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

Nov. 2016
## The Following Terms are Used in This Report

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-ion battery</td>
<td>Lithium-ion battery</td>
</tr>
<tr>
<td>Zn-Mn Battery</td>
<td>Zinc-manganese battery</td>
</tr>
<tr>
<td>Ni-MH Battery</td>
<td>Nickel–metal hydride battery</td>
</tr>
<tr>
<td>Ni-Cd Battery</td>
<td>Nickel-cadmium battery</td>
</tr>
<tr>
<td>LFP Battery</td>
<td>Lithium iron phosphate battery</td>
</tr>
<tr>
<td>LMO battery</td>
<td>Lithium manganese oxide battery</td>
</tr>
<tr>
<td>LCO battery</td>
<td>Lithium cobalt oxide battery</td>
</tr>
<tr>
<td>LSEV</td>
<td>Low-speed electric vehicle</td>
</tr>
<tr>
<td>EV</td>
<td>Electric vehicles</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery electric vehicle</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in hybrid electric vehicle</td>
</tr>
<tr>
<td>PPP project</td>
<td>Public–Private–Partnership</td>
</tr>
<tr>
<td>NCM</td>
<td>Lithium nickel manganese cobalt oxide</td>
</tr>
<tr>
<td>NCA</td>
<td>Lithium nickel cobalt aluminum oxide</td>
</tr>
</tbody>
</table>
Honda Plans to Build Battery Recycling Network, to Solve Resources Wasting

Jun. 28, 2016

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.

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

Aug. 29, 2016

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.

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

Sep. 26, 2016

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.
Abstracts

1. **Li-ion battery recycling industry chain is closed-loop, with high economic value**
   - Used battery is divided into primary battery and secondary battery, which will pollute the 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
1. Used Battery

- Primary Battery
  - Zinc-Manganese Battery
    - Ordinary Zn-Mn Battery
    - Alkaline Zn-Mn Battery
  - Mercury Battery
    - Production Prohibition
    - Obsolete Product

- Secondary Battery
  - Rechargeable Battery
    - Ni-MH Battery
    - Ni-Cd Battery
    - Li-Ion Battery
  - Wet-Charged Battery
    - Lead-Acid Battery
    - Lead carbon 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
Used Battery Disposal

### 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

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**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.
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 dissolve crushing 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

Battery Manufacturer
- BYD
- Tianjin Lishen
- Jinchuan
- Baosteel
- Sanfu New Materials
- Wuhan Fengfan
- Shanxi Taigang
- Baosteel

Cemented Carbide Company

Electroplating Company

Stainless Steel Smelting Company

Battery Recycling Company
- GEM
- Bump Group
- Grantop
- Selot
- Waste Disposal Center
- Small Workshops

Environmental Protection Company

Waste Recycling Company

Battery Energy Storage Company
- Narada
- Topray Solar
- Xiamen Tungsten
- Nbtm New Materials
- Jinchuan

Powder Metallurgy Industry

Cemented Carbide Company

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

Demand Forecasting of Li-Ion Battery in China

- 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

- **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 **create a 10 billion-yuan li-ion battery recycling market**

Source: SMM
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.

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### Process

```
Used Li-Ion Battery -> Battery Pack Recycle
<table>
<thead>
<tr>
<th></th>
<th>Cascade Utilization Market</th>
<th>Battery Pack Scrap</th>
</tr>
</thead>
</table>
```

---

### Problems

- **Battery Teardown**
  - Different teardown process
  - A mass of manual operation

- **Prediction of Left Power**
  - Complex measurement rises costs

- **System Integration Technology**
  - It is unable to disassemble without damage
  - Disunity

- **Secondary Cost Control**
  - Costs of every process affect economic values

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### Application

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

**Outer Layer**
- Plastic

**Inner Layer**
- Electrolyte
- Anode Material
- Binder
- Current Collector
- Diaphragm
- Cathode Materials

Li-Ion Battery

Metal Content in Ternary Material

<table>
<thead>
<tr>
<th></th>
<th>Lithium</th>
<th>Nickel</th>
<th>Cobalt</th>
<th>Manganese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>10</td>
<td>27</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Recovery Rate (%)</td>
<td>90-95</td>
<td>93-97</td>
<td>92-96</td>
<td>97</td>
</tr>
<tr>
<td>Price(1,000/t)</td>
<td>124.5</td>
<td>18</td>
<td>161</td>
<td>10.5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material</td>
<td>Scrap Li-Ion Battery</td>
<td>9,000</td>
</tr>
<tr>
<td>Supporting Material</td>
<td>Acid-base Solution and Extraction Agent</td>
<td>3,000</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>Electricity and Natural Gas</td>
<td>750</td>
</tr>
<tr>
<td>Preprocessing Fee</td>
<td>Crashing and Sorting</td>
<td>500</td>
</tr>
<tr>
<td>Environmental Treatment Fee</td>
<td>Waste Liquid Discharge</td>
<td>350</td>
</tr>
<tr>
<td>Labor Cost</td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Equipment Cost</td>
<td>Maintenance of Equipment</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Depreciation of Equipment</td>
<td>260</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>14,580</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Ternary Battery</th>
<th>LFP Battery</th>
<th>Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenue</strong></td>
<td>16,100</td>
<td>14,110</td>
<td>15,330</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>14,580</td>
<td>14,580</td>
<td>14,580</td>
</tr>
<tr>
<td><strong>Gross Profit</strong></td>
<td>1,520</td>
<td>-470</td>
<td>750</td>
</tr>
<tr>
<td><strong>Gross Profit Rate</strong></td>
<td>9.4%</td>
<td>-3.2%</td>
<td>4.9%</td>
</tr>
</tbody>
</table>

- 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%

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

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## Business Model of Li-Ion Battery Recycling

### Development of Business Model

<table>
<thead>
<tr>
<th>Recycling Model</th>
<th>Recycling Logistics Costs</th>
<th>Recycling Scale</th>
<th>Economies of Scale</th>
<th>Cooperators</th>
<th>Recycling Products</th>
<th>Recycling Capacity</th>
<th>Profits</th>
<th>Operability</th>
</tr>
</thead>
</table>

### Traditional Recycling Model

<table>
<thead>
<tr>
<th>Small Workshops</th>
<th>Specialized Recycling Companies</th>
<th>Government</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Quite High</td>
<td>General</td>
</tr>
<tr>
<td>Small</td>
<td>Quite Large</td>
<td>General</td>
</tr>
<tr>
<td>Lack</td>
<td>General</td>
<td>Lack</td>
</tr>
</tbody>
</table>

- - EV Manufacturers and Battery Lessors
- Various Batteries
- Various Batteries
- Various Batteries

- 20%-50%
- 0-8%
- 0-5%

### Emerging Recycling Model

<table>
<thead>
<tr>
<th>Battery Manufacturers</th>
<th>Industry Alliances</th>
<th>Third Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quite High</td>
<td>General</td>
<td>High</td>
</tr>
<tr>
<td>Small</td>
<td>Large</td>
<td>Quite Large</td>
</tr>
<tr>
<td>Lack</td>
<td>Obvious</td>
<td>General</td>
</tr>
</tbody>
</table>

- EV Manufacturers and Battery Lessors
- Own-Produced Power Batteries
- Power Batteries Produced by Alliance

- 5%
- 5-10%
- 5%

<table>
<thead>
<tr>
<th>Profits</th>
<th>Operability</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Low</td>
<td>Quite High</td>
</tr>
</tbody>
</table>

### Note:
- 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.
- 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.
### Relevant Policies

<table>
<thead>
<tr>
<th>Level</th>
<th>Type</th>
<th>Time</th>
<th>Document</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Policy</td>
<td>Development Program</td>
<td>2012</td>
<td>Energy-Saving and EV Industry Development Program (2012-2022)</td>
<td>Clarify management policies on power battery recycling and encourage specialized battery recycling</td>
</tr>
<tr>
<td></td>
<td>Guiding Opinions</td>
<td>2014</td>
<td>Guiding Opinions of the General office of the State Council on Popularization and Application of EV</td>
<td>It suggests to study how to develop power battery recycling policy and to build a sound recycling system</td>
</tr>
<tr>
<td></td>
<td>Industry Standard</td>
<td>2015</td>
<td>Standard Condition for the Automobile Power Storage Battery Industry</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2016</td>
<td>Industry Standard Condition for the Comprehensive Utilization of Waste Power Storage Batteries of EV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2016</td>
<td>Technology Policy on Prevention Used Battery Pollution (Exposure Draft)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>Cities</th>
<th>Time</th>
<th>Document</th>
<th>Content</th>
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<tbody>
<tr>
<td>Local Policy</td>
<td>Shanghai</td>
<td>2014</td>
<td>Interim Measures for Encouragement of Buying and Using EV in Shanghai</td>
<td>Require EV manufacturers to recycle power batteries, who will enjoin subsidy of 1,000 yuan per set</td>
</tr>
<tr>
<td></td>
<td>Guangzhou</td>
<td>2014</td>
<td>Notice of General office of Guangzhou Government on Issuing Interim Measures for Administration of Popularization and Application of EV in Guangzhou</td>
<td>To build recycling channels for automobile power battery recycling and recycling companies should recycle batteries as required</td>
</tr>
<tr>
<td></td>
<td>Shenzhen</td>
<td>2016</td>
<td>Subsidy Policy on Popularization and Application of EV in Shenzhen (2016)</td>
<td>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</td>
</tr>
</tbody>
</table>

**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**
Problems & Bottlenecks

Great Difficulty in Cascade Utilization

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

Low Profits

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

Take Long for Pattern Transition

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

Difficulty in Policy Promotion

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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<thead>
<tr>
<th>Law &amp; Policy</th>
<th>Dominant Institution</th>
<th>Recycling Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>America</td>
<td>Resource Conservation and Recovery Act, Mercury Containing Battery Management Act etc.</td>
<td>RBRC, PRBA</td>
</tr>
<tr>
<td>German</td>
<td>EU Waste Framework Directive, EU Battery Directive, etc.</td>
<td>Government, The Common Battery Collection and Recycling System</td>
</tr>
<tr>
<td>Japan</td>
<td>Basic Law for Promoting the Creation of a Recycling-Oriented Society, Solid Waste and Public Cleansing Management Act, etc</td>
<td>Battery manufacturers, The PC 3R Promotion Association</td>
</tr>
<tr>
<td>China</td>
<td>Energy-Saving and EV Industry Development Program (2012-2022), Industry Standard Condition for the Comprehensive Utilization of Waste Power Storage Batteries of EV</td>
<td>Central Government Sets Laws and local Government Promote Implementation</td>
</tr>
</tbody>
</table>

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

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.

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Subject</th>
<th>Time</th>
<th>Project Description</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Power Grid Energy Storage</td>
<td>2015</td>
<td>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. 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</td>
<td>Robert Bosch, BMW, Vattenfall</td>
</tr>
<tr>
<td>Germany</td>
<td>Power Grid Energy Storage</td>
<td>2010</td>
<td>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</td>
<td>TUV Sud</td>
</tr>
<tr>
<td>Japan</td>
<td>Household and Commercial Energy Storage</td>
<td>2010</td>
<td>Selling and leasing secondary battery from Leaf for household and commercial energy storage devices in Japan and US</td>
<td>4R Energy</td>
</tr>
<tr>
<td>US</td>
<td>Distributed Generation and Micro-Grid</td>
<td>2010</td>
<td>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. Studying on vehicle Li-ion battery recycling, including smart grid, which is used for energy storage from solar cell system and wind power generation</td>
<td>US National Renewable Energy Laboratory (NREL)</td>
</tr>
<tr>
<td>US/Sweden</td>
<td>Smart Grid</td>
<td>2010</td>
<td>Studying on vehicle Li-ion battery recycling, including smart grid, which is used for energy storage from solar cell system and wind power generation</td>
<td>US General Motors, Sweden ABB</td>
</tr>
<tr>
<td>China</td>
<td>Power Grid Energy Storage</td>
<td>2013</td>
<td>Building pilot project of power battery energy storage in August, 2014, which is the first micro-grid based on used power battery in China</td>
<td>State Grid of Henan, NARI Group</td>
</tr>
<tr>
<td>China</td>
<td>LSEV/Power Grid Energy Storage</td>
<td>2013</td>
<td>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.</td>
<td>State Grid of Beijing, Beijing University of Technology and Pride</td>
</tr>
<tr>
<td>China</td>
<td>Li-Ion Battery Recycling</td>
<td>2012</td>
<td>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</td>
<td>Wanxiang Group</td>
</tr>
<tr>
<td>China</td>
<td>Commercial Energy Storage</td>
<td>2012</td>
<td>A two-year pilot project of 100KWh-energy storage system through cascade utilization was accepted on June 19, 2014</td>
<td>CEPRI, State Grid of Beijing and Beijing Jiaotong University</td>
</tr>
</tbody>
</table>

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

**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”
Contents

1. Used Battery Recycling Industry  
2. Market Analysis of Li-Ion Battery Recycling  
3. Market Development at Home and Abroad  
4. Industry Opportunity Exploring
# Industry Opportunity Exploring & Investment Focus

## 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.

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### 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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