Reuse, Recycling and Recovery of End-of-Life New Energy Vehicles in China

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Abstract

China has the largest quantity and ownership of new energy vehicles (NEVs) in the world. As time progresses, a certain percentage of NEVs will enter the scrap stage every year in China. By examining the status quo and the problems of recycling conventional end-of-life vehicles in China, this study investigated the potential market for end-of-life NEVs and the existing problems in the recycling and reuse systems. It was found that the recycling and reuse systems' needs should be considered ahead of time. Further, various modes and specific methods for the recycling and reuse of end-of-life NEVs and their parts were analyzed. Based on this investigation, several strategies for the recycling and reuse of NEVs are proposed. As a future recycling model for end-of-life NEVs, China should establish an independent industry model for the comprehensive utilization of scrap power batteries from NEVs. This study provides a reference for establishing a sound recycling system for end-of-life NEVs and setting up a recycling and reuse platform for scrapped NEVs in China.

1 Introduction

After years of demonstration and promotion, by the end of 2017, the cumulative number of new energy vehicles (NEVs) in China had exceeded 1.7 million, making China the country with the largest number of NEVs in the world. This means that as time passes, a certain number of NEVs and power batteries will enter the end-of-life stage each year in China. Because of this fact, there is an urgent need to examine issues related to the recycling and reuse of NEVs. China's large-scale promotion of NEVs produces a conflicting scenario. Zero emissions can be achieved, which can greatly help to reduce smog and protect the environment; however, if NEVs, and especially power batteries, are improperly processed, this can create new and more serious forms of pollution. Therefore, China's automotive industry must now consider how to properly dispose of end-of-life NEVs, rationally reuse and recycle key components and materials, reduce pollution caused by NEV waste, and promote sustainable development.

Chen et al. [1-5] analyzed the traditional recycling system of China's end-of-life vehicles and highlighted some key issues in the transformation and upgrading of enterprises that oversee end-of-life vehicle recycling and dismantling. After reviewing the relevant policies and standards for China's end-of-life vehicle recycling and parts remanufacturing, they proposed measures to support the development of China's end-of-life auto industry, which could play an important role in China's automobile scrap recycling industry. Shen et al. [6-8] examined the laws and regulations concerning automotive product recycling in China under the extended producer responsibility system. They suggested that the key to building a complete recycling system for automotive products lies in implementing the extended producer responsibility system and improving the recycling and reuse levels of automotive companies. Drawing lessons from the recycling of scrapped automobiles and parts abroad, Li et al. [9-11] examined the recovery of scrapped automobiles and parts in Germany and Japan. They suggested that China should introduce a law for recycling of end-of-life vehicles and their parts as soon as possible to improve the regulatory system and strengthen law enforcement.

The development of China's NEV industry continues to expand. Annual sales have ranked first in the world for three consecutive years, and annual sales of new energy vehicles have accounted for about half of worldwide sales. Regarding the future industrial development of China's NEVs, Wan et al. [12-13] predicted that the sales volume of NEVs would reach 1 million in 2018. Meanwhile, Miao et al. [14] argued that there are some problems in China's new energy automotive industry, such as the lack in the after-sales service support system, which has had certain negative effects on cultivating the consumer market. Han et al. [15] reviewed the demonstration and promotion of fuel cell electric vehicles in China in recent years and proposed several strategies to promote their marketization. Ding [16] and Yu et al. [17] analyzed the development of the recycling and dismantling industry for China's end-of-life NEVs. They noted that the recycling of scrapped NEVs is different from that of traditional cars and therefore cannot continue under the policies and standards for traditional cars. This issue will undoubtedly create a hurdle in the recycling of NEVs.

Many studies have investigated the recovery and reuse of power batteries. A few researchers [18-23] reported an economic analysis model for the input and output of the power battery recycling process and conducted a quantitative analysis. Regarding the cascade use of power batteries, many researchers have noted that it is a desirable concept but difficult to implement. The main reason for such difficulty is that there are too many types of power batteries in China, and the output is scattered. Regarding the recycling system and recovery model for NEV power batteries, Li et al. noted

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that due to the short time for the marketization of NEVs in China, automotive power batteries have not been scrapped in batch. As such, a domestic power battery recycling system has yet to be commercially formed [24]. Lu et al. [25] suggested that in the future, China might consider establishing a waste power battery recycling network centered on power battery manufacturing companies and new energy vehicle production enterprises. Hou [26] and Peng [27] proposed three models for future power battery recycling: a power battery manufacturer recycling mode, an industry coalition recycling mode, and a third-party recycling mode. Chen [28] simplified the quantitative analysis of the need to recover precious metal materials for proton exchange membrane fuel cells.

Existing research on the recovery of end-of-life automobiles and parts has mainly focused on traditional automobiles. Studies of NEVs have mainly focused on R&D, technology, and demonstration and promotion. While a few studies have investigated the recovery and reuse of NEVs and parts, they mainly focused on one aspect (e.g., recycling modes) or one part (e.g., batteries). Currently, there is a need for research on the recovery and reuse of NEVs and components that is more systematic and conceptual. This article introduces the status quo and problems of China's traditional end-of-life vehicle recycling. Further, it predicts the potential recycling market for China's end-of-life NEVs, followed by a comprehensive and systematic description of recycling modes and methods for China's NEVs and their parts. Finally, several market strategies are proposed to promote the recycling of China's NEVs and their parts and components.

2 Status and Problems of Recycling End-of-Life Conventional Vehicles

2.1 Current Status of Recycling End-of-Life Conventional Vehicles

From 2009 to 2017, China ranked first in the world in vehicle production and sales. In 2017, the annual sales of automobiles in China exceeded 28.88 million, and vehicle ownership reached 217 million. Figure 1 shows the sales volume, growth rate, and ownership of conventional vehicles in China from 2001 to 2017 [29-30]. With this rapid increase in vehicle ownership, the amount of end-of-life vehicles will also greatly increase. Many cities in China cannot dismantle end-of-life vehicles quickly enough, and they pile up in "vehicle graveyards." The annual scrap rate of the international mature automobile market is 5–8% of owned vehicles [2]. From 2018 onward, the annual number of end-of-life vehicles in China is projected to reach 10.85–17.36 million. Vehicle ownership in China was 105 million in 2011, and more than 100 million vehicles have been added in the past six years. The average scrapping time for automobiles is 8–15 years, which means that China's actual scrap amount is currently about six million vehicles. China will face an excess of end-of-life vehicles in five years; such a large amount of scrap is a huge "resource of urban minerals" for China's auto recycling industry.

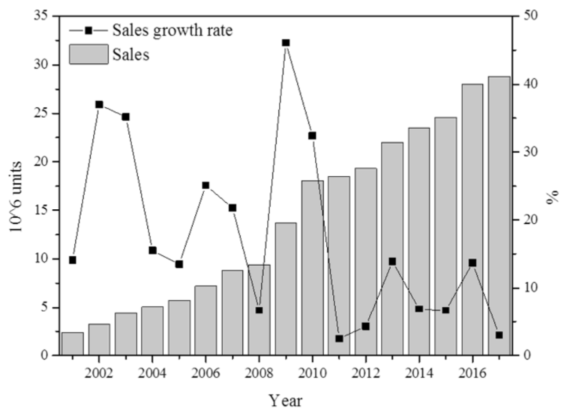

Figure 1. China's automobile sales and annual growth rates during 2001–2017 [29-30]

China's end-of-life vehicle recycling industry started late and has not attracted sufficient attention from the domestic auto industry. In 2001, the Management Rules of Recycling End-of-Life Vehicles were implemented. In 2006, the Technology Policy for Auto Products Recycling was promulgated. Subsequently, China formulated and improved a series of policies and regulations concerning the management of end-of-life vehicle recycling. However, policy implementation has been slow, and the development of the end-of-life automobile dismantling industry lags behind the development of China's automobile industry. China's conventional end-of-life vehicle recycling and dismantling industry has always been a labor-intensive industry with large differences in overall quality. China's enterprises engaged in the large-scale qualified recycling and dismantling of end-of-life vehicles use modern dismantling methods and devices. However, smaller recycling enterprises and illegal recycling enterprises can be relatively backward. Some do not even have special dismantling equipment and basically dismantle vehicles manually, with low efficiency and low social recognition.

Meanwhile, automobile manufacturers rarely consider the recycling performance of their products during the design phase, and the parts recycling rate is low.

The revised version of China's Management Rules of Recycling End-of-Life Vehicles will be introduced soon. It will focus on three reforms: (1) to remove the limit on the total number of end-of-life vehicle recycling and dismantling enterprises, certificates will be issued to these enterprises first, followed by licenses; (2) dismantled parts will be allowed to reenter the market to achieve green vehicle marketing; and (3) giving the "five major assemblies" (engine, transmission, front axle, rear axle, and frame) to qualified remanufacturers for remanufacturing will be encouraged.

2.2 Existing Problems of Recycling Conventional End-of-Life Vehicles

At present, the main problems existing in the recycling of end-of-life vehicles in China are as follows:

The legal scrap rate of end-of-life vehicles is low.

China's 2016 data are taken as an example. According to data released by the Traffic Management Bureau of the Ministry of Public Security of the People's Republic of China, in 2016 vehicle ownership in China reached 194 million, and a total of 5.5 million vehicles had been written off. However, only 1.592 million vehicles were collected by qualified end-of-life vehicle recycling companies. The legal scrap rate was less than 30%. A total of 3.9 million written-off vehicles went to the black market and to second-hand markets; these arrive at remote mountainous regions or rural areas, potentially creating many traffic hazards. Currently, the actual recycling amount recovered by China's qualified end-of-life vehicle recycling enterprises is only 0.5–1.0% of owned vehicles, which is far below the level of 5.0–8.0% in developed countries [2]. Table 1 shows the theoretical estimation of the recovery amount of end-of-life vehicles in China and the actual recovered amount of qualified end-of-life vehicles.

The dismantling level and recovery rate are low.

Most recycling enterprises in China are small, plant sites are crude, and dismantling methods are primitive. Manual processes are often used in these companies, with low dismantling efficiency and great risks to workers' safety. At present, aside from steel and nonferrous metals, most other items cannot be effectively recycled, and the added value of retained parts is low. Parts and components only account for 5–10% of automobile recycling companies' sales, and about 90% are sold as raw materials to steel mills.

Table 1. Prediction of China's end-of-life conventional vehicles and new energy vehicles

Year	Conventional vehicles				New energy vehicles		
	Population (10^6 unit)	Increase (10^6 unit)	End-of-life (10^6 unit)	Recycled (10^6 unit)	Population (10^4 unit)	Increase (10^4 unit)	End-of-life (10^4 unit)
2015	172	24.59	6.16	1.7	49.70	33.11	-
2016	194	28.02	6.88	1.59	100.00	50.70	1.50
2017	217	28.88	7.76	1.47	176.2	77.7	3.0
2018	238	29.74	8.68		279.7	108.8	5.28
2019	255	30.63	9.52		423.6	152.3	8.39
2020	273	31.54	10.2		624.1	213.2	12.7
2021	292	32.48	10.92		848.7	255.8	31.2
2022	314	33.45	11.68		1062.1	307	42.4
2023	336	34.45	12.56		1377.4	368.4	53.1
2024	358	35.48	13.44		1750.5	442	68.9
2025	381	36.54	14.32		2193	530	87.5

Formulae for conventional vehicles:
(1) Increase rate = 3% per year during 2018–2025
(2) Population = (previous population) + increase – (end-of-life)
(3) End-of-life = (previous population) * 4% during 2018–2025
Source: [31]

Formulae for new energy vehicles:
(1) Increase rate = 40% during 2018–2020; 20% during 2021–2025
(2) Population = (previous population) + increase − end-of-life
(3) End-of-life = (previous population) * 3% during 2016–2020; 5% during 2021–2025
Source: [32]

The illegal dismantling and sale of end-of-life vehicles has continued despite prohibitions.

China's Management Rules of Recycling End-of-Life Vehicles clearly stipulates that all companies and individuals are prohibited from assembling vehicles using scrapped cars, and such assembled vehicles and scrapped cars are prohibited from traveling on roads. Due to a lack of effective oversight, small workshops that illegally dismantle automobiles still operate in some localities. Harmful substances such as lead, mercury, cadmium, and hexavalent chromium are freely discharged without treatment, resulting in damage to the environment and risks to human health.

3 Markets of Recycling End-of-Life New Energy Vehicles

3.1 Current Market of Recycling End-of-Life NEVs

The NEV is one of China's seven emerging strategic industries. Developing NEVs is the only way China can transform from a large automobile country into a powerful automobile country. The demonstration and promotion of NEVs in China began 20 years ago with the Shantou Electric Vehicle pilot operation in 1998. Early-stage large-scale promotion projects included the 2008 Beijing Olympic Games, the 2010 Shanghai World Expo, the Guangzhou Asian Games, and the 2011 Shenzhen Universiade, and the "Thousand New Energy Vehicles in Ten Cities" project launched in 2009. Since the beginning of the "Thirteenth Five-Year Plan," China's NEVs have moved from local demonstrations to large-scale, countrywide promotion, and the scope of central subsidies has also extended to the whole country. By 2020, it is expected that the cumulative production and sales volume of NEVs will exceed five million. In January 2016, to further ensure the smooth promotion of NEVs and cultivate a good application environment for such vehicles, the Ministry of Science and Technology issued the Notice of New Energy Vehicle Charging Facilities Incentives and Strengthening the Promotion and Application of New Energy Vehicles during the Thirteenth Five-Year Plan [33]. This notice clarified that during the 2016–2020 period, the central government will continue to arrange funds to award and subsidize NEV promotion and to construct and operate related infrastructures in various provinces (autonomous regions and municipalities). Table 2 shows three levels of China's provinces (autonomous regions and municipalities) for promotion and application of NEVs during 2015–2025. It shows the planned number of NEVs to be promoted each year from 2015 to 2025 and their proportions over the total amount of different vehicles in different levels of provinces. Between 2008 and 2017, the number of NEVs promoted in China was as follows: 500 vehicles at the 2008 Beijing Olympics; 1,300 at the 2010 Shanghai World Expo; 2011 vehicles at the 2011 Shenzhen Universiade; 27,400 vehicles in the "Thousand New Energy Vehicles in Ten Cities" demonstration and promotion project, 2009–2012; 17,643 NEVs promoted in 2013; 74,763 NEVs promoted in 2014; 383,285 vehicles promoted by 88 model cities in 2015; 507,000 vehicles promoted in 2016; and 777,000 vehicles promoted in 2017. By the end of 2017, China's total number of promoted NEVs exceeded 1.77 million, and ownership accounted for 50% of the worldwide total. Thus, China has the largest number of NEVs in the world.

At present, NEVs promoted in China are mainly pure electric vehicles and plug-in hybrid electric vehicles. However, fuel cell electric vehicles have also been steadily promoted. In early 2017, China started a new round of demonstrations for fuel cell vehicles, promoting 112 fuel cell vehicles in Beijing, Foshan, Shanghai, Yancheng, and Zhengzhou, which included 36 buses, 41 cars, 30 logistics vehicles, and 5 logistics trucks. In 2022, Yutong—the first company in China to obtain hydrogen fuel cell bus production qualification—will serve the Winter Olympics at Zhangjiakou with its fourth-generation hydrogen fuel cell buses [33].

Table 2. Planned annually increasing amount of new energy vehicles and their proportions over the total amount, including conventional vehicles, during 2016–2020 in various Chinese provinces and cities [33]

Year	Key areas		Central provinces		Other regions	
2016	30,000	2%	18,000	1.5%	10,000	≥1%
2017	35,000	3%	22,000	2%	12,000	≥1.5%
2018	43,000	4%	28,000	3%	15,000	≥2%
2019	55,000	5%	38,000	4%	20,000	≥2.5%
2020	70,000	6%	50,000	5%	30,000	≥3%

Figure 2. Three levels of China's provinces for promotion and application of NEVs during 2016–2020 [33]

3.2 Market Prediction for End-of-Life NEVs Recycling

In recent years, various favorable factors for the development of NEVs have emerged, and China's NEV industry is developing rapidly. In 2015, the sales volume of NEVs in China exceeded 300,000, accounting for 1.3% of the overall automotive industry, thus marking a turning point in the development of NEVs. In 2017, the proportion of NEVs in the automotive industry reached 2.74%. The Made in China 2025 plan states that by 2020, annual sales of Chinese brands of NEVs will exceed one million in China; by 2025, annual sales of NEVs will reach three million. Chuanfu Wang, president of BYD Auto, has predicted that NEVs will reach 30% of the total number of fossil fuel vehicles in 2025. Based on the above analysis, and according to environmental requirements, technological development trends, and historical promotion data from 2014 to 2017, this study forecasted the sales and scrapping of NEVs in China from 2020 to 2025 (Table 1). The forecast assumes that with various subsidy policies and favorable factors, coupled with continuous improvement in technical performance and continuous reductions in cost and front cardinality, the growth rate of annual sales of NEVs from 2018 to 2020 will be maintained at more than 40%. From 2021 to 2025, the growth rate will be stable at around 20%. As shown in Table 1, by 2025, sales of NEVs will exceed 5.3 million. Table 1 also shows that the number of end-of-life NEVs in China in recent years has been very small. However, by 2020, the number of such vehicles in China will reach 100,000. By 2025, the number of end-of-life NEVs in China will rapidly increase to more than 800,000.

The recycling of end-of-life NEVs in China is still in its infancy, and the amount recycled is very small. It is impossible to rely on market forces alone to establish an independent NEV recycling system. In addition, the recovery of power batteries should take place earlier than the recycling of the whole NEV. The China Automotive Technology and Research Center predicts that by 2020, the cumulative scrap of electric vehicle power batteries in China will reach 120,000–170,000 tons. A 20-gram cell phone battery can pollute 1 square kilometer of land for about 50 years; thus, several tons of NEV batteries will cause more serious environmental damage [16]. Therefore, in view of the great potential harm of scrapped power batteries and the urgency of recovery, the Chinese government should immediately work on establishing a recycling industry system for end-of-life NEVs, and especially a power battery recycling system.

4 Methodologies for Recycling End-of-Life New Energy Vehicles

4.1 Concepts of Cascade Use, Reuse, Remanufacturing, Recycling, Recovery and Residue

Cascade use is a general methodology for the efficient use of device materials and energy. The utilization of end-of-life NEVs and their parts and components can generally be divided into reusing, recycling, and recovering. According to the Technology Policy for Auto Products Recycling, issued in China in 2006, reuse refers to any use of scrapped vehicle parts for their design purposes. The reuse of parts and components retains their highest value. Some parts can be used directly while some must be remanufactured before use. Remanufacturing is necessary if the parts and components cannot be used directly; for example, an excessively worn engine shaft can be reused through remanufacturing by means of plasma spray coating technology. Recycling refers to reprocessing waste material so it can meet its original use requirements or be used for other purposes, not including the process of generating energy. Recovery refers to meeting the original use requirements or being used for other purposes after the waste material is reprocessed, including energy-generating processes. Residue refers to used material that cannot be recycled and is put in a landfill. Domestic and international end-of-life vehicle recycling industries have emphasized two indicators: recyclability rate and recoverability rate. Recyclability rate is the percentage (mass percentage) of a new vehicle that can be recycled or reused; recoverability rate is the percentage of a new vehicle that can be recovered or reused (mass percentage). Table 3 shows the relationships among reuse, recycling, recovery, recyclability rate, and recoverability rate.

China's Technology Policy for Auto Products Recycling of 2006 required that the recoverability rate of automobiles produced and sold in China be synchronized with advanced international levels starting in 2017, and the recoverability rate of all domestic and imported vehicles should reach about 95%, with a material recyclability rate of no less than 85%. Reuse retains the highest value for spare parts. Some used parts and components can be reused directly, and some can be reused after being remanufactured. To maximize use and conserve resources, end-of-life new energy vehicles and their parts are generally considered for reuse or cascade use first. Then, consideration is given to implementing remanufacturing to fully tap the added value of the raw materials, energy, labor, etc., contained in used products. Finally, the recovery of resource-based materials is considered.

China's NEV recycling industry could learn from the development history of the conventional vehicle recycling and dismantling industry over the past two decades. Moreover, it can draw lessons from the development of the conventional end-of-life vehicle industry and increase recycling efficiency of end-of-life NEVs.

Table 3. Relations of recyclability rate and recoverability rate with 4Rs (reuse, recycling, recovery, and residue)

Reuse		Recycling	Recovery		Residue
Reuse of parts	Reuse of materials	Recycling of materials	Recovery of materials	Recovery of energy	Residual materials
Recyclability rate---------------------------------------→					
Recoverability rate--→					
Total mass of vehicle ---→					

Note: Reuse of parts includes different levels, such as cascade use or even reuse after remanufacturing
Source: [34]

4.2 Modes of Recycling and Reuse of NEVs

The biggest difference in dismantling technology between end-of-life NEVs and conventional vehicles lies in the battery packs in NEVs, which often have a voltage of more than 300 V [17]. If batteries are manually dismantled, accidents such as electrical shock are likely to occur. Furthermore, if a power battery short-circuits, its instantaneous current can be 100 A or more, immediately releasing a large amount of heat, which can easily cause a fire or even an explosion. As such, typical conventional vehicle recycling and dismantling enterprises do not have the ability to dismantle end-of-life NEVs. Such vehicles thus require professional recycling and dismantling companies qualified to recycle them. End-of-life new energy vehicles can only be reused after they have been safely recycled.

In January 2017, the Implementation of the Extended Producer Responsibility System, issued by the General Office of the State Council of China, required the integration of basic information regarding automobile production, trading, maintenance, insurance, and scrapping. It required gradually establishing a national unified automobile life cycle information management system and strengthening the recycling management of end-of-life automotive products. The improvement and implementation of the extended producer responsibility system plays an important role in guiding the establishment of a recycling and utilization industrial system for NEVs. Different types of NEV manufacturers, as well as the related parts and components manufacturers, have to be responsible for the recycling of their own scrapped products. The Notice on the Financial Support Policy for the Promotion and Application of New Energy Vehicles for 2016–2020 specifically states that as the main body responsible for the recovery of power batteries, NEV manufacturing enterprises are responsible for the recycling of power batteries.

There are three possible modes for establishing a recycling system for NEVs in China. The first mode is to use the conventional vehicle recycling system and simultaneously increase the recycling capacity of conventional automobile recycling companies. In the current situation, this mode is the most realistic way to recycle NEVs. For example, as a conventional vehicle recycling company, Wuhan Dongfeng Hongtai Automobile has recovered a number of NEVs. The second mode is to establish an independent recycling system for end-of-life NEVs while the government issues NEV recycling qualifications separately. However, this mode is not sufficient to support the profit of recycling companies. The third mode is to establish an independent recycling system for the key parts of NEVs and, in particular, to establish an independent recycling system for scrapped power batteries. This also includes the recovery and reuse of key components such as scrapped motors, controllers, and chargers. The scrapping of NEV bodies and other parts (tires, seats, etc.) is delegated to the conventional automobile recycling system. This mode is particularly suitable for the relevant responsible entities under the current extended producer responsibility system.

At present, the recycling and reuse of scrapped power batteries is the key issue in end-of-life NEV recycling. In 2011, China initiated power battery recycling for NEVs, set up a working group, and signed the Memorandum of Understanding on Cooperation in the Field of Power Battery Recycling with the German Ministry of Environment. Moreover, in 2014, it released the Research Report on the Feasibility of Recycling of Electric Vehicle Power Batteries in China. Since 2016, the Ministry of Industry and Information Technology of China issued, successively, the Recycling Technology Policy of Electric Vehicle Batteries (2015 edition), Industry Standard Conditions for the Comprehensive Utilization of Scrapped Power Batteries for New Energy Vehicles, and the Interim Measures for Management of the Industry Standard Conditions for the Comprehensive Utilization of Scrapped Power Batteries for New Energy Vehicles. These documents identified the main entities responsible for recycling used batteries as well as the standard conditions and management methods for the comprehensive utilization of scrapped power batteries. In January 2018, eight departments in China, including the Ministry of Industry and Information Technology, introduced the Interim Measures for the Management of Recycling of Powered Batteries for New Energy Vehicles. It aims to further strengthen the industrial management of power battery recycling for NEVs, standardize industry development, promote comprehensive resource utilization, and protect the environment. Since March 2018, pilot work on power battery recycling for NEVs has been organized and implemented nationwide. The Chinese government has therefore carried out and begun to implement top-level designs for establishing an independent industry for the comprehensive utilization of scrapped new energy vehicle batteries. China's future recycling model for NEVs thus aims to establish an independent industry model to utilize the scrapped power batteries of NEVs.

4.3 Whole-Vehicle Reuse for End-of-Life NEVs

NEVs are currently being promoted only in some large and medium-sized cities in China, and fuel cell electric vehicles are uncommon in major cities. Therefore, NEV recycling can, at present, serve as a vehicle to promote and spread knowledge about NEVs at schools, science and technology museums, exhibition halls, and so on. Currently, some NEVs that were operated in the Beijing Olympic Games, the Shanghai World Expo, and the Ten Thousand New Energy Vehicles project have been scrapped. It is recommended that NEV demonstration cities or regions should establish local exhibition halls to present these end-of-life NEVs and promote knowledge about them as well as environmental protection and energy conservation. Second, end-of-life NEVs and their key components can also be used as teaching and science materials at various schools. Only by engaging with NEVs can students fully comprehend their working principles as well as the low-carbon environmental protection they provide. Then, students may be motivated to purchase such vehicles in the future.

4.4 Recycling the Key Components of End-of-Life NEVs

Because of their fast growth, the authors identified three key components for recycling of NEVs in China:

Remanufacturing End-of-Life NEVs Parts

Remanufacturing automobile parts refers to mass producing old automobile parts using advanced methods to restore them to the same quality as the originals. The auto parts remanufacturing industry has great potential for development in China. In 2008, China promulgated the Auto Parts Remanufacturing Pilot Management Measures for the recycling and reuse of conventional auto parts. Vehicle manufacturers and auto parts remanufacturing companies were selected to carry out pilot remanufacturing, and the development of the conventional auto parts recycling industry was actively promoted. Compared to new products, the cost of a remanufactured conventional car engine is reduced by approximately 50%; energy savings are approximately 60%, and 70% is saved on raw materials. Remanufacturing is therefore very profitable for parts and components merchants. Studying remanufacturing in the automotive aftermarket, Huisingh et al. [35] noted that remanufacturing is the main link in transforming the automobile industry into one characterized by sustainable development and environmental protection. Accordingly, the China Automotive Industry Association Auto Parts Remanufacturing Branch was established in April 2010 to implement national guidelines and policies to revitalize the automobile remanufacturing industry. Remanufacturing the key components of NEVs can retain the value of the original components, which is the first choice for recycling NEVs. Remanufacturing is also an important step in establishing an independent recycling system for NEVs and their parts. Relevant research institutes and related departments should cooperate with government authorities to explore and promote remanufacturing technologies for NEVs and their parts and components. Currently, highly valued key components, such as motors and electronic controls, are suitable for reuse through remanufacturing technologies.

Cascade Use and Material Recovery of Power Batteries

Under normal circumstances, when power battery capacity is attenuated to 80% of the total capacity, the driving range drops dramatically. At that time, the power battery will need to be replaced by a new one. In addition, transformation and technological innovation also accelerate the renewal of power batteries. Therefore, power batteries are generally replaced 2–3 times during the life cycles of NEVs. After a NEV’s power battery is scrapped, it is generally preferred to consider cascade use first and then consider material recovery and final disposal. Through the recovery and remanufacturing of power batteries and fuel cells, more of the value of the original parts can be retained and cost can be reduced. If these power batteries can be effectively recycled and reused after being scrapped, it can save related resources and reduce the cost of electric vehicles, which can also effectively reduce the price of NEVs and promote their sale. The cascade use of power batteries can be broadly divided into three stages. In the first stage, after testing and processing—provided the battery is intact, is undamaged, and has effective functional components—it can be used in the fields of communication and energy storage (e.g., new energy distribution power stations, street lights, communication stations). In the second stage, when the power battery is eliminated from the energy storage device or low-speed electric vehicle for the second time, there may be a third or fourth reuse, and the maximum value of reuse can be achieved. At the same time, it is necessary to make a file for each recovered battery to record its usage in detail. In the third stage, power batteries that cannot be used in a cascade are recycled, dismantled, and used for resource regeneration—that is, material recycling. Through cascade use, not only is the pollution problem solved but a good recycling model is also formed. At present, China’s NEVs mainly use lithium-ion batteries. The recycling of lithium-ion batteries will become an important means to alleviate resource bottlenecks. To balance energy consumption and water pollution issues, recycling companies mainly adopt the “combination of dry and wet” method to dismantle lithium batteries and recover cobalt, nickel, and other precious metals. Scrapped lithium batteries usually contain 5–15% cobalt, 2–7% lithium, and 0.5–2.0% nickel. Further development is still needed in China’s processing technologies for lithium battery recycling. The cost of recycling lithium carbonate from lithium batteries is still more than five times that of a company’s direct production costs, mainly due to the lack of a unified standard for lithium batteries in China. Battery composition varies. Even with the same kind of ternary materials, the composition ratio can be very different, making it difficult to commercialize the recycling of high-added-value intermediate products (e.g., cathode materials, anode materials, electrolytes, diaphragms) from scrapped lithium batteries. China's Industry Standard Conditions for the Comprehensive Utilization of Scrapped Power Batteries for New Energy Vehicles encourages the combined use of physical and chemical methods to explore biometallurgical methods for recycling. Additionally, with wet smelting, the combined recovery rate of nickel, cobalt, and manganese should not be less than 98%. With the pyrometallurgical method, the combined recovery rate of nickel and rare earths should not be less than 97%. The Ministry of Industry and Information Technology of China has been actively guiding the promotion of pilot projects for the recycling of NEV power batteries and has obtained positive results. China Iron Tower Co., Ltd., has built five power battery cascade-use base stations in Huizhou City, Guangdong Province, and intends to demonstrate the application of energy storage, energy preparation, and peak load shifting at these base stations. Guangdong Guanghua Technology Co., Ltd., built a recycling line of 1,000 tons of end-of-life power batteries in Shantou City, Guangdong Province. Meanwhile, a recycling project involving 10,000 tons of end-of-life power batteries is also under construction in Zhuhai City, Guangdong Province. After cascade use, Tesla Electric Vehicles was able to reduce the cost of the 18,650 cylindrical batteries it used from 2007 to 2012 by about 40% through recycling and scale effects. This shows that a good recycling model can also generate huge economic benefits.

Recycling and Material Recovery of Fuel Cells

Fuel cells are composed of anodes, cathodes, electrolytes, catalysts, separators, and shells. They convert the chemical energy of the fuel into electrical energy through electrochemical reactions. The reaction materials (fuel and oxidants) are continuously consumed during electrochemical reactions to produce electrical energy and constant discharge. Currently, the number of fuel cell electric vehicles in China is very small. The total number of fuel cell sedans, buses, and sightseeing buses in the Beijing Olympics, the Shanghai World Expo, the Shenzhen Universiade, and the 'Ten Thousand New Energy Vehicles' project was only 281. Some of those fuel cell vehicles have already been scrapped. The small scale of fuel cell production and usage has made it difficult for ordinary consumers in China to access it. Therefore, to recycle fuel cell electric vehicles, they should first be used as scientific exhibits and displayed in automobile exhibition halls, science and technology museums, and various types of school laboratories to promote public awareness and science education. In addition, end-of-life fuel cells can also be used as storage power sources to provide energy for certain special cases. For example, they can be used as small independent power sources in remote areas, on islands, and in deserts. They also have broad market prospects in defense communications, combat weapon power supplies, miniature power sources, and sensor devices. Fuel cells that cannot be reused are subject to material recovery. The key materials of the membrane electrode assembly are mainly recovered, including precious metal catalysts (platinum electrocatalyst), proton exchange resins, and gas diffusion layers. Platinum cannot be artificially synthesized and is a very scarce and expensive element. Its recovery method mainly uses concentrated sulfuric acid, concentrated nitric acid, or the mixed acid of any ratio of concentrated sulfuric and concentrated nitric acid to treat the scrapped membrane electrode. Acid treatment reduces the interactions between proton exchange resin chains in the proton exchange membrane and in the catalytic layer, and it separates proton exchange resin chains from each other to disperse in acid to form a solution. The carbon carriers of the supported catalyst are oxidized, and the catalyst noble metals are fully separated.

5 Strategies for Recycling End-of-Life New Energy Vehicles

5.1 Designing and Manufacturing NEVs with Easy Dismantling Structures

Automotive recyclability and detachability designs are the basis for improving the recovery and reuse of NEVs. In the early stages of designing and manufacturing automobiles, NEV manufacturers must consider the issue of recycling and reusing scrapped vehicle parts, consider improving the utilization rates of these dismantled parts and materials, and constantly improve the process technology. Designers should fully consider the detachability of the car structure design. This includes having as few connecting points as possible; having a unified connection method where a few simple tools can disassemble most connection points; and avoiding cutting, stripping, and other projects as much as possible. Only in the initial stage of product design, taking detachability as the design goal, can we ultimately achieve efficient product recycling. At present, many NEVs have not yet taken shape and are still in the process of design and improvement. The above design principles can thus be implemented and embodied in the design of NEVs. To facilitate the recycling of scrapped automotive materials, when designing NEVs, designers should try to choose environmentally friendly materials that are easy to recycle and control the use of toxic and hazardous substances (e.g., lead, mercury, cadmium, and hexavalent chromium) while reducing the number of material types, unifying materials, and achieving unified material standardization and marking. Toyota and Ford are negotiating using the same materials to design the same parts as much as possible, showing the possibility of an international unification of automotive materials and the standardization of parts materials. These efforts aim to facilitate the classified disposal of auto parts after dismantling.

5.2 Increasing the Recoverability Rate and Recycling Price of End-of-Life Vehicles

End-of-life vehicles (ELVs) are a very important material resource and have high added value. The automotive recycling method directly determines the recoverability rate and utilization level. Remanufacturing is an advanced form of circular economy in the automotive industry that can maximize the retention of high added value in products. Therefore, we must use remanufacturing methods to recycle scrapped auto parts. The revised version of China's Management Rules of Recycling End-of-Life Vehicles is due to be released. It is understood that the revised measures will eliminate the mandatory melted destruction of the five major assemblies of ELVs and allow them to be sold to remanufacturing enterprises, thus realizing the recycling of end-of-life vehicle resources. Parts remanufacturing can save resources while greatly increasing the added value of ELVs. This helps expand the profitability of automobile dismantling companies, allows companies to recycle ELVs at higher prices, and increases private owners' enthusiasm for writing off used cars. Taking the automotive gearbox as an example, the total weight of its materials is only about 45 kilograms, and its value will not exceed 1,000 CNY if it is sold as metallurgical materials. If the part is remanufactured, its value will exceed 7,000 CNY. Therefore, the comprehensive utilization of ELVs needs to create a full-industry-chain collaboration model under which scrapped vehicles' recycling, dismantling, remanufacturing, sorting, and parts processing all take place.

5.3 Improving Regulations for NEV Recycling and Establishing an Efficient Recycling System

Although NEVs have not been marketed on a large scale globally, the recycling system for power batteries has attracted the attention of governments and enterprises in many countries. Japan has established a nickel-hydrogen-powered battery recycling system for battery production, sales, recycling and reprocessing. China is gradually establishing a complete vehicle power battery recycling system. At present, recycling NEVs still depends on the recycling system for conventional cars, which faces increasing numbers of conventional end-of-life vehicles. In addition, the recovery of power batteries, as well as fuel cells, requires special processes and technologies for recycling and reuse. Reliance on conventional vehicle recycling channels will hinder the recycling of NEVs and power batteries. Therefore, China should seek to establish an independent NEV recycling system, improve the laws and regulations for NEV recycling, and grant independent recycling qualifications for NEVs and parts to enterprises with recycling capability. Even if establishing an independent NEV recycling company is feasible, conventional vehicle recycling companies will need to establish independent NEV recycling departments as separate businesses. Departments of automobile management, quality supervision, industry and commerce, and environmental protection can strengthen legal supervision and control and effectively increase the actual recycling rate of new energy automotive products in China. Relevant scientific research institutes and related departments should cooperate with government authorities to explore policies, management systems, and regulatory systems that will promote the development of NEV parts recycling and remanufacturing industries. Moreover, they should study domestic NEV parts trading and remanufactured product sales to adjust relevant management policies and accumulate experience to establish technical standards for remanufacturing, market access conditions, and circulation supervision systems.

5.4 Improving the Exit Mechanism of End-of-Life Vehicles in China

To promote the orderly development of the dismantling industry for end-of-life vehicles, it is recommended to first establish reasonable policy guidance and industrial planning, and improve the exit mechanism for end-of-life vehicles. The current exit mechanism for end-of-life vehicles is incomplete. In particular, the implementation of mandatory vehicle scrapping is not effective. An owner is allowed to purchase a new vehicle without having his or her end-of-life vehicle recycled. Furthermore, illegal dismantling and underground transactions are still rampant, which means that many (quasi) end-of-life vehicles more likely go to the illegal dismantling market than to scrapping. To solve the problem of where end-of-life vehicles go, the key is to establish a linkage mechanism, strengthen coordination between departments of commerce, public security, environmental protection, and transportation, and open up the blockage points in the whole life cycle of automobile production, circulation, and scrapping. It is necessary to strengthen market supervision and crack down on illegal dismantling and black-market transactions; on the other hand, vehicle owners need to be actively guided to go to official vehicle recycling companies to scrap their vehicles. Owners should be made aware that if their vehicles are sold to the illegal dismantling market, the license plate cannot be canceled and the vehicle will still be attached to their name. In the event of a traffic accident or other violation, the original owner would therefore have to take responsibility. Therefore, it is equally important to increase awareness of safety risks among vehicle owners while also strengthening crackdowns on illegal operations.

5.5 Strictly Implementing the Extended Producer Responsibility Policy

Since the manufacturer's recycling responsibility policy lacks needed improvements and enforcement, most Chinese automobile manufacturers are only responsible for the production of cars, and they are less concerned with recycling. At the beginning of 2017, the General Office of the State Council issued the Implementation of Extended Producer Responsibility Policy and proposed that electric vehicle and power battery manufacturing enterprises should be responsible for establishing a waste recycling network. In March 2018, seven ministries and commissions jointly issued the Interim Measures for the Management of Recycling of Powered Storage Batteries for New Energy Vehicles, emphasizing the need to implement the extended producer responsibility policy. Under the requirements regarding who produces and who is responsible, vehicle manufacturers assume the main responsibility for power battery recycling, and related production companies fulfill the corresponding responsibilities in each step of recycling. It is very convenient for vehicle manufacturers to recycle. They are more familiar with the parts they produce, can more easily dismantle vehicles, and have inherent advantages in parts remanufacturing. Component manufacturers and raw material producers are responsible for recycling their own parts or raw materials. They can provide technical support, provide the relevant testing and dismantling required by the process of raw material development and parts composition for the related resource recycling companies, and provide financial support. For raw materials recovered by new energy auto parts and resource recycling companies, the corresponding raw material manufacturers and parts manufacturers can fulfill the purchases of a certain ratio of recovered materials. In the recycling of end-of-life NEVs, relevant government departments, NEV manufacturers, and recycling companies need to take measures to build a sound new energy vehicle and parts recycling system. For government departments, they can first establish sound policies, appropriate regulations, and a good development environment for the automotive recycling industry. Second, they need to strictly implement the producer responsibility system, establish a recycling database, and incorporate recoverability rate into the new product certification system of manufacturing companies. Finally, they can use various economic and taxation levers to increase the competitiveness of auto recycling companies and promote their healthy development. Automobile manufacturers need to make great efforts to develop green designs and manufacturing technologies that increase the recoverability rate. Recycling companies can improve vehicle dismantling and remanufacturing technologies. China's end-of-life NEV recycling industry will only experience continuous development with the implementation of a sound recycling system and constant improvements in production and recycling technologies.

6 Conclusions

Based on the current status and problems associated with the recycling and reuse of traditional end-of-life vehicles in China, the present study has investigated the current state of NEVs' market promotion and forecasted their production and sales in China. Furthermore, this paper analyzed in detail the models and the specific recovery and reuse methods for reclaiming and reusing upcoming end-of-life NEVs and their key components. Finally, a number of marketing strategies have been proposed to promote the recycling and reuse of end-of-life NEVs. Based on the above analysis, this paper draws the following conclusions: (1) The system for constructing and recycling new energy vehicles should be planned in advance. (2) China's future recycling model for NEVs should establish an independent industrial model for the comprehensive utilization of scrapped power batteries for NEVs. (3) For the recycling of end-of-life NEVs and their key components, the government, as well as NEV production and recycling enterprises, must take action to create a sound NEV and parts recycling system. Implementing the producer responsibility system is key. (4) The recovery and reuse of power batteries is the core aspect of the recycling of end-of-life NEVs. Thus, it is necessary to focus on improving power battery recycling policies and systems.

7 Zusammenfassung

China hat weltweit die meisten „New Energy Vehicles" (NEV). Im Laufe der Zeit wird ein Teil dieser NEV jedes Jahr ausrangiert werden. Dieser Beitrag untersucht den potenziellen Markt für NEV am Ende ihres Lebenszyklus sowie bestehende Probleme in den Wieder- und Weiterverwertungssystemen Chinas, indem Status Quo und Herausforderungen beim Recycling konventioneller Fahrzeuge betrachtet werden. Es zeigte. sich, dass die Anforderungen an das Recycling- und Weiterverwertungssystem frühzeitig geplant werden sollten. Zudem wurden verschiedene Verfahren zum Recycling und zur Wiederverwendung von NEV und deren Komponenten analysiert und darauf aufbauende Strategien entwickelt. China sollte als zukünftiges Recyclingsystem für NEV das Modell einer unabhängigen Industrie wählen, um die in NEV enthaltenen Batterien umfassend zu nutzen. Die durchgeführte Studie stellt einen Referenzpunkt für ein robustes NEV-Recyclingsystem sowie zur Umsetzung einer Recycling- und Wiederverwendungsplattform dar.

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