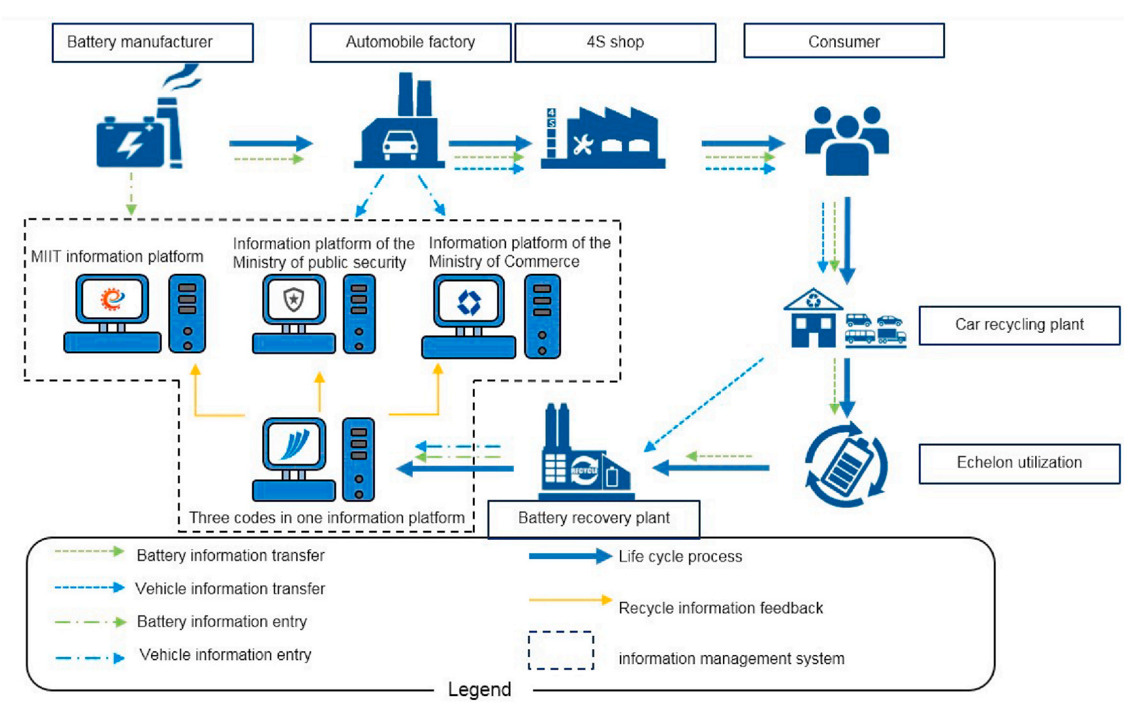


Fig. 2. Logic diagram of three codes in one.

manufacturer with annual production of complete vehicle and/or incomplete vehicle≥500, the first part of the three character code is used (see Fig. 3(a)); for a vehicle manufacturer with a production capacity of less than 500 vehicles, its manufacturer's identification code consists of three characters in the first part and three, four and five characters in the third part, a total of six characters (see Fig. 3(b)).

Only Arabic numerals and capital Roman letters other than I, O and Q shall be used in the vehicle identification number. For the first part of vehicle identification code, according to the provisions of GB 16737-2019 *Road vehicle world manufacturer identification number (WMI)* [71], the first two digits of China's vehicle manufacturer identification code are L0-L9 or LA-LZ; for the second part of VDS, the standard can be put forward in the vehicle characteristics description of informative Appendix B from the following aspects Description: Vehicle type, including passenger car, truck (including tractor), bus, trailer, motorcycle, moped and incomplete vehicle; Vehicle structure features, including body type and drive type . Vehicle device features, including engine characteristics, restraint system type, transmission type, suspension type, brake type, transmission mode/start Method; and technical characteristics parameters of vehicle, including dimension parameters, mass parameters, etc. The standard further specifies the characteristics of different types of vehicle models (see Table 4).

Except for the characteristic information of the vehicle, an inspection code is set in the VDS to check the accuracy of the vehicle identification code record. The inspection code is the last digit of the VDS (that is, the ninth character code of the VIN). In the third part of the VIN, the first character of the vehicle indication part represents the year of manufacture and the second represents the assembly plant. If the annual production of complete vehicles and/or incomplete vehicles produced by the vehicle manufacturer is ≥ 500, the remaining 6 digits of this part are used to indicate the production sequence number. In other cases, the third, fourth and fifth digits of this part together with the three digits of the first part represent a vehicle manufacturer, and the remaining 3 digits are used to indicate the production sequence number. Through the analysis of vehicle VIN code, it can be found that the vehicle VIN code mainly carries the character segment of vehicle manufacturing information, which is relatively simple in structure. In the process of one-dimensional or two-dimensional information transformation, it can inherit the vehicle model (commercial or passenger) information well, and the manufacturer information and serial number can be given up selectively, so that 50%-character segment information can be obtained simply. The remaining space of the code can be used for the secondary matching and recombination of the battery code without affecting the cancellation of the vehicle in the public security system.

Table 4
Model features to be included in VDS for different models.

Vehicle type	Vehicle characteristics
Family car	Body types and Engine types[a]
Truck (including tractor)	Body types, Maximum gross vehicle mass and Engine types[a]
Passenger car	Vehicle length and Engine types[a]
Trailer	Body types and Maximum gross vehicle mass
Motorcycles and mopeds	Vehicle types and Engine types[a]
Incomplete vehicle	Body types[b], Maximum gross vehicle mass[b] and Engine types[c]

[a] The engine characteristics shall at least include a description of the fuel types, displacement and/or power.
[b] A description of the incomplete vehicle used to make a train.
[c] A description of the incomplete vehicle to be manufactured as a passenger car, in which case the engine characteristics shall at least include a description of the fuel types, engine arrangement types, displacement and/or power.

4.2. Analysis of battery coding structure

Similar to the vehicle identification code, the vehicle power battery code represents the identity of the vehicle power battery product. China's current national standard of GB/T 34,014–2017 *coding rules for automotive power batteries* is the first domestic standard on battery coding rules, which was implemented on February 1, 2018. The standard specifies the coding object, code structure, code identification method and data carrier of automotive power battery. It is not only suitable for automotive power batteries, but also for super capacitors and other rechargeable energy storage devices [72]. The national standard of

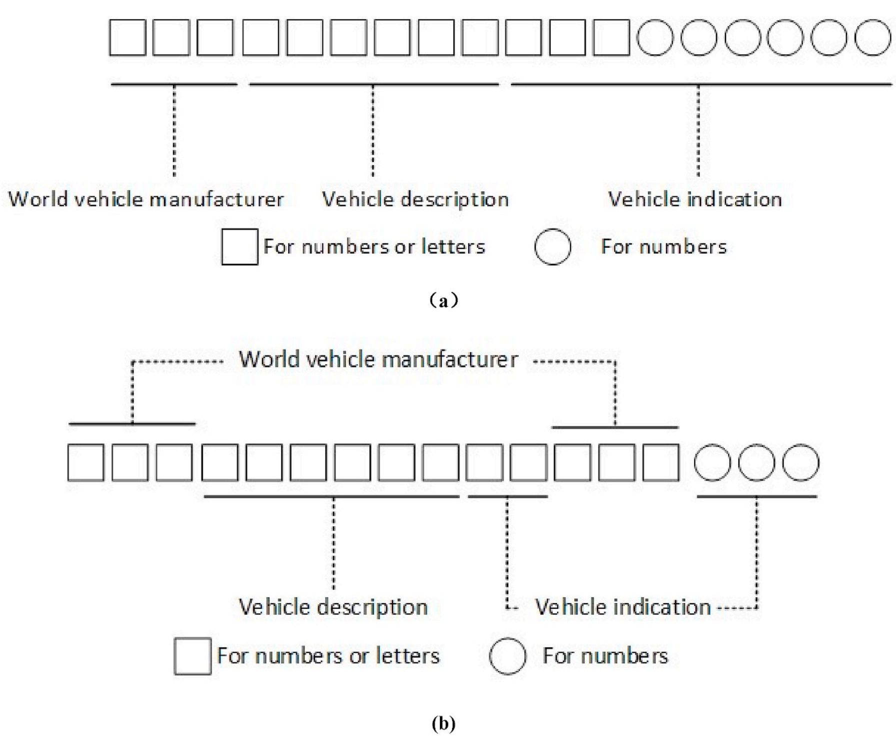


Fig. 3. Structure diagram of vehicle identification code.

GB/T 34,014-2017 divides coding information into two parts: the first part of design information and the second part of production information, shown in Tables 5 and 6. The two parts are composed of basic structure information and extended structure information. The contents of each part are as follows:

The coding code is represented by Arabic numerals 0–9 and English capital letters, among which the manufacturer code is assigned by the competent department, and the product type code is one of P, M and C, which corresponds to the battery pack, battery module and battery cell respectively, and the battery type is also only one digit, which is represented by English letter, as shown in Table 7.

The production date code has three digits, respectively representing the month, year and day of production, and the serial number is composed of seven digits. The cascade utilization code is only applicable to the cascade utilization products, which is represented by two capital English letters-RP representing direct cascade utilization of power battery package, RM representing direct cascade utilization of battery module, and RC representing single battery cascade utilization.

For new power battery products, the code is 24 digits in total:

For the products of step-by-step power battery, the code is 19 digits in total:

The differences between them are as follows:

(1) The new power battery products have traceability information codes, while the cascade power battery products have no traceability information codes;
(2) At the end of the step utilization power battery product, a 2-digit special step utilization code must be added.

It should be noted that for the cascade utilization products, the original power battery product code needs to be retained. The standard does not specify the information to be included in the traceability information code, nor does it unify the coding rules of this part of the code. The author speculates that it may be used to trace the product flow within the enterprise. In addition, for the multi-level use of the battery products, the author thinks that the product code should include the product code of the multi-level use of the battery products in addition to the original power battery product code, so as to realize the traceability of the related cascade use enterprises. Under this premise, in order to avoid over coding, the coding rules of multi-level echelon utilization products may need further research and discussion. Through the analysis of the battery code, it can be found that the battery code mainly carries the battery manufacturing information character segment, the structure is more complex than the vehicle VIN code, and it also involves the multi-level problem of pack (P)-module (M)-cell (C). Due to the uncertainty of P, the battery factory may only be the manufacturer of C, or the manufacturer of M. Therefore, the integration of P is particularly important. MC source code information should be enriched and bound with VIN to realize the integration of battery code and body code.

However, on March 9, 2018, China Automotive Technology Research Center held a seminar on "construction of traceability management system of new energy vehicle power battery" in Beijing. At the seminar, battery and vehicle manufacturers reported their problems in traceability management filing, one of which was that the filing code could not be entered, which indicated that the current customized code part still needs to be improved. However, nearly two years later, the revision of power battery recycling coding rules and standards has not been put on the agenda. This further shows that there is a mechanical blocking problem between the battery code and the vehicle body code VIN code. There is no character segment of the same structure between the two codes, and there is no interworking of the logical architecture. At the beginning of the design, the compatibility of the two codes has not been considered. Under the premise of the integration of one or two codes, if the recycling enterprises continue to operate at will in the recycling code link, it will be difficult to fundamentally solve the problem of out of control flow of retired power batteries. Therefore, it is very important and urgent to consider deeply binding battery code and vehicle VIN code when decommissioning the power battery.

Table 5
Design information code structure.

Basic structure	Extended structure 1	Meaning
X1 X2 X3 X4 X5 X6 X7	X8 X9 X10 × 11 X12 × 13 X14	
X1 X2 X3		Manufacturer code
X4		Product type code
X5		Battery type code
X6 X7		Specification code
	X8 X9 X10 × 11 X12 × 13 X14	Traceability information code

Table 6
Production information code structure.

Basic structure	Extended structure 2	Meaning
X15 × 16 X17 × 18 × 19 × 20 X21 × 22 X23 × 24	X25 × 26	
X15 × 16 X17		Production date code
X18 × 19 X20 × 21 × 22 × 23 X24		serial number
	X25 × 26	Step utilization code

Table 7
Battery type code description.

Battery type	Code
Nickel metal hydride battery	A
Lithium iron phosphate battery	B
Lithium manganate battery	C
Lithium cobalt battery	D
Ternary material battery	E
Supercapacitor	F
Lithium titanite battery	G
Others	Z

4.3. Analysis of recovery coding structure

Battery recycling code is developed and used by each battery recycling enterprise. Each enterprise compiles battery information, recycling information and system requirements according to its own. The recycling code of a battery recycling enterprise in China is shown in Fig. 4. where.

KD indicates the code of the battery recycling enterprise, which is the prefix of the code identification used internally, and does not account for the number of coding digits; The manufacturer's code is the code compiled by the battery recycling enterprise to the cooperative unit, which is composed of 1-digit letter code and 2-digit code; The warehousing date code is 6-digit code, which is respectively mm/DD/YY, and the year, month and day are composed of 2-digit code; The batch code is a 2-digit number code to distinguish the power battery recycling of each batch in a day; The battery code is one letter code B, for distinguish the power battery from other auto parts; The material code is a 4-digit code, which matches the material type code in the internal warehouse code of the enterprise; The material serial number code is a 2-digit code to represent different battery packs in the same batch. The serial number of the battery module under the current package is a 2-digit code, which is used to associate the module disassembled from the same battery package with the corresponding battery package; The serial number of the battery cell under the current module is a 4-digit code, which is used to associate the cell obtained from the disassembly of the same battery pack and battery module with the corresponding battery pack and

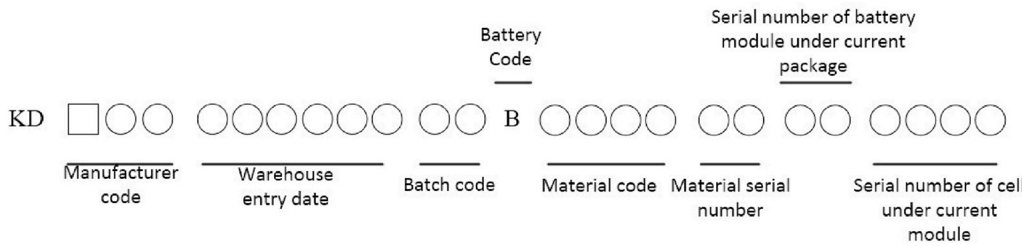


Fig. 4. Coding structure of power batteries.

module.

Example: Power Battery Code: kdb132019082802b500010310032, the meaning of each code is as follows:

KD is the KD battery recycling company, B0 is the BM company by checking the supplier table, 2,019,082 represents the storage time of power battery, 02 is the second batch, B is the battery code, 5001 is the material type code of package, 01 is the first package, 03 is the third module under the first package, 0032 is the 32nd monomer under the third module in the first package.

Through the analysis of recycling code, we can find that among the recycling enterprises in operation in China, enterprises with recycling traceability system, whose recycling code mainly carries the recycling stock information character segment, including the basic functions of purchase, sale and storage, with relatively simple structure, and characterized by the flow record function. If we want to inherit the battery and vehicle source code information as well as the secondary flow direction battery information, the character segment structure of the recycling code needs to be topology extended, and has the conversion function of one and two dimensions. Based on the analysis of the current situation of the three codes, the author thinks that it has the core conditions of building the three codes in one. According to the input and output logic architecture of "source code input gene inheritance" and "flow output gene association", the "three codes in one" infrastructure is built with the recycling end as the control core.

4.4. Three codes in one logic architecture

According to the principle of "three codes in one" infrastructure, the coding design is shown in Fig. 5 with 37 bits in total, which are divided into three parts: input, output and control end. From left to right, the first part is battery production information part (11 bits), the second part is automobile information part (13 bits), and the third part is battery recovery information part (13 bits). The battery production information part includes: battery manufacturer code (3 digits), product type code (1 digit), battery type code (1 digit), specification code (2 digits), battery production date code (3 digits), echelon utilization code (1 digit). The automobile information part includes: WMI code (3 digits), VDS code (6 digits), automobile year code (1 digit), WMI supplementary code (3 digits). The battery recovery information part includes: recovery date (3 digits), batch code (2 digits), battery pack serial number (2 digits), serial number of battery module under current package (2 digits), serial number of battery unit under current module (4 digits).

The vehicle related codes in this set of coding rules mainly refer to GB 16735–2019 *road vehicle identification number (VIN)*; the coding of battery pack adopts the content applicable to power battery pack in GB/T 34,014–2017 *coding rules for automotive power battery*, and the biggest difference between this coding and GB/T 34,014–2017 is to add module traceability code and single traceability code Trace the battery pack, module and battery cell. The coding rules are as follows:

In the first part, the battery manufacturer code includes manufacturer, cascade utilization manufacturer and importer. It is represented by three English capital letters, numbers 0–9 or combination of letters and numbers, and uniformly distributed by the industry management department, which is consistent with the battery manufacturer code in the coding rules of automotive power battery. The product type code, battery type code, specification code and battery production date code in the first part are consistent with the relevant requirements in GB/T 34,014–2017. In the first part, the echelon utilization code is expressed in capital letters. For batteries without echelon utilization, "0" is used. For batteries with one echelon utilization, "F" is used. For batteries with two echelon utilization, "S" is used. For batteries with three echelon utilization, "T" is used. The content requirements of WMI code in part II are consistent with the relevant requirements in GB 16735–2019. The content requirements of the VDS code in the second part are consistent with the relevant requirements in GB 16735–2019. The first five digits of the VDS code are vehicle characteristic code, and the sixth digit of the VDS code is inspection code. The calculation method of the inspection code is as follows. The 20th character code of recycling code (the 6th digit of VDS code in the second part) is inspection code, which can be any number or letter "X" in 0–9. After determining the other 34-bit code,

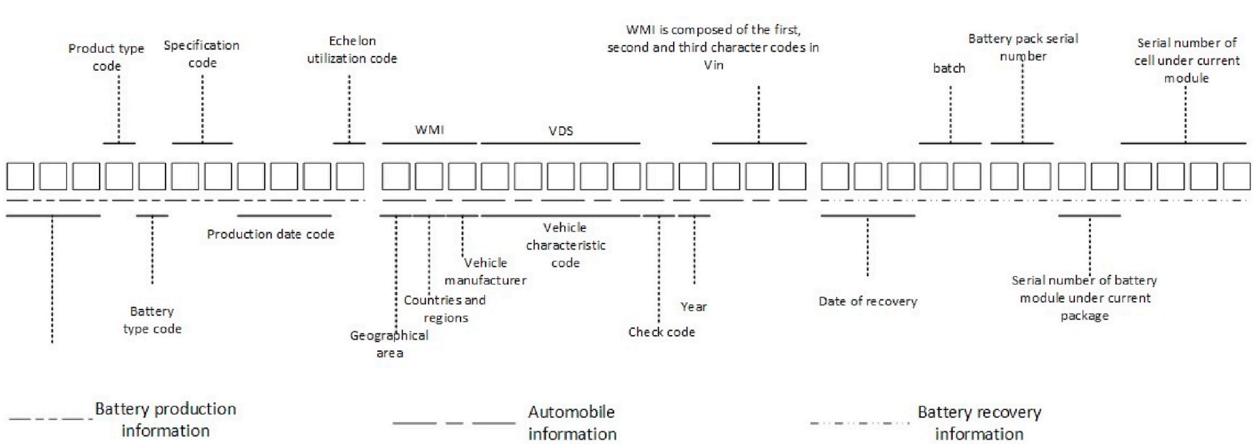


Fig. 5. Schematic diagram of integrated coding structure.

the recovery code shall be calculated by the following method.

a) The corresponding values of numbers and letters in the recycling code are shown in Tables 8 and 9.

The recovery code without check code is: 201CE0366D0LBVKY910KR929AB121A412351

Example:

$$\text{check code} = \text{rem}\left(\begin{array}{l} 2\times 8+0\times 7+1\times 6+3\times 5+5\times 4+0\times 3+3\times 2+6\times 10+6\times 9+4\times 8 \\ +0\times 7+3\times 6+2\times 5+5\times 4+2\times 3+8\times 2+9\times 10+1\times 9+0\times 8 \\ +2\times 7+9\times 6+2\times 5+9\times 4+1\times 3+2\times 2+1\times 10+1\times 9+4\times 8 \\ +1\times 7+2\times 6+3\times 5+5\times 4+1\times 30 \end{array}\right) \Big/ 11 = 2$$

Then the complete recycling code is: 201CE0366D 0LBVKY9102KR929AB121A412351.

The content requirements of vehicle year code in part II are consistent with the relevant requirements in GB 16735–2019. The WMI supplementary code in the second part is the VIS code of the third to fifth digits in the VIN code consistent with the relevant requirements in GB 16735–2019. For the power battery that is not loaded (such as the internal test battery of the power battery manufacturer), the codes of the second part are all supplemented with 0. The recovery date code in part III is represented by three capital letters and numbers. The first digit is the year, the year code is used in accordance with Table 4 in GB 16735–2019 (once every 30 years), the second digit is the month, in hexadecimal value, and the third digit is the natural day, which is used in accordance with Table 5 in GB 16735–2019. The batch code in the third part is represented by two capital letters and numbers, hexadecimal values, and is defined by the enterprise itself. The battery pack traceability code in the third part represents the relationship of each battery pack in each batch, which is defined by the enterprise itself. In order to realize the traceability function of the code, each enterprise needs to establish a special database and information platform for authorized users to query and obtain the information of battery pack on the platform by inputting specific battery pack traceability source code. The module trace code in the third part represents the corresponding relationship between the battery pack and the constituent module, which is defined by the enterprise itself. In order to realize the traceability function of the code, only the code is not enough. In addition, a special database and information platform should be established for authorized users to query and obtain the information of battery pack components on the platform by inputting the codes of the aforementioned parts of the battery pack. The monomer traceability code in the third part represents the corresponding relationship between the battery pack and the constituent monomer, which is defined by the enterprise itself. The realization of its traceability function also requires the establishment of a database for authorized users to access, and by inputting the codes of the preceding parts of the battery pack (including the module traceability code) to obtain the monomer information of each module of the power battery pack on the designated database.

Table 8
Number corresponding value.

Recycle numbers in code	0	1	2	3	4	5	6	7	8	9
Corresponding value	0	1	2	3	4	5	6	7	8	9

5. Application analysis of three codes in one

According to the principle of "the source can be checked, the destination can be traced, and the nodes can be controlled", this paper designs the overall framework, and carries out the actual scene application for the battery manufacturers, automobile sales and users, battery recycling manufacturers and other roles. Through the three in one technical means and methods, the whole battery life cycle is penetrated, and the management methods for the battery life cycle are provided.

This chapter will introduce the application effect of the three code in one technology from the practical application cases of the three ports of the sales end, the circulation end and the processing end. As shown in Fig. 6, it is the platform system home page.

As shown in Fig. 6, the main interface of the three in one information management system will display the relevant information of the three in one code (Information acquisition system, Analysis and decision system, Data sharing system, Information inquiry system, etc.), which is entered by the recycling personnel and can be edited only by the information management personnel.

5.1. Three in one application case (sales side)

The sales side, as the starting point of entering the market after the installation of power batteries, represents the source of the retired power battery with a lot of information about the battery and automobile products. The three in one code is designed by combining the battery production design information, relevant vehicle parameter information and echelon utilization information, so that the battery recovery enterprise can trace the front-end information, and the recovery enterprise determines the power battery recovery process flow according to the battery production related information, the new energy vehicles and echelon utilization information carried, and feeds back to the sales side of power batteries The missing part of the destination information of the power battery at the sales side provides the content required for data information integration for the power battery sales side, and improves the product management of the whole life cycle of the power battery. The information that the sales side can query is shown in Fig. 7. The sales side can query the recycling situation of the sold battery through the three in one code information management system, and can know when, where and by whom the battery is recycled, and can obtain the relevant information of the recycling processing link through the system (recycling processing time node, recycling material information).

The application case is located in Shanghai, which is being used by Shanghai SA automobile company and its 20 4 S stores in 25 cities across the country. At present, 2100 pieces of operation information from installation to sales have been collected. At the same time, the information should be synchronously shared to its battery pool supplier and recycling service provider through ports with different authorities for the maintenance and recycling of battery circulation link in advance Police.

5.2. Three codes in one application case (flow terminal)

The flow terminal, as the longest link of the whole life cycle of power batteries, has a lot of problems of information non interoperability. According to the three code in one method, the establishment of three

Table 9
Letter corresponding value.

b) Assign a weighting factor to each bit in the recovery code according to Table 10.

Recycle numbers in code	A	B	C	D	E	F	G	H	J	K	L	M
Corresponding value	1	2	3	4	5	6	7	8	1	2	3	4
Recycle numbers in code	N	P	R	S	T	U	V	W	X	Y	Z	
Corresponding value	5	7	9	2	3	4	5	6	7	8	9	

Table 10
Weighting coefficient.

c) Multiply the weight coefficient of each 36 bits of the test code by the corresponding value of this digit or letter, then add the products, and the sum obtained is divided by 11.
d) The remainder divided is the inspection code. If the remainder is 10, the inspection code is the letter X.

Recycle numbers in code	1	2	3	4	5	6	7	8	9	10	11	12	13
Corresponding value	8	7	6	5	4	3	2	10	9	8	7	6	5
Recycle numbers in code	14	15	16	17	18	19	20	21	22	23	24	25	26
Corresponding value	4	3	2	10	9	8	*	7	6	5	4	3	2
Recycle numbers in code	27	28	29	30	31	32	33	34	35	36	37		
Corresponding value	10	9	8	7	6	5	4	3	2	10	9		

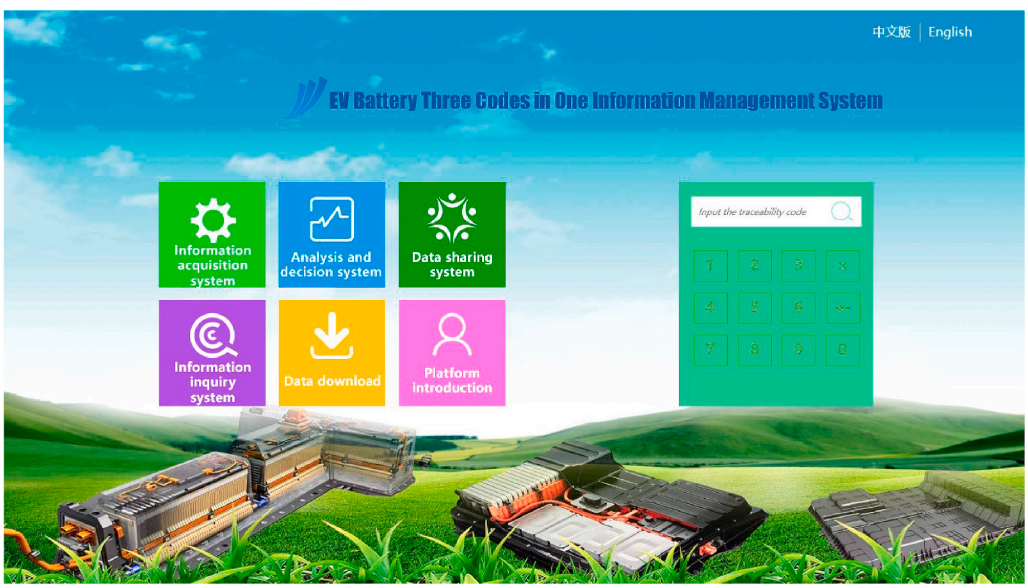


Fig. 6. Three codes in one information management system information home page.

code in one information platform can provide recycling information feedback for flow terminal, make the battery related information and automobile related information establish a connection, so as to make them more compatible, and provide the direction for automobile enterprises information. As shown in Fig. 8, the information can be inquired at the flow terminal. The information content that can be obtained by the flow terminal mainly includes the transportation stage of recycling and the recycling result information, which can guarantee the safety of the recycling transportation stage for the flow terminal. Once problems are found in the recycling process, it will alarm in time and upload the information to the three code integrated information management system.

The application case is located in 20 4 S stores in 25 cities, such as Shanghai, Shenzhen, Changsha, Guangzhou, etc., which use the system and directly connect with the system platform of Shanghai SA automobile enterprise. At present, the operation information of thousands of circulation links collected has been uploaded to the system background synchronously. It includes more than 10 battery pack (P) removal diagnosis, 25 module (M) replacement records, and 3 PMC retirement information. In the operation of the flow terminal, a scanning gun with RFID function is required. Any handheld PDA can complete the scanning, and the information can be recorded and uploaded to the computer or mobile terminal in real time. The whole operation only takes a few minutes to complete, which provides a very convenient experience for information collection and upload at the flow terminal.

5.3. *Three codes in one application case (processing side)*

From the point of view of the processing side, the application of three codes in one is conducive to the management of battery recovery, making the battery production and battery use more intuitive, and for the battery recovery enterprises to collect. Through the information of the first two, a large number of available data are provided for the battery recovery enterprise process and battery recovery report. The recycling enterprise uploads the information to the platform so that the battery products can be traceable at the front end, traceable at the back end, and controllable at the fixed point. The processing side is the result of information integration of three codes. The interface is shown in Figss. 9–11.

The processing side information integrates the front-end

Fig. 7. Sales side query information window.

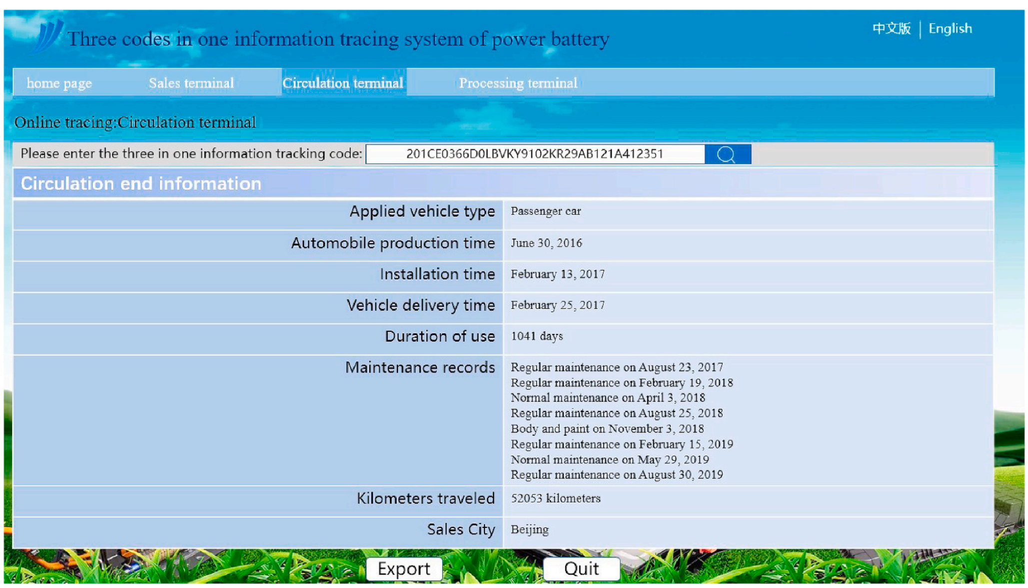


Fig. 8. Flow terminal query information window.

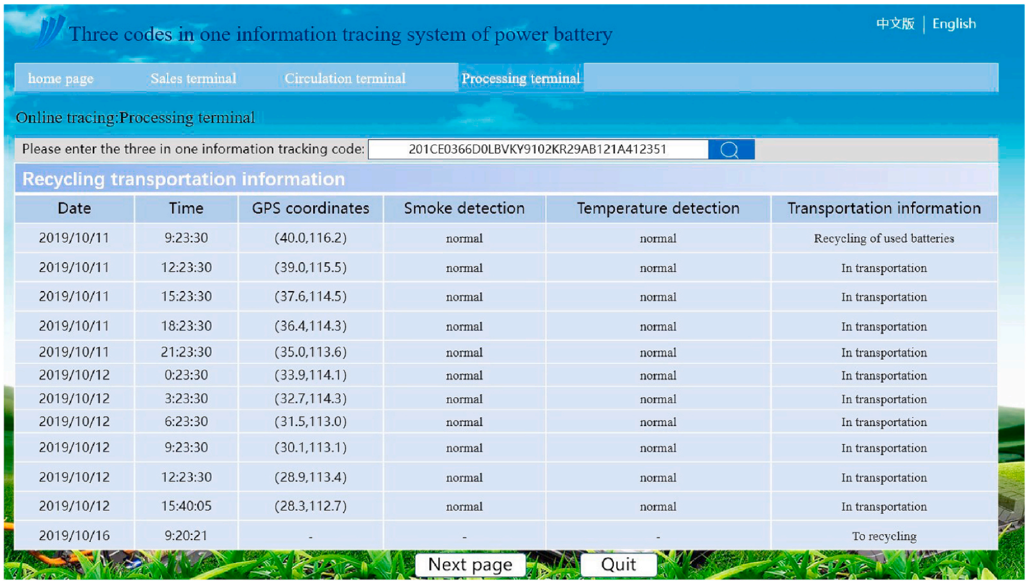
information, including battery transportation information, battery recycling processing node information, battery recycling raw material recycling information and relevant environmental reports. It can provide a lot of data information for recycling enterprises to improve product reports, and build product recycling database based on it.

The application case is located in the PX recycling enterprise in Changsha, which is directly connected with the system platforms of Shanghai SA automobile enterprise and Shenyang BM automobile enterprise. At present, the online use time should exceed 2600 h, and nearly 10,000 pieces of information in the recycling link have been collected. Including the diagnostic evaluation data, photos, packaging information, transportation path, arrival time, inspection and warehousing time, ex warehouse and disassembly time, processing and disposal time and recovery rate report data of 4 S stores nationwide. All the information is sent directly to the vehicle enterprise and the battery owner through the background in real time, so that the user can participate in the whole recycling process at the first time, so that the user has full sense of participation and right to know. It has independent and responsible supervision effect on the whole life cycle traceability of retired power battery.

Through the practical application of this case, it is proved that the three codes in one technology is feasible, leading and practical, which has a strong commercial application value and the potential of large-scale promotion and application.

6. Conclusion and prospects

Traceability is a must for filing. It is paid attention to by the national standard research and development. On February 1, 2018, the technical service center of CRRC, entrusted by the Ministry of industry and information technology and engaged in the technical review and technical services in the management process of the administrative licensing project *vehicle production enterprise and product announcement*, issued the notice on opening the vehicle power battery coding filing system (ZJH



Date	Time	GPS coordinates	Smoke detection	Temperature detection	Transportation information
2019/10/11	9:23:30	(40.0,116.2)	normal	normal	Recycling of used batteries
2019/10/11	12:23:30	(39.0,115.5)	normal	normal	In transportation
2019/10/11	15:23:30	(37.6,114.5)	normal	normal	In transportation
2019/10/11	18:23:30	(36.4,114.3)	normal	normal	In transportation
2019/10/11	21:23:30	(35.0,113.6)	normal	normal	In transportation
2019/10/12	0:23:30	(33.9,114.1)	normal	normal	In transportation
2019/10/12	3:23:30	(32.7,114.3)	normal	normal	In transportation
2019/10/12	6:23:30	(31.5,113.0)	normal	normal	In transportation
2019/10/12	9:23:30	(30.1,113.1)	normal	normal	In transportation
2019/10/12	12:23:30	(28.9,113.4)	normal	normal	In transportation
2019/10/12	15:40:05	(28.3,112.7)	normal	normal	In transportation
2019/10/16	9:20:21	-	-	-	To recycling

Fig. 9. Processing side query information window (First page).

Date	Time	Status information	Information entry personnel
2019/10/16	9:20:21	The waste power battery pack is disassembled into battery unit	Yao QH
2019/10/17	15:26:39	Discharge treatment of waste power battery	Yao QH
2019/10/17	11:46:32	Pyrolysis treatment of waste power battery monomer	Yao QH
2019/10/17	19:10:11	Crushing and sorting of waste power battery cells	Yao QH
2019/10/17	19:41:30	Regeneration of battery raw materials	Yao QH
2019/10/22	10:23:14	Recycling of used batteries has been completed	Yao QH

Fig. 10. Processing side query information window (Second page).

[2018] No. 73), which includes the general requirements and manufacturers for the filing work. The application and distribution of codes, the filing of coding rules and other aspects are described in detail. The release of this notice marks that the automotive power battery has officially entered the nationwide filing management stage, in which the filing stage is required to provide a standardized and traceable traceability scheme, which has become a necessary option.

Three in one was implanted into the national standard. At the same time, the National Standards Committee issued the national standard announcement for the identification of power battery echelon utilization. At present, the standard has entered the third round of technical demonstration stage. The standard has absorbed the technical concept and application suggestions of “three in one”. In the future, the product identification of cascade utilization will be matched with “three in one” bar code sign to ensure the recovery and traceability of retired power battery polar action.

In the future, based on the integration of three codes, the following problems should be cared and solved:

(1) The information registration, exchange, review, and reporting and disclosure system will be established and improved;
(2) The information management responsibilities and authorities of relevant responsible parties should be clearly traced, including battery manufacturers, automobile manufacturers, automobile dealers and service providers, battery dealers and service providers, echelon utilization enterprises and recycling enterprises, etc [73,74];
(3) A unified, safe, reliable and efficient national traceability information system should be built to ensure the orderly development of data management and the safety of information sharing;
(4) The change from recommendation of power battery standard to compulsory should be sped up, and the common cost of the industry should be reduced;

Material name	quality	Wastage	Recovery rate
iron	422.30	0	100.00%
Plastic	51.34	0	100.00%
nickel	27.02	0.267	98.81%
cobalt	6.89	0.068	98.96%
manganese	80.45	0.794	98.74%
lithium	15.21	0.150	98.99%
aluminum	332.64	0.527	99.84%
copper	68.35	0.602	99.05%
graphite	111.47	1.112	99.85%

Fig. 11. Processing side query information window (Third page).

(5) In line with international standards, the implementation of the extended producer responsibility system should be strengthened and the enterprise credit system must be linked with it;
(6) With the increase on the demand of xEV battery market, it attracts the attention of many researchers. It is worth noting that the new standards on xEV batteries reuse and recycling are under development.

CRediT authorship contribution statement

Haijun Yu: Writing - original draft, Writing - review & editing. **Hongliang Dai:** Supervision. **Guangdong Tian:** Supervision. **Benben Wu:** Writing - original draft, Writing - review & editing, Visualization, Investigation. **Yinghao Xie:** Visualization, Investigation. **Ying Zhu:** Investigation, Software. **Amir Mohammad Fathollahi-Fard:** Investigation, Software. **Qi He:** Visualization, Investigation. **Hong Tang:** Visualization, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Dozein MG, Mancarella P. Application of utility-connected battery energy storage system for integrated dynamic services. In: 2019 IEEE milan power tech. Milan: IEEE; 2019. p. 6.
[2] Hanisch C, Loellhoeffel T, Diekmann J, Markley KJ, Haselrieder W, Kwade A. Recycling of lithium-ion batteries: a novel method to separate coating and foil of electrodes. J Clean Prod 2015;108:301–11.
[3] Pan YJ. Recycling and reuse of spent lithium-ion battery that is used $LiFePO_4$ as cathode material. M.S. thesis. Harbin, China: Dept. Chem. Eng., Harbin Institute of Technology; 2012 [In Chinese)].
[4] China National Resources Recycling Association. 2020, the scrap volume of electric vehicle batteries will reach 120000-170000 tons. China Resour Compr Util 2016;2:43 [In Chinese)].
[5] Li L, Bian YF, Zhang XX, Guan YB, Fan ES, Wu F, et al. Process for recycling mixed-cathode materials from spent lithium-ion batteries and kinetics of leaching. Waste Manag 2018;71:362–71.
[6] Wang MM, Zhang CC, Zhang FS. Recycling of spent lithium-ion battery with polyvinyl chloride by mechanochemical process. Waste Manag 2017;67:232–9.
[7] Yun L, Linh D, Shui L, Peng XB, Garg A, Phung LEML, et al. Metallurgical and mechanical methods for recycling of lithium-ion battery pack for electric vehicles. Resour Conserv Recycl 2018;136. 198-08.
[8] Tian X, Wu YF, Hou P, Liang S, Qu S, Xu M, et al. Environmental impact and economic assessment of secondary lead production: comparison of main spent lead-acid battery recycling processes in China. J Clean Prod 2017;144:142–8.
[9] Richa K, Babbitt CW, Nenadic NG, Gaustad G. Environmental trade-offs across cascading lithium-ion battery life cycles. Int J Life Cycle Assess 2017;22(1):66–81.
[10] Ahmadi L, Young SB, Fowler M, Fraser RA, Achachlouei MA. A cascaded life cycle: reuse of electric vehicle lithium-ion battery packs in energy storage systems. Int J Life Cycle Assess 2017;22(1):111–24.
[11] Hu JT, Zhang JL, Li HX, Chen YQ, Wang CY. A promising approach for the recovery of high value-added metals from spent lithium-ion batteries. J Power Sources 2017;351:192–9.
[12] Yao YL, Zhu MY, Zhao Z, Tong BH, Fan YQ, Hua ZS. Hydrometallurgical processes for recycling spent lithium-ion batteries: a critical review. ACS Sustainable Chem Eng 2018;6(11):13611–27.
[13] Huang YF, Han GH, Liu JT, Chai WC, Wang WJ, Yang SZ, et al. A stepwise recovery of metals from hybrid cathodes of spent Li-ion batteries with leaching-flotation-precipitation process. J Power Sources 2016;325:555–64.
[14] Alvarez R, Zubelzu S, Diaz G, Lopez A. Analysis of low carbon super credit policy efficiency in European Union greenhouse gas emissions. Energy 2015;82. 996-10.
[15] Gao WF, Zhang XH, Zheng XH, Lin X, Cao HB, Zhi Y, et al. Lithium carbonate recovery from cathode scrap of spent lithium-ion battery: a closed-loop process. Environ Sci Technol 2017;51(3):1662–9.
[16] Terazono A, Oguchi M, Iino S, Mogi S. Battery collection in municipal waste management in Japan: challenges for hazardous substance control and safety. Waste Manag 2015;39:246–57.
[17] Ordonez J, Gago EJ, Girard A. Processes and technologies for the recycling and recovery of spent lithium-ion batteries. Renew Sustain Energy Rev 2016;60. 195-05.
[18] Hoyer C, Kieckhafer K, Spengler T. Technology and capacity planning for the recycling of lithium-ion electric vehicle batteries in Germany. J Bus Econ 2015;85(5):505–44.
[19] Codani P, Petit M, Perez Y. Participation of an electric vehicle fleet to primary frequency control in France. Int J Electr Hybrid Veh (IJEHV) 2015;7(3):233–49.
[20] Rodriguez AS, de Santana T, MacGill I, Ekins-Daukes NJ, Reinders A. A feasibility study of solar PV-powered electric cars using an interdisciplinary modeling approach for the electricity balance, CO_2 emissions, and economic aspects: the cases of The Netherlands, Norway, Brazil, and Australia. Prog Photovoltaics 2019. https://doi.org/10.1002/pip.3202.
[21] Caballero-Guzman A, Sun T, Nowack B. Flows of engineered nanomaterials through the recycling process in Switzerland. Waste Manag 2015;36:33–43.
[22] Uddin K, Gough R, Radcliffe J, Marco J, Jennings P. Techno-economic analysis of the viability of residential photovoltaic systems using lithium-ion batteries for energy storage in the United Kingdom. Appl Energy 2017;206:12–21.
[23] Barik SP, Prabaharan G, Kumar L. Leaching and separation of Co and Mn from electrode materials of spent lithium-ion batteries using hydrochloric acid: laboratory and pilot scale study. J Clean Prod 2017;147:37–43.

[24] Gaines L. Lithium-ion battery recycling processes: research towards a sustainable course. Sustain Mater technol 2018;17. UNSP e00068.
[25] Li L, Zhai LY, Zhang XX, Lu J, Chen RJ, Wu F, et al. Recovery of valuable metals from spent lithium-ion batteries by ultrasonic-assisted leaching process. J Power Sources 2014;262:380–5.
[26] Ministry of industry and information technology of the people's Republic of China. Interim Measures for the management of the recycling of new energy vehicle power batteries. http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c6068823/content.html/. [Accessed 25 May 2020].
[27] Ministry of industry and information technology of the people's Republic of China. Interim provisions of the traceability management of the recovery and utilization of new energy vehicle power battery. http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057542/n3057544/c6245200/content.html/. [Accessed 25 May 2020].
[28] China Locomotive and vehicle technical service center. Notice on opening vehicle power battery coding record system. http://www.dldcw.cn/News/119307.html/. [Accessed 25 May 2020].
[29] Tian GD. Research probability evaluation methods and programing models for product disassembly. PhD thesis. Changchun, China: Dept. Vehicle Oper. Eng., Jilin University; 2012 [In Chinese)].
[30] Zhu SG, He WZ, Li GM, Zhou X, Zhang XJ, Huang JW. Recovery of Co and Li from spent lithium-ion batteries by combination method of acid leaching and chemical precipitation. T Nonferr Metal Soc 2012;22(9):2274–81.
[31] Moradi B, Botte GG. Recycling of graphite anodes for the next generation of lithium ion batteries. J Appl Electrochem 2016;46(2):123–48.
[32] Swain B. Recovery and recycling of lithium: a review. Separ Purif Technol 2017;172. 388-03.
[33] Wanger TH. The Lithium future—resources, recycling, and the environment. Conserv Lett 2011;4(3):202–6.
[34] Tian GD, Liu YM, Xiong MY, Sun Y, Chu JW, Xu G. Quantitative analysis method of product disassembly cost based on maximum entropy principle. J Jilin Univ 2011;41(6):641–5 [In Chinese)].
[35] Wang X, Gaustad G, Babbitt CW. Targeting high value metals in lithium-ion battery recycling via shredding and size-based separation. Waste Manag 2016;51:204–13.
[36] Boyden A, Soo VK, Doolan M. The environmental impacts of recycling portable lithium-ion batteries. In: 23rd CIRP conference on life cycle engineering, berlin. vol. 48; 2016. p. 188–93.
[37] Schauerman CM, Ganter MJ, Gaustad G, Babbitt CW, Raffaelle RP, Landi BJ. Recycling single-wall carbon nanotube anodes from lithium ion batteries. J Mater Chem 2012;22(24):12008–15.
[38] Heelan J, Gratz E, Zheng ZF, Wang Q, Chen MY, Apelian D, et al. Current and prospective Li-ion battery recycling and recovery processes. JOM (J Occup Med) 2016;68(10):2632–8.
[39] Zhang T, He YQ, Ge LH, Fu RS, Zhang X, Huang YJ. Characteristics of wet and dry crushing methods in the recycling process of spent lithium-ion batteries. J Power Sources 2013;240:766–71.
[40] Chen XP, Chen YB, Zhou T, Liu DP, Hu H, Fan SF. Hydrometallurgical recovery of metal values from sulfuric acid leaching liquor of spent lithium-ion batteries. Waste Manag 2015;38:349–56.
[41] Foster M, Isely P, Standridge CR, Hasan M. Feasibility assessment of remanufacturing, repurposing, and recycling of end of vehicle application lithium-ion batteries. J Ind Eng Manag 2014;7(3). 698-15.
[42] Huang FL, Xu YF, Peng B, Su YF, Jiang F, Hsieh YL, et al. Coaxial electrospun cellulose-core fluoropolymer-shell fibrous membrane from recycled cigarette filter as separator for high performance lithium-ion battery. ACS Sustainable Chem Eng 2015;3(5):932–40.
[43] Kang J, Sohn J, Chang H, Senanayake G, Shin SM. Preparation of cobalt oxide from concentrated cathode material of spent lithium ion batteries by hydrometallurgical method. Adv Powder Technol 2010;21(2):175–9.
[44] Chen L, Tang XC, Zhang Y, Li LX, Zeng ZW, Zhang Y. Process for the recovery of cobalt oxalate from spent lithium-ion batteries. Hydrometallurgy 2011;108(1–2):80–6.
[45] Olivetti EA, Ceder G, Gaustad GG, Fu XK. Lithium-ion battery supply chain considerations: analysis of potential bottlenecks in critical metals. Joule 2017;1(2):229–43.
[46] Richa K, Babbitt CW, Gaustad G. Eco-efficiency analysis of a lithium-ion battery waste hierarchy inspired by circular economy. J Ind Ecol 2017;21(3):715–30.
[47] He LP, Sun SY, Song XF, Yu JG. Recovery of cathode materials and Al from spent lithium-ion batteries by ultrasonic cleaning. Waste Manag 2015;46:523–8.
[48] Guo Y, Li F, Zhu HC, Li GM, Huang JW, He WZ. Leaching lithium from the anode electrode materials of spent lithium-ion batteries by hydrochloric acid (HCl). Waste Manag 2016;51:227–33.
[49] Patry G, Romagny A, Martinet S, Froelich D. Cost modeling of lithium-ion battery cells for automotive applications. Energy Sci Eng 2015;3(1):71–82.
[50] Xie YH, Yu HJ, Li CD. Research on systems engineering of recycling EV battery. In: 2nd international conference on advances in mechanical engineering and industrial informatics (AMEII); 2016. p. 1570–4. Hangzhou.
[51] Zhang CJ, Liu CC, Li JK. A fast detection method for residual energy of retired lithium battery. China: 201910549921.6, 2019-06-24. (In Chinese).
[52] Miao Y, Hynan P, von Jouanne A, Yokochi A. Current Li-ion battery technologies in electric vehicles and opportunities for advancements. Energies 2019;12(6):1074.
[53] Zhu B. A life prediction method of echelon utilization power battery. China : 201910465428.6, 2019-05-30. (In Chinese).
[54] Wu SH, Zhang T, Li LH. Exploration on the construction of the life cycle database of traction battery and the selection of residual value evaluation index. Aut Appl Technol 2019;(14). 40-41,72. (In Chinese).
[55] Hu JY, Yang SS. Residual value evaluation method of used batteries. China: 201810098625.4, 2018-01-31. (In Chinese).
[56] Ma YJ, Qiu KQ. Recovery of lead from lead paste in spent lead acid battery by hydrometallurgical desulfurization and vacuum thermal reduction. Waste Manag 2015;40:151–6.
[57] Zeng XQ, Li M, Abd El-Hady D, Alshitari W, Al-Bogami AS, Lu J, et al. Commercialization of lithium battery technologies for electric vehicles. Adv Energy Mater 2019;9(27):1900161.
[58] Zeng XL, Li JH, Liu LL. Solving spent lithium-ion battery problems in China: opportunities and challenges. Renew Sustain Energy Rev 2015;52:1759–67.
[59] Xiao JF, Li J, Xu ZM. Recycling metals from lithium ion battery by mechanical separation and vacuum metallurgy. J Hazard Mater 2017;338:124–31.
[60] Grey CP, Tarascon JM. Sustainability and in situ monitoring in battery development. Nat Mater 2017;16(1):45–56.
[61] Gu XY, Ieromonachou P, Zhou L, Tseng ML. Optimising quantity of manufacturing and remanufacturing in an electric vehicle battery closed-loop supply chain. Ind Manag Data Syst 2018;118(1). 283-02.
[62] Liu TF, Zhang YP, Chen C, Lin Z, Zhang SQ, Lu J. Sustainability-inspired cell design for a fully recyclable sodium ion battery. Nat Commun 2019;10(1):1965.
[63] Al-Zareer, Dincer Rosen. A novel approach for performance improvement of liquid to vapor based battery cooling systems. Energy Convers Manag 2019;187. 191-04.
[64] Qu XH, Han HD, Wong SC, Tse CK, Chen W. Hybrid IPT topologies with constant current or constant voltage output for battery charging applications. IEEE Trans Power Electron 2015;30(11):6329–37.
[65] Ministry of industry and information technology. Ministry of science and technology, Ministry of environmental protection, Ministry of transport, Ministry of Commerce, General Administration of quality supervision, inspection and quarantine, and energy administration. Pilot implementation scheme for the recycling of new energy vehicle power battery. http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057542/n3057544/c6274998/content.html/. [Accessed 25 May 2020].
[66] Tao ZJ, Jia XF. Research on business model for recycling power battery. Auto Ind Res 2018;10:33–42 [In Chinese)].
[67] Zhu Ly Chen M. Research on reverse logistics model and network for used electric vehicle batteries. China Mech Eng 2019;30(15):1828–36 [In Chinese)].
[68] GB/T 35788-2017 Security technical requirement for the electronic identification of motor vehicles. Beijing: China standard press; 2018.
[69] GB/T 35789.1-2017 General specification for the electronic identification of motor vehicles—Part 1: Automobile. BeiJing: Standards Press of China; 2018.
[70] GB 16735-2019 Road vehicle—vehicle identification number (VIN). Beijing: Standards Press of China; 2019.
[71] GB 16737-2019 Road vehicle—world manufacturer identifier (WMI) code. Beijing: Standards Press of China; 2019.
[72] Liu KL, Hu XS, Yang ZL, Xie Y, Feng SZ. Lithium-ion battery charging management considering economic costs of electrical energy loss and battery degradation. Energy Convers Manag 2019;195:167–79.
[73] Tian GD, Chu JW, Hu HS, Li HL. Technology innovation system and its integrated structure for automotive components remanufacturing industry development in China. J Clean Prod 2014;85:419–32.
[74] Hu XS, Feng F, Liu KL, Zhang L, Xie JL, Liu B. State estimation for advanced battery management: key challenges and future trends. Renew Sustain Energy Rev 2019;114. UNSP 109334.