

The Recycling of Spent Power Battery: Economic Benefits and Policy Suggestions

Xiaoming Ma^{1,2}, Yuan Ma^{1,2}, Jiping Zhou³, and Siqin Xiong^{1,2,*}

1 School of Environment and Energy, Peking University Shenzhen Graduate School, Shenzhen, China

2 College of Environmental Sciences and Engineering, Peking University, Beijing, China

3 State High-Tech Industrial Innovation Centre, Shenzhen, China.

E-mail: xionsiqin@pku.edu.cn

Abstract. With the rapid development of the electric vehicle industry in China, the number of spent power batteries has increased. Recycling of spent power batteries is necessary not only to eliminate the environment pollution, but also to reduce the resources usage. However, whether it is necessary for the government to take economic incentives in the recycling process has not been clearly analyzed. Combined the existing literatures and the market investigation, this paper estimates the economic profits of recycling spent power batteries, in terms of LiFePO₄ (LFP) battery and Li(NiCoMn)O₂ (NCM) battery. The results show that the recycling process is profitable, therefore, we suggest the government should not implement additional economic incentives, like subsidies or tax reduction, but focus on the establishment of compulsory recycling mechanism and the market permission system.

1. Introduction

With the increasingly broad utilization of electric vehicles in China, power battery industry experiences a spurt of growth, and meanwhile yielding an increasing volume of spent battery [1]. In 2012, the sales volume of electric vehicle was just 11,375, but it reached 409,000 in 2016. Additionally, Ministry of Industry and Information proposed that the production volume of electric vehicles and plug-in hybrid electric vehicle should be two million by 2020[2]. As the core component of the new energy automobile, the power battery market shows a trend of outbreak after the sharply rise of new energy automobile. The power battery production jumped to 28 GWh in 2016 from 3.7 GWh in 2014, an increase of more than six times [3]. In China, under the average driving condition that the annual mileage of cars is about 16,000 kilometers, the lifetime of LiFePO₄ (LFP) battery is estimated about 4-6 years, while the lifetime of Li(NiCoMn)O₂ (NCM) battery is about 3-5 years. Combined existing literatures and our market survey analysis, this paper estimates the quality of spent power batteries, as shown in Figure 1



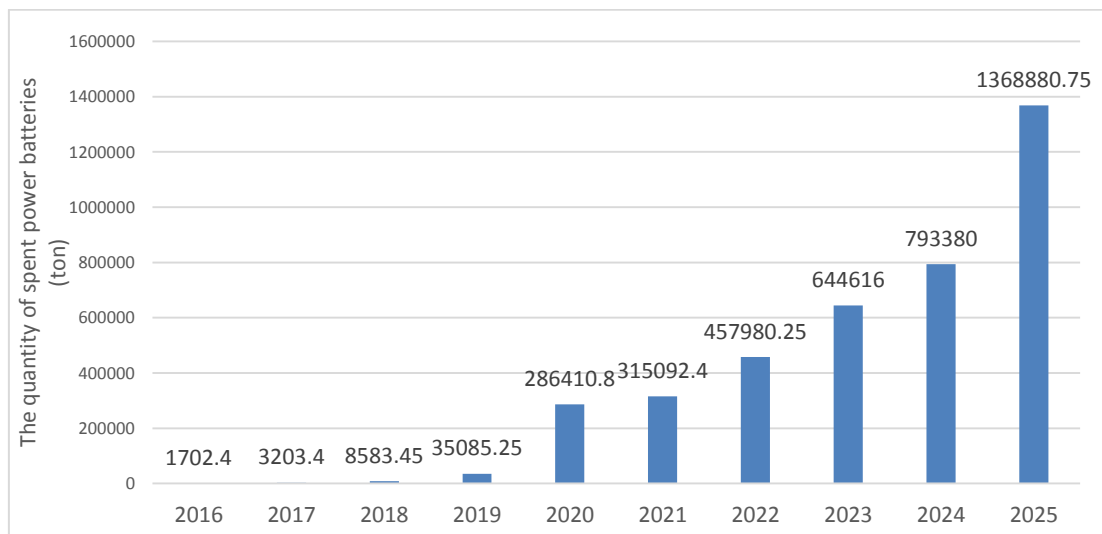


Figure 1. Estimation of spent power battery quantity.

The estimated quantity of the spent power battery is 28.6 thousand tons in 2020 and 1.36 million tons in 2025. Although the replacement from internal combustion engine to power batteries is regarded as energy saving and environmental friendly, and the LFP batteries and NCM batteries do not contain mercury, cadmium, lead or other toxic heavy metals, this does not mean that power batteries are completely non-polluting products[4]. The staggering quantity of power battery contains large amounts of nickel, cobalt, manganese, toxic electrolytes, organic chemicals and plastics, posing a risk on human health, water and soil pollution if not properly disposed of. Therefore, how to effectively recycle the vast amount of spent batteries is an urgent task to resolve.

As an emerging environmental and social issue, the recycling system of spent power battery has not been mature, therefore, government regulation is an indispensable aspect of establishing the recycling mechanism. We reviewed the international policies and found that the United States, European Union, Japan and other developed countries are actively exploring the power battery recycling mechanism, researching economic profits from recovery and technical feasibility. The U.S. government charges additional environmental cost to promote the establishment of a battery recycling network. New York and California have passed state laws that require retailers to take back batteries. Germany has established a relatively perfect legal system of recycling, stipulating that battery manufacturers and importers must assume the responsibility to organize their dealers to recycle the discarded battery and hand over to the designated agencies. European Union has regulated that member states must recycle at least 45% waste batteries in 2016, and the processing and utilization rate of lead, nickel and isolation should not less than 50%. Besides, there are also some related demonstration projects and business operations. For example, in 2011, General Motors (GM) cooperated with ABB to test how to use the scrap battery pack to collect electricity and to realize the residential and commercial power supply. Germany's environment ministry has fund for two power battery recycling demonstration projects in the research of recycling use. Japanese battery manufacturers have already set up a set of "battery production-sales-recycling-renewable processing" battery recycling system[1].

Chinese government has also implemented some policies in terms of spent battery recycling. In 2012, the State Council published "Energy Saving and New Energy Auto Industrial Plan for 2012–2020"[2], which was the first official document for power batteries and was committed to establishing a recycling mechanism. In the beginning of 2016, the National Development and Reform Commission and other four ministries jointly published "The Technical Policy for the Recovery and Utilization of Electric Vehicle Power Battery (2015Edition)"[5], proposing the extended producer responsibility system (EPR) to stipulate the battery manufacturers, importers and related businesses to assume responsibility for the recycling of spent batteries. Later in 2016, "Interim measures for recycling management of traction batteries for new energy vehicles (draft)" changed to explicate that the producers should assume main responsibility for recycling[6]. In addition, China firstly reported three

national standards for power battery recycling, including “Dimension of traction battery for electric vehicles”, “Coding regulation for automotive traction battery” and “Recycling of traction battery used in electric vehicle-test of residual capacity”[7]. These standards regulate the general battery size, disassemble technical requirements, operation procedures, inspection and complementary energy test methods and the implement of them will effectively help recycling industries ensure the security, improve procedure efficiency, reduce treatment pollution, as well as maximize the recovery rate. Since 2012, some local governments have tried to issue related measures to encourage power battery recycling. For example, Shanghai Municipal government subsidizes 1000 yuan per electric vehicle as a special fund for the battery recycling enterprises. Shenzhen requires the local new energy vehicles manufactories to set aside special provisions for power battery recycling in the standard of 20 yuan per KWH, and then government will give subsidies based on 50% of the audited provisions[1].

The related cycling policies in China is expected to stimulate the recycling of spent power batteries. However, spent power battery packs will retain approximately 80% of their energy performance, and the recycling entrepreneurs can gain some revenues by recovering the profitable mental. Whether the subsidies or economic incentives are necessary concerning the recycling battery’s economic benefits and what kind of policies should be taken to effectively realize the complete recycle have not been discussed to date.

To fill this gap, this paper aims to forecast the economic profitability of recycling the spent power batteries at the current situation and then give specific policy recommendations. There are various types of power batteries, including LiFePO₄ series (LFP), LiMn₂O₄ series, Li(NiCoMn)O₂ series (NCM), Li(NiCoAl)O₂ series (NCA), and LiCoO₂ series[8]. Due to the safety, stability and high-cycle capacity of LiFePO₄ battery and the high energy capacity of NCM battery, these two batteries account for nearly 95% in Chinese market in 2015[9]. Therefore, we just take LFP battery and NCM battery as the proxy to analyse in this paper.

2. Economic Benefits

2.1. Recycling revenue

The spent power batteries contain an amount of cobalt, nickel, lithium and other valuable metal. By estimating the mental values of each battery, we predict the recovery revenue.

$$R = \sum_i^m P_i * \alpha_i * \beta_i \quad (1)$$

Where R denotes the recycling revenue of each battery; P_i is the primary commodity market price for the i th mental; α_i is the i th mental composition quantity of that kind of battery, and β_i is the recycling rate of each mental; m is the number of mental types; this paper includes the cobalt, nickel, lithium, manganese, iron, aluminum and copper as the valuable mental, thus, m equals to 7. We adopted the related parameters as Table 1:

Table 1. The recycling revenue of spent LFP batteries and NCM batteries

It is notable that the material composition in spent power batteries would vary between different

Mental	Prices (yuan/ton)	Composition (kg/ton 100KWH)		Recycling rate	Recycling revenue (yuan/100KWH)	
		LFP	NCM523		LFP	NCM523
Cobalt	443,000	0	48.48	89%	0	19,114.21
Nickel	98,275	0	80.8	62%	0	4,923.18
Lithium	860,000	8.99	9.59	80%	6,185.12	6,597.92
Manganese	10,900	0	30.13	53%	0	174.06
Iron	660	71.95	0	52%	24.69	0
Aluminum	15,380	65	87	42%	420	562
Copper	53,510	82	112	90%	3,949	5,394
Total					10,578.81	36,765.38

battery types. The main NCM type is NCM523 in China, which accounts for almost 75% in the total NCM series. Therefore, we take the NCM523 as the representative NCM type to predict the cycling revenue, cost and profits. To reflect the current situation, the value of materials is obtained from the current commodity metals prices from the website of Shanghai nonferrous metal mesh for November, 2017[10]. The composition parameter and recovery are obtained by literature reviews and our investigation of manufacturers[11-13]. The energy capacity of an electric vehicle is about 50 KWH, with its 500 kg mass. So, the recycling revenue of spent LFP and NCM batteries are about 10578.81 yuan/ton and 36765.38 yuan/ton, respectively.

2.2. Recycling costs

The recycling costs of spent power battery includes two parts: variable costs (C_v) and fixed costs (C_f), varying from power battery capacity, recycle technology level, geographic location and other factors. Variable costs are dependent on the volume of recycled batteries while fixed costs refer to the labor salaries, rents of plant, and depreciation allowances of equipment and always keep constant within a fiscal year. Because of China's power battery has not yet reached the batch scrap stage, many power battery recycling enterprises can't collect enough waste battery pack to realize large-scale operation, causing great difficulties for cost calculation. Wang etc. summarized variable cost and fixed cost of 15 international power battery recycling programs through literature reviews and reported that the average variable cost is \$2800 per ton[14]. But since the sample is mainly from developed countries, such as Australia, the United States and France, it may not coincide with China's conditions. Hou etc. analyzed China's power battery recycling costs by market investigation and research and showed that the total recycling cost is about 18500 yuan/ton[15]. But when calculating the cost, he does not distinct the battery types and not take the storage cost and transport cost into consideration.

Based on the literature views and the market research of battery producers and recycling enterprises, this paper estimates variable cost and fixed cost of spent LFP batteries and NCM batteries respectively. Table 2 shows the results. text of your paper should be formatted as follows:

Table 2. The recycling costs of the spent power batteries

	Item	Content	Cost (yuan/ton)	
			LFP	NCM
Cv	Material recovery cost	Spent battery	0	1,2018
	Accessory material cost	Solution and extraction solvent	2,500	2,500
	Fuel cost	Electricity, natural gas etc.	620	620
	Pretreatment cost	crushing and separation	500	500
	Environmental handling expenses	Waste water treatment	330	330
		Residue and ash disposal cost	120	120
	Labor charges	Salary	470	470
	Transportation expenses	Fuel fees, Toll, etc.	2,000	2,000
Cf	Fixed costs	Maintenance of equipment	100	100
		Depreciation allowances	536	536
C (Total)			7,176	1,9194

The material recycle cost means the cost that recyclers pay to the battery owners. According to our survey, the recycling of LFP batteries does not need to pay fees or the fee is small enough to be ignored at current situation. The cost to pay the spent NCM batteries adopts the 50% value of the cobalt and nickel composition. The accessory material cost and fuel cost are taken from other literatures. The pre-treatment cost and environment handling expenses are obtained from other literatures and the investigation. Fixed costs include the depreciation allowances of plant construction,

machinery equipment, recycling network construction, and maintenance of equipment. The residual value for fixed assets is set as 5% and the depreciable lives are set as 10 years and 30 years for equipment and plant, respectively. The labour charges and transportation expenses are obtained from market investigation in Shenzhen. At all the costs are estimated at the full load circumstances. The results indicate that the recycling cost of LFP is about 7176 yuan, of NCM is about 19194 yuan.

2.3. Recycling profits

Based on the above analysis, we can get the recycling profits by the following equation:

$$B=R-C_v-C_f \quad (2)$$

Where B presents the recycling profits of spent power battery. And the recycling profits are shown as Table 3.

Table 3. The recycling profits of the spent power batteries

Type	B (yuan/ton)	R(yuan/ton)	C (yuan/ton)
LFP	3394	10,570	7,176
NCM	17571	36,765	19,194

At current situation, the recycling of both spent LFP batteries and spent NCM batteries are profitable, with the profits of 3394 yuan/ton and 17571 yuan/ton, respectively. Note that the recycling profits are closely related to metal prices. At present, due to the high demand of new energy vehicle industry and scarcity of resources in China, especially cobalt, we believe that the metal price will not sharply decline in the short term, thus, the power battery recycling is profitable, at least, is to balance of payments. Besides, the power batteries have only been in commercial use for approximately 5 years in China and have not reached the massive scrapping stage, many power battery recycling businesses cannot realize the full capacity. So, with the large-scale spent power battery collected and the process efficiency improved, the operation costs that have been distributed to unit battery would be lower.

3. Economic benefits

3.1. Economic incentives are unnecessary

According to the above analysis, the recycling of spent power battery is profitable, therefore, there is no need for government to take no additional economic incentives, like subsidies or tax reduction. Driven by interests, the entrepreneurs would automatically take on the recycling and strenuously maximize the recovery rate. However, if the added economic incentives were given, some companies were inclined to take informal measures, like subsidies deception, which is unfavorable to the market competition instead.

3.2. Establish the compulsory recycling mechanism

Without the economic incentives, it does not mean any regulation is unnecessary. The government should establish compulsory recycling mechanism by legislations or regulations, to ensure the closed loop circulation of power batteries. During a normal life of an electric vehicle, it needs at least two batteries and the battery replacement is unavoidable. This paper suggest that power battery replacement should be complied with “old change new”. Car makers and battery suppliers must collect the spent old power batteries before giving the new batteries to replace. Automotive scrappage stage is another key stage of spent battery collection. We suggest that only by the spent batteries remove from the automobiles to the recycling network, the scrap automobiles can enter the following dismantling process. Note that these regulations should be implemented on the basis of information traceback and management platform.

3.3. Stipulate the qualification for recycling enterprises

Like other electronics, power batteries also pose a potential hazard to human health and the environment if not properly treated. So, government should license the qualified recycling entrepreneurs. The permitted entrepreneurs should be equipped with secure storage or disposal facilities and all recycling process should meet the environmental requirements. Here, we suggest the electric carmakers, battery producers and the waste recycling entrepreneurs with the waste electronic processing qualification, are more favourable to be licensed.

4. Conclusion

By estimating the recycling revenue and costs under the current situation, we find that the recycling of spent power batteries is profitable, even if the material value slightly declines or the material composition changes. Therefore, we suggest the government not to take any economic incentives to stimulate the recycling. What counts more for the government is to perfect the relevant laws and regulations to establish compulsory recycling mechanism and avoid illegal recovery.

5. References

- [1]. Askci, The power battery recycling development present situation and main problems. 2017.
- [2]. The State Council, C., Notice of energy saving and new energy vehicles industry development planning (2012-2020). 2012.
- [3]. OFweek, Analysis on power battery market pattern in 2016. 2012.
- [4]. Zeng, X., J. Li and L. Liu, Solving spent lithium-ion battery problems in China: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, 2015. 52: p. 1759-1767.
- [5]. NDRC, et al., The Technical Policy for the Recovery and Utilization of Electric Vehicle Power Battery(2015Edition). 2017.
- [6]. MIIT, Interim measures for recycling management of traction batteries for new energy vehicles (draft). 2017.
- [7]. OFweek, Three power battery national standards recently released. 2017.
- [8]. Zeng, X., J. Li and N. Singh, Recycling of Spent Lithium-Ion Battery: A Critical Review. *CRITICAL REVIEWS IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY*, 2014. 44: p. 1129-1165.
- [9]. Mahmoudzadeh Andwari, A., et al., A review of Battery Electric Vehicle technology and readiness levels. *Renewable and Sustainable Energy Reviews*, 2017. 78: p. 414-430.
- [10]. Market, N., The price of non-ferrous metals. 2017.
- [11]. Swain, B., Recovery and recycling of lithium: A review. *SEPARATION AND PURIFICATION TECHNOLOGY*, 2017. 172: p. 388-403.
- [12]. Wang, X., et al., Economic and environmental characterization of an evolving Li-ion battery waste stream. *Journal of Environmental Management*, 2014. 135: p. 126-134.
- [13]. Wang, W. and Y. Wu, An overview of recycling and treatment of spent LiFePO₄ batteries in China. *Resources, Conservation and Recycling*, 2017. 127: p. 233-243.
- [14]. Wang, X., et al., Economic, Environmental and Security Implications of Plug - in Vehicles. *Journal of Environmental Management*, 2014. 135: p. 126-134.
- [15]. Hou, B., Research on Power Battery Recycling Mode of Electric Vehicle Research on Power Battery Recycling Mode of Electric Vehicle. 2015, Chongqing University of Technology.