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The lead and lead-acid battery industries during 2002 and 2007 in China☆

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ABSTRACT

In the past 15 years, the center of the international lead market has shifted to China. China has become the largest producer of raw and refined lead, plus the largest consumer. This paper reviews the status of the lead and lead-acid battery industries in China, including lead mining, lead refining, secondary lead production, the lead-acid battery industry, new opportunities for lead-acid batteries, and the environmental problems associated with lead and lead-acid batteries. The output of raw and refined lead has increased annually in China, and now accounts for more than 30% of the world total. As a result of a change in the Chinese government's policy regarding the export of lead, plus an increase in the price of lead, the profits of Chinese lead manufacturers were significantly reduced, the trade deficit of the Chinese lead industry increased, the operating rates of lead smelter enterprises greatly reduced, and some small enterprises were forced to shut down. At the present time, an increasing number of enterprises have begun to produce secondary lead, and the scale of production has expanded from tens of tons to tens of thousands of tons. In 2006, the output of secondary lead in China reached 700,000 tons, but outdated technology and equipment limited development of the secondary lead industry. Because of serious pollution problems, raw material shortages, and fierce price competition in the battery market, changes in the development of the lead-acid battery industry have been dramatic; approximately one thousand medium-sized and small lead-acid battery producers have been closed in the past 3 years. The output of large lead-acid battery enterprises has not been reduced, however, as a result of their manufacturing technology and equipment being comparable to those in other advanced industrial countries. In China, the flourishing development of electric bicycles, electric tricycles, and photovoltaic energy systems should provide ongoing opportunities for the lead-acid battery industry.

1. Lead mining and refining in China

In China, lead and zinc deposits are located in the Northeast, Hunan, Yunnan, Sichuan, Gaungdong, Guangxi, the Northwest, Henan and Anhui. However, the lead deposits of the Northeast, Hunan, Yunnan, Sichuan, Guangdong and Guangxi are rapidly being depleted. The manufacturers of raw lead are located in Henan, Hunan, Yunnan, Guangdong and Qinghai Provinces. In the first half of 2007, the total Chinese output of refined lead was 1.355 million tons, an increase of 3.48% compared with the same period in 2006. Table 1 presents the output of refined lead, in kilotons, from the top ten Provinces in the first half of 2007, which accounted for 93.5% the total lead output in China. In the months during January and July of 2007, the Chinese output of lead concentrate was 0.384 million tons, an increase of 9% compared with the same period of 2006.

The total output of lead concentrate from the top five Provinces (shown in Table 2) made up 60.8% of the total for China. And the profits from Chinese lead increased rapidly in 2007, especially for those corporations with lead mines.

In 2007, the amount of lead concentrate imported by China was 687 kton, and the amount of lead exported was 133 kton. The Chinese lead smelter plants imported lead concentrates mainly from Peru (18%), Australia (13%), and the USA (3%) during this period, and the trade deficit for lead increased from 0.07 billion RMB in 2006 to 0.44 billion RMB in 2007. Table 3 indicates that the exported amounts of refined lead in 2007 decreased greatly compared those of 2006 [1].

Table 4 [2] provides the amounts of refined lead exported from China from 2002 to 2006, which accounted for 6–8% of global lead consumption, and about 10% of the lead supply for western countries.

For Chinese lead smelting enterprises, the major profit came from the return of machining fees, but in 2007 this fee was reduced by the overseas lead mines from 150 to 80 US $ ton^{-1}, even 50 US $ ton^{-1} [3]. In addition, the export tariff for refined lead from China was increased by 10%, effective June 1, 2007. This effectively meant

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Table 1
Refined lead output from the top ten Provinces in China for the first half of 2007.

	Province									
	Henan	Hunan	Yunnan	Anhui	Guangxi	Guangdong	Jiangsu	Ningxia	Hubei	Gansu
Refined lead output/kton	465.1	216.1	190.3	149.0	76.1	52.5	47.8	25.8	24.2	17.9

Table 2
Lead concentrate output in China for the first half of 2007.

	Province					
	Neimenggu	Hunan	Guangdong	Sichuan	Qinghai	Other
Lead concentrate output/kton	81.5	46.7	39.0	35.9	30.5	151.0

Table 3
China's exports of refined lead for January–July, 2007.

Exported to	Exported amount January–July 2007 (tons)	Compared with the same period the previous year (wt%)
Korea	37169	−20.6
Singapore	35598	−52.1
Taiwan	26728	−42.0
Japan	7990	−56.4

Table 4
The amount of Chinese lead exported in recent years.

	Year				
	2002	2003	2004	2005	2006
The amount of exported lead (kton)	360	410	400	420	500

that domestically refined lead could only be sold in China. Lead smelting enterprises using imported lead concentrates were therefore at a disadvantage, because the prices of domestic concentrates were now much lower.

Fig. 1 presents the status of lead and lead smelter plants. It can be seen that Chinese smelter plants experienced a difficult period, which brought great changes in the world lead structure. In 2007, the price of lead futures was rising rapidly, and lead mining enterprises benefited greatly, but domestic lead smelting enterprises were unable to make a profit. Many domestic lead smelting enterprises had to reduce output because of losses due to the cost of imported concentrates; of the new smelting equipment, planned to produce 50–60 kton from 2006 to 2007, enough to produce only 30 kton was actually started up.

Table 5
Projections for the lead industry.

Lead smelting capacity	5 kton year^{-1}
Existing production scale of secondary lead	10 kton year^{-1}
Expansion project of secondary lead	20 kton year^{-1}
New investment project of secondary lead	50 kton year^{-1}

From Fig. 1, some of the reasons for the increase in the price of lead can be gleaned. Firstly, in September 2006, the Chinese government cancelled a tax rebate of 13% for the lead and lead-acid battery industries, and, effective June 1, 2007, China increased the export tariff for lead ingots by 10%. Secondly, at the end of 2006, the nine national ministries controlling lead and zinc investment issued the policy "Notice on guiding opinions of standardizing lead and zinc industry investment and quickening structural adjustment" to control the development of the lead industry, and in March 2007, "Access Criterion of Lead and Zinc Industry" (Table 5) was instituted, the aim of which was to limit the annual total production capacity to 4 million tons, to develop regenerated lead and zinc industries, and to increase the consumption of regenerated resources to 30% of the total.

Thirdly, power cuts and power limits were experienced in small-scale smelter and lead-acid battery plants; electricity supply became yet another problem. According to the requirement of the National Environmental Protection Bureau, power cut measures were applied to enterprises with draggle smelting craftwork and equipment, such as "agglomeration hollowware", or "agglomeration trays", by China Electricity Supervise Office. Lastly, there was an objective reason: lack of resources in China. Fig. 2 indicates the condition of nine non-ferrous mines in China. The estimated longevity

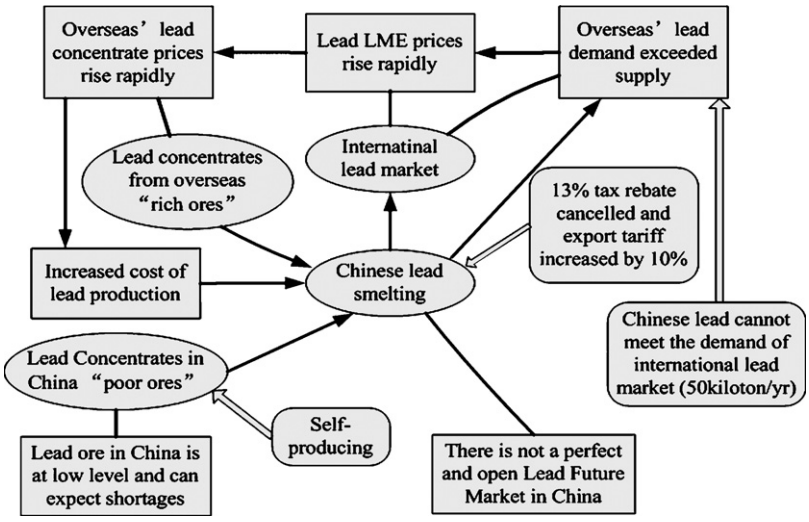

Fig. 1. The status of lead and lead smelter plants.

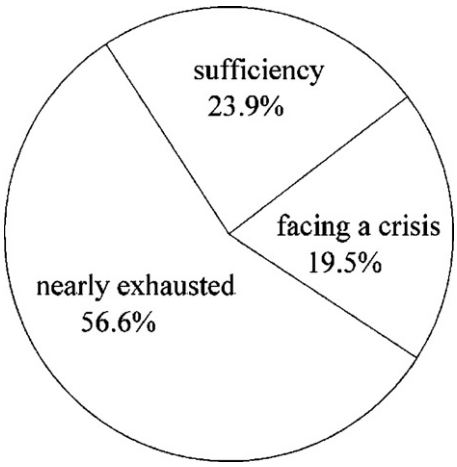

Fig. 2. The condition of nine non-ferrous mines in China.

for a dynamic mining operation with existing lead reserves was only 6–8 years (calculated from existing lead consumption).

Currently, the Chinese non-ferrous metals mineral resources face a serious situation, but not pessimism, because in the Western Provinces there are vast areas with good geological ore-forming conditions, thus we may find many new metallic mineral resources there. The ownership of the Wusu river Pb–Zn mine, which contains 605 ktons metal in Yaan city, Sichuan Province, was auctioned openly at the end of 2006. The GanLuo Pb–Zn mine in Liangshan state of Sichuan, which contains an estimated 619 ktons of metal, was auctioned openly to society in June 2005; the highest bid was 5.3 billion RMB [4].

2. The secondary lead situation in China

The main manufacturers of secondary lead are located in Henan, Jiangsu, and Hubei Provinces. Table 6 provides the annual output of secondary lead in China, indicating a rapid increase. According to incomplete statistics from the China Non-ferrous Metals Industry Recycling Metal Branch, the output of secondary lead in China was 320 tons for January–September, 2007, an increase of 12.8% relative to 2006.

There are now about 300 secondary lead plants in China; the scale differs from tens of tons to thousands of tons. Their equipment includes traditional small reverberators, blast furnaces and cupolas, although some small plants and individuals still use outdated methods [5]. Some large-scale secondary lead enterprises, for example, Yuguang Gold & Lead in Henan, Chunxin Alloy Group in Jiangsu, Jinxian Company in Hubei, and Feilun Company in Shanghai each have an annual output of approximately 10 kton year^{-1}; their output provides the bulk of that of the whole country.

In China, lead for recycling comes mainly from four sources:

(i) 500,000 tons of used lead comes from automotive batteries, e-bicycle batteries, motorcycle batteries, etc.
(ii) 60,000 tons used lead comes from VRLA batteries, industrial batteries, etc.
(iii) 35,000 tons used lead comes from cables, printing, etc.
(iv) 100,000 tons used lead comes from lead slag, lead dust, lead mud, etc.

Waste lead-acid batteries are recycled mainly by the following approaches:

(a) Private recycling (60%)
(b) Battery retails (18%)
(c) Repair and 4S shops (5%)
(d) Battery manufacturers (8%)
(e) Secondary lead plants (9%)

There have been many problems in the waste lead-acid battery recycling system. Waste lead-acid batteries have been mainly purchased by trade companies in Fuyang and Jieshou of Anhui Province, and Henan Province. Individual recovery of waste batteries has accounted for more than 50% of the total quantity; most illegal peddlers poured the spent acid solution directly into the sewers.

Primary lead smelter enterprises have begun to become involved in the secondary lead industry. For example, the 100,000 ton year^{-1} regenerated lead separation program of Henan Yuguang Gold & Lead was established in May 2006. The Henan Yuguang Gold & Lead plant can handle 150,000 tons of waste lead-acid batteries to produce 40,000 tons of lead alloy plus 64,000 tons of lead ingot.

With the increased emphasis on recycling, some Chinese companies increased their efforts to generate and use secondary lead. Anhui Huaxin Lead Co. Ltd. developed an industrial zone for recycling used lead-acid batteries and producing secondary lead; Jiangsu Chunxing Shengke Alloy Co. Ltd. accelerated the development of an overseas recycling market; Henan Yuguang Gold and Lead Co. Ltd., Anyang Yubeijinqian Group, and Hubei Jinyang Metallurgical Incorporated Co. Ltd. improved their production techniques [6].

3. The lead-acid battery industry in China

3.1. Lead-acid battery enterprises in China

According to incomplete statistics, there were 3000 lead-acid battery enterprises in China in 2003. Most of the manufacturers of lead-acid batteries are located in the Changxing region of Zhejiang, the Baoding region of Hebei, the Pearl River delta area of Guangdong, the Quanzhou region of Fujian, the Jiyuan region of Henan, the Subei region of Jiangsu, and the Jiaodong region of Shandong. However, Chinese battery manufacturers face a different challenge. Their capacity has grown faster than domestic market demand [7]. As a result of serious pollution problems, raw material shortages, and intense battery price competition, 1000 lead-acid battery enterprises were closed over a period of 3 years. Fig. 3 illustrates the decline in the number of lead-acid enterprises in China. It is predicted that there will be fewer than 300 enterprises in China by 2015.

Table 7 provides the major battery types, the main lead-acid battery manufacturers of each type, and the expected service life.

Electric bicycle lead-acid batteries were first manufactured in the Changxing region of Zhejiang toward the end of the 1990s. The manufacturing technology for electric bicycle lead-acid batteries

Table 6
Annual output of secondary lead in China.

	Years					
	1990	1994	1997	2000	2005	2006
Output of secondary lead (tons)	28,000	95,000	124,000	300,000	600,000	700,000

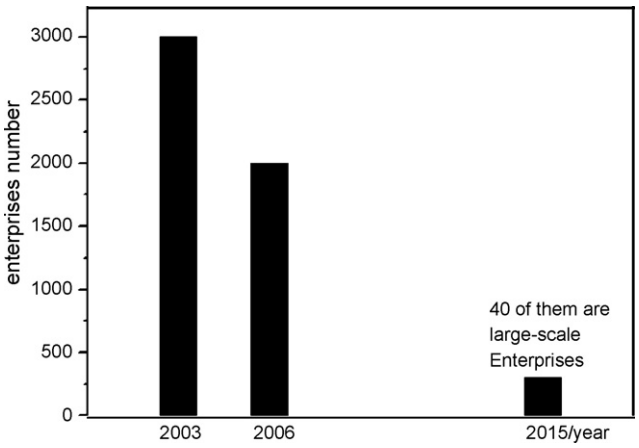

Fig. 3. Number of lead-acid battery enterprises in China.

was among the best in the world, but the overall level and quality of enterprises in 2000 were 15–20 years behind those of the advanced industrial countries; in particular, the quality of the raw materials, the manufacturing techniques, the precision of the equipment, the level of quality control, the management skills, and the ability of the workers were lacking. The manufacturing technology and equipment of the large enterprises is now comparable to that of the advanced industrial countries, especially for auto, large, medium, and small VRLA, and motorcycle batteries.

In recent years, some Chinese lead-acid battery enterprises have established overseas operations, for example, Jiangsu Shuangdeng in the British market, Zhejiang Tianneng in the Hong Kong market, Shenzhen Ritar in the American market, and Zhejiang Chaowei is planning to enter the British market. Meanwhile, foreign enterprises have begun to invest money in the lead-acid industry in China (Table 8). Sales of overseas brand batteries in China have remained strong, however, in the Chinese telecommunication, mobile and electric power fields, imported batteries have been typically selected. Enersys (Huada) snatched the Chinese telecommunication and mobile industry market in 2007 by offering the lowest price, and began a strategy of offering the lowest price, based upon its extensive capital funds. While many domestic lead-acid battery companies closed or half closed, Fiamm in Wuhan cancelled their vacation and accelerated production in August 2007.

Table 7
The main lead-acid battery types and their manufacturers in China.

Battery type	Enterprises	Service life of battery
Automotive lead-acid battery	Shanghai Johnson Controls Shunde Yuasa Tianjin TONG YEE Baoding Fengfan	More than 3 years
Large VRLA battery	Jiangsu Shuangdeng Shenzhen HWADAR Harbin Coslight Hangzhou Nandu	More than 5 years
Medium & small VRLA battery	Shenyang Panasonic Guangdong B&B Shenzhen Leoch Wuhan Changguang	More than 3 years
Motorcycle battery	Tianjin Yuasa Tianjin TONG YEE Dongguan Tongyong	More than 2 years
Electric bicycle battery	Zhejiang Tianneng Zhejiang Chaowei Shanghai Haibao Jiangsu Shuangdeng Shenyang Panasonic	More than 1 year

Table 8
Foreign lead-acid battery enterprise investments in China.

Foreign lead-acid battery enterprises	Investment location
Enersys	Shenzhen, Guangdong
C&D	Shanghai
Johnson Controls	Shanghai
National	Shenyang, Liaoning
B&B	Raoping, Guangdong
Fiamm	Wuhan, Hubei
Hoppecke	Wuhan, Hubei
Hitachi	Dongguan, Guangdong

3.2. The market for lead-acid batteries in China

In China, lead-acid batteries power more than 95% of all electric vehicles. In 2006, 70 million lead-acid batteries were sold in China, and approximately 50–60 million waste batteries are generated every year. During recent years, because of the development of electric bicycles and tricycles, automobiles and motorcycles, the demand for lead-acid batteries has been increasing rapidly, approaching 100 million. In addition, the value of large and medium VRLA batteries, used in the telecommunication, electric power, and uninterruptible power systems (UPS) was 7 billion RMB; that used in rural telecommunication network and photovoltaic energy systems was 90 billion RMB; and others applications accounted for more than 2 billion RMB. In 2005, the power output from lead-acid batteries reached 25 million KVAh [8], third only to America and Japan in the world. The main reasons for the increasing demand for lead-acid batteries were as follows:

(1) Rapid development of the automobile, motorcycle, and communication industries.
(2) Rapid development of electric bicycles and tricycles in China.
(3) Rapid development of the photovoltaic (PV) industry.

After the tax rebates were cancelled, the foreign market for lead-acid batteries changed. Fifty million lead-acid batteries were exported between January and April of 2007, a decrease of 12.2% versus January through April 2006. The export value of lead-acid batteries between January and April of 2007 was 3.7 billion US $, increasing by 16.5% compared to January through April 2006; the main reason for this was the increased cost of lead.

3.3. The influence of the price of lead on the lead-acid battery industry in China

Table 9 [9] illustrates the rapid increase in the price of lead during 2007; Table 10 provides lead and lead alloy prices on August 24, 2007.

With the increases in the cost of lead, the selling price of lead-acid batteries was repeatedly adjusted upward. However, the price of domestic waste lead-acid batteries was much more expensive than that of foreign countries.

Table 9
Lead prices in the first half of 2007.

	Year				
	2003	2007			
		March	The beginning of June	The end of June	The end of July
Lead price (US $ ton^{-1})	519	1813	2202	3026	3420

Table 10
Lead and lead alloy prices at August 24, 2007.

Alloy	Price
Pb–Sb alloy	3461 US $ ton^{-1}
Pb–Ca alloy	3513 US $ ton^{-1}
London Metal Exchange (LME)	3265 US $ ton^{-1}
Refined lead in Shanghai	3414 US $ ton^{-1}

Because of the rise of lead prices in China, most of lead-acid battery factories and alloy smelter plants began to use a new lead slag-reducing compound to reduce the lead residue; about 40 lead alloy plants and lead-acid battery manufacturers have used it in their operations. This slag-reducing compound is composed of a few inorganic compounds, which react in molten lead and lead alloys, effectively separating the lead from the slag, and improving the utilization ratio of elements in the lead alloys; it can be used in the Pb–Ca intermediate and Pb–Ca–Sn–Al alloy manufacturing processes, the grid casting process, and waste lead recycling. The utilization ratio of elements in lead alloys can be increased by 1–3%, and about 10–30 kg of lead per ton of lead alloy can be saved.

High lead prices may cause lithium ion batteries to be substituted for lead-acid storage batteries. Miners' lamp batteries were originally almost all lead-acid batteries, but during 2004–2006, more than 90% of the miners' lamp batteries had already been replaced by lithium ion batteries in China. The lithium ion battery industry is developing rapidly in China; the technology of lithium manganese oxide, lithium iron phosphate and other new lithium secondary battery materials is also being rapidly developed. Safety problems must still be resolved, however, and the prices remain high. Lithium ion batteries have been used as the power sources for electric bicycles and tricycles in some factories, such as Zhejiang Chaowei Power Co., Ltd. and Jiangsu Shuangdeng Power Co., Ltd. Batches of electric bicycles using lithium ion batteries were exported from Shanghai. If the price of lead rises to 35,000 RMB ton^{-1}, the cost of electric bicycles using lithium ion batteries will be the same as those with lead-acid batteries. Some lead-acid battery enterprises now also produce lithium ion batteries.

During July and August of 2007, many of the lead-acid battery factories were forced to either stop or severely reduce production, or went bankrupt; only 20% of the major lead-acid battery factories and lead smelter plants maintained full production. It was the first time that so many lead-acid battery factories had to puzzle over their future. What is the fate of the Chinese lead-acid battery industry?

Because the Chinese lead-acid battery industry was declining constantly, manufacturers began to transfer their factories to underdeveloped countries such as Viet Nam; for example, JSB, Yuasa and Meimei moved from China to Vietnam, which has lead mines with rich deposits, and policies similar to those of China in the past. In China, lead-acid battery producers in the Pearl River delta area of Guangdong began to move to the northern mountainous areas of Guangdong (Shaoguan, Qingyuan), or Jiangxi and other Provinces. Part of the lead-acid battery plate producers in Changxing city, Zhejiang Province moved to Jiyuan city, Henan Province, and others to the mountainous area of Anhui, Jiangsu, and Shandong Provinces. The production of battery plates could be eliminated in the Pearl River delta area of Guangdong Province in the next 3–5 years; 1200 polluting enterprises will be closed in the next 3 years, including the lead-acid battery plate producers in Dongguan city, Guangdong Province.

In 2008, the Lead price dropped suddenly, the status of the great depression in Chinese lead-acid battery industry became worse and worse. Many lead-acid battery manufacturers stopped or reduced production, and dealer of battery stopped buying batteries and kept looking on. Many middle and small lead-acid battery manufacturers have begun to reduce or stop production, and stop buying lead from about 20 October 2008, just finished their lead. Some lead-acid battery manufacturers kept producing just for keeping workers in factory. Most large and middle VRLA battery manufacturers just reduced production a little, because they had a long contract and a stable price.

We thought that Great Depression is short lived because of huge battery market in china after we visited most of largest lead-acid battery manufacturers 23–29 October 2008. It is estimated that Great Depression will continue at least one month. After Great Depression in October–November 2008, many lead-acid battery manufacturers such as electric bicycle, electric tricycle, electric forklift, low speed electric vehicles must develop rapidly. In China, application areas of lead-acid batteries are expanding, such as e-bike, e-tricycle, e-forklift, locomotive and railway communication. And there will be a flourishing market of lead-acid batteries.

4. New opportunities for lead-acid batteries in China

At present, although the lead-acid battery industry is in recession, flourishing development of the electric bicycle, electric tricycle, and the photovoltaic (PV) energy system will bring some opportunities to the lead-acid battery industry.

4.1. The electric bicycle

There were 58 thousand electric bicycles in 1998, 12.11 million in 2005, and all of them had been sold out. Production and sales for the electric bicycle industry were booming in 2006. There were 19.5 million electric bicycles, an increase of 6.1% compared with 2005, and electric bicycles accounted for 18.7% of the total bicycle output in China in 2006 [10]. But in April 2007 the sales numbers began to decline; 40–50% of electric bicycle battery factories stopped production or cut production in half as the market for electric bicycles entered into a recession. The reasons were:

(1) Different interpretations of the new policy were held by different departments and Provinces.
(2) Agreement on a standard for the electric bicycle could not be reached; there were many disputes about a potential standard.
(3) Quality problems with electric bicycles and their lead-acid batteries.
(4) The price of lead was too high.

However, although 20% of the electric bicycle lead-acid battery factories closed in 2007, a large exchange market for lead-acid batteries still existed; from 1998 to June 2007, 44.33 million electric bicycles were sold in China (according to statistics of China Bicycle Association). By the end of 2007, there were more than 50 million electric bicycles in existence (being used) in China. Each electric bicycle needs a 36 V/10 Ah (weight 12.6 kg) or a 48 V/10 Ah (weight 16.8 kg) lead-acid battery per year. Some electric motorcycles need a 36 V/20 Ah lead-acid battery each year. If every electric bicycle needs 10 kg lead, the electric bicycle industry in China alone will require 500,000 tons of lead per year.

4.2. A new star, the electric tricycle is developing rapidly in China (Fig. 4)

According to incomplete statistics, the electric tricycle output was 900,000 vehicles in 2006 in China, an increase of 69% from 2005. In fact, the actual output of electric tricycles was closer to 3 million vehicles in 2006 in China. Usually, an electric tricycle needs 4–5 lead-acid batteries, some models require up to 7 bat-

Fig. 4. The electric tricycle.

Table 11
Development of the photovoltaic (PV) industry in China.

	Year				
	2002	2003	2005	2006	2007
Output (MW)	2	50	139	400	700

teries. In the coming years, 3 million electric tricycles will demand more than 8 million batteries (12 V/120 Ah).

Why is the electric tricycle so popular in China? The reasons are:

(1) Low price.
(2) Convenience.
(3) Farmers like it.
(4) It is friendly to the environment.

However, high lead prices will limit its development. As domestic demand for electric tricycles increases sharply, there will be 10 million electric tricycles in the next 3–5 years, and several enterprises with annual outputs of 0.3–0.4 million electric tricycles will need to be built.

4.3. Photovoltaic energy systems in China—a huge opportunity for lead-acid batteries in the future

Photovoltaic energy systems in China are developing rapidly. In 2006, the output was 270 MW, but in 2007, the output was 700 MW (Table 11) [11]. The "Renewable Energy Law" became effective in China on January 1, 2007. This law encourages a growth rate of more than 50% for the domestic photovoltaic (PV) industry in the next few years; lead-acid batteries will probably be selected as the energy storage component of these PV systems.

5. The environmental problems of lead and lead-acid batteries in China

China began to say "No" to environmental pollution, along with many leading global corporations. The"2006.10–2007.8" list of polluting enterprises included more than 6000 Chinese enterprises and over 100 multinational corporations. However, the multinational corporations considered the Chinese enterprises to be worse than them, so they refused to provide pertinent data and to cooperate with the local environmental organizations, even though their emissions clearly exceeded the recommended standards.

Many lead-acid battery enterprises have created environmental problems in recent years; some have been reported in newspapers or on TV because of pollution problems or the high lead content in their workers' blood. Increasing numbers of lead-acid battery enterprises are being cited for creating environmental problems as greater attention is paid to global sustainability.

The government of Guangdong is requiring lead-acid battery enterprises to meet cleaner production standards, and it is anticipated that 1200 polluting enterprises will be closed within the next 3 years, including the lead-acid battery plate producers in Dongguan city, Guangdong Province. Six lead-acid battery enterprises were obliged to adopt cleaner production standards in 2006 and 2007 in Guangdong Province. In December 2007, 17 lead-acid battery manufacturers were closed by the Guangde County Government in Anhui Province. Most of them had moved from Changxing, Zhejiang Province; now, they are being told by the local government to move again.

6. Conclusions

In order to continue to develop a moderately prosperous society, China must adopt more and more sustainable approach to growth. Dramatic changes within the structure of the lead mining, refining and manufacturing industries have been essential in order to eliminate the ineffective and heavily polluting operations. As the known domestic deposits of lead are being rapidly depleted, far greater emphasis must be given to the recycling of existing lead products, in particular lead-acid batteries. Education of the people, improved separation techniques, and more efficient refining and alloying technologies are critical factors.

Huge opportunities for lead-acid battery applications can be foreseen, and the use of improved alloys to improve the effectiveness of this approach is important, yet we should not overlook the longer term solutions to a sustainable existence; biomimicry will be an essential component of our future; adenosine triphosphate (ADP), the rechargeable battery within our cells, should be the model we strive to emulate for our energy storage systems.

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