Situation analysis of the recovery and utilization of used lead-acid batteries in China

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Abstract. In this article, the details regarding used lead-acid batteries in China, including their production, recovery and utilization technologies, major regulatory policies and environmental management are summarized. This paper focuses on an analysis of the main problems and specific methods of recovery and utilization. These issues include the diversified development of the used battery collection process, the high level of unstandardized collection and treatment rates, the overcapacity of the secondary lead industry and the urgent demand to improve regulatory policy. Solutions to problems that exist in the system of used lead-acid battery recovery and utilization in the following stages are also discussed. This includes the implementation of the extended producer responsibility and ensuring top-layer design, the strengthening of the comprehensive rectification of the used battery recovery and utilization industry, the end of the unstandardized industrial chain of used battery collection and treatment, the improvement of relevant regulatory policies and construction of experimental corporates for the collecting and transferring systems, the promotion of whole-process management and control schemes, and the construction of a public information service platform for its recovery and utilization.

1. Introduction

A lead-acid battery is a kind of direct-current power supply that can store chemical power converted from electricity and then convert such chemical power into electricity during use [1]. A lead-acid battery is composed of 5 main components, i.e., the positive electrode, the negative electrode, the electrolyte, the diaphragm and the container. The energy conversion operates via an oxidation-reduction reaction, and such batteries can be recharged and used repeatedly [2]. This kind of battery has a long history with the widest application as well as the highest consumption due to its significant advantages in cost, stability and safety, among other. It is used widely in the fields of traffic and transportation, communications, electricity, railroads, mines, ports, national defense, and computer and scientific research, and it will still play the leading role in the battery market for long into the future [3, 4].

A lead-acid battery has an average life expectancy of approximately 2 years in China [2]. Along with the increasing demand for lead-acid batteries in automobiles, electric bicycles, energy-saving devices and other fields, the quantity discarded is increasing annually as well. A used lead-acid battery is composed of 74% lead and its compounds, 20% sulfuric acid and 6% plastics, and has a high-level recovery and utilization value. Recycling lead from used lead-acid batteries can not only reduce the quantity of the primary mining of lead but also effectively reduce the environmental health risks caused by lead [5, 6]. It is estimated that approximately 65 kilograms of standard coal, 235 cubic

meters of water, 128 tons of solid waste emissions and 0.03 tons of sulfur dioxide emissions could be saved during the production of one ton of secondary lead [7].

At present, the manufacture and use of lead-acid batteries are relatively clean in China, and lead pollution caused by lead-acid batteries mainly comes from the recovery process [8]. Many research studies have been conducted to improve the utilization efficiency of lead resources by advanced technology [9, 10], to extend battery life cycle [11] and to recover valuable components from used lead-acid batteries [12, 13], and notable achievements have been obtained [14]. However, the key factors of lead pollution in China are due to the flawed recycling system [15, 16] and the mismatched regulatory system of used lead batteries [17].

In this paper, the current state of recycling and utilization of used lead batteries in China is summarized, the main problems and specific reasons are analyzed, and then some suggestions for improvement are proposed.

2. Overview of the lead-acid battery manufacturing industry in China

China has become the largest lead-acid battery producer and consumer in the world [18]. The production of lead-acid batteries reached approximately 205.13 million KiloVolt-Ampere (kVA) in 2016 (See Figure 1), which accounted for over 40% of the world's total production, making China the market leader. With the increasingly strict environmental protection laws and regulations in recent years, the number of lead-acid manufacturers in China has dropped from 2,000 to 400 (See Figure 2). They are now mainly located in Zhejiang, Jiangsu, Guangdong and Shandong Provinces. The production in these four provinces accounts for 50% of the total output in China, though there are also several relatively large-scale manufacturers in Hebei, Tianjin, Hubei and Fujian [19].

3. The recovery and utilization of lead-acid batteries

It is estimated that the number of used lead-acid batteries in China reached approximately 3.50 million tons in 2016 (See Figure 3). Currently, used lead-acid batteries have become the second-largest source of metallic lead and the largest source of secondary lead in China. In 2016, the total output of lead in China approached approximately 4.65 million tons, and that of secondary lead reached approximately 1.9 million tons, accounting for 40.08% of the total output (See Figure 4). Currently in China, 85% of the raw materials required for the production of secondary lead originate from used lead-acid batteries, while 80% of the products can then be used to produce such batteries in turn.

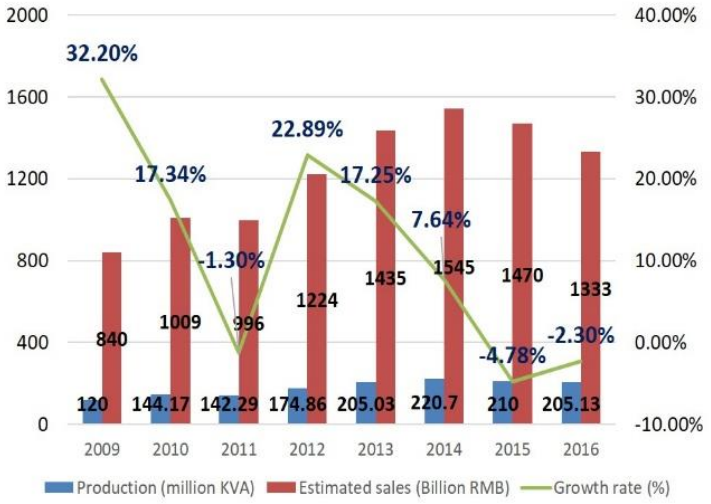

Figure 1. Production, sales and variation trends of lead-acid batteries in China (Data source: China Battery Industry Association).

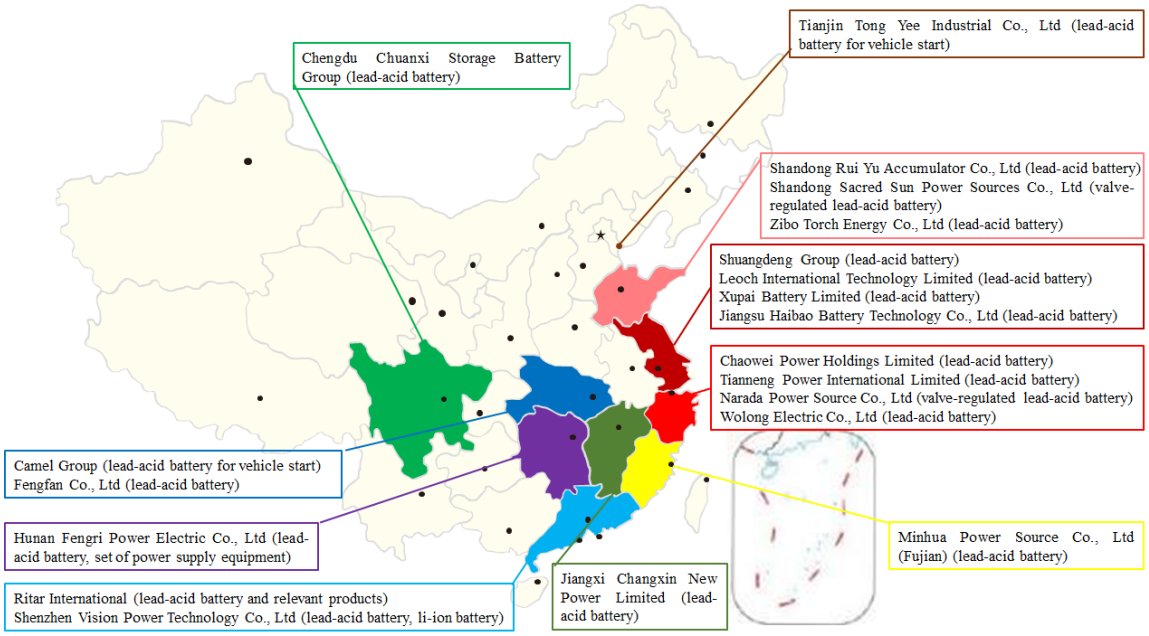

Figure 2. List of lead-acid battery manufacturers and their main products in China (top 20 with the most sales revenue in 2015) (Data source: China Battery Industry Association).

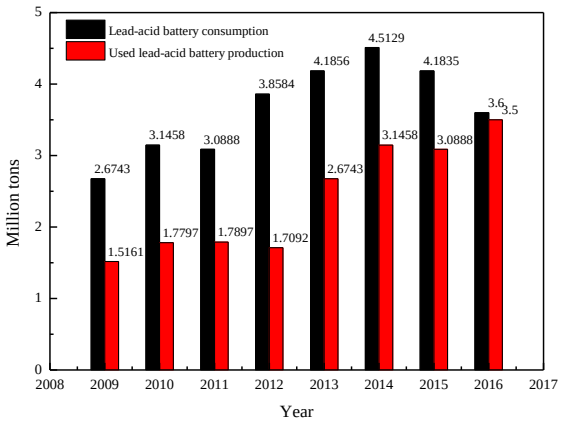

Figure 3. Consumption of lead-acid batteries and production of used lead-acid batteries from 2009 to 2016 in China (Data source: China Battery Industry Association).

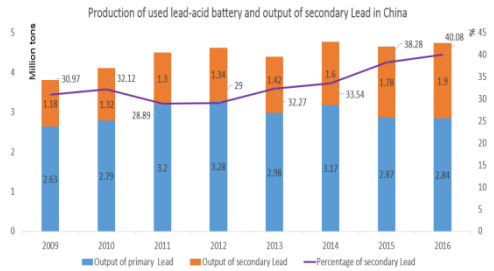

Figure 4. Refined lead and secondary lead production from 2009 to 2016 in China(Data source: China Non-Ferrous Metals Industry Association).

For unbroken used lead-acid batteries, in which the lead-acid solution is sealed, their environmental and health risks are similar to those of lead-acid batteries during storage and transportation processes [20]. However, used lead-acid batteries that have been improperly disassembled or deliberately destroyed will cause leakage of the lead-acid solution and can contribute to the severe environmental pollution of water and soil [21]. Lead will enter the food chain of mankind via various pathways and then accumulate in certain human organs, causing chronic poisoning [22]. This will damage the central nervous system and negatively influence the human body's hematopoietic functions, kidneys and skeleton, among others.

4. Overview of the secondary lead industry in China

4.1. Recovery and utilization technology

The recovery and utilization of used lead-acid batteries concentrates mainly on lead resources, including grid re-melting and diachylon smelting, and the latter is the difficulty for processing used lead-acid batteries [14, 23]. Diachylon accounts for approximately 48%-50% of the total weight of used lead-acid batteries, among which lead sulfate accounts for 60%, lead dioxide accounts for 28% and lead oxide accounts for 9%. The current diachylon smelting techniques can be divided into pyrometallurgy techniques and hydrometallurgy techniques; the former is used in most the processes, accounting for over 90% [24].

4.1.1. Pyrometallurgy technique. Generally, diachylon is placed into a melting pot and melts under temperatures greater than 1000°C during the pyrometallurgy process [14]. The typical process of pyrometallurgy is described as follows:

1. Smelting of secondary lead directly with diachylon

The main smelting process is: breaking - selecting - diachylon - desulfurization - sealed rotary kiln oxygen-enriched combustion. This technique is currently adopted by some large enterprises, such as the Jiangsu New Chunxing Resource Recycling Group and Hubei Jinyang Metallurgical Incorporated Co., Ltd. [5].

2. Mixed Smelting of Lead Sulfide-diachylon

The main characteristics of this techniques are: adopting primary lead smelting equipment, then the lead sulfide reacts with sulfur dioxide and the lead sulfate in the diachylon, thereby generating sulfur dioxide and lead oxide, which is then reduced into crude lead by liquefied gas. The mixed smelting of lead concentrate and diachylon can be achieved through such a technique, and the exhaust gas generated can be made into acid. This technique does not have a desulfurization process and possesses several advantages, including a short processing period, low construction and operation costs, a high oxygen utility rate and a high-level desulfurization rate. It is used for the mixed smelting of lead concentrate and diachylon or other secondary materials but is not suitable for diachylon alone [7]. It is now adopted by Henan Yuguang Gold and Lead Group Co., Ltd., which is a large enterprise in China [23, 25].

4.1.2. Hydrometallurgical technique. The diachylon smelting process in the hydrometallurgy technique is transferred into the liquid phase, and the diachylon is treated with a chemical approach to overcome the shortcomings of the pyrometallurgy technique, such as a high energy waste, a high lead volatility, and a high amount of pollution Instead, it has several advantages, such as a high production efficiency of pure metal, a large output quantity and a low emission [26]. Since environmental protection requirements in China are getting increasingly stricter, the hydrometallurgy technique has drawn more and more attention.

The hydrometallurgical technique has witnessed two stages of development, i.e., the recycling of metallic lead from diachylon and the retrieval of lead oxide from diachylon. The former has continued as the core of the pyrometallurgy technique, which is also a main research direction for both domestic and overseas scholars [1]. Recycling lead oxide from diachylon turns out to be a new research direction in the lead recovery field in China. This method directly transforms diachylon into lead oxide via chemical reactions based on the demands of lead oxide by lead-acid battery corporates. Currently, Yunnan Xiangyun Feilong Recycling Technology Co., Ltd. and Guizhou Cenxiang Resources Technology Co., Ltd. in China have accomplished industrialization [10].

4.2. Development of secondary lead corporates

In recent years, influenced by both policies and the market, secondary lead corporates in China have entered into a deep industrial structure adjustment stage, and the degree of industrial centralization has been obviously improved [7]. Almost 40 of these companies have produced over 0.1 million tons of

lead annually. By the end of 2015, the treatment capacity of used lead-acid batteries in China amounted to 7.2 million tons (see Figure 5) with an actual secondary lead production of 1.78 million tons. Hubei, Jiangsu and Anhui Provinces have become the major areas of production.

Secondary lead corporates in China can be roughly divided into three categories [20]:

First, conventional corporates, such as Jiangsu Chunxing Alloy (Group) Limited, Hubei Jinyang Metallurgical Incorporated Co., Ltd., Anhui Huaxin Lead Group and Anhui Huabo Lead Group, possess an obvious advantage in regard to possessing the equipment for secondary lead technology and environmental protection.

Second, lead-acid battery manufacturers such as Camel Group, Tianneng Power International Limited, Chaowei Power Holdings Limited hope to extend the industrial chain and establish their own secondary lead corporates successfully. The corporates listed above all have obvious advantages in their size, technological equipment and environmental protection. They have become a major force in the secondary lead industry and have brought about a positive influence on the construction of the recycling system of used lead-acid batteries.

Third, primary lead or other non-ferrous metals smelting corporates, such as Henan Yuguang Gold and Lead Group Co., Ltd., have established a project that can handle 0.18 million tons of used lead-acid batteries in Jiangxi Province. The project has been active since May 2014, and its annual treatment capacity has reached 0.54 million tons.

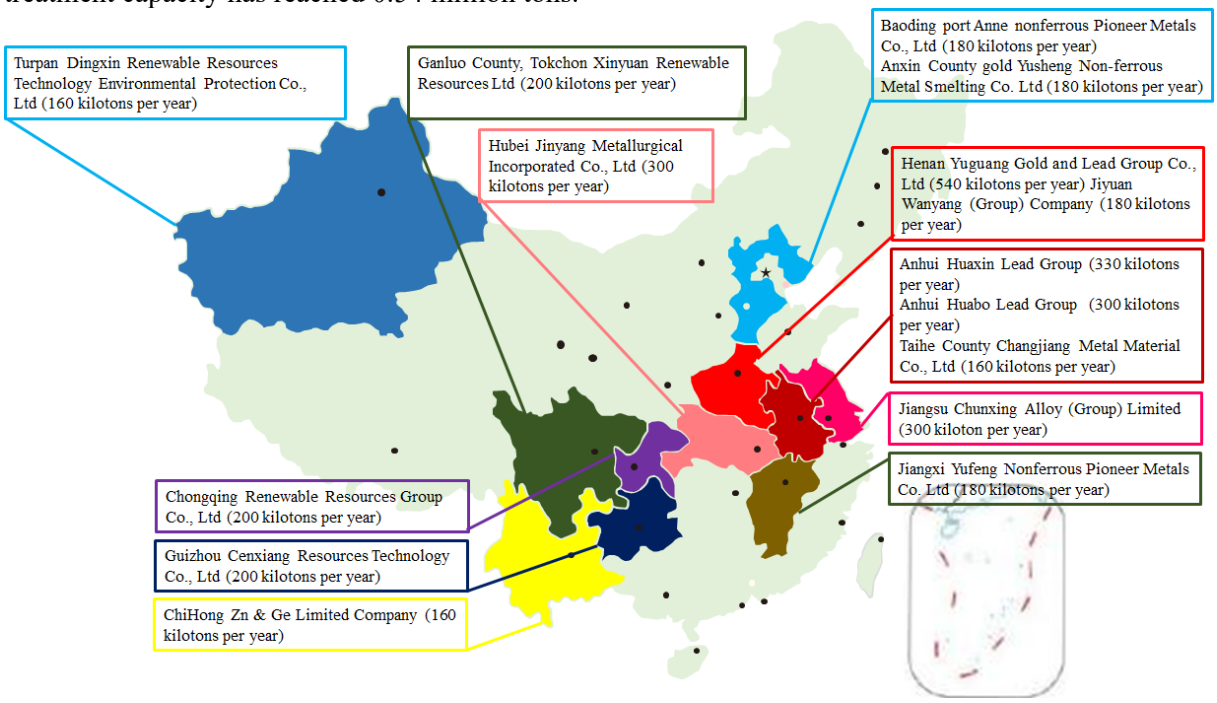

Figure 5. The top 15 secondary lead corporates in China and their treatment capacity in 2015 (Data source: China Non-Ferrous Metals Industry Association).

5. Law and regulatory system of recovery and utilization

5.1. Constructing regulations and a standardized system

An improved regulation system for the recovery and utilization of used lead-acid batteries has been established. Existing regulation standards can be roughly divided into 5 categories: industrial policies, hazardous waste management, clean production, pollution prevention and treatment, and quality control of secondary lead products.

5.1.1. Policies on supporting the development of the secondary lead industry. To guide the development of the secondary lead industry, there must be a promotion of the industrial structure adjustment and industrial upgrades, an improvement of the resource utilization efficiency, and a reduction in environmental pollution caused during the manufacturing of secondary lead. To accomplish the sustainable development of the secondary lead industry, the Ministry of Industry and Information Technology established Standards on the Secondary Lead Industry. The Ministry of Finance also issued Preferential Directories for Resources Comprehensively Used Products and Service Value-added Tax to render a 30% value-added tax discount for the comprehensive utilization of used lead-acid batteries and the disassembly products from the perspective of industrial development.

*5.1.2. Regulations and standards of strict hazardous waste management.*Used lead-acid batteries have been listed in The National Hazardous Waste List (2016) in China. Consequently, corporates involved in the collection, storage, utilization and treatment of used lead-acid batteries must hold permits as required by the Law of the People's Republic of China on Prevention of Environmental Pollution Caused by Solid Waste, Opinions of the Supreme People's Court and the Supreme People's Procuratorate on Certain Issues Concerning the Applicable Laws on Environmental Pollution Criminal Cases, Measures for the Administration of Permit for Operation of Dangerous Wastes, Management of Hazardous Wastes Duplicated Form and other regulations as well as the Technical Specifications for the Collection, Storage and Transportation of Hazardous Wastes (HJ 2025-2012), Pollution Control Standards for the Storage of Hazardous Wastes (GB18597-2001) and other standard specifications. The collection, storage, transportation, utilization and treatment of used lead-acid batteries should strictly conform to the relevant regulations and standards for hazardous wastes.

5.1.3. Promoting the secondary lead industry's clean production. To promote the clean production level of secondary lead industries, the Development and Reform Commission, Ministry of Environmental Protection, Ministry of Industry and Information Technology and other relevant departments successively issued several standard documents, such as the Evaluation Index System of Secondary Lead Industry's Clean Production, Cleaner Production Standard-Lead Smelting Industry (HJ 512-2009), Cleaner Production Standard-Waste Lead-acid Battery Recycling Industry (HJ 510-2009), Clean Production Standard-Lead Electrorefining Industry (HJ 513-2009), Norm of Products Energy Consumption Per Unit Product of Recycling Lead (GB 25323-2010) and other relevant standard documents.

5.1.4. Strengthening the pollution control of the secondary lead industry. To prevent and control environmental pollution during the collection and treatment processes, the Ministry of Environmental Protection issued Emission Standards of Pollutants for Secondary Copper, Aluminum, Lead and Zinc Industry (GB 31574-2015), Policies on the Regeneration of Lead-acid Batteries and the Prevention and Treatment Technology of Production Pollution, Policies on the Pollution Prevention and Treatment of Waste Batteries, and Technical Specifications of Pollution Control for Treatment of Lead-acid Battery (HJ 519-2009) as well as other standards, regulations and technical policies.

5.1.5 Improving the quality of secondary lead products

To control and improve the quality of secondary lead products, China has successively issued many standards, such as Lead Ingots (GB/T 469-2013), Secondary Lead and Alloy Ingots (GB-T 21181-2007), and Crude Lead (YS/T 71-2013).

5.2. Implementing extended producer responsibility

On December 25th 2016, the Chinese government issued Implementations of Extended Producer Responsibility to implement the extended producer responsibility for lead-acid batteries and 3 other products (General Office of the State Council, 2016). It requires the producing corporate to carry out

ecological design, use secondary raw materials, standardize recovery and utilization, and strengthen information disclosure.

The Implementations of Extended Producer Responsibility proposes a clear target and requirement for the illegal recovery of used lead-acid batteries and lead resources recyclable utilization rate. Through 2020, a relevant policy system of extended producer responsibility will gradually be implemented. The ecological design of products will achieve a significant improvement, and the standardized recovery and lead resource' recyclable utilization rate will reach 40%. By 2025, a relevant policy system will be basically accomplished and in operation. The ecological design of products will be generally implemented, and the secondary raw materials of lead-acid batteries will have a utilization proportion of 20%. The illegal recovery and lead resources' recyclable utilization rate will achieve 50%.

To achieve the above mentioned goals, work will be conducted as follows: (1) strengthen the credit evaluation for lead-acid battery production corporates, establish a credit information collection system for the implementation of extended producer responsibility in lead-acid battery manufacturing, connect with national credit information sharing platforms and jointly administer cross-department punishment on credit-breaching corporates; (2) establish reporting and notification systems concerning the performance of the extended producer responsibility in lead-acid battery manufacturers and carry out experimental units in certain corporates, establish the third-party credit certification and evaluation system of extended producer responsibility and introduce third-party authority to evaluate and confirm the corporate's compliance, and regularly issue the implementation report of extended producer responsibility; (3) edit the Law of People's Republic Of China on Circular Economy Promotion and enact management methods of the recovery and utilization of lead-acid batteries as well as the extended producer responsibility, establish and improve regulations for product ecological design, recovery and utilization, and information notification, support the standards of teams who establish their extended producer responsibility, carry out experimental units for the standardization of ecological design and establish unified standards as well as certification and identification systems for green products that cover ecological design products, secondary products and reproduced products; and (4) conduct special rectification on secondary resource collection and distribution facilities, prohibit unstandardized recycling stations and standardize the management of special products such as lead-acid batteries, strictly follow relevant regulations and standards, punish corporates that refuse to meet the environmental emission and safety standards by law, investigate corporates without permits, and establish regular supervision and selective examination systems to control illegal behaviors such as the collecting and treating of used lead-acid batteries without permits.

Meanwhile, the Implementations of Extended Producer Responsibility clarifies the essential task assignment and scheduling of each governmental department. In 2018, the national recovery and utilization goal for used lead-acid batteries will be confirmed, and the regulations for promoting the application of secondary lead products and raw materials will be established. In 2019, the credit information collecting system for the extended producer responsibility will be established, and the Regulation for the Evaluation of Extended Producer Responsibility as well as its corresponding policies and guidance will be enacted, implementing the goal management of green procurement in the meantime.

5.3. Carrying out experimental units for the collection and transportation management

To encourage lead-acid battery industries to fulfill their extended producer responsibility and strengthen the collection and transportation management of used lead-acid batteries, the Solid Waste and Chemicals Management Center of Ministry of Ecology and Environment has organized and carried out an experiment for the collection and transportation management since 2016, with Beijing, Tianjin, Hebei, Liaoning, Shandong, Ningxia, Hainan and Tongren Guizhou designated as pilot areas. Every experimental corporate has issued its own plan as required and clarified its implementation range, occupation period, contents, requirements, procedures and publicly enrolled participants.

Large lead-acid battery manufacturers and secondary lead corporates have actively participated in the experiment, including the Camel Group, Fengfan Co., Ltd., Chaowei Power Holdings Limited, and Shandong Sacred Sun Power Sources Co., Ltd. They make full use of a sales network to recycle used lead-acid batteries via the "Old for New" program and then distribute them to large secondary lead corporates for further utilization and treatment. These corporates include the Jiangsu New Chunxing Resource Recycling Group, Hebei Gang'an Environmental Protection Technology Co., Ltd., Henan Yuguang Gold and Lead Group Co., Ltd., and Hubei Chukai Metallurgy Co., Ltd. After a year-long experiment, every pilot area and corporate involved has actively explored the improvement of the collection, storage, transfer, utilization and treatment of used lead-acid batteries.

6. Major problems and cause analysis

6.1. Diversity of collection processes

At present, the collection system for used lead-acid batteries in China gives priority to individual collection, while legal corporate collection accounts for a relatively small share, presenting a diversified developing trend (See Figure 6). Driven by market interests, an extra-corporate circulation industrial chain for their recovery and utilization has developed that is composed of individual collectors, unstandardized secondary lead corporates and battery manufacturers [20].

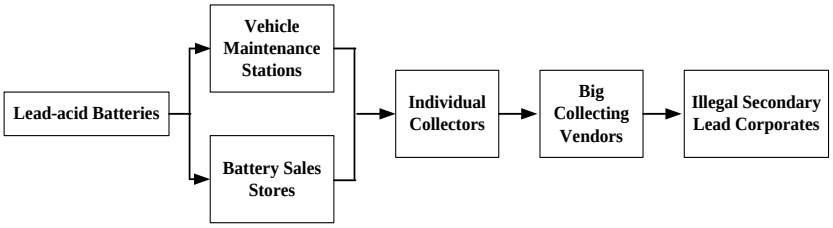

Figure 6. Flow of used lead-acid batteries' illegal collection and treatment.

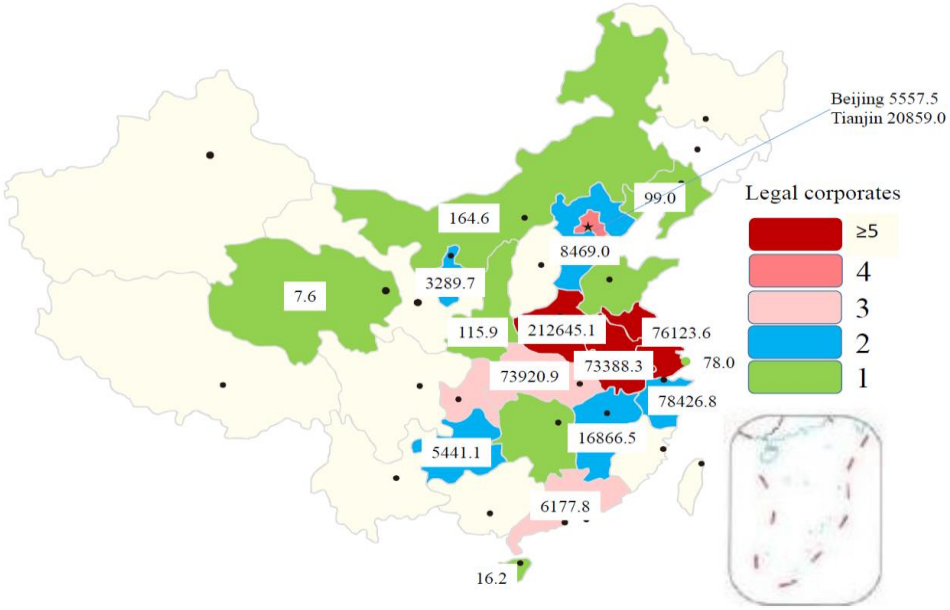

Figure 7. The utilization and treatment of used lead-acid batteries by certified companies in 2016.

With the help of simple transportation tools (tricycles, vans or minivans), individual collectors purchase used lead-acid batteries in cash from local sales stations and vehicle maintenance stores. To

reduce transportation costs, they will usually dump the lead acid from the used lead-acid batteries and then sell the batteries to big vendors or give them directly to secondary lead corporates. Big vendors will sell batteries to those secondary lead corporates or conduct manual disassembly of those batteries first and then sell the diachylon to secondary lead corporates and sell the cases to plastics manufacturing factories.

Legal corporates lag behind individual collectors and illegal secondary lead corporates due to their higher cost and lower purchase prices. Statistics show that in 2015, 32 secondary lead corporates holding permits treated a total of only approximately 0.5665 million tons of waste batteries (See Figure 7), most of which were unqualified products as well as batteries from power grid and communication companies.

6.2. Overcapacity of secondary lead

Statistics from the China Non-Ferrous Metals Industry Association show that by the end of 2015, the used lead-acid battery treatment capacity in China had reached 7.2 million tons and maintained a rapid expansion, while the production quantity in that year was only approximately 3.1 million tons. Due to the severe overcapacity and insufficient raw materials of used lead-acid batteries, secondary lead industries are now encountering difficulties, and malignant competition has appeared.

Unstandardized secondary lead corporates are usually scattered, disordered and dirty. Free from tax burdens and environmental protection costs, they can purchase used lead-acid batteries at a price much higher than legal batteries and then sell secondary lead products at a lower price. Consequently, they can easily reappear in another place after being shut down due to their advantages, causing a serious impact on the operational environment of legal corporates.

6.3. Regulations and standards need to be improved

First, the admittance threshold for used lead-acid battery collection is rather high. As hazardous waste, its collection requires hazardous waste operation permits. Based on The Measures for the Administration of Permit for Operation of Hazardous Wastes, collection permits are currently not available for used lead-acid batteries, and only corporates with comprehensive operation permits can collect them. On the basis of hazardous waste storage and transporting standards, constructing a collection and transportation network for used lead-acid batteries is costly and requires a great quantity of manpower, material and financial resources. However, many corporates holding comprehensive permits are not qualified.

Second, the transferring management system is limited. Legal corporates are distributed in only certain provinces, and therefore, many collected used lead-acid batteries require a trans-provincial transportation network that strictly abides by the approval and duplicated form system of hazardous waste transferring. However, the trans-provincial approval efficiency in some provinces is relatively low, which restricts legal corporates trying to provide the trans-provincial collection and transfer of used lead-acid batteries.

7. Sustainable development path

7.1. Ensuring the top-layer design and coordination

The Implementations of Extended Producer Responsibility in lead-acid battery industries should be enacted, and lead-acid battery industries should be pushed to carry it out. Then, the overall requirements, target, focus, scheduling, and organization management should be clarified, and measures that are required to implement the extended producer responsibility based on the analysis and summary of the existing experiment should be guaranteed. Balance, promote and fulfill the used lead-acid batteries standardized recovery and recyclable utilization rate goal proposed by Implementations of Extended Producer Responsibility of the State Council, and lead-acid battery production corporates' utilization proportion goal of secondary lead raw materials.

Conditioned areas to continue the experiment should be organized, experimental corporates and areas should be broadened, relevant laws and regulations concerning the extended producer responsibility should be improved, and the implementation of the extended producer responsibility should be promoted.

7.2. Strengthening comprehensive rectification

A long-term mechanism for the comprehensive rectification of pollution in used lead-acid battery recovery industries and secondary lead ones should be established while working together with the police to incorporate illegal secondary lead corporates into the small scattered, disordered and dirty organizations for further rectification. Illegal used lead-acid battery collection and illegal lead-acid solution dumping should be fought, and illegal secondary lead corporates should be strictly prohibited. Joint reports should be issued on used lead-acid batteries collection and illegal treating without permits as well as other environmental illegal behaviors, such as secondary lead corporates purchasing used lead-acid batteries that dump the lead-acid solution. Disciplinary mechanisms should be enacted, and the offenders should be held accountable by law.

The supervision over lead-acid battery manufacturers and secondary lead corporates should be strengthened. Relevant regulations and standards should be strictly followed, and corporates that cannot meet the legal environmental emission and safety standards should be punished while investigating corporates without certificates. Corporate layouts should be combined, the regional environmental influence and overall emission reduction of heavy metal pollutants should be evaluated together, the regulations of secondary lead industries and environmental protection standards should be strictly followed, inefficient repeated construction should be avoided, secondary lead corporates should be encouraged to utilize advanced techniques and upgrade their equipment , the overall lead pollution prevention standards should be improved, and the emission of pollutants and the total capacity of the secondary lead industry should be reduced. Manufacturers should be encouraged to purchase secondary lead products directly from corporates with a certificate.

7.3. Improving Relevant Regulations

The Measures for the Administration of Permit for Operation of Hazardous Wastes and Management of Hazardous Wastes Duplicated Form should be edited continuously, and the Examination Guidelines on the Permits of Used Lead-acid Batteries should be enacted and issued while clarifying permit requirements for the collection of used lead-acid batteries and encouraging lead-acid battery manufacturers to establish their own collection network based on their sales channels. Management requirements should be enacted for the collection, transportation, transfer and storage of used lead-acid batteries, and the Technical Specifications of the Utilization and Treatment Pollution Control of Used Lead-acid Batteries should be edited as long as the environmental risks are controllable. The examination and approval procedures for the cross-provincial transfer of used lead-acid batteries should be simplified, and a record system for certified collection enterprises and legitimate secondary lead enterprises with long-term cooperation agreements should be implemented.

7.4. Promoting whole-process management control

Research should be conducted on a unified identification and encoding system for lead-acid batteries and used lead-acid batteries. As for lead-acid battery manufacturers and corporates specialized in the collection and treatment of used lead-acid batteries, an information management system for collection and treatment data should be established to accurately record the quantity, number, condition (broken or whole), source, and location of the used lead-acid batteries to be collected, stored, transferred, utilized or treated. A public information service platform for battery collection and treatment should be constructed, corporates' collection and treatment data should imported into the platform, the management of the producing sources should be strengthened, and traceability should be achieved during the whole process to effectively suppress illegal disassembly and treatment behaviors.

8. Conclusions

The dilemma facing the recycling and utilization of used lead-acid batteries in China is the imperfect recovery system and regulations. The current regulation system for recycling is applicable to industrial hazardous waste, which makes it difficult to meet the needs of social hazardous wastes, such as used lead-acid batteries, which are scattered and numerous. Currently, the levels of production of the lead-acid battery manufacturing industry and secondary lead industry are relatively high in China. If a perfect recycling system for used lead-acid batteries is established by implementing the extended producer responsibility and if the laws and regulations are improved, lead-acid batteries will be able to achieve sustainable development in China.

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