Multi-angle Analysis of Electric Vehicles Battery Recycling and Utilization

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Abstract—Under the dual pressure of resource and environment, electric vehicles (EVs) will gradually replace fuel vehicles as a new trend. Among them, the recycling and utilization of EV batteries have attracted much attention. This article indicates the classification of EV batteries and the importance of battery recycling, and proposes some measures to recycle batteries. The research in this paper shows that the current EV batteries mainly include lead-acid batteries, nickel-hydrogen batteries, lithium-ion batteries, lithium iron phosphate batteries, and ternary lithium batteries. It was emphasized that heavy metals leaked from waste batteries cannot be normally degraded by microorganisms in water bodies and soil, and heavy metals can endanger human health through the food chain through water bodies, plants, animals, etc. At the same time, the recycling of precious metals and valuable metals in the battery can realize resource recycling. Faced with the problems in the EV battery recycling and utilization industry, the customers should strengthen their awareness of battery recycling. The enterprises should work closely with other related enterprises to form a more complete battery recycling industry chain. The government should issue policies and regulations for supervision and management. And the recycling system for battery recycling, cascade utilization, and resource reuse should be improved. This article provides a way to maximize the utilization of EV battery resources, reduce the adverse impact on the environment, and achieve the goal of carbon neutrality as soon as possible.

1. Introduction
In the context that carbon neutrality and carbon peaking have attracted worldwide attention, the development and utilization of clean energy have also received more attention. At the same time, under the dual pressure of resource and the environment, the automotive industry is undergoing a new round of revolution. EVs will gradually replace fuel vehicles and become more people’s choice. Recent evidence suggests that the EV industry has potential market. Among them, the recycling and utilization of EV batteries have not only attracted much attention but also have great significance for the vigorous development of the entire EV industry. At present, a large number of EV batteries have been or will be scrapped. Therefore, the main purpose of doing this research is to make more people pay attention to the problem of battery recycling and utilization, and through the cooperation of everyone, the problems of battery recycling and utilization can be solved as soon as possible.

At present, there are not enough literature studies and examples to analyze the recycling of EV batteries from the perspectives of the consumers, enterprises, government, and so on. The battery recycling and utilization industry have not yet formed a certain industrial chain. Customers’ awareness of battery recycling needs to be strengthened. Some enterprises have relatively complete battery
recycling procedures, while others use informal methods to dispose of used batteries, which will cause waste of resources and new environmental pollution problems. At the same time, the government also needs to put forward corresponding policies for the different needs of customers and enterprises to support the further development of the EV industry. In addition, the technology and processes in battery recycling modes are not fully mature, and further research is still needed. All in all, we need to strengthen information exchanges among customers, enterprises, and governments. And we can cooperate in a variety of ways to make a certain contribution to the entire society and the environment while satisfying individual interests.

The article introduces the main types of batteries currently equipped with EVs, analyzes the reasons why EVs will replace fuel vehicles to become the mainstream, and elaborates that EV batteries may cause harm to water, soil, organisms, etc., as well as the battery recovery value. The main purpose of this article is to analyze some problems in the current battery recycling industry with EVs through the research of consumers, enterprises, governments, and recycling modes from multiple perspectives, and propose corresponding feasible solutions. The purpose is to maximize the recycling and utilization of EV battery resources, reduce its adverse effects on the environment, and strive to achieve the goal of carbon neutrality.

2. Electric Vehicles

2.1. Classification of EVs batteries
The core of EVs is the batteries for EVs, and the batteries for EVs are the main breaking point in the modern industry. The development of EVs is inseparable from the innovation of batteries, and large manufacturers are constantly innovating the battery quality and capacity of EVs. At present, the mainstream EV battery types on the market are roughly classified into the lead-acid battery, nickel-metal hydride (Ni-MH) battery, lithium-ion battery, lithium iron phosphate battery, and ternary lithium battery (nickel cobalt manganese acid lithium batteries). Table 1 indicates a number of significant differences of the advantages and disadvantages of five different types of EV batteries.

2.1.1 Lead-acid battery
The lead-acid battery has the advantages of low cost, tolerating low temperatures, cost-effectiveness, and the shortcomings of low energy density, short life, large volume, and poor safety. Due to the low energy density and service life, EVs used as power cannot have a good speed and high cruising range and are generally used for low-speed vehicles.

2.1.2 Ni-MH battery
Ni-MH battery has the advantages of low cost, mature technology, long life, durability, and the disadvantages of low energy density, large volume, and low voltage. Ni-MH batteries are much larger than lithium batteries, but although their performance is better than lead-acid batteries, they contain heavy metals which will pollute the environment after being abandoned.

2.1.3 Lithium-ion battery
The lithium-ion battery is one of the most technologically advanced batteries at present. This kind of battery has high energy density and can store more electricity; it has a long cycle life, can be charged and discharged more times, and can be used for a long time. There are two main types of lithium batteries currently used in EVs: lithium iron phosphate batteries and ternary lithium batteries.

2.1.4 Lithium iron phosphate battery
Lithium iron phosphate battery has the characteristics of good thermal stability, safety, low cost, and long life, but at the same time, it has the disadvantages of low energy density and low-temperature fear. Thermal stability is the best among power lithium batteries. However, the low energy density results in
a heavier battery, a larger volume, and an average vehicle range. The biggest pain point is the problem of low-temperature charging. When the temperature is lower than -5°C, the charging efficiency is low.

2.1.5 Ternary lithium battery
The ternary lithium battery has the characteristics of high energy density, long cycle life, and tolerating low temperatures, but its stability is insufficient at high temperatures. The energy density can reach the highest, but the high-temperature performance is relatively poor. Pure EVs that require cruising range are the mainstream direction, and the battery is more stable at low temperatures.

| No. | EVs Battery Types         | Advantage                                      | Disadvantage                                      |
|-----|---------------------------|------------------------------------------------|--------------------------------------------------|
| 1   | Lead-acid battery         | Low cost, Tolerate low temperatures, Cost-effective | Low energy density, Short life, Large volume, Poor safety |
| 2   | Ni-MH battery             | Low cost, Mature technology, Long life, Durability | Low energy density, Large volume, Low voltage     |
| 3   | Lithium-ion battery       | High energy density, Store more electricity, Long life | High temperature, Unstable                       |
| 4   | Lithium iron phosphate battery | Good thermal stability, Safety, Low cost, Long life | High temperature, Unstable                       |
| 5   | Ternary lithium battery   | High energy density, Long life, Tolerate low temperatures | High temperature, Unstable                       |

2.2. Reasons for the popularity of EVs
In the economic and social development of our country, we are faced with the dual pressure of resource and the environment. Of all the greenhouse gas (GHG) emission sectors, transportation is the fastest-growing contributor to GHG emission and one of the largest contributors to global warming [1]. With the popularization of fuel vehicles, Human life has become more convenient. However, due to people's dependence on fuel vehicles, a series of problems such as automobile exhaust pollution and the greenhouse effect are caused. Meanwhile, the industrial society that depends on fuel vehicles is also facing the possibility of depletion of fossil energy in the future. On the contrary, EVs use batteries as the main power. Although water pollution, air emission, and solid wastes may generate during batteries manufacturing, which is harmful to human health as well as the environment [2]. The pollutant emissions from the battery manufacturing process are controllable, and the battery use process will not release harmful substances. After being scrapped, because the battery material has a high reuse value, it is also conducive to the recycling industry. In the meantime, many people are convinced that the EVs industry and related industries will become the main revenue stream in the coming 10 to 30 years [3]. Therefore, in terms of global carbon peak and carbon neutrality trends, EVs should be the development direction of the automotive industry. What can be clearly seen in Fig. 1 is the continual growth of the sales of EVs which is predicted by IEA in the next 10 years. EV sales share shows a growing trend, and Plug-in hybrid EV (PHEV) share in EVs is relatively stable. It can be seen that EVs will become more and more popular in the future.
2.3. The harm caused by EV batteries
First of all, from the perspective of the process of EV battery disposal, given that the current amount of end-of-life EV lithium batteries is quite small, the recycling cost is still high but the profit is low, which prevents EV and battery manufacturers from effectively recycling used batteries [5]. Due to the lack of a large-scale recycling system, the recycling behaviour is easily driven by profits and lacks constraints. Some batteries are directly thrown into garbage stations or small recycling plants with incomplete equipment. Strong acids and alkalis are used to recycle batteries, generating toxic and harmful gases or wasting liquid [6]. For example, although the number of lithium-ion batteries produced and sold is huge, only 29.5% of people can collect them correctly, while the proportion of lithium-ion batteries stored at home is 59.6%, and the proportion that throws them in the trash can is 15.9% [7]. Secondly, waste batteries contain heavy metals, flammable electrolytes, and toxic electrolytes. It is worth mentioning that improper handling can cause these substances to leak [8]. When heavy metals are leaked into the water, they cannot be normally degraded by microorganisms in the water, nor can they eliminate the harm of metal pollution utilizing the self-purification of the water. They will inhibit the photosynthesis of organisms and affect its growth. When heavy metals enter the soil, the mobility in the soil is poor, the residence time is longer. They are not easily degraded by microorganisms, directly affecting the growth and development of crops. Moreover, heavy metals can endanger human health through the food chain through water, plants, animals, etc. The common hazards of heavy metals to the human body include varying degrees of adverse effects on the liver, kidney, heart, lung, and skin. Studies have shown that nickel can cause lung and nose cancer, reduce lung function, and cause bronchitis. Cobalt can cause serious health problems such as asthma and pneumonia, it may also be a carcinogen. Exposure to manganese can cause respiratory problems, loss of coordination and other nervous system problems. Third, by recycling precious metals and valuable metals in waste power batteries, if they can be recycled, it will bring certain economic value [9, 10], and also reduce the demand for raw materials, ensure the supply chain of alternative raw materials, and apply them in the manufacturing of new power batteries or other fields, to realize the recycling of resources [11]. In short, the recycling of batteries in the future will be paid more attention.

3. Measures

3.1. Customers
From the perspective of customers, many customers are willing to recycle batteries, but lack recycling channels. While other customers are not aware of battery recycling and lacking the knowledge of battery
recycling. According to research, the service life of EV batteries is generally 6-8 years [12]. When the EV battery purchased by the customer reach the recycling standard, the customer needs to contact the original manufacturer or a regular battery recycling enterprise to replace the EV battery or get a certain remuneration. Meanwhile, the government and enterprises can increase some publicity methods to popularize battery recycling-related knowledge and adopt a battery deposit system to help customers pay more attention to battery recycling. The enterprises and governments should also adopt some incentive measures to encourage citizens to actively participate in the recycling of waste batteries. For example, with the implementation of the waste battery collection points system, people can earn points by collecting waste batteries, and then these points can be exchanged for some daily necessities or honorary titles, etc. [13]. In conclusion, the customers should increase their battery recycling awareness. The enterprises and governments can take rewards and punishments to help customers participate in battery recycling.

3.2. Enterprises

From the perspective of enterprises, the battery recycling locations are scattered, and the battery transportation and recycling costs are high. Moreover, the sources of resources required for battery manufacturing are extensive. If the enterprises cannot recycle and reuse their batteries, and the supply of raw materials exceeds supply, it will bring certain difficulties to the development of the enterprises. Taking China as an example, when the enterprises manufacture NCM-G batteries, China’s total lithium demand will reach about 5.67 Mt in 2031, exceeding China’s current lithium reserves of 5.29 Mt [14]. Lithium, cobalt, and nickel are main components for the efficient operation of EV batteries. They are also relatively scarce as resources. As shown in Fig.2, EIA predicts that the demand for various metals from the perspective of EV sales will continue to expand in the next 20 years. At present, according to statistics, there are many small enterprises engaged in the recycling of lithium, cobalt, and nickel. Generally, most of them proceed from their own interests and rarely consider battery recycling from the perspective of environmental and resource sustainable development. In addition, these enterprises do not have complete and efficient battery processing equipment and technology, so it is difficult to ensure maximum recovery efficiency, and it is easy to cause secondary pollution and safety hazards to the environment [15]. All in all, the enterprises should reduce the cost of battery recycling by setting up funds or applying for government subsidies and choose more advanced and efficient battery recycling methods and modes. In view of the current situation that more customers choose to buy EVs, the enterprises should establish a complete battery recycling mechanism and increase the number of high-quality battery recycling points. The enterprises should not only strengthen the battery recycling system that is coordinated with battery enterprises, recycling enterprises, logistics enterprises, but also gradually form a mature industrial chain to maximize battery recycling efficiency and benefits. Also, the enterprises should use new EV supervision platforms and other methods to establish battery traceability mechanisms to prevent battery loss.
3.3. Government
From the perspective of government, on the one hand, countries including many European countries have stated that they plan to ban the sale of gasoline and diesel vehicles by 2040 or earlier. California also announced that the state will gradually switch to EV to reduce greenhouse gas emissions, and plans to ban the sale of gasoline and diesel vehicles from 2035. On the other hand, the government is also facing difficulties in effectively implementing battery recycling and disposal policies, and the issue of industry standards that need to be improved urgently needs to be resolved. Currently, African governments rarely issue industry-specific regulations to enforce pollution control technologies or limit emissions from lead battery recycling plants. Moreover, according to statistics, most countries rely on general regulations in environmental laws to monitor the performance and operational requirements of lead battery recycling plants [17]. Driven by the four major driving forces of China’s technology upgrade, air pollution control, carbon emission reduction, and energy security, the government has shown a strong willingness to develop the EV industry [12]. In 2018, seven Chinese departments jointly formulated the "Interim Measures for the Administration of Recycling and Utilization of Power Batteries for New EVs", each department manages and supervises the recycling and utilization of batteries within their respective responsibilities, and the state supports scientific and technological research on battery recycling and utilization to promote the sustainable and healthy development of the EV industry. Japan has promulgated corresponding laws and regulations from three levels of basic law, comprehensive law, and special law. They established a recycling system of "battery production-sales-recycling". The recycling of used batteries in the United States is mainly regulated by the market. The government regulates the recycling of used batteries through environmental protection laws, which stipulate that battery manufacturers are mainly responsible for the recycling of batteries [18]. In addition, the European Union issued a draft proposal for a new battery law on December 10, 2020, abolishing the current EU battery directive. The implementation mode has changed from "instructions" to "regulations". A prominent feature of the new regulations is that the requirements cover all stages of the battery's full life cycle: from the production and processing of battery raw materials to the use of battery products, in order to recycle scrap and end-of-life batteries. In addition, the new version of the EU circular economy action plan lists batteries and new EVs as one of the seven value chains that focus on the development of a
circular economy. It can be seen that various countries’ governments have paid great attention to the recycling and utilization of EV batteries. Therefore, the government should strengthen information sharing in accordance with the actual needs of enterprises and the market, and issue policies and regulations for supervision and management to make the battery recycling mode operate smoothly and efficiently. The government subsidies are a meaningful way to adjust the strategies of EV manufacturers to produce cars and recycle batteries [19]. In general, the government can help the enterprises through monetary subsidies and technology subsidies. According to the current shortage of raw materials for manufacturing batteries, the government can also formulate practices and governance strategies that allow sustainable exploration of natural resources, and authorize personnel from relevant scientific research institutions to explore effective recycling processes that can reduce the pressure on natural resources [20].

3.4. Recycling mode
From the perspective of recycling methods, the recycling of EV batteries can currently be divided into cascade utilization and recycling. Studies have shown that when the battery capacity drops to 80% of the rated capacity, it will not be able to meet the needs of EV and can enter the ranks of obsolescence [21, 22]. First, if the battery is not severely damaged and can continue to be used, cascade utilization is our first choice. The process of applying used batteries (or battery packs/battery modules/single cells) to other fields can be used at one level or at multi-level utilization. These batteries have been re-tested and analyzed, and they can be used in other areas where operating conditions are relatively simple and battery performance requirements are relatively low to continue to play their role, such as renewable energy devices in buildings, fast-charging stations for EV, energy storage applications, and portable Generators, electric bicycle applications, etc. If a large number of batteries can be used, it will not only save profits but also save resources [23, 24]. However, if the battery is severely damaged, the waste battery will be disassembled, crushed, separated, purified, smelted, etc. Tesla's entire battery recycling process does not involve high-energy smelting, so emissions are minimized, and more than 70% of the materials in the battery can be recycled (by weight). The products of this recycling process are carbon dioxide, water, and dust, without any other pollutants. The dust will also be recycled and buried through the dust removal device. Chinese enterprise BYD has done a good job in battery recycling. When there is a customer request or the battery of a scrapped vehicle needs to be replaced, the dealer will take out the battery and transport it to the BYD factory for preliminary inspection. If they can be reused and continue to be used, these batteries will continue to be used for home energy storage or base station backup power. Batteries that cannot be reused will be shipped to the material factory for disassembly and recycling. On the whole, BYD has successfully built a complete battery recycling process system with high recycling efficiency. In short, we need to develop and improve the recycling system of battery recycling, cascade utilization, and resource reuse as soon as possible. This is the most basic and powerful guarantee. Only when a certain scale is formed can battery recycling be considered on the right track.

4. Conclusion
In recent years, EVs have been widely accepted by more people, and the accompanying problems of EV battery recycling and utilization need to be solved urgently. The research in this paper shows that the common EV batteries mainly include five types: lead-acid batteries, nickel-hydrogen batteries, lithium-ion batteries, lithium iron phosphate batteries, and ternary lithium batteries. If the waste batteries are not handled properly, the heavy metals cannot be degraded by microorganisms in the water and soil after they are leaked. Heavy metals can cause varying degrees of harm to water, plants, animals, etc. More importantly, heavy metals can endanger human health through the food chain. In the meantime, metals recycling in the battery can realize resource recycling. To solve the current problems in the battery recycling and utilization industry, the measures include: increasing the customers’ awareness of battery recycling, strengthening the enterprises collaboration and information sharing with battery, recycling, and logistics enterprises to improve the power battery recycling system, issuing targeted policies and regulations for supervision and management, and improving the recycling system of battery recycling,
cascade utilization, and resource reuse as soon as possible. To achieve the goal of carbon neutrality and carbon peaking as soon as possible, the recycling and utilization of batteries requires the cooperation and support of the customers, enterprises, and governments.

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