Biweekly 008 Nov/21

“Turn Stone into Gold” - Li-Ion Battery Recycling

Nov. 2016

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SMM
Shanghai Metals Market

The Following Terms are Used in This Report

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Acronym	Definition
Li-ion battery	Lithium-ion battery
Zn-Mn Battery	Zinc-manganese battery
Ni-MH Battery	Nickel–metal hydride battery
Ni-Cd Battery	Nickel-cadmium battery
LFP Battery	Lithium iron phosphate battery
LMO battery	Lithium manganese oxide battery
LCO battery	Lithium cobalt oxide battery
LSEV	Low-speed electric vehicle
EV	Electric vehicles
BEV	Battery electric vehicle
PHEV	Plug-in hybrid electric vehicle
PPP project	Public–Private–Partnership
NCM	Lithium nickel manganese cobalt oxide
NCA	Lithium nickel cobalt aluminum oxide

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Hot News

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1

Jun. 28, 2016

Honda Plans to Build Battery Recycling Network, to Solve Resources Wasting

Source: Netease Auto

By the spring of 2017, Honda Motor plans to obtain a permit from the Environment Ministry for collecting and processing industrial waste, its own used batteries, across production lines. If succeeds, **Honda will become the first auto manufacturer to enter the battery recycling market**, with the help of Tohoku University, as well as Japan Metals & Chemicals. As Honda's partner, Japan Metals & Chemicals will build a prototype battery recycling plant within three years, aiming to recycle the pure substances from battery waste by hydrometallurgical process with less cost than by traditional pyrometallurgical process.

2

Aug. 29, 2016

Chaowei Chuangyuan: "IDBMS" Helps Li-Ion Battery Maintenance and Recovery

Source: China Battery

China EV100 and Henan's government jointly hosted China EV100 Summer Forum (2016). In the meeting, Sun Yanxian, General Manager of Zhejiang Chaowei Chuangyuan Industrial Company, indicated **that the company is designing a li-ion battery system called IDBMS**, which will set an electronic device with GPRS and a chip for data reading in every li-ion battery, **and batteries thus can be traced through their whole life cycle**, which will be helpful for battery recycling.

3

Sep. 26, 2016

China First Li-Ion Battery Recycling Production Line Have Been Built in Henan

Source: Securities Times

After a year's repeated innovation and test, Electric Power Research Institute of Electric Power of Henan built **the first full-automatic product line for power battery recycling by dry process in China**, realizing efficient and environment-friendly li-ion battery recycling.
The project, abandoning power-hungry and high-polluting disposing technology, such as hydrometallurgical process and traditional pyrometallurgical process, recycles used li-ion battery more efficient and environmental by dry process without further pollution. **The recovery utilization rate of used battery increases to above 90%** with disposing capacity at 800kg/hour and 5,000mt/yr.

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Abstracts

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1 Li-ion battery recycling industry chain is closed-loop, with high economic value

- Used battery is dived into primary battery and secondary battery, which will pollute environment with inappropriate treatment(e.g. **deep bury solidified, deposited in the mine and waste recycling)**
- Li-ion battery has high recycling value and recycling technique is divided into **physical teardown, pyrometallurgy and hydrometallurgy**
- Li-ion battery recycling industry chain operates in closed-loop, and **downstream and upstream can interconvert**

2 Power li-ion battery end demand rises & Used li-ion battery market may break through 10 billion yuan in 2020

- Li-ion battery is mainly divided into power battery, 3C battery and energy storage battery and **power li-ion battery increased sharply** in 2015 and is expected to boom in the future
- Rapid growth of li-ion battery demand indicated rising amount of used li-ion battery in the future. **Used li-ion battery market may boom in 2018**, and market scale is expected to **break through 10 billion yuan in 2020**

3 Used Li-ion battery can be utilized in a cascade way or can regenerate metal

- Used li-ion battery can be utilized in **electric bicycle, mini electric vehicle and energy storage market** in cascade way. However, its cascade utilization still faces many problems, including forecasting left power of battery and controlling of secondary costs
- Used li-ion battery processes clear characteristic of resources, among **which the recycling value of the anode material is high**, from which cobalt, lithium and nickel can mainly be recycled
- Li-ion battery recycling shows positive revenue but gross profit rate is relatively low, with **the highest gross profit rate of 9.4% at ternary material battery recycling**

4 Business model of battery recycling is in transition with confirming of responsibility subject, waiting for subsidy policies

- Used battery is mainly recycled by small workshops traditionally, which may easily lead to potential accident and environmental pollution. Chinese enterprises are searching for new recycle models, including **battery recycling by battery manufacturers, industry alliance and third party**, to build scientific power battery recycling system
- Power battery recycling policies are introduced in a row, which **confirm subject of responsibility** and clarify "**Extended Producer Responsibility System**" and local governments provide active coordination, releasing relative **subsidy policies**

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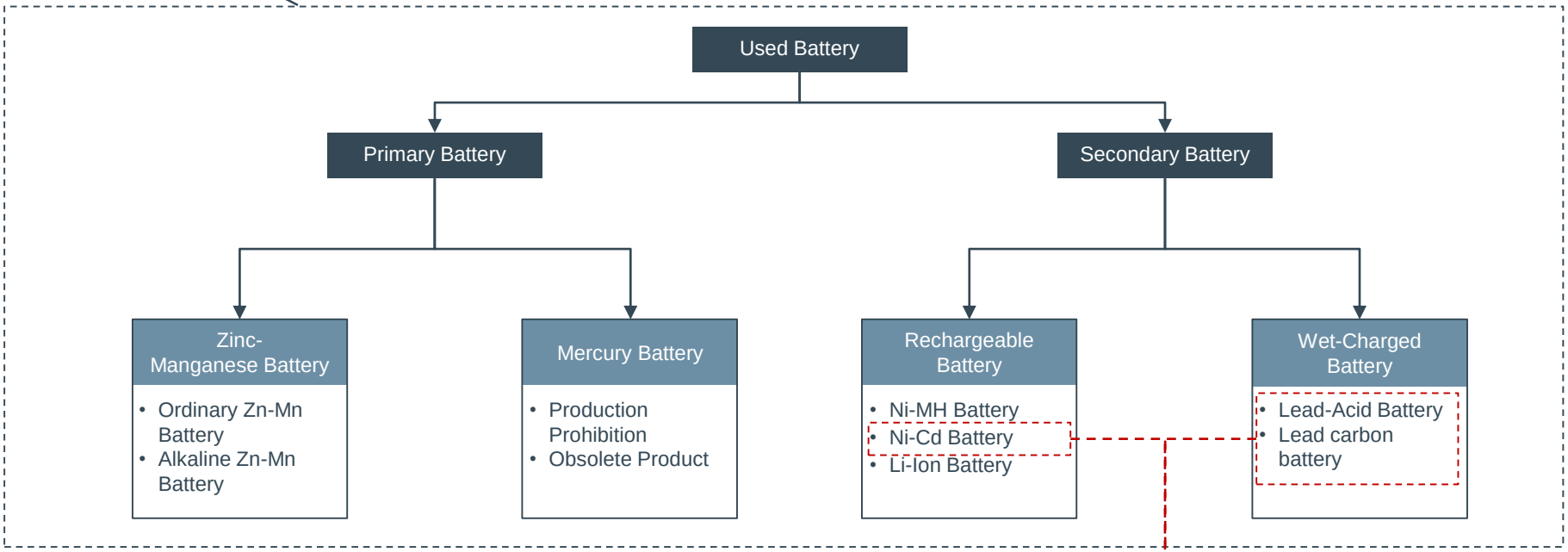
Used Battery

1.Used Battery



Note: Used battery is batteries can not get to rated capacity even after fully charged and is used over service life

2. The Harm of Used Battery

- Heavy Metal Pollution: Batteries contain toxic heavy metals, such as mercury, silver, lead and zinc, parts of them will lead to carcinogenic, neurasthenic, blood toxic and renal trauma effects
- Electrolyte Leakage: It can change PH of soil and water, effecting growth of plants and crops, and finally enter human tissues via various ways
- Secondary Air Pollution: Some volatile heavy metals in battery will become heavy metal fume after high-temperature incinerating, resulting in severe air pollution

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Used Battery Disposal

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Used Battery Disposal

Solidified-Deep Bury

- To wrap used batteries into inert materials with physical and chemical method and then collect them and bury deeply

Deposited in Mine

- Take advantage of abandoned mine to bury used battery without pollution

Waste Recycling

- Pyrometallurgy
- Hydrometallurgy
- Vacuum pyrometallurgy

Characteristics and Recycling Purpose of Various Used Batteries

① Zn-Mn Battery

- Characteristic: More safety for majority is without mercury
- Purpose: To recycle steel and copper

② Mercury Battery

- Characteristic: High property, stable power releasing, but polluted heavy metals containing
- Purpose: To recycle mercury to avoid pollution

③ Ni-Cd Battery

- Characteristic: Quick charge, durable, but polluted heavy metals containing
- Purpose: To recycle cadmium to avoid pollution.

④ Ni-MH Battery

- Characteristic: Better property than Ni-Cd battery, but more expensive
- Purpose: To recycle nickel, zinc and steel

⑤ Li-Ion Battery

- Characteristic: New rechargeable battery, high property, environmental friendly
- Purpose: To recycle cathode, anode and part of electrolyte, with high economic value

⑥ Lead-Acid & Lead-Carbon Battery

- Characteristic: Widely-used, low prices, but contains polluted heavy metals
- Purpose: To recycle cadmium to avoid pollution, with relatively high economic value

Note:

- *The main purpose of recycling mercury, Ni-Cd and lead –acid batteries is to **avoid pollution from heavy metals***
- *Non-polluted battery recycling is mainly **for recyclable metal with high economic value***

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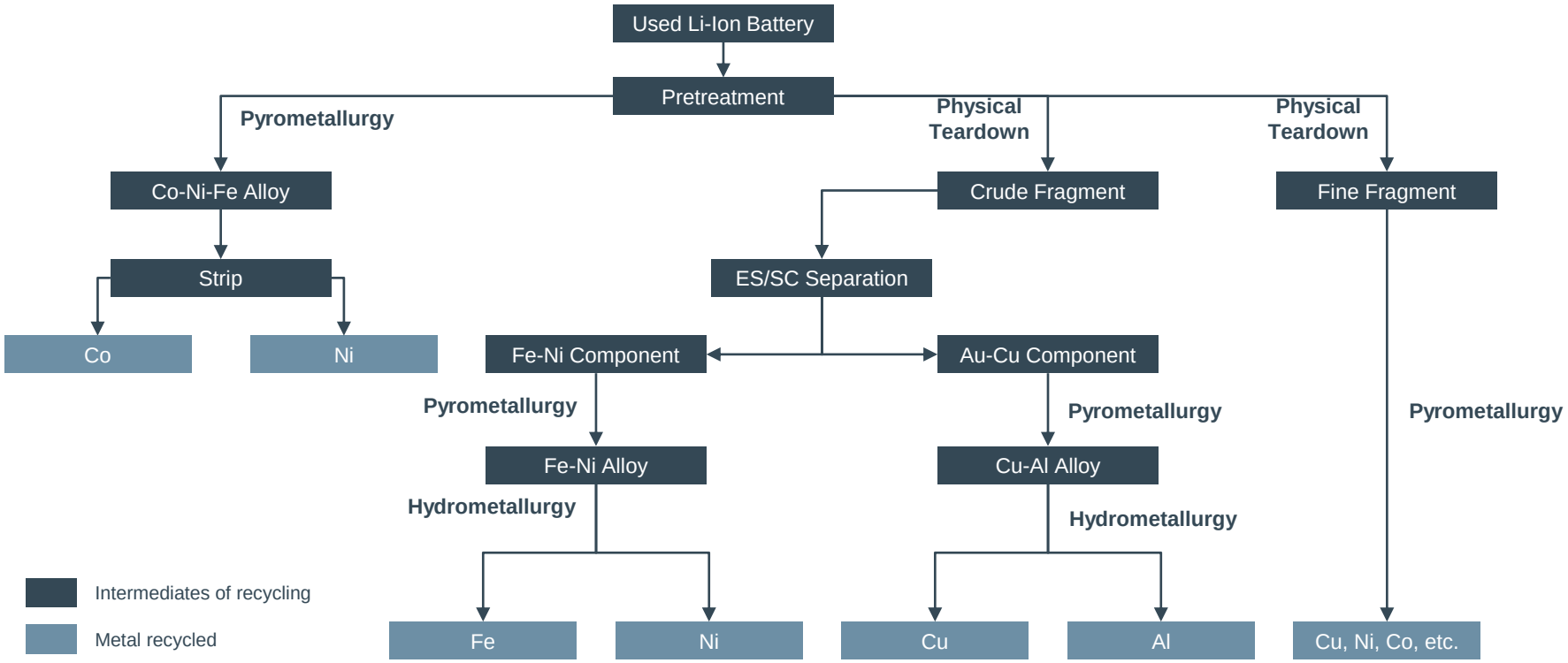
Recovery Process of Used Li-Ion Battery



Note: Pretreatment is preparations, including sorting, power releasing, peeling and shelling; ES refers to active material; SC refers to current collector; Every process has appropriate loss

- Physical Teardown: To get high content material through crashing, sorting, magnetic separating and fine grinding
- Characteristics: Low efficiency, time-consuming and environmental friendly

- Pyrometallurgy: To get fine powder with metals and metallic oxide containing through high-temperature roasting
- Characteristics: Simple technique, available for large stale disposing, composition of combustion is polluted

- Hydrometallurgy: To selectively dissolute crashing battery through appropriate chemical reagent to separate metallic elements
- Characteristics: Stability, available for small and medium-size recycling, high costs, waste liquid needs to dispose further

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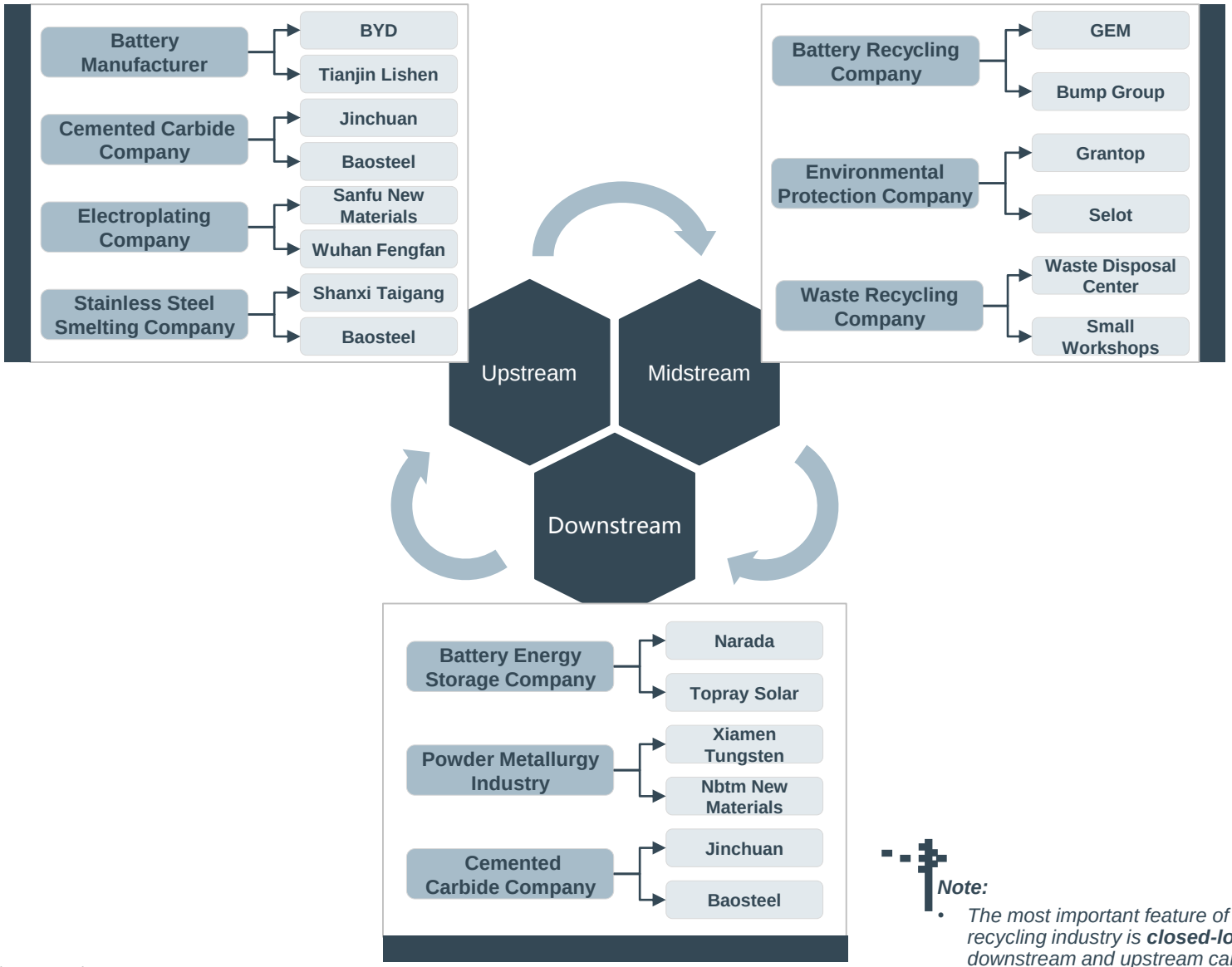
Industry Chain of Li-Ion Battery Recycling



Note:

- *The most important feature of battery recycling industry is **closed-loop chain and** downstream and upstream can interconvert*

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China Li-Ion Battery Recycling Market

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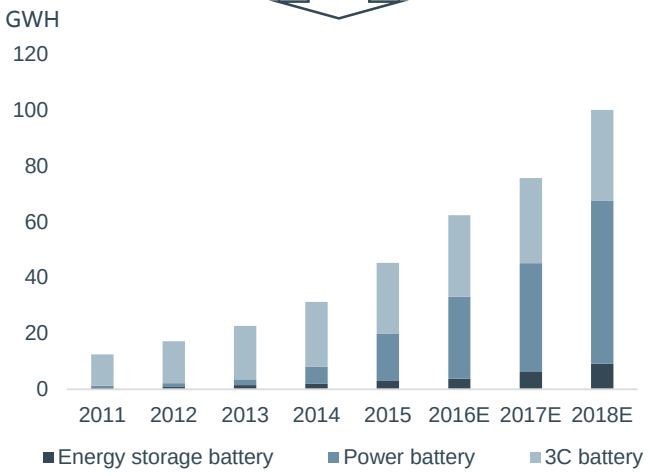
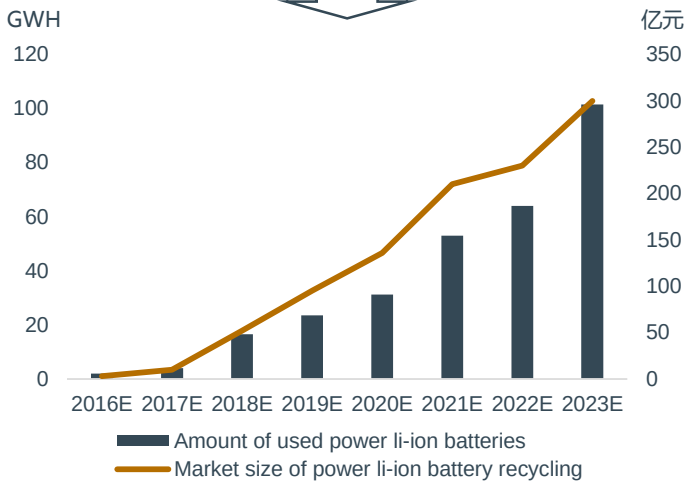
Demand Forecasting of Li-Ion Battery in China



Source: QD li-Ion Battery, SMM

- Three major application fields of li-ion battery: **Power battery, energy storage battery and 3C battery**
- Output of power Li-ion battery has **more than tripled** to 16.9GWH in 2015 in China on a yearly basis. The growth is much higher than other two kinds of batteries. Power Li-ion battery is expected to boom in the future
- **Service life of Li-ion battery is generally 3-5 years.** The amount of used li-ion batteries will be as large as demand of li-ion battery increases

Forecasting of Power Li-Ion Battery Recycling Market in China



Source: Sinolink Securities, SMM

- EV will develop rapidly **in the next 3-5 years**, so, the amount of used li-ion batteries **may boom in 2018**
- Economic scale of li-ion battery recycling market may **start booming to 5.2 billion yuan in 2018** and is expected to increase to 13.6 billion yuan in 2020 and may be over 30 billion in 2023

Note:

- *The booming amount of used li-ion batteries is expected to **creat a 10 billion-yuan li-ion battery recycling market***

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Li-Ion Battery Recycling: Cascade Utilization

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Cascade Utilization of Li-Ion Battery

- **Definition:** Life-ending li-ion battery ,which is used for EV, will be reused in other ways. And this also be called degrade utilization
- **Purpose:** To extend service life of li-ion battery and reduce using costs with maximum use, and reduce waste by direct elimination and reduce cost in other productions using old li-ion battery

Process

Problems

Cascade Utilization can maximize product value, but there remains many problems

Battery Teardown	Prediction of Left Power	System Integration Technology	Secondary Cost Control
• Different teardown process • A mass of manual operation	• Complex measurement rises costs	• It is unable to disassemble without damage • Disunity	• Costs of every process affect economic values

Application

Application Fields	Market Status	Development Trend
Electric Bicycle Market	Market is mature but also approaches to saturation, with **rising attention on cost effectiveness**	**To increase cost effectiveness**
Mini Electric Vehicle market	It develops rapidly and is close to market demand but regulatory gaps leads to **different product qualities**	**To promote product performance and guarantee range per charge**
Energy Storage market	It is pillar and cornerstone of Internet, but **high cost** is the urgent issue	**To expand energy storage application and to reduce costs**

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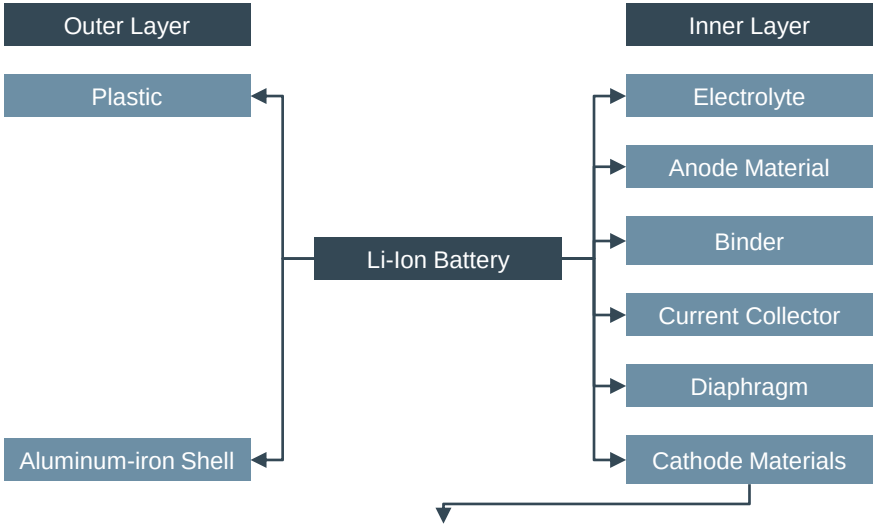
Li-Ion Battery Recycling: Metal Regeneration

- Used li-ion battery can be main source of revenue creating and cost reducing by appropriately recycling with clear characteristic of resources

Structure and Compositions of Li-Ion Battery



Metal Content in Ternary Material

	Lithium	Nickel	Cobalt	Manganese
Content (%)	10	27	22	19
Recovery Rate (%)	90-95	93-97	92—96	97
Price(1,000/t)	124.5	18	161	10.5

Source: Research Progress on Recycling Technology of Waste Lithium Ion Battery, SMM
Note: Electrolyte refers to lithium carbonate, nickel sulfate, cobaltosic oxide and manganese dioxide

- Li-ion battery composition is complex, and every part can be recycled through different techniques, including **metals and nonmetal**
- There are various recyclable metals in used Li-ion battery, among which economic value of cobalt and lithium is the highest. So, **cathode materials which contain lithium and cobalt are the mainly recycles**

Costs on Li-Ion Battery Recycling in 2016 (RMB/t)

Item	Content	Cost
Raw Material	Scrap Li-Ion Battery	9,000
Supporting Material	Acid-base Solution and Extraction Agent	3,000
Fuel Cost	Electricity and Natural Gas	750
Preprocessing Fee	Crashing and Sorting	500
Environmental Treatment Fee	Waste Liquid Discharge	350
	Slag and Ash	120
Labor Cost	Labor	500
Equipment Cost	Maintenance of Equipment	100
	Depreciation of Equipment	260
Total		14,580

Source: Sinolink Securities, SMM

Earnings Forecasting of Li-Ion Battery Recycling in 2016 (RMB/t)

	Ternary Battery	LFP Battery	Integration
Revenue	16,100	14,110	15,330
Cost	14,580	14,580	14,580
Gross Profit	1,520	-470	750
Gross Profit Rate	9.4%	-3.2%	4.9%

Source: SMM, Public data
Note: Integration refers to integration of recycling of LFP battery, LMO battery, LCO battery and ternary battery

- Raw material accounts for **62%** of total battery recycling costs and **8%** for treatment costs. It is available to **reduce costs by cutting treatment costs through technical promote** at present
- Different type of Li-ion batteries has various revenue of used battery recycling. **Gross profit rate of ternary battery recycling is 9.4% while LFP battery recycling may suffer losses**. So, most recycling companies prefer to recycle ternary batteries. In fact, recycling Li-ion battery contains various types of batteries with **comprehensive gross profit rate of 4.9%**

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Business Model of Li-Ion Battery Recycling

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Development of Business Model: **Traditional Recycling Model** → **Emerging Recycling Model**

Recycling Model	Small Workshops	Specialized Recycling Companies	Government	Battery Manufacturers	Industry Alliances	Third Party
Recycling Logistics Costs	High	Quite High	General	Quite High	General	High
Recycling Scale	Small	Quite Large	General	Small	Large	Quite Large
Economies of Scale	Lack	General	Lack	Lack	Obvious	General
Cooperators	-	EV Manufacturers and Battery Lessors	-	EV Manufacturers and Battery Lessors	Power Battery Manufacturers and EV Manufacturers Alliance	-
Recycling Products	Various Batteries	Various Batteries	Various Batteries	Own-Produced Power Batteries	Power Batteries Produced by Alliance	Various Batteries
Recycling Capacity	Low	Quite High	General	Quite High	High	General
Profits	20%-50%	0-8%	0-5%	5%	5-10%	5%
Operability	High	High	Quite High	High	Low	Quite High

Source: Public Data, SMM

Source: Sinolink Securities, SMM

- **Recycling profits of small workshops are generally higher** than that of other recycling companies, which is largely due to **tax evasion**. What matters more is that those small workshops dispose batteries recycled **simply and roughly**, leading to **potential accident and environmental pollution**

Note:

- *Chinese Li-ion battery recycling industry is under period of **transition** from traditional model to new model, and **those two models will coexist for some time***
- *New recycling model is based on **multi-level corporation**, and it is difficult to operate in early time. But this will **benefit to building power battery recycling system**, which is **development direction of Chinese battery recycling industry***

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Relevant Policies

Level	Type	Time	Document	Content
National Policy	Development Program	2012	*Energy-Saving and EV Industry Development Program (2012-2022)*	Clarify management policies on power battery recycling and encourage specialized battery recycling
	Guiding Opinions	2014	*Guiding Opinions of the General office of the State Council on Popularization and Application of EV*	It suggests to study how to develop power battery recycling policy and to **build a sound recycling system**
	Industry Standard	2015 2016	*Standard Condition for the Automobile Power Storage Battery Industry* *Industry Standard Condition for the Comprehensive Utilization of Waste Power Storage Batteries of EV*	It suggests that recycling companies should study on battery recycling treatment with EV manufacturers. **Confirming the subject of responsibility** and enhance industry management and regulation
	Technology Policy	2015 2016	*Technology Policy on Power Battery Recycling for Electric Vehicles (2015)* *Technology Policy on Prevention Used Battery Pollution (Exposure Draft)*	Clarify the establishment of power battery code, **to build traceability system** **It needs qualifications to recycle Li-ion battery** and encourage recycling companies to research and develop recycling techniques

Level	Cities	Time	Document	Content
Local Policy	Shanghai	2014	*Interim Measures for Encouragement of Buying and Using EV in Shanghai*	Require EV manufacturers to recycle power batteries, who will **enjoin subsidy of 1,000 yuan per set**
	Guangzhou	2014	*Notice of General office of Guangzhou Government on Issuing Interim Measures for Administration of Popularization and Application of EV in Guangzhou*	To build recycling channels for automobile power battery recycling and recycling companies should recycle batteries as required
	Shenzhen	2016	*Subsidy Policy on Popularization and Application of EV in Shenzhen (2016)*	EV manufacturers have to make a specialized provision for recycling batteries with **20 yuan per KWH**, and local government will provide subsidy, which will **not be above 50% of the provision**

Note:

- Clarify "**Extended Producer Responsibility System**", EV manufacturers are the subject of responsibility for power battery recycling
- local relative **subsidy policies is expected to be issued**

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Problems & Bottlenecks

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Difficulty in estimation of used battery quality and standardization of cascade utilization, which will lead to large losses and **high costs**

Various types of used batteries, **part of which are recycled with low economic value**, and limited used ternary batteries

Small workshops will not eradicate in a short term. New recycle model **needs a long time to build and operate**

China's used battery recycling policy framework is almost finished but it is difficult to promote and **relative subsidy policies remain to be implemented**

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Battery Recycling Market Development at Home and Abroad

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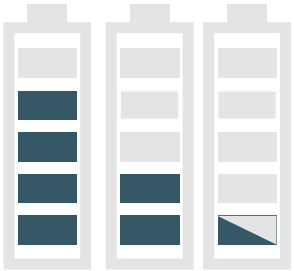

Battery Recycling Market

Used battery recycling market is a market for battery recycling through recyclers **(to bury, destroy or recycle)**, according to laws, with participants of **governments, management institution, consumers and various enterprises**.

	Law & Policy	Dominant Institution	Recycling Method
America	*Resource Conservation and Recovery Act, Mercury Containing Battery Management Act etc.*	RBRC, PRBA	Deposit system, environmental fees, to build battery recycling system and implement Extended Producer Responsibility System
German	*EU Waste Framework Directive, EU Battery Directive, etc.*	Government, The Common Battery Collection and Recycling System	To compel to recycle, deposit system, funding system and build battery recycling system
Japan	*Basic Law for Promoting the Creation of a Recycling-Oriented Society, Solid Waste and Public Cleansing Management Act, etc*	Battery manufacturers、The PC 3R Promotion Association	Voluntary-based and build battery recycling system “Battery Manufacture – Sales – Collecting - Recycling”
China	*Energy-Saving and EV Industry **Development Program** (2012-2022), **Industry Standard Condition** for the Comprehensive Utilization of Waste Power Storage Batteries of EV*	Central Government Sets Laws and local Government Promote Implementation	To confirm subject of responsibility of used battery recycling and it needs Hazardous Wastes Qualification for Li-ion battery recycling

Note:

- *Battery recycling laws are complete in developed countries while **that in China remains to be improved***
- *Autonomy of battery recycling is high at abroad, supported by institutions, with clear recycling method and normalization of operation. However, battery recycling system **is government-dominated in China without** any supporting institutions, clear recycling method and **sound recycling system***

Note: RBRC refers to The Rechargeable Battery Recycling Corporation; PBRA refers to The Portable Rechargeable Battery Association

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Pilot Projects of Cascade Utilization of Power Battery at Home and Abroad

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Country	Subject	Time	Project Description	Participants
Germany	Power Grid Energy Storage	2015	Robert Bosch builds a large photovoltaic plant energy storage system, with 2MW/2MWh, through used power batteries from BMW's vehicles, including ActiveE and i3 BEV	Robert Bosch, BMW, Vattenfall
Germany	Power Grid Energy Storage	2010	Cascade utilization of EV batteries project is supported by German Energy and Climate Research Institutions and establish an energy storage application demonstration project in Germany	TUV Sud
Japan	Household and Commercial Energy Storage	2010	Selling and leasing secondary battery from Leaf for household and commercial energy storage devices in Japan and US	4R Energy
US	Distributed Generation and Micro-Grid	2010	NREL indicated that used battery can be used in wind power generation, photovoltaic cell and independent power supply in remote areas after studying on Li-ion battery recycling from PHEV and BEV	US National Renewable Energy Laboratory (NREL)
US/Sweden	Smart Grid	2010	Studying on vehicle Li-ion battery recycling, including smart grid, which is used for energy storage from solar cell system and wind power generation	US General Motors, Sweden ABB
China	Power Grid Energy Storage	2013	Building pilot project of power battery energy storage in August, 2014, which is the first micro-grid based on used power battery in China	State Grid of Henan, NARI Group
China	LSEV/Power Grid Energy Storage	2013	Refitting used power batteries from electric tracks, forklift and power substation system. Used battery is better than traditional lead-acid battery with higher economic value through measuring	State Grid of Beijing, Beijing University of Technology and Pride
China	Li-Ion Battery Recycling	2012	Recycling technology of Wanxiang Group and a production line of used power battery recycling can recycle Li-ion battery of 20 t per year without damage	Wanxiang Group
China	Commercial Energy Storage	2012	A two-year pilot project of 100KWh-energy storage system through cascade utilization was accepted on June 19, 2014	CEPRI, State Grid of Beijing and Beijing Jiaotong University

Source: Public data, SMM

Note:

- *Both foreign countries and China pay great attention to cascade utilization but **foreign countries start the study earlier***
- *Cascade utilization is small-scale in China, and most are under R&D, **which cannot enter into commercial operation yet***

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GEM, The Pioneer of the Used-Battery Recovery in China

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Basic Information

- **Headquarter:** Baoan New Central Zone, Shenzhen
- **Market Value:** 20 billion yuan
- **Cooperators:** BYD, Xian Sanxing Huanxin Motive Battery Co., local governments in Hubei, ECORPO, Samsung SDI, Remondis

Main Business

- Utilization of used Li-ion battery (energy storage) - Used Li-ion battery disposal - Cobalt, nickel and copper recycling - Oxide from precursor of Li-ion battery cathode - **Cathode material, complete recycling system of Li-ion battery**
- E-waste - Metal extraction (copper, nickel, aluminum and gold) - Rare earth extraction - ITO and phosphor - Recycled glass optically - Waste plastic regenerative pelletizer - **Complete industry chain of WPC and E-waste**
- Disposal of waste liquid and sludge – Bury - Disposal of heavy metals and hazardous liquid wastes – Bury - Sanitation outsourced - Recycling project - **PPP Project, complete recycling model with garbage classification and reduction at the beginning**

Industry Distribution

- **Li-Ion Battery Materials Industry Chain:** The company launched a 5,000-tonnes production of NCA precursor, 10,000-tonnes NCM ternary cathode materials and NCM ternary precursor, based on 5,000-tonnes NCM precursor capacity
- **Used Vehicle Teardown:** Completing 8 core recycling production line for used vehicle parts and cooperate with BYD to build new energy industry and recycling chain through material redesign-battery recycling-EV production-power battery recycling. The three large teardown bases for used vehicles are developing

Waste Recycling Model

- **Urban Mining Recycling:** Installing over 10,000 recycling boxes in over 100 cities and building Wuhan Mode through paid payment and Pearl River Delta mode in primary and second schools
- **Industrial Recycling:** Building cooperation between downstream and upstream and build a directional-flow-resource and specialize recycling system by signing contracts with enterprises, who produced large amount of wastes
- **Recycling Terminal Market based on Internet of Things**: To set a terminal market, 7 specialized sorting market, and build a system of large recycling terminal market, trading, information and logistics

Note:

- *GEM has developed a core business, including **recycling of waste nickel-tungsten-cobalt, e-waste, used power battery** and will further develop **Li-ion battery material industry chain and scrap vehicle teardown***
- *GEM creates several recycling models, including **Urban Mining Recycling, Industrial Recycling, and Recycling Terminal Market based on "Internet of Things"***

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Industry Opportunity Exploring & Investment Focus

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Battery Recycling Companies

1 Battery recycling company

- **Used battery recycling will gain certain profits** for high economic value metals containing. However, recycling technique, policy implementation and development **model remain to be improved in China**

2 Company integration of battery producing and recycling

- To maximize utilization of resource through integration of battery producing and recycling, and **maximize profits through cutting costs**
- Integration of battery producing and recycling is not only for **two businesses in a company** but also for win-win corporations like **alliance** among companies

Power Institutions

1 Electricity generation Company

- Wind power and photovoltaic generation, using renewable resources to generate, have high demand for energy storage. Those companies can **cut energy storage costs** though cascade utilization of used power Li-ion battery

2 Electricity sales company

- Electricity sales company can **reduce energy storage costs and enhance competitiveness** through cascade utilization of used power Li-ion battery

Key Companies to Focus:

- **GEM: Specialized used battery recycling company**, the first listed recycling company in China, enjoying the largest production line for used battery disposal and three large teardown bases for scrap vehicles, who has incomparable advantages both in technology and waste resources
- **Ningbo Shanshan: Involves in power battery recycling and cascade utilization actively**, and enjoys economic revenues from battery recycling initially, and steps up study on construction of pilot base of battery cascade utilization
- **BYD: One of global leading secondary rechargeable battery producers,** and one of global competitive mobile parts and assembly enterprise, with significant advantage in battery producer. The company cooperate with GEM to recycle used battery through new model to reduce costs and enhance profits after determining of Extended Producer Responsibility System
- **Chaowei Power: To develop intelligent battery recycling system "IDBMS", with 100% of recovery rate,** and introduced Standard Mode under per Kilowatt-Hour, increasing recovery rate
- **Narada:** Revenue increases significantly in 2016 **with closed cycle of battery manufacture, energy storage station and recycling.** The leading enterprises in energy storage industry, who also involves in Pb-C and Li-ion battery

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