Management of used lead acid battery in China: Secondary lead industry progress, policies and problems

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Review

Management of used lead acid battery in China: Secondary lead industry progress, policies and problems

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ABSTRACT

The amount of used lead acid batteries rises along with the rapid development of battery manufacture in China. The battery manufacture and recycling industry has developed sharply in these recent 5 years. The annual production of secondary lead from used lead acid batteries in China increased rapidly to 1.5 million tonnes (MT) in 2013, making china the world's largest secondary lead producer. Secondary lead enterprises are mainly located in the middle and eastern regions of China, with a legal production capacity of 3 MT/year. Environmental pollution problems began to happen frequently from 2009. After 2011, the government began to put in efforts to promote pollution control, eliminate outdated production capacity, support advanced production and technology innovation research, and has achieved remarkable results. However, the main existing problems are that the proportion of secondary lead production is only 30% of the total lead production, no formal recycling network has been established and the overall level of industrial technology and equipment is outdated. Compared with developed countries, this paper predicts that, secondary proportion will reach 44% in 2015 and 60% in 2028. Finally some countermeasures are given to the recycling mode and technology promotion.

Contents

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1. Introduction

With the development of industrialization and urbanization in China, especially since 2000, vehicle production has kept growing rapidly with electric bicycles popularizing across the country. In 2013, the social possession of vehicles and electric bicycles reached 137 million (Shang, 2014) and 200 million (Zhang, 2013), respectively. The use of lead-acid batteries accounted for 100% of automotive lead-acid batteries start power (Wang et al., 2011), and 90% of the electric bicycle motive power (Han, 2013). In 2013, lead-acid battery (LAB) production reached 205 million KVAh (Guo, 2013).

Refined lead is the main raw material of batteries. The annual production in China increased from 1.2 million tonnes (MT) in 2001 to 4.64 MT in 2013(CNMA, 2014). Till now, the annual production in China has ranked first in the world for 11 consecutive years (Zhang, 2012). The consumption of lead acid batteries accounts for up to 84% of lead consumption (Prengaman, 2000), and its lifecycle is generally two years (Van den Bossche et al., 2006). This results in the generation of large amounts of scrap lead-acid batteries and this number is constantly increasing every year. The scrap amount accounts for more than 90% of scrap lead the whole society (Wei, 2012).

Other used lead is present in much lower amounts than scrap LAB and is hard to recycle. Only about 16% of lead is used in other products (Zeng and Mao, 2010a), such as lead pipe, plate, pellet, metal alloy, cable sheath, oil paint, and special glass, etc. Because lead is not the main component of these products, most of them are dissipated during use or at the disposal stage (Zeng and Mao, 2010b). In China, like other developed countries, the health risk of residents increased and laws to restrict the use heavy metal in household products were enacted. Due to this, the amount of the use of lead will decrease in future (Peng, 2013). Currently, lead cannot be replaced with any other material in manufacturing cheap and stable high-capacity battery (Andreas, 2013). Scrap lead is mostly gotten from the LAB.

Scrap lead-acid battery is included in the "China hazardous waste List" (Li and Fan, 2011). If four kilograms of waste batteries are randomly embedded or abandoned, two square meters of land will be contaminated (Ge and Jiang, 2011). In addition, although China has the world's second-largest lead resources in the world with the lead reserve in China being about 14 MT, representing 16% of global total reserve, the quality of lead ore in China is relatively low. In 2012, national average quality of lead dropped to 2.88% (Peng, 2013), and mining the rest of the lead has also proven to be difficult. Therefore, in these recent five years, the annual amount of lead ore concentrate imported from abroad has been maintained at more than 1.4 MT (CNMA, 2014). According to related researchers (Zuo, 2011), it is predicted that by 2015, the consumption of lead in China will reach 5.6 MT, and that domestic primary lead resources cannot support such a high demand (Zhang, 2011a,b).

The Secondary lead industry has made enormous contributions to reduce environmental pollution and ease resource shortage related pressure. However, because the concentration of the secondary lead industry is low in China and the scale of plants are generally small, different recovery technologies are used (Qing, 2012). Lots of small illegal plants employ workers to cut the batteries using axes and smelt the batteries together with their plastic boxes and lead grids in a reverberatory furnace without any protective equipment thereby endangering employees and the environment as well (Chen and Wang, 2011). The recovery efficiency of this technology is very low with high emission of pollutants. In recent years, especially from 2009, lead pollution incidents have happened frequently in China (Yang et al., 2012; Zhang and Li, 2010). To cope with the increasing amount of scrap lead-acid batteries and solve all kinds of problems existing in the industry, the government issued a series of documents, including policies, regulations, standards and technical guidelines and has achieved remarkable results. In spite of all these measures there still exist outdated recycling channels among other issues.

The Secondary lead industry is important in the development of the circular economy in China. Therefore, this paper studies the current development of China's secondary lead industry, summarizes the adjustments executed by the government and spells out the main results achieved. Also, this paper will compare the status of the secondary lead industry in China with that of foreign developed countries, analyze the various existing problems and propose countermeasures for the future.

2. Industry progress

For years, the production and capacity of the secondary lead industry has rapidly increased and a basic industry pattern has been formed.

2.1. Increased output in the last decade

The secondary lead industry started from the 1950s in China with independent professional plants established after 1978 (Chen et al., 2009). In 1978, the annual secondary lead production was only 18.6 kton and accounted for 12.8% of total production. Before 2000, production hovered around 100 kton, which accounted for less than 20% of total refined lead production. The production of secondary lead increased rapidly from 0.21 MT in 2001 to 1.5 MT in 2013 but the secondary proportion only increased slowly to 30% of total production (Zhang, 2008). See Fig. 1 for more details.

Production in 2013 decreased because many illegal lead plants were closed by authorities. Also, the price of refined lead dropped due to bad macroeconomic policies in China and overseas.

2.2. Location pattern of output

Secondary lead production is widespread throughout China with more than 80% scaled lead plants mostly located in the middle and eastern regions (Zhang, 2011a,b). Secondary lead distribution and production areas are basically formed in some cities and countries and these locations are close to the downstream battery manufacturers. In 2013, the total recovery capacity of the top 20 lead production provinces was 3 MT, which was located in 8 main provinces (CNMA, 2014). See Fig. 2 for more details.

2.3. Production capacity progress

According to ANTAIKE statistics, national production capacity of secondary lead was only 0.24 MT. Until the end of 2013, the production capacity achieved was more than 3 MT (illegal small smelting capacity excluded), and the annual increase rate was over 24%. However, the capacity utilization rate continues to decrease, falling from 95% in 2011 to 50% in 2013 (Hu, 2013). See Fig. 3 for more details.

In 2013, there were 6 projects including new projects, renovation and expansion projects (Shang, 2014; Ma and Shang, 2013). It was estimated that after all the projects were put into operation, national secondary lead production capacity would increase by 0.5 MT per year. See Table 1 for relevant projects.

The Huaxin lead group did not increase its capacity. The local government therefore forced this company to upgrade its smelting system from the reverberatory furnace to a new type furnace and install some environment protection equipment.

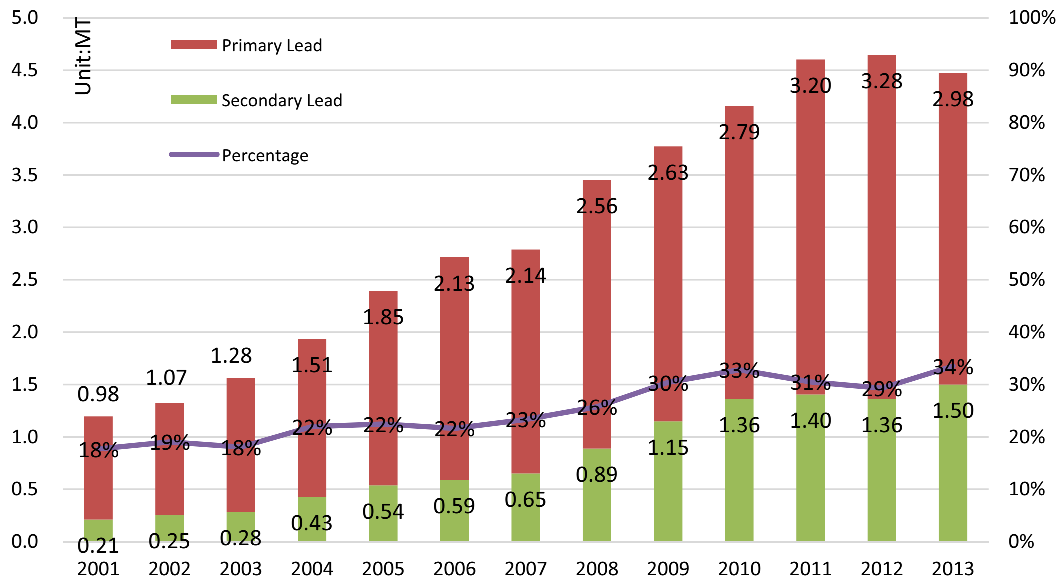

Fig. 1. Refined lead and secondary lead production from 2001 to 2013 (Chen et al., 2009; CNMA, 2014).

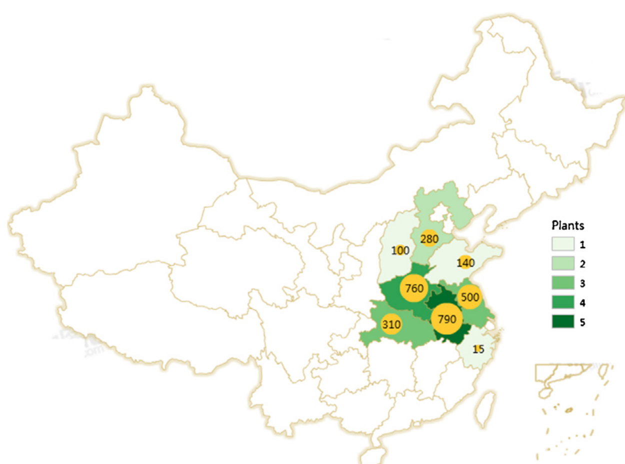

Fig. 2. Secondary lead production in main provinces (Unit: *k* tons) (CNMA, 2014).

3. Government policies and achievements

For the problems that came out with these developments, government ministries intensively published various kinds of policies and documents finally obtaining some achievements.

3.1. Abatement of industry pollution

According to the estimation of W.H.O., 1.2 billion people are over-exposed to lead-polluted environments in the world. About 99% of the most serious incidents happen in China and other underdeveloped countries (Du and Cao, 2009; Raghupathy and Chaturvedi, 2013). Major cases of lead pollution erupted from 2009 to 2011. In 2009, during the blood lead incident in Fengxiang City of Shanxi Province, the heavy metal contamination caused excessive amounts of lead in the blood of 4035 people and caused 32 very serious casualties. In 2010, there were 9 blood lead incidents (Watts, 2009; Zhang, 2011a,b). In 2011, there were 7 blood lead incidents (Li, 2012; Shi, 2012). Until early 2011, there were more than 60 incidents involved with lead pollution and about 24 incidents caused by lead smelting and battery plants were reported by the media (Wang, 2012). The lead content in environments near lead plants is higher than the average level in China. Lead content in air is 5.74 $\mu g/m^3$, which is 3.83 times of standard value. Lead content in river water is 1.8 mg/m^3, which is 1.8 times of standard value and highest lead content in soil is 625 mg/kg, which is 2.03 times of standard value (Chen et al., 2012; Du and Cao, 2009). Losses in food production caused by heavy metal contamination was over 10 MT and food contaminated by heavy metals was 12 MT. The total economic loss was at least 20 billion RMB (Wang and Zhang, 2013).

3.1.1. Series of laws released

Related regulations concerning secondary lead have been promulgated by the government since 2003. However from 2009, the State Council, the Ministry of Environment and the Ministry of Judiciary started to publish specific documents to solve secondary lead contamination problems (see Table 2 for more details). In 2011, the 12th Five-year plan was implemented and this marked a historical turning point for lead plants in China. In Feb 2011, for the first time, the State Council officially put environmental and ecological

Table 1
List of new (renovation and expansion) projects in 2013.

Year	Province	Project	Production capacity (kton/year)	Property
2013	Jiangxi	Jinyang Company	60	Removal
2013	Anhui	Dahua Engery in Taihe County	100	New
2013	Jiangxi	Industry Park in Duchang County	60	New
2013	Shandong	Industry Park in Dancheng County	150	New
2013	Chongqing	Industry Park in Youting County	Pending	new
2013	Jiangxi	Yuanfeng company in Ji'an County	60	new
2013	Anhui	Huaxin Lead Group	330	Technologically upgrading
2013	Tianjin	Dongbang company	60	expansion

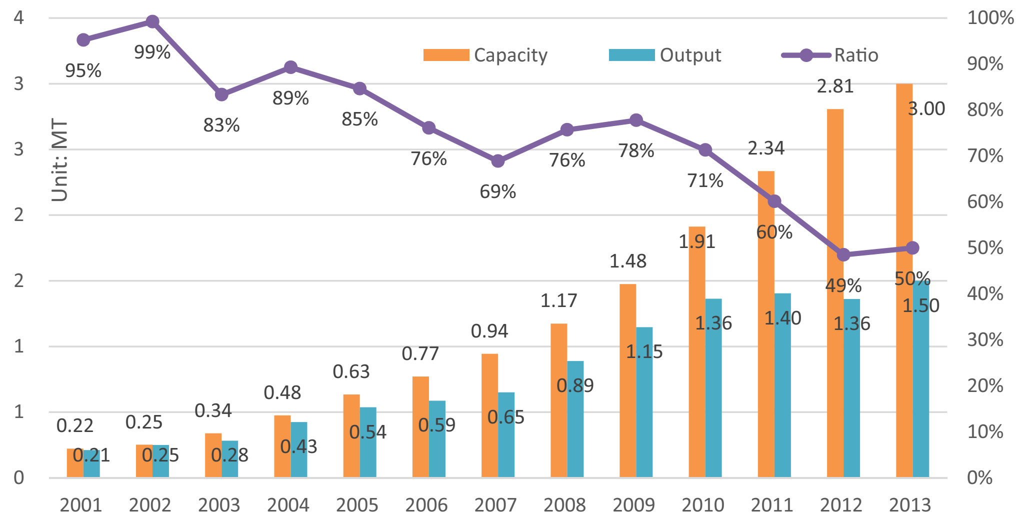

Fig. 3. National secondary lead smelting capacity and utilization rate (Hu, 2013; Zhang, 2008).

protection in the first place of country planning and 14 provinces were included in the heavy metal key-managed regions.

3.1.2. *Strict regulation of emission*

Before 2013, although there were some regulations about the hazardous waste and smelting industry, each province chose to follow different regulations and so there were no uniform standards. In 2013, MEP launched the "*Lead & zinc Industrial Pollutant Emission Standards*", which was the first special regulation for the lead industry. The environmental standard was unified and became strict with 6 indices been modified based on previous data specifically for emission standards of secondary lead (see Table 3).

Lead dusts in waste gas should be treated by adopting the sack de-dusting technology, electrostatic precipitation technology and wet-process de-dusting technology. Production workshops should set up ventilation de-dusting systems to collect and treat lead-containing smoke and gas in the workshops (MEP, 2012a).

The law also controls lead concentrate in slag strictly. If the lead concentration is higher than 5 mg/L, it is classified as a hazardous waste and must be deposited in special waste landfills (MEP, 2007). In reality, the authorities could not identify the extraction toxicity easily so they simplified this operation by stating that lead concentration must be lower than 2% by weight (MEP, 2012a).

3.1.3. *Environment inspection special action*

Government departments continue to amend and improve the rule requirements from clean production standards, pollution control norms, control systems, control technologies, judicial interpretation, emission standards and so forth. Also, from 2011 to 2012, due to the high incidence of child lead poisoning, the Ministry of Environment launched the first environmental inspection special action (Li, 2012). In 2013, influenced by air pollution, heavy metal pollution prevention and control, the ministry of environment launched another environmental inspection special action (Hu, 2013). Before the end of 2015, all plants which do not pass environment inspection will be banned completely.

Eventually, the frequency of lead pollution incidents decreased in 2012. Events directly handled by the ministry of environment were 33 cases, of which there were two blood lead incidents. In 2013, there were no massive blood lead incidents.

3.2. *Elimination of outdated illegal plants*

Before 2011, the rapid growth of China's lead industry was simply an increase in the number of smelting plants and production (Wang and Zhang, 2013). In 2011, the total national capacity was 5.59 MT. Advanced production capacity was less than 2.5 MT (Li, 2012), and more than 95% were private plants (Yang and Ma, 2005). There were 10 plants with an annual capacity of over 100 kton. On the contrary, the secondary lead production in foreign countries is concentrated in a few large plants. In the same state in the U.S, the government usually only allows the establishment of 1 or 2 secondary lead plants with an annual capacity of over 20 kton (Xiao, 2012). The comparison between China and the U.S. is seen Table 4.

Table 2
Laws and regulations of secondary lead industry released in recent years.

Date	Laws and regulations	Ministry
Aug 2003	Strengthening Environmental Management Announcement of Waste Electrical and Electronic Equipment	SEPA
Oct 2003	Waste Batteries Pollution Control Technology Policy	SEPA
Aug 2008	National Hazardous Wastes List	MEP
Nov 2009	Cleaner Production Standard-lead Acid Batteries Scrap Recycling Industry	MEP
Nov 2009	Opinions on Strengthening the Prevention of Heavy Metal Pollution	State Council
Mar 2010	Treatment of Waste Lead-acid Batteries Pollution Control Technical Specifications	MEP
Feb 2011	Integrated Pollution Prevention and Control of Heavy Metals "Twelfth Five Year Plan"	State Council
May 2011	Notice on Strengthening Secondary Lead Industry Pollution Prevention and Control Work	MEP
Jun 2011	Opinions on Strengthening Environmental Monitoring of Heavy Metal Pollution	MEP
Mar 2012	Lead and Zinc Smelting Industrial Pollution Control Technology Policy	MEP
Mar 2012	Notice on Conduct Environmental Verification of Lead-acid Batteries and Secondary Lead Industry	MEP
Mar 2013	Storage and Transportation of Hazardous Waste Collection Technical Specifications	MEP
Jun 2013	Interpretations on Environmental Criminal Cases Applicable Law Issues	Supreme Court
Aug 2013	Lead & zinc Industrial Pollutant Emission Standards	MEP

Note: SEPA: State Environmental Protection Administration; MEP: Ministry of Environment Protection; SEPA reformed into MEP in 2008.

Table 3
Emission comparison between old and new limit.

No.	Item	New limit (mg/m^3)	Old limit (mg/m^3)	Reference law
1	Particulate matter	10	200	GB9078-1996
			100	GB18484-2001
			120	GB16297-1996
2	SO_2	100	850	GB9078-1996
			400	GB18484-2001
			550	GB16297-1996
3	NO_2	100	500	GB18484-2001
			240	GB16297-1996
4	Sulfuric acid mist	20	45	GB9078-1996
			45	GB16297-1996
5	Pb	2	35	GB9078-1996
6	Hg	0.5	3	GB9078-1996

Resource: GB 9078-1996: Emission standard of air pollutions for industry kiln and furnace; GB18484-2001: Pollution control standard for hazardous waste incineration; GB16297-1996: Atmospheric Pollutant Integral Discharge Standard. Note: There are 3 levels within the limits of previous law and this paper lists the lowest number.

Table 4
The comparison table between China and US.

Index	China	US
Production	1.4 MT	1.2 MT
Number of plants	240	14 (Zhang, 2008)
Average production	6 kton	86 kton
Distributed provinces	27/34(Chen and Wang, 2011)	10/50 (Ding, 2012a,b)
Proportion of Top 10	40% (Zhang, 2011a,b)	95%
Proportion of small scales	>50%	1%

In response to this phenomenon, China continues to improve the industry's access conditions in recent years. In 2003, the Ministry of Environmental Protection issued a requirement for secondary lead companies (Ye and Wong, 2006), but with the rapid development of the lead-acid battery industry, this standard could not be met. See Table 5 for new regulations which were introduced subsequently.

The production capacity of two-thirds of plants in China was less than 30 kton. After the implementation of the laws and regulations in 2012, a large number of small plants were eliminated. In order to execute access conditions strictly, in March 2013, MIIT and other four ministries set up a joint working group to implement this regulation.

The closing down of outdated production capacities has achieved remarkable results. From 2011 to 2012, the total number of lead-related plants in China was investigated and from the provincial investigation and remediation results, most of the secondary lead plants have now been closed down or in remediation status (Li, 2012). In 2011, the Ministry of Environment monitored 100 plants with licenses. After government verification, 22 plants were banned, eliminating a total production capacity of about 0.2 MT and 41 plants were shut down involving a production capacity of 1.33 MT. Eventually, only 23 plants were allowed to continue production with an average recovery capacity of about 66 kton. See Fig. 4.

In contrast, the large and medium-sized enterprises represented by listed companies within the industry may become the maintained enterprises in the regulation storm through rectification or removal. In addition, in 2013, in the list of outdated production capacity of enterprises released by MIIA, 0.8 MT of lead was involved. From 2009, the outdated lead and zinc production capacities eliminated accumulated to more than 3.7 MT, equivalent to about one-third of the total capacity.

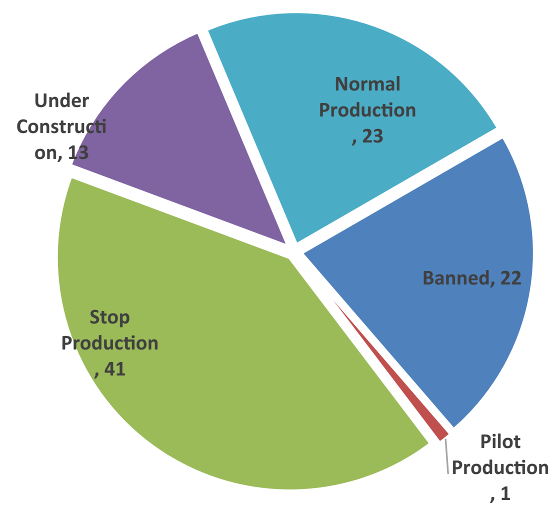

Fig. 4. Verification results at the end of 2012 (MEP, 2012b; Wang and Zhang, 2013).

In addition, in the conventional secondary lead industry gathering area, a large number of small-scale plants prefer the mode of consolidation. By the end of 2001, 12 smelters in Jieshou merged into Anhui Huaxin Secondary Nonferrous Metals Company. These 12 production plants formed a loosely-organized Commonwealth. In 2006, Huaxin put financial efforts into constructing a compact plant. In April 2007, a new Huaxin Secondary Lead smelting technology was officially put into production with a non-polluting technology which completely replaced the indigenous smelting technology. This new plant has an annual processing capacity of

Table 5
Changes of industry access conditions over the years.

Year	Laws and regulations	Capacity limitation of existing plant (kton/year)	Capacity limitation of new plant (kton/year)	Technology limitations	Recycling rate (%)
2003	Waste Batteries Pollution Control Technology Policy	5	10	No provisions	>95
2007	Lead and Zinc Industry Access Conditions (Chen and Wang, 2011)	10	50	Eliminate small reverberatory furnace	>97
2012	Secondary Lead Industry Access Conditions (MEP, 2012a)	30	50	Eliminate all reverberatory Furnace	>98

Table 6
National key enterprises of lead-acid battery recycling industry.

Company	Tianying	Jinyang	Chunxing	Jitianli	Yuguang
Urban Mineral demonstration base	May 2010	Oct 2011	Oct 2011	Jul 2012	None
Circular Economy pilot plant	Dec 2007	Dec 2007	Nov 2005	None	Nov 2005
Location	Jieshou, Anhui	Gucheng, Hubei	Pizhou, Jiangsu	Yangquan, Shanxi	Jiyuan, Henan
Recycling Capacity	330 kton/year	100 kton/year	300 kton/year	100 kton/year	360 kton/year
Industrial park	Yes (Yu, 2013)	Yes	Yes (Zheng, 2008)	Yes	None
Separation Process	Automatic Cutter by self-developed	CX Break process from Italy	Break Process modified by MA(USA)	CX Break process from Italy	CX Break process from Italy
Melting Process	Oxygen oxidation by Bottom blown—Reduction by side-blown	Rotary Furnace with Pure CH_4 & O_2	Rotary Furnace with Pure CH_4 & O_2 & Heavy Oil	Rotary Furnace with Pure CH_4 & O_2	Oxygen oxidation by Bottom blown mixed with Primary Lead

Data resource: Publicized information of Ministry of Environment.

330 kton of waste lead-acid batteries and an annual production capacity of 200 kton of secondary lead and completes the transition from a small-business association to a modern enterprise business consortium (Zhang, 2008). In 2008, Lanshan District in Shandong Linyi tried to build a secondary lead recycling economy industrial park around the local companies integrating 17 small lead smelting enterprises into four joint-stock companies. It was expected that the annual production of refined lead would be 300 kton. Similar mergers and consolidations are inevitable in the future.

It is estimated that in the next five to ten years, restructuring in the industry will accelerate. By 2015, scaled secondary lead enterprises will from 30 to 50 competitive secondary lead enterprises through integration and the average production capacity can increase to 50 kton (Shi, 2008). Also, national production can reach 2.5 MT, accounting for 50% of lead consumption (Peng, 2010).

3.3. Support to advanced pilot plants

Whilst shutting down small-scale plants, the government is constantly developing and supporting advanced large-scale enterprises. In 2005 and 2007, the National Development and Reform Commission (NDRC) and 6 other ministries launched two batches of national circular economy pilot work. In 2010, the NDRC specifically launched Urban Mining demonstration based construction work for the scrap metal recycling industry. So far, four batches have been examined and 39 enterprises have been approved (NDRC, 2012), of which there are 4 lead-acid battery recycling demonstration bases.

In February 2011, the “Secondary non-ferrous metal industry promotion plan” put forward that in 2015, the secondary lead industry will form a batch of large-scale enterprises with an annual production of more than 50 kton. Industrial concentration of the top 10 enterprises will reach more than 50% forming a number of key areas of industry agglomeration. With production capacity accounting for more than 80%, secondary lead production accounts for 40% (Xin, 2011).

China has established a number of modern enterprises with an annual handling capacity of more than 100 kton of waste batteries. See Table 6 for summarized information.

These enterprises mainly use foreign technologies. Batteries are crushed by a machine and separated into lead paste, plastic, lead grids, and waste acid. This is an automatic process associated with the foreign technologies. The lead paste and grids are fed into a furnace separately because their melting points are different and this reduces energy consumption (Genaidy et al., 2009). The recovery rate reached is at least 98% with a demonstration and promotion of technology. Four of these enterprises introduced downstream lead-acid battery plants and formed a close-loop secondary lead production mode in the industrial park.

Fiscal policies were executed simultaneously to help in the development of formal enterprises. Since January 2009, all secondary lead companies VAT exemption polices were canceled and the policy became 70% tax rebate in 2009 and 50% tax rebate in 2010. In 2011, the tax rebate policy was stopped and this policy greatly increased the secondary lead enterprises' operating burden. After that, through a series of petitions, this policy was changed to only give formal enterprises preferential taxation (Shang and Ma, 2013). In November 2011, the Ministry of Finance and the State Administration of Taxation issued new regulations on waste batteries as raw materials in the production of non-ferrous metals such as lead, and issued the implementation of a 50% VAT refund policy. The government is now considering raising the tax rebate rate to make formal enterprises able to compete with small illegal enterprises in operating costs.

3.4. Innovation research of recycling technology

Some formal enterprises introduced the pretreatment auto dismantling system of Italian Engitec, American MA companies and other foreign companies, and this ratio keeps rising year by year(Genaidy et al., 2009; Hu, 2013). Except introducing foreign advanced technologies and equipment, China has also carried out a large number of independent technology researches and developments (Ma, 2012). The innovations and research of main technologies in recent years are seen in Table 7 below.

In recent years, due to the strict emission limit on furnaces, many universities and companies have started to focus on the hydrometallurgical process of recycling lead paste. The local universities have very good cooperation with the large-scale plants in China. Hydrometallurgical process based on a hydrogen-lead oxide fuel cell has completed the pilot plant test stage and entered the industrialization promotion stage. A small capacity equipment is installed in the workshop of Chaowei Group, which is the biggest LAB manufacturer (Pan et al., 2013). Other local technology is been tested in the pilot plant and will be promoted in future (Chen and Wang, 2012; Zhu et al., 2012).

4. Problems and sustainable development path

4.1. Low secondary proportion

In 2011, the total production of refined lead was 9.99 MT and secondary lead production was 4.76 MT. Total lead production in China accounts for 46.1% of global production. China has become a global refined lead production center but its proportion in the world's total secondary lead production is still relatively low, accounting for only 29.5% of total global production (CNMA, 2014). Currently, the proportion of secondary lead production in total lead production in China is only 30%, while the production of secondary lead accounts for more than 60% of total lead production in European and American countries (See Fig. 5 for specific production). As

Table 7
Enterprise and university cooperate to research secondary lead technology.

University	Enterprise	Technology	Stage	Resource
Central South University	Changsha	Recycling of waste lead storage battery by vacuum methods	Completion of experiment	Lin and Qiu (2011)
Beijing University of Chemical Technology	Chaowei, Zhejiang	hydrometallurgical process based on a hydrogen-lead oxide fuel cell	Industry Promotion	Pan et al. (2013)
Huazhong University of Science and Technology	Jinyang, Hubei	Leaching of paste components by sodium citrate and acetic acid	Completion of experiment	Zhu et al. (2012,2013)
Wuhan University of Science and Technology	Chukai, Hubei	Preparation lead citrate from Lead Paste	Completion of experiment	Chen and Wang (2012)

can be seen from the figure, the United States is also a large producer of lead-acid batteries. Its secondary lead production is similar to China but the proportion accounts for more than 91%. DoeRun in the US is the world's ‘s second-largest supplier which ranks only second to BHP Billiton. This company has announced that its Herculaneum primary lead smelter will be closed in 2013 which is the last lead smelter in the US (Xiao, 2012).

The author analyzes the reasons. First, European and American countries are highly developed and their societies maintain a large number of lead-acid batteries (Stevenson, 2009). About 94% of the scrap lead used in US secondary lead production comes from waste lead-acid batteries and the development of the automotive industry drives the consumption and elimination of lead-acid batteries, which provides the market demand and raw material sources for the development of secondary lead (Xiao, 2012). Second, large quantities of lead-acid batteries are imported every year but according to the provisions of “Control of Trans boundary Movements of Hazardous Wastes and their Disposal, Basel Convention”, the scrap batteries can only be recycled and used in their own country. Third, in recent years, the growth in demand for lead batteries and other lead-containing products is very small. Therefore, secondary lead can meet their own needs and primary lead will not be used in great amount.

Except for the lack of resource recycling ability and public environmental awareness, there are other objective reasons. In March 1990, China became a signatory of the “Basel Convention” and so our secondary lead raw materials can only come from domestic sources (Hu, 2013). The total demand for lead in China in recent years has maintained a high growth with the social accumulation of lead products maintaining a low amount and so its own amount of scrap recycled is not sufficient to supply such high demand.

Thus, the main factor which restricts China's secondary lead production growth is the social stock of raw materials. At the same time, its ratio is also affected by the amount of annual demand growth. Currently, electric bikes have a huge potential for development in small cities and rural markets because of their low prices

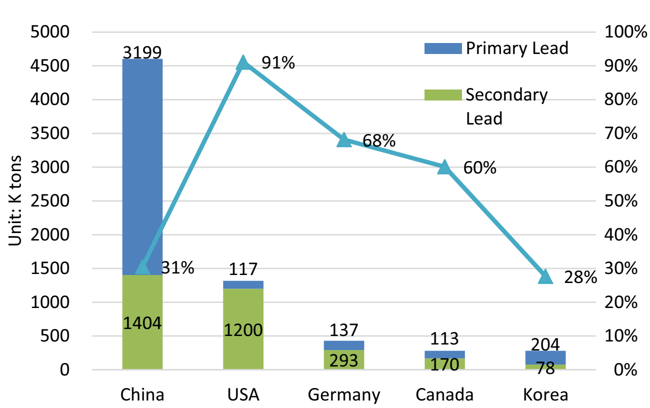

Fig. 5. Production of minerals and secondary lead in the World's main Countries (Xiao, 2012; CNMA, 2014).

and energy saving ability and other advantages (Weinert et al., 2008). Some major battery manufacturers are trying to improve productivity with a large number being into the production of electric bicycles and car batteries.

According to the current application inventory, the total lead possession amount can be estimated. The weight of various kinds of batteries differs. Small LAB is mainly used in portable small household electrical appliances, computers and uninterrupted power supply. Medium-sized LAB is used in auto starting, lighting ignition as well as the electric bicycle and car driving. Large LAB is widely used in telecommunication, instantaneous backup power supply, large UPS power supply, supporting energy of solar and wind power generation system, and it also has more applications in terms of the electricity load peak (Cherry et al., 2009; USGS, 2006; Zeng and Mao, 2010a; Wang et al., 2010), (see Table 8 for a summary of the lead content of typical batteries in the main application products). According to the social possession of applied products published in 2012, the total amount can be calculated. Combined with their respective average life, it is calculated that the theoretical scrap amount will be 2.48 MT in 2014.

From the table as above, the supply of scrap lead will be close to 2.48 MT by 2015. In addition, according to “China Nonferrous Metal Industry Development Plan (2011–2015)”, it is shown that the average increase rate of refined lead production in China is 5.2% per year, and will reach 5.6 MT in 2015. Calculated this way, the production of secondary lead will be 44% of total lead production.

The Secondary lead industry in every country will go through 3 stages. These are the growth stage where amount increases but rate does not, the stable stage where amount and rate increase together, and the acceleration stage where amount increases and rate keeps rising high. Some scholars compared the secondary lead development history in China and US, and pointed out that, the proportion of secondary lead is only 30% of total lead production currently. This shows that china is in growth stage and this is equivalent to the level of USA in 1930s. From the macroeconomic perspective, it is assumed that there is a regression curve between the GDP and secondary rate, and according to the average annual growth rate of 8% of China's per capita GDP, China will enter the stable stage in 2028 where the secondary rate will reach 60% (Zhang, 2012).

4.2. Disordered recycling system

Until now, there are still neither enterprises which establish a nationwide recycling network nor establish a standardized regional recycling network (Zhang and Li, 2013). The waste battery recycling system is disordered and the details are shown in Fig. 6. According to ANTAIKE research and calculations, in the recent decade, the accumulated amount of waste batteries in China has basically maintained a double-digit growth. Together with other waste materials that can be used, the theoretical operating rate of secondary lead smelters should be at least 70% or more (Hu, 2013), but the largest secondary lead producers in China are unable to collect enough waste lead-acid batteries (Li and Fan, 2011).

Table 8
Lead content of various kinds of batteries.

Application type	Classification	Lead content (kg)	Social possession (million)	Total weight (kT)	Average life	Scrap amount (MT)
Passenger vehicle	Passenger car/light truck	9.7	86.83	837	2.5	0.34
Cargo truck	Truck	17.5	2.6	50	2.5	0.02
Motorcycle	Motorcycle	2.86	104	300	2	0.15
Electric bicycle	Electric bike	16	150	2310	1.5	1.60
Low-speed short-range vehicle	Low-speed electric car	18.6	11.45	210	1.5	0.14
Wind energy/photovoltaic	Wind energy/PV plant	/	/	70	2	0.04
Telecom base station	Large stationary, UPS	/	1.65	570	6	0.1
UPS	UPS	3.8	/	520	5	0.1
Total				4950		2.48

Note: It is difficult to estimate the weight of battery used in power stations and telecommunication base stations. Energy storage battery is mainly calculated by proportion in past years.

Even in first-tier cities such situations are not avoidable. In 2013, the annual output of waste electric bicycle batteries was about 20 kton in Beijing and 60% of this was flowed into small plants. The amount of waste lead-acid batteries in Shanghai was about more than 80 kton and the legitimate collection rate was less than 10% (Chen et al., 2009; USGS, 2006).

Waste batteries in China is traded through multiple intermediary traders resulting in a high cost of production for secondary lead plants (Li and Fan, 2011). Usually in foreign countries, when the users or traders sell the scrap LAB to secondary lead plants, they can get money at a good price level as it only includes the collecting and transport cost. However in China, apart from the collecting and the transport costs, the price of scrap LAB also depends on the its lead content in the current international price of refined lead. This makes scrap lead prices 2.5 to 3 times higher than the international average market price. For example, scrap lead price in China accounts for 55% of the LME price whilst in Malaysia it accounts for only 35% of the LME price, and it is even lower in other developed countries (Shi, 2008).

The United States has established three effective ways to recycle lead-acid batteries. First, recycling through the sales network of lead-acid battery manufacturers. Second, the government introduces documents and approves the setting up of professional recycling collection agencies which recycle lead-acid batteries and other lead-containing wastes. These agencies then supply the recycled lead-containing waste materials to secondary lead plants with production licenses and with certain production scale for processing. Third, levying environmental taxes, prepaying mortgage to buy a car and other methods helps to provide funding for recycling by secondary lead manufacturers (Xiao, 2012).

The battery manufacturing enterprise Jitaly in Shanxi Province has begun to try the recycling network system construction using combination of points, lines and phases. The only professional recycling company in Shanghai is also cooperating with the government to carry on mechanized construction. The government should also propose the extended producer responsibility and confirm that battery manufacturing enterprises should have the obligation to recycle their products (Fang and Huang, 2007). It is suggested that the government should levy consumption tax on lead-acid batteries to subsidize the cost of manufacturing recycled products. A standardized recycling disposal system should be established, forming a vicious cycle among users, recyclers, secondary lead plants and the battery plants.

4.3. High proportion of outdated technologies

The secondary lead industry in China is in the advanced stage with advanced technology co-existing with traditional technology. Building a regular lead-acid battery recycling plant needs an investment of at least 200 million RMB, of which the cost of dismantling machinery will be 50 million RMB, the cost of smelting furnace will be 60 million RMB, the cost of dust, water treatment devices will be 60 million RMB and the cost of land and plant construction also be taken into account (Ding, 2012a,b). However, illegal recycling plants, like a small workshop with not more than 10 workers can recycle lead-acid batteries using artificial dismantling, simple furnaces, and the total cost is of this is less than 100,000 CNY (Ding, 2012a,b). Eventually, part of these plants transfer to underground production in the environmental rectification, and with inadequate supervision of local government, illegal production enterprises carry on extensive production which leads to the inundation of underground illegal production. It is difficult for formal legal smelters to compete with illegal smelters at the same price of raw materials. This leads to the lack of raw materials for legal enterprises (Hu, 2013).

The secondary lead plants with capacity less than 150 kton mainly use manual dismantling, accounting for 60% to 70% in the industry. Many plants use direct fired reverberatory furnace, cupola and other outdated technologies, and some even use the original smelting kiln with no environmental protection facilities (Raghupathy and Chaturvedi, 2013). In China, the energy consumption of general secondary lead enterprises is 500 to 600 kg of standard coal/ton of lead (Shang, 2006), which is three times higher than foreign plants and the consumption of water is approximately

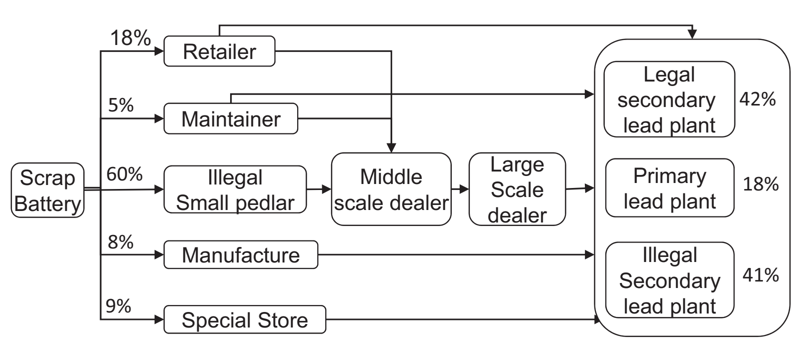

Fig. 6. Current situation of the secondary lead recycling network in China (Ge and Jiang, 2011; Li and Fan, 2011).

$5\,m^3$/t of lead (Smaniotto et al., 2009). In 2006, it was studied that a lower lead recycling rate was only 0.312 t/t, which meant that nearly 70% of old lead scrap is not recycled based on official statistics (Mao et al., 2006). Higher lead emissions was also 0.324 t/t, which means that nearly 33% of the lead inputs used in the LAB system was lost into the environment in China (Mao et al., 2009). In 2013, about 3 MT of waste batteries was processed in the recycling stage and the total recovery rate was about 90%. Nearly 0.2 MT of lead and other metal elements were lost in this process, with an annual output of waste been about 600 kton coupled with serious lead vapor and lead dust (Guo, 2013).

Tokyo and Osaka in Japan and metropolitan cities in other developed countries have built secondary lead plants (Shi, 2012). Due to comprehensive laws and effective management, their pollution is far less serious than in China. According to U.S. statistics in 2002, lead emissions in the secondary lead industry was only 46 t, ranking sixth in all kinds of polluting industries and accounting for only 3.7% of total lead emissions. Therefore, as long as reasonable regulations on the relevant industry are implemented, this environmental phenomenon can be solved (Ding, 2012a,b; Qu, 2012).

To enable the rapid development and growth of advanced technology enterprises, the country should use tax, credit, funding, prices, bonuses and other economic tools to support these enterprises. The government should be encouraged to build business-oriented, market-oriented and university-industry collaboration technological innovation system (Li, 2011). Currently, some secondary lead enterprises in China already have world-class recycling technologies and can ensure clean and efficient recycling of resources. The challenge in the future will be generalizing environment-friendly and automation technologies into the secondary lead industry throughout the country. The construction of secondary lead industry standardization system should be promoted. Secondary lead industry standards should be set, revised and publicized combined with the country's overall requirements and industry's demands. State ministries have begun to emulate foreign countries to formulate the "Best Available Technology Guide" of recycling technologies. It is one of the important principles of the NDRC selection of "Urban Mining" demonstration bases. This can also ensure the promotion of advanced technologies.

5. Conclusion

As the annual secondary lead output increased sharply in recent years, some problems came out frequently. The government began adjusting and controlling the secondary lead industry from 2011, put in efforts to promote pollution renovation, eliminate outdated production capacities, provide advanced production support and promote technology independent research. Till now, remarkable results have been achieved as the frequency of lead pollution incidents has decreased sharply. Also, lots of illegal plants have been closed down or will be closed down in the near future, some advanced demonstration plants have been established, and some green hydrometallurgical processes have been developed by domestic institutes.

However, the main existing problems are that, the proportion of secondary lead production is only 30% of the total lead production, the formal recycling network is chaotic and the overall level of industrial technology and equipment is outdated. Compared with developed countries, this paper predicts that secondary proportion will reach 44% in 2015 and 60% in 2028. Three typical American recycle models, including recycling led by battery manufacturers, secondary, and specialized recycling companies are suggested to be carried out in China. Finally more financial support and "Best Available Technology Guide" are suggested to be implemented by government to promote the advanced clean process to be applied nationwide.

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