Executive Summary of

STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA

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SUMMARY OF STUDY OBJECTIVES

- Avicenne completed a comprehensive study that included 8 Chinese recyclers, and discussions with more than 50 industry contacts.
- Major Objectives:
  - Determine recycling values and costs in Chinese recycling market – are they value positive?
  - Identify barriers to commercializing industrial scale, value positive Li Ion recycling in North America
  - Summarize recycling players including interactions and involvement in the value chain, volumes and international expansion plans
  - Assessment of recycling technologies utilized
  - Logistics costs assessment
  - Regulatory factors impacting the recycling ecosystem for xEV batteries

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

SUMMARY OF STUDY FINDINGS

- Recyclers expect positive value (including paying for NMC packs and logistics/dismantling) when volumes meet process economics (~20,000 tons/yr) – some are at that volume today, many others expected by 2020
- Recycling volumes are on the verge of a significant acceleration
- There are a large number of emerging and established Li Ion recyclers in China (>25), 11 were profiled in detail by Avicenne
- Regulation on battery recycling in China is significant:
  - Interim rules require OEMs to set up facilities for collection and recycling of batteries
  - Battery makers, sales units and car makers must also set up a traceability system
  - In January 2018, China banned the import of 24 recyclable materials including batteries
  - A "white list" was established for enterprises that meet criteria. Only these companies will receive subsidies from the government

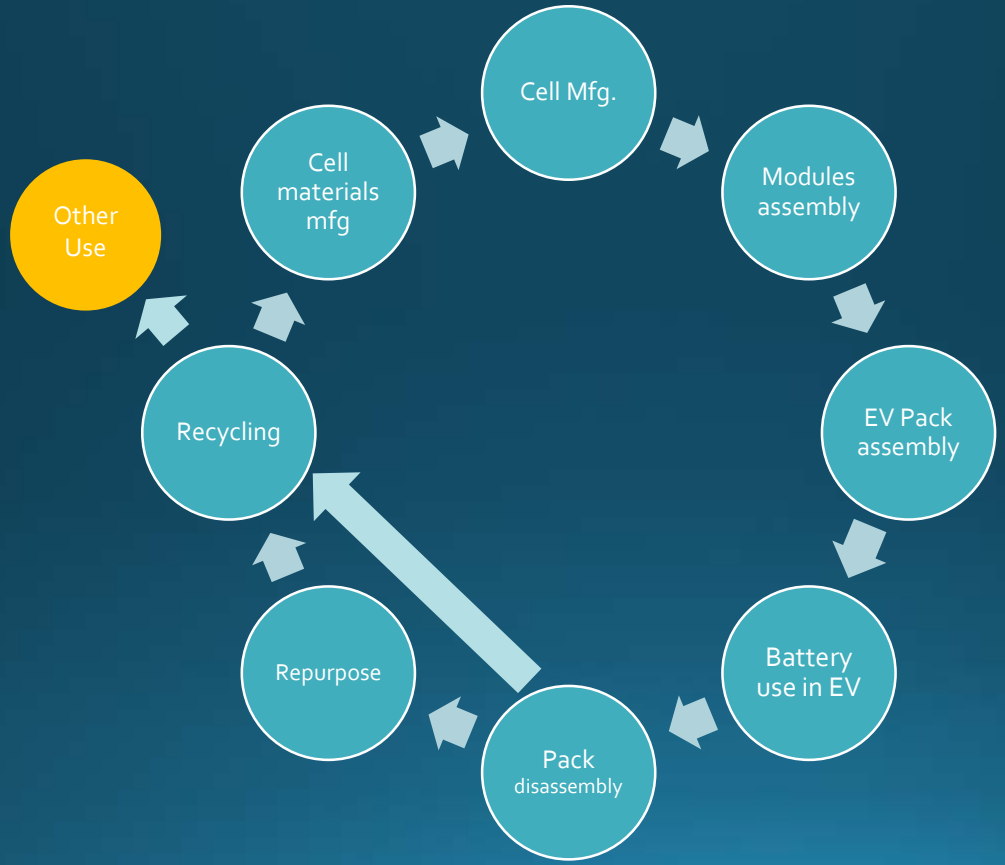
Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

CHINESE COMPANIES INVOLVED IN LI ION BATTERY RECYCLING

	Companies included in the scope of the survey	Others involved in Li-ion battery recycling
Recyclers	2	6
Metal suppliers	2	2
Battery component suppliers	1	1
Li-ion / lead acid battery manufacturers	3	7
OEM		1

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

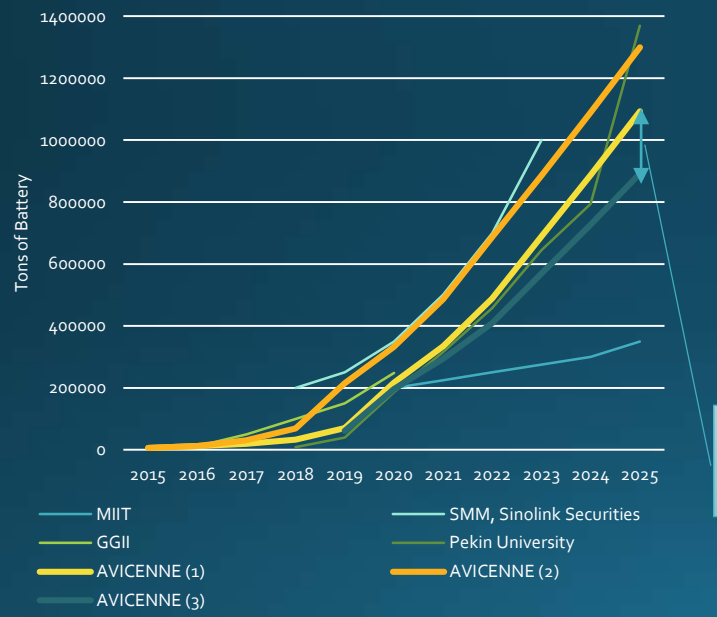
LITHIUM ION REPURPOSE & RECYCLING STEPS



Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

BATTERY RECYCLING MARKET IN CHINA

The NEV(1) lithium ion battery pack to be recycled, including mfg. Scrap will reach 200 kT in 2019-2020 and 400 kT in 2020-2021



Rationales

- Explosive growth of new energy vehicles in China will pose a great challenge to battery recycling
- Today, manufacturing scrap portion is quite significant but percentage will decrease rapidly and will become a non significant part as the portion of End Of Life batteries increase.
- Ministry of Industry and Information Technology said it expects retired batteries will together weigh around 200,000 Tons by 2020.
- The China Automotive Technology and Research Center estimated that figure would reach 350,000 Tons by 2025.
- According to China Securities Journal, the battery recycling segment is a new gold mine thanks to its market size, which stands at 5 billion yuan ($788 million) this year, and is expected to double by 2020. Chinese Institutes has the same figures
- We identified more than 35 players in the Li-ion battery recycling business. There are probably more.
- Estimated lithium ion battery recycling capacity: 100 000 Tons in 2018, 500 000 Tons in 2020 and > 1 million Tons in 2025.

(1) Scenario 1 – Battery life time: 6 years

(2) Scenario 2 – Battery life time: 5 years

(3) Scenario 1 + considering 20 GWh annual market in 2025 for 2nd life batteries used for ESS, back-up for Telecom, etc… (50% of the total ESS market) ; 20GWh will represent roughly 20% of the end-Of-Life batteries.

(1) NEV: New Electric Vehicle (EV + PHEV)

(2) Sources: GGII: Gaogong Industry Research Institute, SMM: Shanghai Metals Market, Avicenne Energy 2018

*Source: **STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA**, AVICENNE Energy, 2018*

CHINA LITHIUM ION BATTERY REGULATION

Regulation continues to evolve and are not complete

- Process started in mid-1990s as the "problem" was starting to be defined with consumer batteries – review of 1996 – 2018 progress in the appendix
- 2018 was a year of many changes to the regulatory and white listed landscape for Lithium Ion Batteries, the China Government took many steps to manage key issues that remain:
  - **Interim Measures on Traction Battery Recycling (February 2018) – direct translation of summary in appendix**
  - **Interim Administrative Measures on the Traceability of Traction Battery Recycling (July 2018)**
  - **White List of five NEV battery recycling enterprises which meet the requirements of the "Standard Requirements for the Comprehensive Utilization of Decommissioned NEV Power Batteries". (July 2018)**
  - **Implementation of Pilot Projects on Traction Battery Recycling (July 2018)**
- China Industry Minister did not complete the comprehensive new battery recycling rules that were expected by year end 2018.
- Some programs like white listing, economic uncertainty for many chemistries and the pilot projects suggest further evolution will be needed for lithium ion battery recycling regulations in China.

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

THE LI-ION BATTERY RECYCLING REGULATION

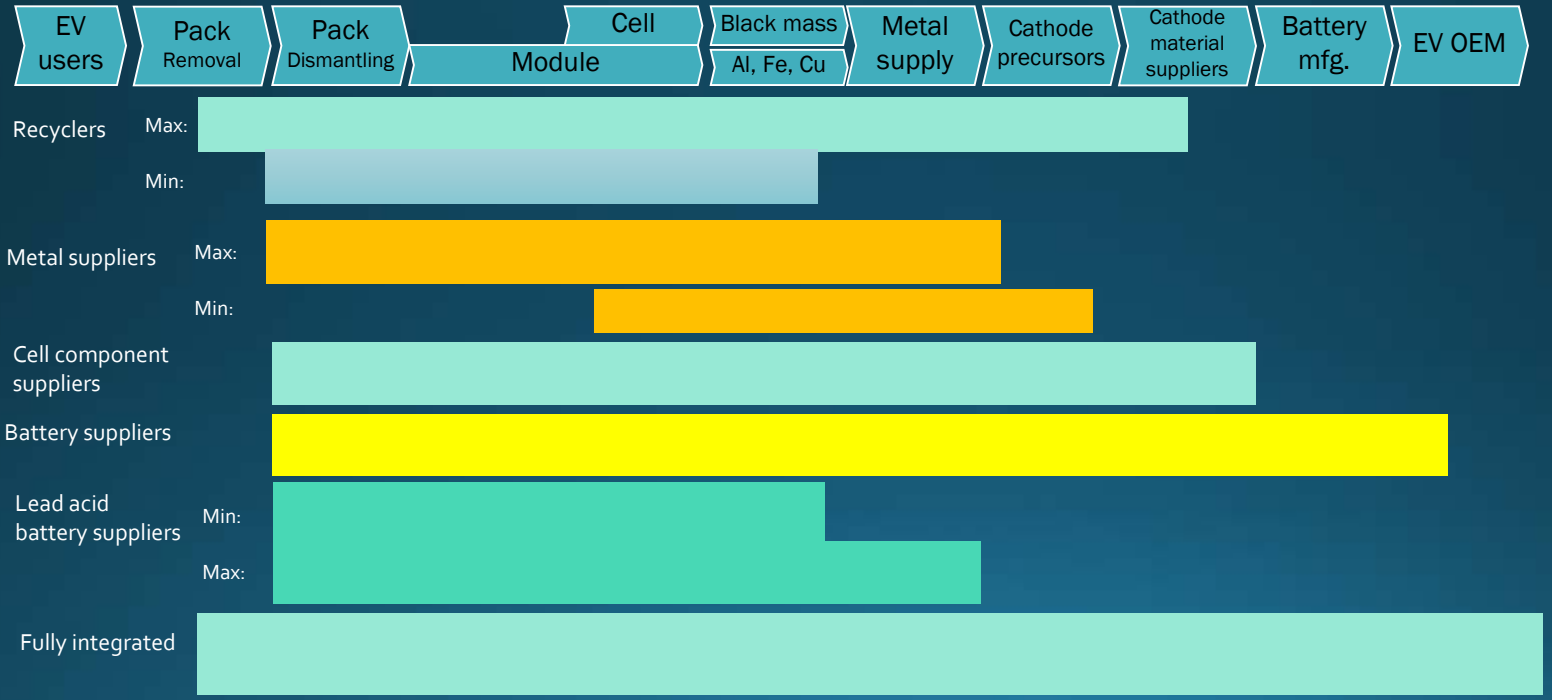
Regulatory Environment still has lots of remaining issues

- Low professional standards (not true for all the players), poor safety, low barriers to entry, and unscrupulous dismantling in domestic power battery recycling enterprises
- The relevant technical specifications are not yet perfect, the recycling system has not yet been established
- The lack of power battery recycling penalties mechanism (some rules are in place but no penalties if company do not follow the rules)
- Today the business is not profitable across the industry
  - **Most volumes are not meeting process economics and LFP systems are not profitable**
  - **Understanding business models of recyclers was difficult (timing wise) as they seem to be presently lobbying government for subsidies and thus reluctant to share 'positive' business models**
- The urgent need to develop incentives for the implementation of battery recycling regulations, the establishment of a clear reward and punishment mechanism.
- Most of the lithium batteries to be recovered in the current stage have no economic value and enterprises are not enthusiastic about recycling.
- Today, no government incentive for collection / transportation or recycling EV batteries.
- It is expected that "White listed" companies will get incentives at least to recycle LFP packs (not decided yet)

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

THE LI-ION BATTERY RECYCLING VALUE CHAIN IN CHINA

Recycling attracts lot of different players from metal suppliers, cathode suppliers, cell mfg., lead acid battery mfg., OEM and E-waste recyclers



Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

RECYCLING PROCESS IN CHINA

- Most of the companies are still at a pilot scale
- Most have the same process steps:
  - Manual dismantling of the pack
  - Then, module dismantling or direct smelting
  - Standard process in China:
    - Soaking in salt solution
    - electrical discharge
  - Mechanical separation
  - Leaching
  - Refining with hydro metallurgical process

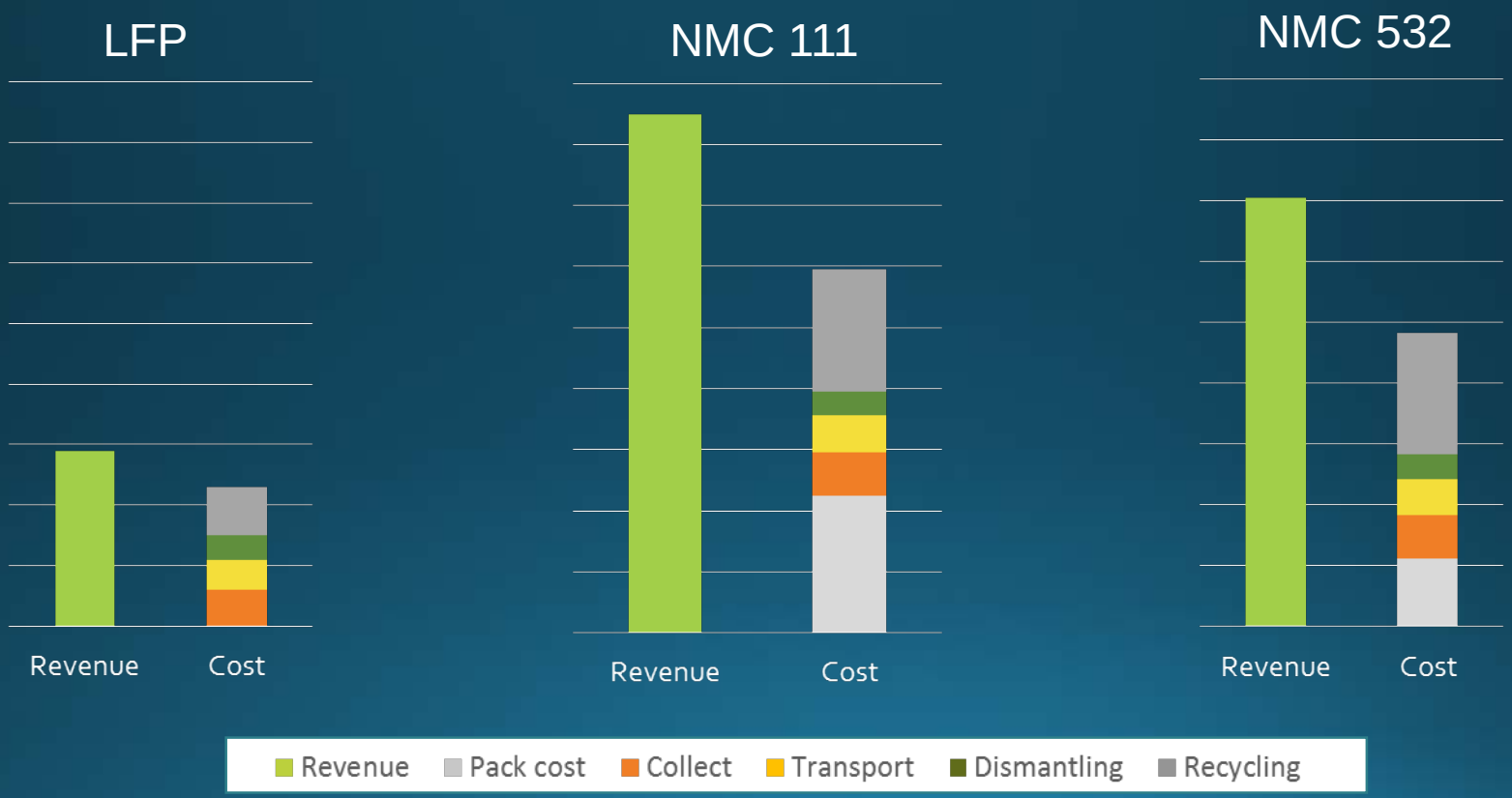
Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

BATTERY RECYCLING VALUE IN CHINA

- The value extracted from battery recycling is highly dependent on
  - Metal pricing
  - Recovery efficiency
  - Recycler then may provide precursor or cathode active material
- Costs include:
  - Pack Cost (amount paid by recycler to OEM for battery)
  - Collection costs
  - Transportation costs
  - Dismantling costs
  - Recycling costs

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

COST & REVENUE OF RECYCLING IN CHINA



Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

For > 20,000 Tons of battery pack recycled / year

Appendix - Regulatory Framework Details

CHINESE RECYCLING REGULATION

- China will make manufacturers of electric vehicles (EV) responsible for setting up facilities to collect and recycle spent batteries, as part of its efforts to tackle mounting waste in the sector, **new interim rules published on February 2018**.
- EV manufacturers have to set up recycling channels and service outlets where old batteries can be collected, stored and transferred to specialist recyclers
- Together with battery makers and their sales units, carmakers must also set up a "traceability" system enabling the identification of owners of discarded batteries
- Dr. Zhang Tongzhu and Mr. Hu Jian are responsible for the battery recycling standard system in China
- China's industry ministry urged the sector to introduce standardized designs and raise technology to "international" levels by 2020. **It plans to publish comprehensive new battery recycling rules before the end of 2018 – not issued yet.**
- While carmakers are technically liable for recycling batteries, in practice they sign deals with suppliers to recycle batteries on their behalf. The OEM will have to pay for the collection and any recycling costs.
- **On January , 2018, China banned the import of 24 recyclable materials, including plastic, paper, and e-waste such as batteries.** However, China imported large volume of used batteries as components of phones, laptops and other electronic devices. (not included in the scope of the survey)

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

RECYCLING POLICY/INCENTIVES

- China is launching an electric car battery recycling standard as old batteries are expected to come back in high numbers as EV adoption ramps up in the country.
- The Ministry of Industry and Information Technology has already pushed a standard for tracking the entire life cycle of batteries in electric vehicles, but it is now establishing a new scheme with automakers to recycle the batteries at the end of life.
- The ministry also promised to draw up policies to support battery recycling, making full use of existing tax incentives and creating innovative new financing methods.
- The ministry has already published draft rules to create a "traceability management platform" aimed at tracking the entire life cycle of electric car batteries from production to disposal.
- Feb 2018, "interim" rules: (take effect in August 1st, 2018)
  - manufacturers of electric vehicles (EV) are responsible for setting up facilities to collect and recycle spent batteries
  - The carmakers must also establish a maintenance service network allowing members of the public to repair or exchange their old batteries conveniently
  - Together with battery makers and their sales units, carmakers must also set up a "traceability" system enabling the identification of owners of discarded batteries
  - battery makers are also encouraged to adopt standardized and easily dismantled product designs, to help automate the recycling process. They must also provide technical training for car makers to store and dismantle old batteries
  - The guidelines encourage battery-makers to strengthen cooperation with companies that can make a better and rational use of used batteries removed from new energy cars. Today, Guidelines are not subject to penalties or incentives.

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

INTERIM ADMINISTRATIVE MEASURES ON THE TRACEABILITY OF TRACTION BATTERY RECYCLING

Issued by the Ministry of Industry and Information Technology (MIIT) on 03.07.2018)

- In accordance with the "Interim Measures on Traction Battery Recycling" released this February, MIIT issued in July 2018 the "Interim Measures on the Traceability of Traction Battery Recycling". The document announced the establishment of an administrative platform (http://www.evmam-tbrat.com/) where information concerning traction batteries will be collected.
- Battery producers, automakers, vehicle recycling and scrapping enterprises, enterprises in the business of battery cascade utilization as well as battery recycling enterprises are responsible for uploading information on the batteries. Provincial Industry and Information Departments will be responsible for supervision and monitoring and for tracing the batteries in conjunction with relevant authorities at the same level. This regulation shall come into effect on 1 August 2018.

Source: ***STUDY OF LARGE FORMAT EV LITHIUM-ION BATTERY RECYCLING IN CHINA,*** *AVICENNE Energy, 2018*

WASTE BATTERY POLLUTION PREVENTION AND TECHNOLOGY CONTROL

First, the general rule

- (I) In order to carry out the Law of the People's Republic of China on Environmental Protection, "Law of the People's Republic of China on Prevention and Control of Environmental Pollution by Solid Wastes" and other relevant laws and regulations, prevent and control environmental pollution, ensure ecological security and human health, guide environmental management and scientific pollution control and lead pollution Prevent technological progress, and promote the use of waste batteries, the development of this technology policy.
- (II) This technical policy is applicable to the prevention and control of mixed waste, substandard products, scrapped products and outdated products arising from the production, transportation, sale, storage, use, maintenance, utilization and remanufacturing of various batteries. Waste batteries under key control include waste lead-acid batteries, lithium-ion batteries, nickel-hydrogen batteries, nickel-cadmium batteries and mercury-containing button cells.
- (III) This technical policy is the guiding document, which mainly includes the pollution prevention and control technology for the collection, transportation, storage, utilization and disposal of waste batteries and the new technologies for encouraging research and development so as to provide technical guidance for the environmental management and pollution prevention and control of waste batteries .
- (D) waste battery pollution prevention and control should follow the closed-loop and green recycling, resource utilization priority, reasonable and safe disposal of the comprehensive prevention and treatment principles.
- (5) To gradually establish an information supervision system for the collection, transportation, storage, utilization and disposal of waste lead batteries, waste energy batteries for new energy vehicles, etc., and encourage the adoption of information technology to build a supervisory system for the entire process of waste batteries.
- (6) Waste batteries that are listed in the national list of hazardous wastes or that are identified as hazardous wastes in accordance with the national standards for the identification and identification of hazardous wastes are managed in accordance with the guidelines for hazardous wastes.

Source: http://www.zhb.gov.cn/gkml/hbb/bgg/201612/t20161228_378325.htm

WASTE BATTERY POLLUTION PREVENTION AND TECHNOLOGY CONTROL

Second, collect

- (A) Encourage the collection of waste batteries by category in areas with access to resources.
- (B) to encourage battery manufacturing enterprises, waste battery collection enterprises and the use of enterprises and other building waste battery collection system. Encourage battery manufacturers to fulfill producer extended responsibility.
- (III) Encourage waste battery collection enterprises to establish waste battery collection system by using information technologies such as "Internet of Things +" and promote efficient recycling of waste batteries through information disclosure and other means.
- (D) waste battery collection enterprises should establish a marked identification of waste battery collection facilities. Encourage consumers to waste batteries sent to the corresponding waste battery collection network device.
- (E) During the collection process, the structure and shape of waste batteries should be kept intact. It is forbidden to break the waste batteries by themselves. The damaged batteries should be stored separately. This is translated at the cell level only, not modules or packs.

Third, transport

- (A) waste batteries should take effective packaging measures to prevent leakage of toxic and hazardous substances in transit caused pollution.
- (II) Waste Lithium-ion batteries should be pre-discharged before shipment, independent packaging and other measures to prevent explosion caused by impact or short-circuit caused by environmental risks.
- (3) It is forbidden to dump and discard used batteries during transport.

Source: http://www.zhb.gov.cn/gkml/hbb/bgg/201612/t20161228_378325.htm

WASTE BATTERY POLLUTION PREVENTION AND TECHNOLOGY CONTROL

Fourth, storage

- (A) Waste batteries should be classified storage, storage in the open air is prohibited. Damaged batteries should be stored separately. (Intent was for damaged cells with potential leakage to be stored in separate areas, potentially with different pollution control and safety requirements – but not defined in mandate). Storage should be regularly cleaned.
- (B) storage of waste lead-acid batteries should prevent leakage of electrolyte. Waste lead-acid batteries should be stored so as to avoid flooding.
- (C) waste lithium-ion batteries should be stored before storage safety testing, dark storage, should control the storage place of the ambient temperature to avoid spontaneous combustion caused by high temperature and other environmental risks.

Source: http://www.zhb.gov.cn/gkml/hbb/bgg/201612/t20161228_378325.htm

WASTE BATTERY POLLUTION PREVENTION AND TECHNOLOGY CONTROL

Fifth, use

- (A) Prohibit artificial, open-air dismantling and crushing waste batteries.
- (B) should be selected according to the characteristics of waste batteries dry smelting, hydrometallurgical and other technologies to use waste batteries. Dry-process smelting (direct translation from the Chinese – Pyro-metallurgical) should be carried out in negative pressure facilities, and the unorganized emission of exhaust gas in the treatment process should be strictly controlled.
- (C) waste lithium-ion battery should be used (at end of cell life) prior to discharge treatment should be disassembled under low temperature conditions to prevent electrolyte volatilization. The mandates encourages the use of acid-base dissolution - precipitation, high-efficiency extraction, fractional precipitation and other techniques recovery of valuable metals. Or to use high concentrations of ammonia wastewater generated during the process. The mandate encourages the use of distillation, membrane treatment and other technical treatment and reuse of chemicals.
- (Iv) Waste mercury-containing batteries are encouraged to be recycled by techniques such as vacuum distillation using fractional control.
- (E) scrap zinc manganese batteries and waste nickel-cadmium batteries should be broken in a closed device.
- (Vi) dry-process smelting (Pyro-metallurgical) should be used adsorption, bagging and other technologies to deal with waste gas.
- (G) Hydrometallurgical extraction of valuable metals produced wastewater should adopt membrane separation method, adsorption of functional materials and other processing techniques.
- (VIII) Wastewater and waste gas emissions from waste lead-acid batteries shall implement the "Emission Standard for Industrial Pollutants for Recycled Copper, Aluminum, Lead and Zinc" (GB 31574). Other Waste Battery Dry Utilization Enterprises' emissions should refer to the implementation of the "Hazardous Waste Incineration Pollution Control Standard" (GB18484), wastewater discharge should meet the "Integrated Wastewater Discharge Standard" (GB 8978) and other corresponding standards.
- (IX) The technical policies for the prevention and control of pollution by the use of lead-acid batteries are stipulated in the Technical Policy for the Prevention and Control of the Production and Recycling of Lead-acid Batteries.

Source: http://www.zhb.gov.cn/gkml/hbb/bgg/201612/t20161228_378325.htm

WASTE BATTERY POLLUTION PREVENTION AND TECHNOLOGY CONTROL

Sixth, disposal

- (A) Waste batteries should be not discarded into domestic waste incineration plant or compost fermentation plant.
- (2) Waste batteries that have not been collected and are not yet used in a cost-effective manner should be classified into landfills for future use.
- (3) Waste batteries should not be disassembled, rolled and other crushing operations prior to and during disposal of waste batteries, so as to ensure the integrity of the waste batteries and reduce and prevent the exudation of harmful substances.

Seven, encourage the development of new technologies

- (A) high value-added batteries and all-component use of technology.
- (B) intelligent waste battery dismantling, crushing, sorting and other technologies.
- (C) automation, high efficiency and high safety of new energy vehicles power battery module separation, directional recycling and reverse dismantling technology.
- (D) waste lithium-ion battery separator, electrode material utilization technology and electrolyte membrane separation technology.

Source: http://www.zhb.gov.cn/gkml/hbb/bgg/201612/t20161228_378325.htm

CHINA EVOLVING RECYCLING DIRECTIVES

China 1996-2016 Summary – Waste Management & Research

In view of the serious environmental problems caused by waste LIBs and valuable materials in waste LIBs, China has paid great attention to them, and has actively taken measures to management waste LIBs. The List of Wastes Prohibited for Import based on the Basel Convention is the first legal document related to WEEE management in China, and was released in 1996. Waste batteries are on the list. In 2003, the State Environmental Protection Agency of China, together with nine other government agencies, co-issued a policy on battery recycling called the "Policy on Pollution Prevention Techniques from Waste Batteries." The policy required that battery industries should take responsibility for collecting waste batteries and for proper labeling (MEP, 2003).

The companies China Mobile, Motorola and Nokia launched a recycling campaign, "Green Box Environmental Program," in December 2005 to recycle waste mobile phones and accessories (waste LIBs included). Six other cell-phone manufacturers joined the campaign the year after. The campaign collected more than 150 t of phones and LIBs in 300 cities in China (Zeng et al., 2015).

During June 2009 to December 2011, China launched a program called "Old for New" for Household Appliances, which laid a solid foundation for establishing a formal WEEE collection and recycling system in China. In addition, some web-based recycling companies launched the old-for-new service of WEEE. For instance, "Love Recycling Network" has established more than 200 service points in China, built a 5000-member service team to cover the business in many cities in China and recycled more than 20 million units of WEEE containing LIBs since 2011 (Love Recycling, 2017).

In 2012, relevant Chinese government departments issued the "Administrative Measures on the Collection and Using of Waste Electrical and Electronic Equipment Treat Fund," which stipulates that manufacturers or importers are responsible for the fund collection. This fund is used to enable qualified enterprises for the recycling of WEEE.

Source: https://journals.sagepub.com/doi/pdf/10.1177/0734242X17744655

CHINA EVOLVING RECYCLING DIRECTIVES

China 1996-2016 Summary – Waste Management & Research (Cont'd)

The Fund has been successfully applied in the recycling of air conditioners, TV sets, refrigerators, washing machines and computers (Yu et al., 2014).

With the soaring increase of small WEEE, the "Directory of Waste Electrical and Electronic Equipment Treatment (2014)" (including LIBs) was introduced in February 2015 and put into effect in March 2016, which means that waste LIBs were officially added to the scope of the Fund (NDRC, 2015). This would increase the enthusiasm of the qualified enterprises of WEEE to collect and recycle waste LIBs. Currently, there were 109 licensed recycling enterprises, which can process 4 Mt of WEEE every year in China (Li et al., 2015).

The New Policy on Pollution Prevention Techniques from Waste Batteries was released by the Ministry of Environmental Protection (MEP) on 26 December 2016, which regulates the collection, transportation, storage, utilization, and treatment of waste LIBs (MEP, 2016). The main contents of this legislation are as follows.

1. Mixed waste, substandard products, waste products, and expired products in the production, transportation, sale, storage, use, maintenance, utilization, remanufacturing, and other processes of all kinds batteries are included in the policy. Waste lead-acid batteries, lithium-ion batteries, nickel hydrogen batteries, nickel cadmium batteries, and mercury containing button cell are focused on.
2. Recycling enterprises are encouraged to use "Internet of Things plus" and other information technology to establish a complete waste battery collection system. Battery manufacturers are encouraged to fulfill the extended producer responsibility. Consumers are encouraged to send waste batteries to the corresponding waste battery collection points.
3. Effective waste battery packing measures should be taken to prevent the leakage of toxic and harmful substances during transportation. Pre-discharging, independent packaging, and other measures for waste LIBs before the transportation are required to prevent environmental risks caused by impact or short circuit explosion. Dumping and discarding waste batteries during transportation is forbidden.

Source: https://journals.sagepub.com/doi/pdf/10.1177/0734242X17744655

CHINA EVOLVING RECYCLING DIRECTIVES

China 1996-2016 Summary – Waste Management & Research (Cont'd)

4. Safety testing and light-resistant storage should be carried out before the storage of waste LIBs. The environmental temperature of the storage place should be controlled to prevent the environmental risks caused by spontaneous combustion.

5. Open burning, simple incineration, and rough extraction of metals from waste batteries are banned. Waste LIBs should be disassembled at low temperature in order to prevent the volatilization of electrolyte. Acid/alkali dissolution-precipitation, efficient extraction, fractional precipitation, and other technologies are encouraged to recover valuable metals from waste LIBs.

6. Waste batteries should be avoided in the domestic waste incineration plant or the composting plant. In the process of landfill disposal of waste batteries, waste batteries should not be disassembled, rolled, and crushed, and the integrity of waste batteries should be ensured to reduce and prevent the leakage of harmful substances. 7. Intelligent dismantling, crushing, sorting, high value-added, and full-components utilization of waste batteries are encouraged. The utilization technology for separators and electrode materials, and the membrane separation technology for electrolytes from waste LIBs should be developed and used. Through many years of effort and development, China has made much progress in waste LIB management. However, China was still lagging behind the developed countries, due to lack of a complete collection system, mature recycling technology, and detailed guidance for both consumers and producers of lithium batteries in China.

Source: https://journals.sagepub.com/doi/pdf/10.1177/0734242X17744655