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China Lithium Industry
Deloitte POV 3.0: Sustainable Future of Lithium Recycle

Deloitte Consulting China | November, 2022

Key Takeaways

With the rapid growth of global new energy vehicle industry, the upstream resource constraint has become one of the burning issues. While various countries continue to perfect the EV battery recycling policy system under the carbon neutral requirements, the EV battery recycling industry has been flourishing, and the upcoming battery retirement tide will further drive the development of the EV battery recycling industry. The EV battery recycling market is promising in technology development, business model, and industry chain synergy, but there are still many key challenges.

From the **technology development** perspective, the process and technical route of EV battery recycling is relatively clear. **Based on actual business expectations, direct recycle will dominate the recovery method in the medium- to long-term**:

- The two main ways of EV battery recycling are **reuse and direct recycle**. The large-scale development of reuse faces enormous challenges due to safety issues, insufficient market regulation, the impact of vicious competition, and the lack of industry standards. In the medium- to long-term, **recycle with relatively mature technologies and commercial applications is expected to be the dominant approach**
- In the material recovery process, **pyro- and hydro-metallurgy are the mainstream battery-grade raw material purification and regeneration techniques, which has high technical and scale barriers**, while creating higher economic benefits, leading companies need to address the supply stability of front-end battery recycling channels and actively layout raw material recycling capacity to achieve higher commercial value

From the **business model** perspective, **third-party and battery manufacturer recycling** have been well-practiced. **The construction of recycling networks and closed-loop regeneration** are essential success factors:

- **The market mechanism is the main challenge for the current development of the EV battery recycling industry**. It forces the leading recycler enterprises to enhance their scale and break through the profitability bottleneck
- Third-party recycling companies have **the advantage of recycling technology**, while battery manufacturers and automotive OEMs gained **the advantage of recycling and resale channels**; in the current EV battery recycling market, the key to successful business models lies in **the construction of recycling channel networks and a closed-loop ecology for recycling materials for reuse**

From the **industry chain synergy** perspective, the multiple sectors of the Li-battery and NEV industry chain have shown the trend of **extending to battery recycling** in different forms and degrees:

- Upstream lithium and new energy vehicle industry technology and market trends, such as battery material innovation, integration technology, battery banks, etc., bring impact to the power battery recycling industry, and opportunities and challenges coexist
- **An industry alliance** of upstream and downstream enterprises in the industry chain **may be an ideal model for the recycling industry**, as each member enterprise can complement each other's strengths and weaknesses for mutual benefits. However, due to the long industry chain and many stakeholders involved, the model is still in **the exploration stage of actual commercial operation**

Deloitte Observations and POV

Trend of EV Battery Recycle Development

01 Industry overview and prospects of EV battery recycle

02 Value chain analysis of EV battery recycle

03 Market challenges and business implications

Industry overview and prospects of EV battery recycle

The Imperative EV Battery Recycling: Alleviation to The Constraint of Upstream Resources

The scarcity of upstream resources is a long-term constraint to the development of downstream application market. The lithium resource supply and demand gap is expected to emerge and expand gradually after 2025, reaching 145 tonnes of lithium carbonate equivalent in 2030. EV battery recycling will alleviate the constraints of resource supply and demand imbalance on industry development to a certain extent.

Supply: resource pressure

Resource shortage in China

High-quality mineral resources are relatively scarce in China. There are few high-quality hard rock lithium mines, and the technology and production capacity of lithium extraction from salt-lake brine require breakthroughs.

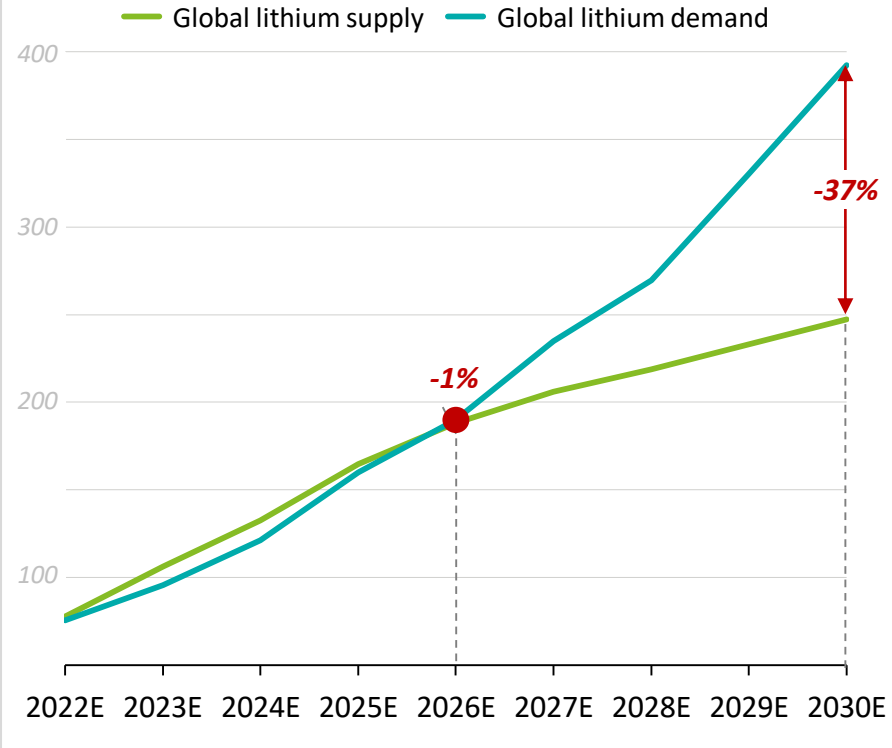
Uncertainty of international supply

The supply of global raw materials is concentrated, and the production fluctuates wildly. Emergencies such as the epidemic outbreak and the Russian-Ukrainian conflict have exacerbated the uncertainty of the global supply chain.

Long capacity development cycle

The development cycle of raw materials and minerals is relatively long. The resource production expansion cycle is about four times that of the EV batteries expansion cycle, thus leading to the mismatch between supply and demand.

Global lithium resource supply and demand projection (Ten thousand tonnes/LCE)



Demand: surging EV market

Strong application demand

The EV market, as the main application scenario of lithium resources, has entered a period of rapid growth, and the sales volume of EVs in China increased by more than 150% year-on-year in 2021.

Difficulty in alternative R&D

The R&D of EV batteries with different chemicals is challenging. In the long run, Li-batteries, which have a relatively fixed demand for mineral resources, will still be the mainstay, and it is hard to find an alternative solution in the short term.

Intensive competition

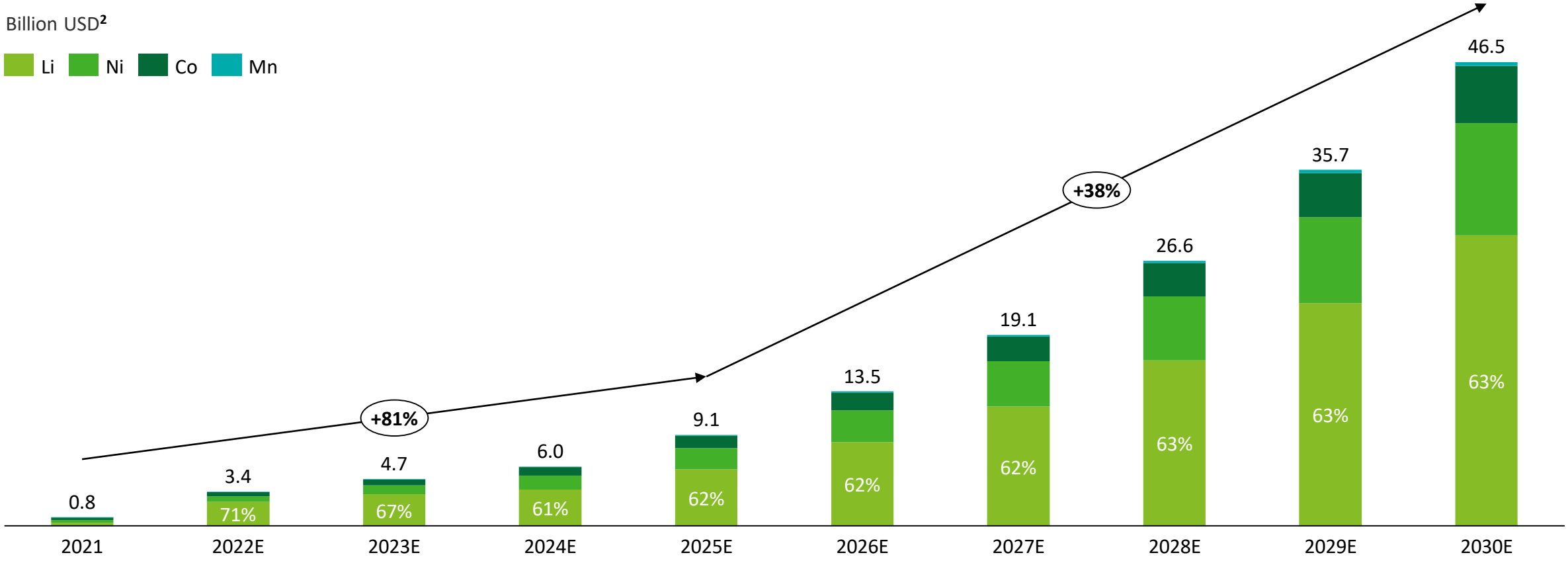
Battery companies maintain a rapid pace of expansion to seize market share and drive the demand for upstream resources, amid the increasingly fierce competition in the EV battery industry.

Source: CAAM, Minmetals Securities, public information, Deloitte analysis

Global EV Battery Recycling Market Size Prospects

The development of the global EV battery recycling market is about to accelerate, which is expected to exceed 10 billion dollars in the next five years, among which the recycling market of the lithium is the most considerable

Global EV battery recycling market size projection[1]



Source: Anson Securities, Wind, public information, Deloitte analysis

Remarks: 1. Estimate based on the theoretical recyclable quantity and price of lithium, nickel, cobalt and manganese; 2. Converted at the annual average exchange rate of USD to RMB in 2021 (1USD = 6.45RMB)

EV Battery Recycling Market Drivers - Macro Policy Guidance

After years of development, battery recycling policies and legislation in developed countries are complete with stricter requirements; China has significantly accelerated the introduction of battery recycling policies over the past decade, aiming to promote and ensure the construction of recycling systems and guide the standardized and integrated development of the industry

Policy and legislative systems in developed countries started early and are relatively mature

China's policy guidance has been strengthened in recent years

North America

Complete federal, state and local battery recycling regulations

The U.S. DOE 2021

Enables the end-of-life reuse of lithium-ion batteries and recycling of critical materials at scale, plan the construction of **a full competitive value chain** in the United States, and **promote the development of cost-effective recycling technology**

National Blueprint for Lithium Batteries 2021-2030

The U.S. EPA 1996

Creates the framework for the proper management of hazardous and non-hazardous solid waste, including rechargeable batteries, lithium-ion car batteries, etc.

The Resource Conservation and Recovery Act

The U.S. State Governments

Makes regulations for the types of waste recycling, disposal methods, cost, etc. to **encourage** all parties in the industry chain to collaborate to help **properly recycle batteries**

Europe

Enhanced requirements and strengthen regulatory systems

EU 2022

The proposed battery regulations set increased targets related to power battery recycling, with stricter requirements for **battery recycling measures and battery metal material recovery rates**

New EU Regulatory Framework for Batteries

Switzerland 2022

Guide to Waste issued by the Federal Office for Environmental clarify rules for recycling lithium batteries for vehicles and encourage automotive OEMs to implement environmentally sound disposal system

FOEN *Guide to Waste*

Germany 2021

Regulatory agencies (Stiftung EAR) have the responsibility to regulate the battery manufacturing market and to check the collection and recycling efficiency of each recycling system and report market participation

BattG2

Japan & South Korea

Regulate the industry from the legislative level

South Korean's Parliament 2021

Ease regulation for mandatory battery recycling of previously registered vehicles and allow for environmental-friendly utilize of end-of-life batteries **to improve the secondary utilization rate of power batteries**

Clean Air Conservation Act

The Ministries of Japan 2004

The Japan Portable Rechargeable Battery Recycling Center (JBRC), jointly authorized by Japan's two central ministries, aims **to promote the comprehensive recycling of used rechargeable battery materials**

Diet of Japan 2001

Manufacturing enterprises should fulfill the responsibility of recycling the used products, follow the 3R principle, and **encourage that end-users send end-of-life batteries to special recycling sites**

The Law for Promotion of Effective Utilization of Resources in Japan

China

Gradually improve the establishment of the policy system to strengthen the regulation and policy implementation

MIIT and other two 2022

To develop and introduce new energy vehicle power battery **recycling management methods** and related departmental rules

Implementation Plan for Industrial Carbon Dioxide Peaking

MIIT and other seven 2022

To promote **upstream and downstream cooperation in the industry chain** to build recycling channels

Accelerating the Promotion of Comprehensive Utilization of Industrial Resources

NEA 2021

Request for establishing the **battery consistency management**, and make requirements for the evaluation, monitoring and supervision of energy storage projects **for secondary use**

The Management Standards for New Energy Storage Projects (Provisional)

MIIT 2020

To promote the NEV power battery recycling **system development**, and to establish a number of exemplary enterprises for the secondary use and recycling of waste power batteries

Key Points of Energy Conservation and Comprehensive Utilization in Industry in 2020

MIIT and other six 2018

Implementation of **the extended producer responsibility system**, clarify the primary responsibility fulfillers of battery recycling

Interim Measures for the Management of Recovery and Utilization of New Energy Vehicle Power Battery

MIIT 2018

Establish a "**comprehensive management platform for traceability**" to collect information on the whole process from production to recycling of power batteries

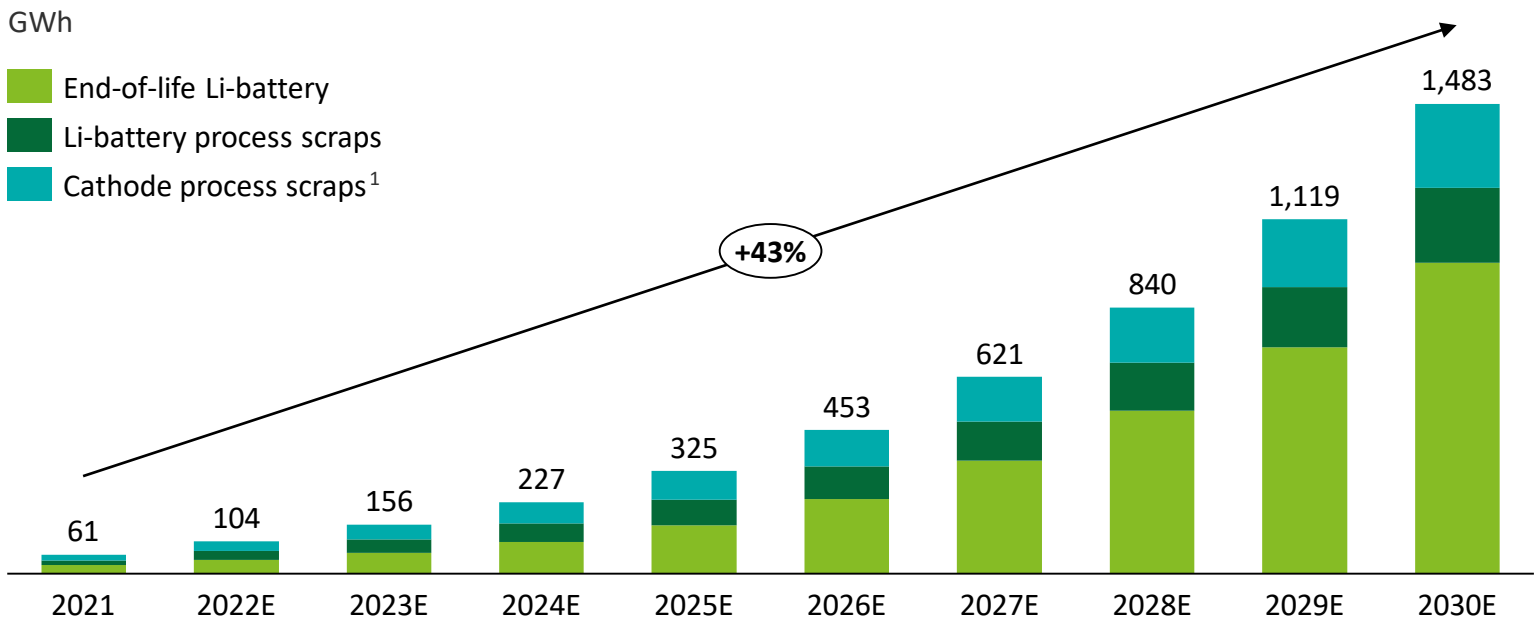
Interim Provisions on the Management of Traceability of New Energy Vehicle Power Battery Recycling

Source: government website, Everbright Securities, public information, Deloitte analysis

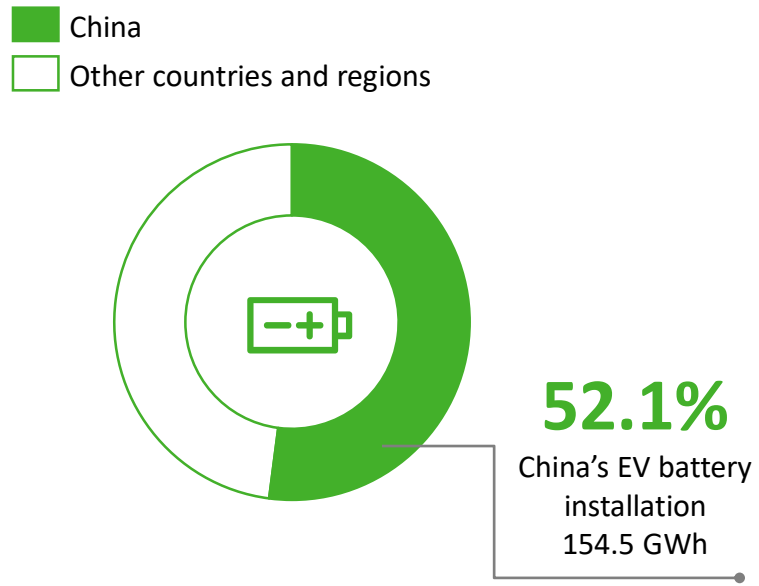
Driving Factor of Battery Recycling Market: The Upcoming Trend of EV Battery Retirement

The retirement tide of EV batteries has promoted the gradual release of recyclable battery waste and driven the development of the global lithium recycling market, with the volume of end-of-life batteries and process scraps rising at a CAGR of 43% over the next decade; The Chinese market, which leads the global EV market, is also expected to usher in considerable growth in the field of Li-battery recycling

The projection of global recyclable end-of-life Li-batteries and battery production scraps



Global EV battery installation shares in 2021



- With the vigorous development of the global EV market, the installed capacity of EV batteries has risen rapidly. The service life of EV batteries is about 5-8 years. Therefore, the first batch of batteries put into the market has ushered in a "retirement tide", especially in the Chinese market, where the production output and sales of EVs and EV batteries have soared since 2015.
- End-of-life batteries are the primary "raw materials" for EV battery recycling. The advent of the EV battery retirement tide will continue to provide recyclable waste for the Li-battery recycling.

Source: SNE Research, China Automotive Battery Innovation Alliance, Wind, Anson Securities, public information, Deloitte analysis

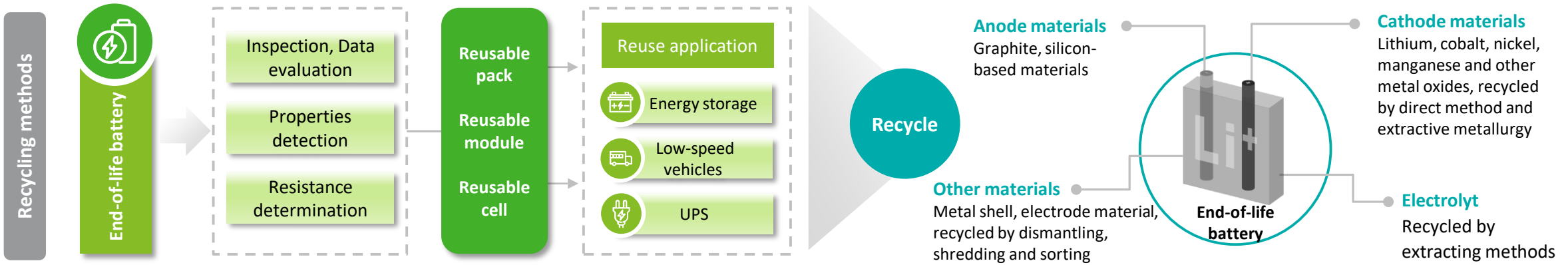
Remarks: 1. Converted to the amount of EV batteries that can be produced

Recycling Methods of EV Battery

Reuse and direct recycle are the most generally acceptable and environmentally friendly methods of batteries disposal. Large-scale applications of EV battery reuse is challenging, and EV battery recycling might be dominated by direct recycle in the medium and long term

Reuse: utilization of the residual capacity of battery

Recycle: recovery of metal materials and other resources



Pros

+ **Increase value:** optimize the utilization of batteries and maximize the residual value
+ **Cost reduction:** reduce the cost of energy storage, low-speed electric vehicles and other related industries, and promote the development of the circular economy
+ **Reduce pollution:** effectively reduce the pollution of waste lithium-ion batteries and reduce waste of resources

+ **High recovery rate:** Mature in technology, thus the resource recovery rate is high
+ **Simple process:** The process is more straightforward than reuse, and there is no need for screening and safety assessment
+ **Complementary techniques:** a combined approach can be applied to improve the economic benefits of recycling and solve the problem of energy over-consumption

Cons

– **Applicable limitations:** not suitable for ternary (NMC) lithium battery, difficulty to maintain economies of scale subject to many qualifications
– **Inefficiency:** The evaluation process of batteries is time-consuming and inefficient
– **Potential safety risks:** The internal safety hazards of retired batteries are highly concealed, which affects the remaining life and safety of the battery pack

– **Cost issues:** The pyro has a large investment and high energy consumption in the early stage, while the hydro is relative time-consuming
– **Environmental pollution:** Both pyro and hydro cause severe environmental pollution easily, and the requirements for pollution treatment are high
– **Uncertainty:** Emerging techniques such as biological processes and supercritical CO_2 extraction are still in startup

Source: CAAM, Anson Securities, public information, Deloitte analysis

Reuse: Development Limitation Factors

The reuse industry has significant development limitations and bottlenecks at the current stage. The downstream application development is expected to be slow before the policy system is improved and the industry standard is established

Policy Factor

- **The reuse industry management system still needs to be improved:** The policy management system for the reuse of EV batteries is still in the initial stage of establishment, and it takes time to improve the national regulatory system and local implementation
- **Policy guidance maintains a moderately positive attitude:** Although the policy intends to promote reuse, it also emphasizes the importance of strict management of the safety of EV battery reuse, and is especially cautious towards reuse in energy storage scenarios.

2022.02

Accelerating the Promotion of Comprehensive Utilization of Industrial Resources

Requirements to improve the recycling system and management system of end-of-life power batteries, strengthen traceability management within the whole life cycle of battery, promote the safe reuse application of end-of-life power batteries in the field of power backup, charging and replacement

2021.09

The Management Standards for New Energy Storage Projects (Provisional)

Require newly-built energy storage projects to establish a battery consistency management and traceability systems and obtain the safety assessment reports issued by corresponding qualified organization for reuse of batteries

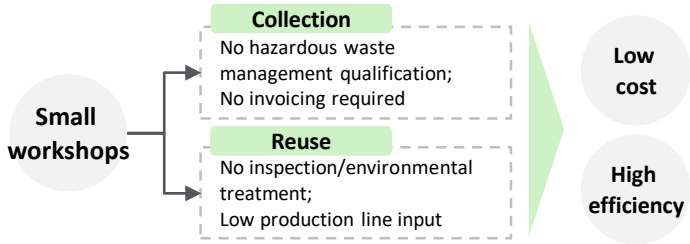
Market Factor

Demand side - uncertain potential:

- **Low acceptance in the downstream market:** Due to unclear standards and immature regulatory system, frequent accidents of battery reused for energy storage have led to low market acceptance. Users are concerned about the safety and consistency of reused batteries
- **Impact of potential alternative products:** the rise of sodium-ion batteries and fuel cells and other technologies may replace and squeeze the market of LFP batteries for secondary use

Supply side - "bad money drives out good":

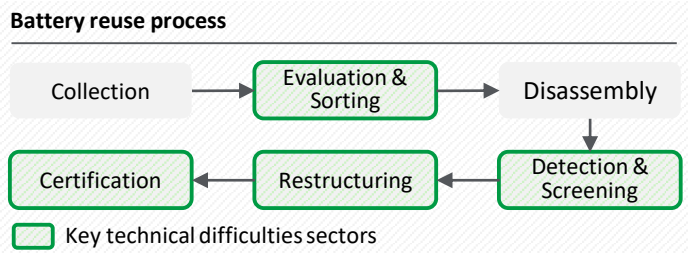
- **Long-standing market confusion:** In the absence of effective regulation, many non-compliant small workshops have long been entrenched in the reuse market, and it is difficult for enterprises with high investments to profit and survive in the vicious competition



Technology Factor

- **Key technologies to be broken through, industry standards to be established:** The battery life-cycle traceability management and industry-standard system are to be established, and technical problems still exist in several sectors of the reuse technology process

Evaluation and sorting - Battery specifications are complex, and life evaluation is difficult
Detection and screening - Lack of battery use records, complicated detecting technology
Restructuring - High technical barriers to battery consistency management
Product certification - For the formation of industry standards, product certification is difficult

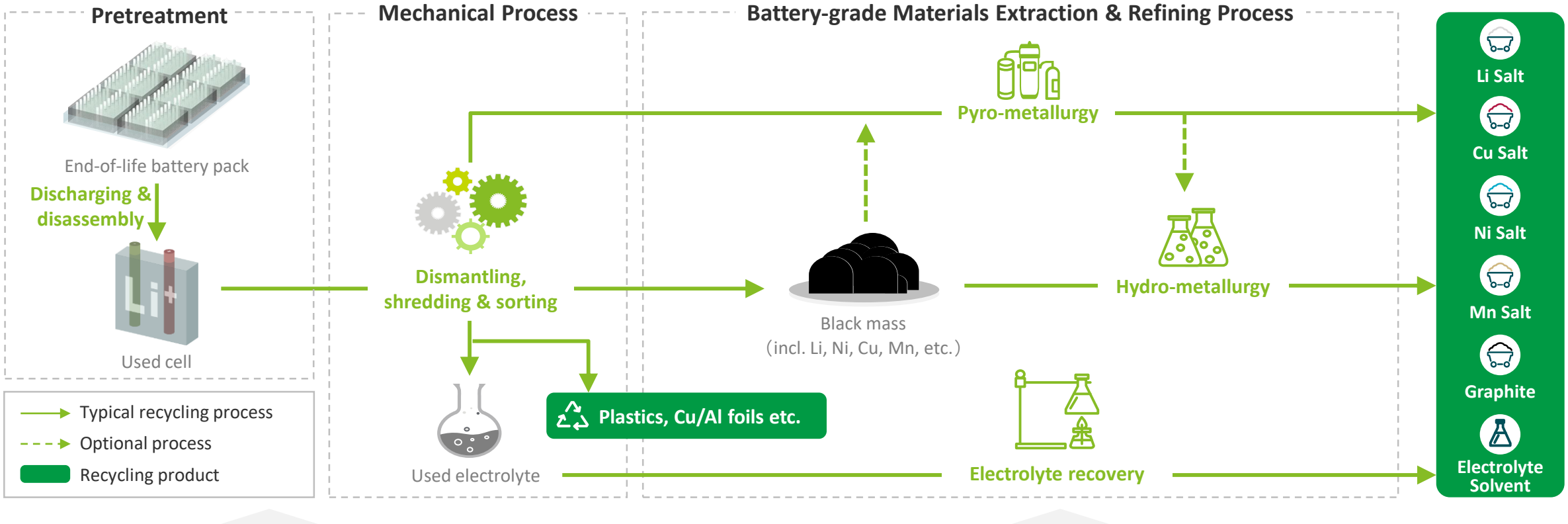


The current market situation: the current commercialization cases of EV battery reuse are few. Most of the projects are pilot programs, with only a few regular enterprises with qualifications participating, such as GEM, China Tower, etc.; the current reuse market is not yet standardized and in chaos. Market confusion caused by non-compliant small workshops forces the regular enterprises into a dilemma, which makes the market less attractive to enterprises that have not entered, and the market is difficult to scale up in the short term

Source: government website, public information, Deloitte analysis

Recycle: Process Flow of EV Battery Recycle

The main challenge of power battery dismantling and recycling lies in the instability of front-end battery recycling channels that make it difficult to scale up the production of back-end battery grade raw material refining



The instability and high cost due to the highly-fragmented battery recycling channels, and **the difficulties of pretreatment** due to wide range of battery pack specifications are the two main difficulties in the disassembly and recycling process

The mechanical process and the metal refining process after the pretreatment of the battery pack have been relatively mature, can realize the effective conversion of the end-of-life EV batteries to recyclable high-purity raw materials; in the situation of sharply-rising lithium metal raw material prices, large-scale production, stable supply of end-of-life batteries and client relations can realize considerable economic returns

Source: public information, Deloitte analysis

Recycle: Mainstream Battery-grade Material Extraction Techniques

Recycling enterprises generally refine the valuable metals in end-of-life EV batteries through hydro or pyro-metallurgy, which are highly-technical maturity and with clear steps, while other emerging processes, such as biological processes and supercritical CO_2 extraction, are still in the early stages of research and development; currently, in China, EV battery recycling enterprises' processes are mainly based on hydro

	Hydrometallurgy	Pyrometallurgy
Process characteristics	• Use acids to dissolve the metal components of batteries and then separate the constituent elements as inorganic salts and metallic oxide through solvent extractions, chemical precipitation, and electrolysis steps. Hydro is suitable for the recycling of small and medium-scale end-of-life batteries.	• Use high-temperature to convert metal oxides end-of-life in battery materials to metals or metal compounds, which proceeds to condensation and refining. Pyro has high compatibility and is applicable to large-scale recycling of various types of end-of-life Li-batteries.
Facilities/Energy cost	Low cost and energy-efficient	High investment and energy-intensive
Efficiency/Period	High recovery and purity, but relatively long recycle period	The recovery rate is relatively lower, but is capable of recovering various heavy metals such as Hg and Zn
Process complexity	Relatively more complicated, and needs to be adjusted optimized for certain battery chemistries	Simpler pretreatment methods but not effective for Lithium-iron-phosphate (LFP) batteries
Pollution treatment	Require process effluent treatment to avoid water pollution	Require gas clean-up process to avoid toxic air emission
Representative enterprises	Li-Cycle, Fortum, GEM 格林美, 邦普循环 BRUNP RECYCLING	umicore, ACCUREC, GanfengLithium 赣锋锂业

Source: Anson Securities, Dongguan Securities, public information, Deloitte analysis

Recycle: Prospects of Battery Recycling in Different Chemical Systems

The distinctions in battery chemical structure and properties determine the recycling mode, reuse method, value and market size of end-of-life EV batteries. The development of reuse of LFP is restricted to the current conditions, and the future recycling market is expected to be dominated by the direct recycle of ternary (NMC) batteries

Comparison of batteries in different chemical systems

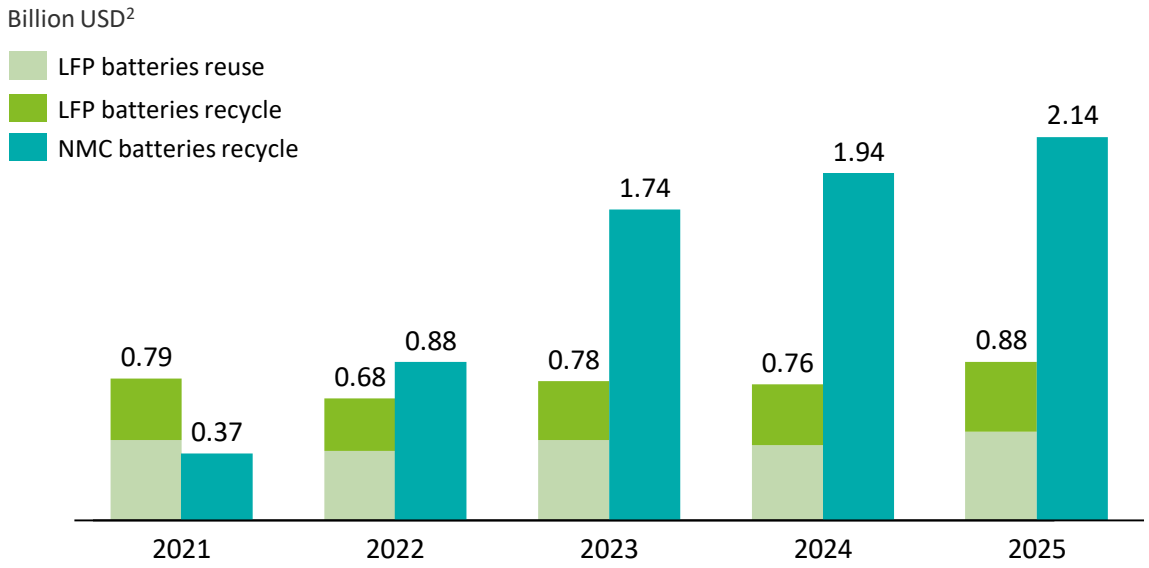
Comparison of recovery related characteristics

- The chemical properties of batteries determine their different recycling methods:

	LFP batteries	Ternary (NMC) batteries
Recycle value	No valuable metals contained, the theoretical recovery value is about 1,441 USD/tonne	Contain nickel, manganese and cobalt. The theoretical recovery value is about 6,651 USD/tonne
Cycle life	The average cycle life is about 4,000, and the capacity declines slowly	The average cycle life is estimated at 2,000 times or lower
Battery safety	More stable, less likely to experience thermal runaway and ignition at high temperatures	At abnormally high temperatures, the possibility of fire and explosion is relatively large

- **LFP** batteries are more **suitable for reusing** due to their relatively low material cost, good stability and long lifespan
- **NMC** batteries are more **suitable for recycling** due to their relatively high material cost, poor stability and short lifespan**.**

Projection on the China recycling market size by battery type[1]



The development of NMC batteries starts later than LFP, and the recovery rate also lagged. End-of-life LFP batteries are more suitable for reuse. However, reuse has not yet achieved technical breakthroughs currently, and it is challenging to achieve economies of scale. **It is projected that the recycling market of NMC batteries will continue to lead in the short and medium term.**

Source: CICC, Everbright Securities, Tianfeng Securities, public information, Deloitte analysis

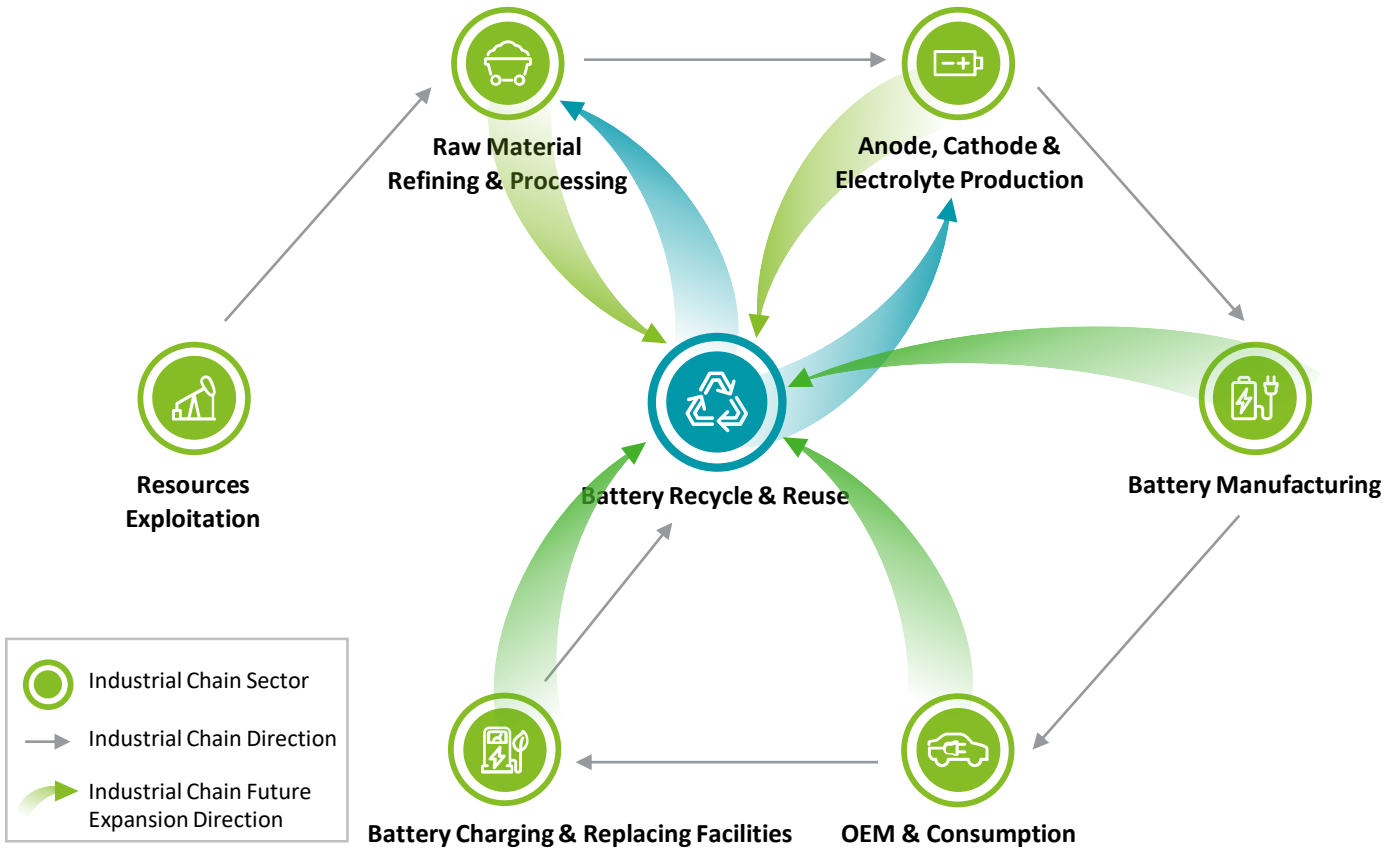
Remarks: 1. Estimated based on the predicted average metal price of respective year; 2. Converted at the annual average exchange rate of USD to RMB in 2021 (1USD = 6.45RMB)

Value chain analysis of EV battery recycle

Development Trend of Li-battery and NEV Industrial Chain

With the transformation of the industry to market-driven development, the lithium battery and NEV industry will further evolve from a chained-form to a mesh ecology with deeper cooperation and mutual empowerment, in which each sector of the industry chain shows the trend of extending to battery recycling in various forms and different degrees

Lithium battery industrial chain extends to battery recycling



Source: public information, Deloitte analysis

Enterprises in multiple sectors extend to battery recycling

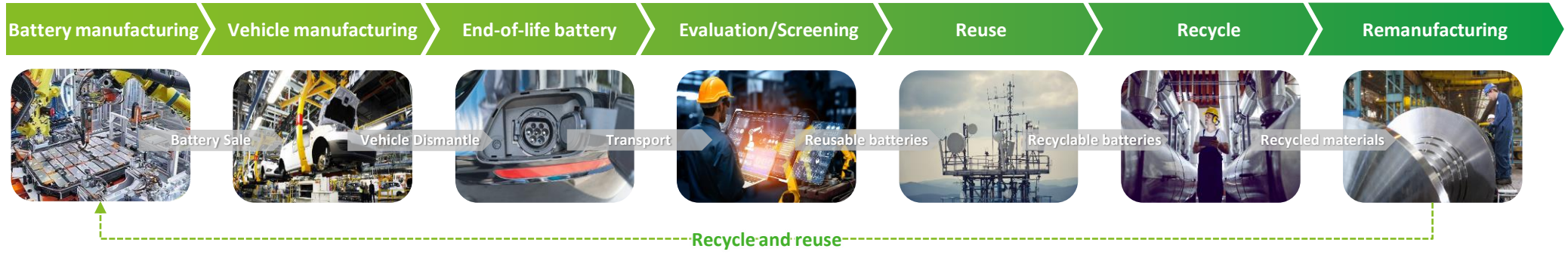
- **Technology-based extension:** Resource refining enterprises and anode, cathode raw material manufacturers have the technical similarity in recycling and extraction technology, which drives their extension to the recycling.
- **Resource-based extension:** Battery enterprises, OEMs and battery banks and other power exchange service companies are predicted to take advantage of resources to expand downwards into the recycling and establishing a recycling system.

Battery recycling enterprises extend to other sectors

- Through dismantling end-of-life batteries, recycling enterprises are likely to expand to raw materials, cathode materials manufacturing etc., forming a closed loop within the industry chain.

EV Battery Recycling Industrial Chain

Lithium battery recycling, which has a substantial development momentum, is taking shape to support a sustainable EV supply chain. Up and downstream players in the industry use their advantages to develop vertical cooperation and seek opportunities to gradually extend the industry chain coverage, forming a closed-loop industrial chain from battery recycling to battery material reproduction and integration



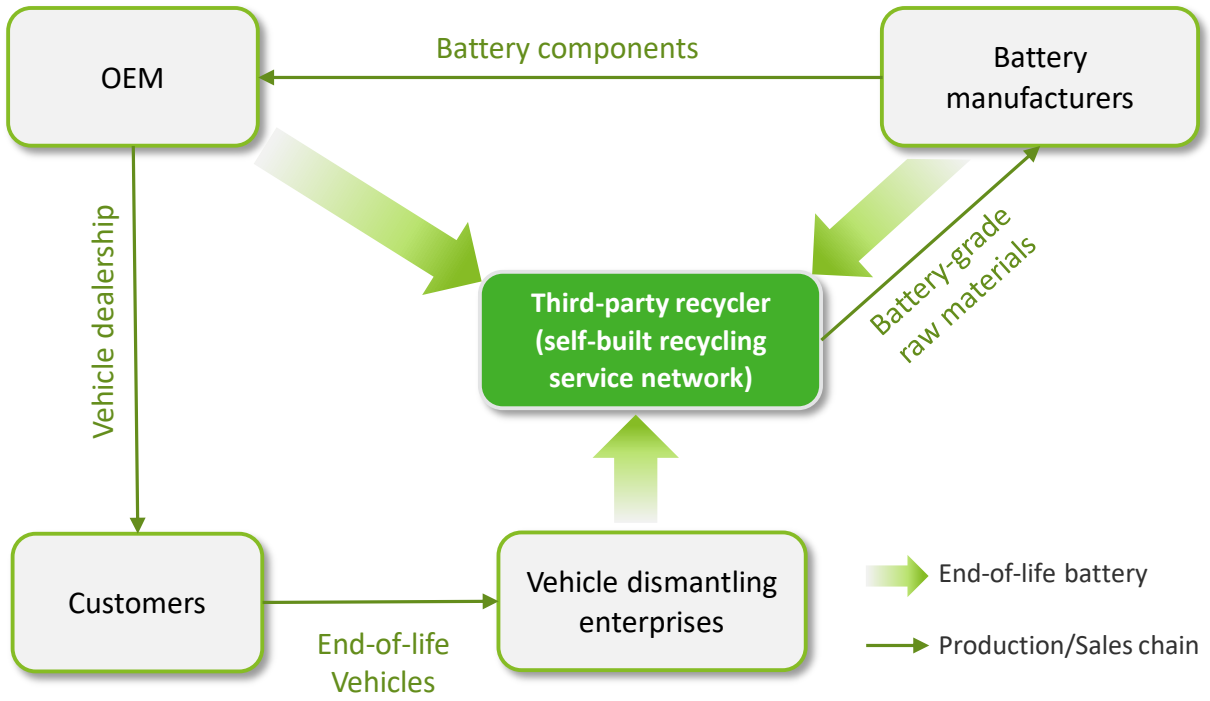
Key Players	Business Model Features	
Third-party recycler	Extend from recycling to both ends of the industry	GEM; Miracle Automation Engineering / Golden Tiger
	Focus on commercial recycling solutions to create economies of scale	Li-Cycle; Cirba Solutions; Redwood Materials
Battery manufacturers	Extend to the whole industry chain through self construction/ acquisition (excluding vehicle manufacturing)	CATL; GXHT; CATL; Brunp Recycling; Guoxuan High-Tech (GXHT)
OEM-led alliance	Forming a closed loop of the whole industry chain through self-built/industrial alliances	BYD; TESLA; TESLA; Umicore

Source: company website, public information, Deloitte analysis

Business Model: Third-party Recycling

Third-party recycling companies, as the primary recycler of EV batteries, independently establish a recycling service network to complete the process from battery recycling to resource utilization

Illustration of third-party recycling



Business model analysis

Model features

Third-party recycling companies, as the primary recycler of EV batteries, generally are entrusted by battery and vehicle manufacturers to complete the transportation, recycling and subsequent resource utilization of end-of-life EV batteries

Pros

Highly mature and professional recycling processes, which are widely used, can realize more efficient recycling of end-of-life EV batteries

Cons

The self-built recycling service network poses severe challenges on its high recycling costs, difficulties in transportation and storage, and limited material resale channels

Key players

GEM 格林美 · 天奇股份 MIRACLE AUTOMATION · GHTECH 光华科技 · Li-Cycle · umicore · ACCUREC

Source: CITIC Securities, Everbright Securities, Tianfeng Securities, public information, Deloitte analysis

Third-party Battery Recyclers: GEM (1/2)

GEM pays attention to the construction and maintenance of recycling networks and industrial ecology. Meanwhile, the company is committed to building a new energy life-cycle value chain and has established an industrial chain advantage in the field of power battery green treatment

The pioneer circular enterprise of end-of-life battery comprehensive utilization

GEM, incorporated in 2001, started with the recycling of nickel-cobalt resources and mobile phone batteries and has gradually expanded to the recycling of waste electrical, electronic equipment, end-of-life vehicles and EV batteries. Over the past 20 years, GEM has been committed to the dual-track driven strategic development of "exploiting urban mines + developing new energy materials".

KSF 1: Secured resource channels and strong recycling network

Through deepened collaborative development of the industrial chain, the company continues to expand its recycling and resale channels and successfully construct EV battery recycling facilities and laboratories in South Africa, South Korea, Indonesia, etc., with its partners. It is expected to deploy a recycling business in Europe in 2022 to accelerate its global business layout

Stable resource channels

GEM has reached recycling cooperation with **more than 500** OEMs and battery suppliers worldwide:

Car manufacturers

BYD, TOYOTA, XPENG

Battery suppliers

SAMSUNG, EVE 亿纬锂能, FARASIS, LISHEN

National recycling network

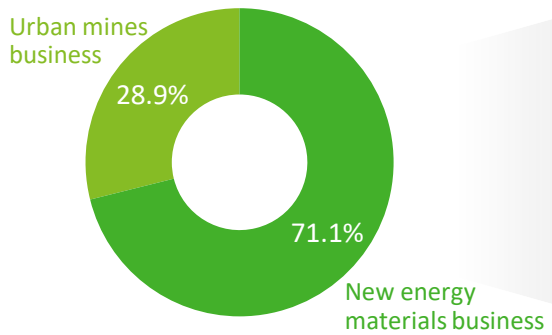
Country-wide integrated recycling networks and the unique "2+N+2" pattern of power battery recycling businesses

- 2 — Two **battery recycling** centers
- \+
- N — Other recycling networks covering **more than 60%** of total NEV in China
- \+
- 2 — Two **resource utilization** and **remanufacturing** parks

KSF 2: Globally-advanced new energy life-cycle value chain

In order to create a closed-loop value chain for the entire life-cycle of EV batteries, the company has tackled many technical challenges in recycling. It is working to ensure the safety of the raw material supply system for new energy material recycling, address the urgent need for the supply chain of critical new energy raw materials, and realize the recycling and deep processing from waste to raw materials for high-end brand products.

GEM Revenue share by business in 2021



"Recycle + Remanufacturing"

The company builds a collaborative recycling industry chain system, and upgrades its business from waste recycling to new energy material manufacturing. **The revenue share of new energy material manufacturing increased from 26.5% in 2016 to 71.1% in 2021**

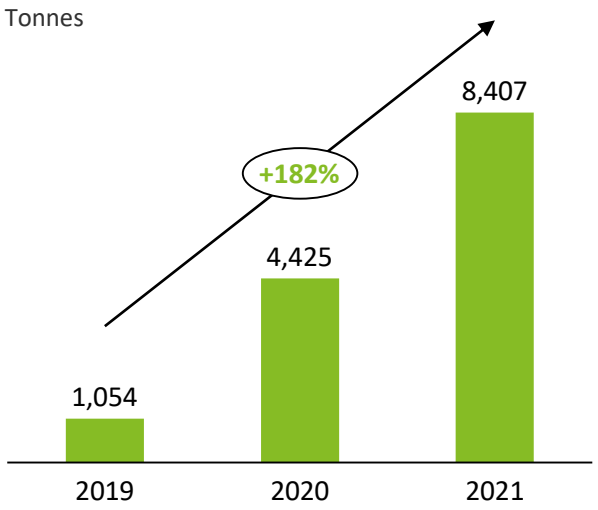
Source: company website, company annual report, public information, Deloitte analysis

Third-party Battery Recyclers: GEM (2/2)

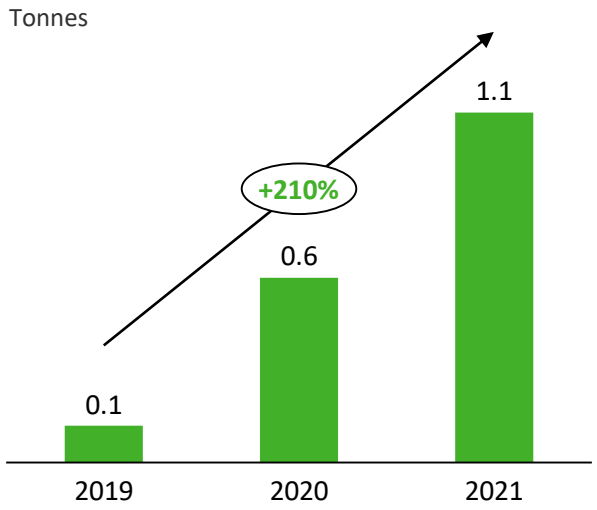
GEM's battery recycling capacity and business income have rapidly grown in recent years. The company has included "expanding recycling" as one of its development strategies. With the advent of the battery retirement tide, GEM will further expand the comprehensive utilization scale of the company's EV battery in the near future

Rapidly rising battery recycle and reuse capacity

Recycle amount



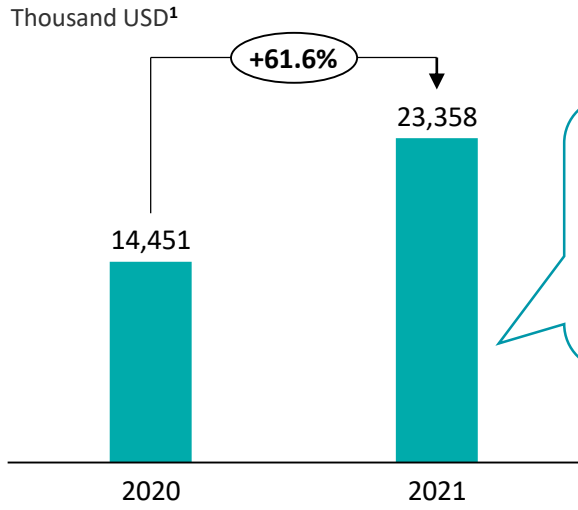
Reuse amount



- GEM's EV battery recycling and reuse business has shown substantial development momentum, expecting to recycle 30,000 tonnes of EV batteries and reuse around 2Gwh EoL batteries in 2022.
- It has been announced that GEM has had a total dismantling, processing and recycling capacity of end-of-life is 215,000 tonnes/year, the total planned capacity in the future for dismantling and recycling is close to 700,000 tonnes/year, and the total planned capacity for reuse exceeds 11GWh.

One of the future business growth engines

Battery comprehensive utilization revenue



In 2021, the YOY growth of EV battery comprehensive utilization business ranked first in GEM's comprehensive utilization sector, **exceeding the growth rate of 54.83% of the total revenue**

- GEM continues to make technological breakthroughs to improve the recycling capacity of EV batteries. In 2025, the company's recycling target will be more than 20 times the recycling capacity in 2021. With the advent of the battery retirement tide, GEM's EV battery recycling and reuse business is projected to become one of the main contributors to the company's future revenue.

Source: company website, company annual report, public information, Deloitte analysis
Remarks: 1. Converted at the annual average exchange rate of USD to RMB in 2021 (1USD = 6.45RMB)

Third-party Battery Recyclers: Li-Cycle (1/2)

Li-Cycle is working to address the increasing demand for lithium-ion battery materials through innovative recycling solutions and upstream-downstream collaboration and focus on the transformation and sustainable development of global "green energy"

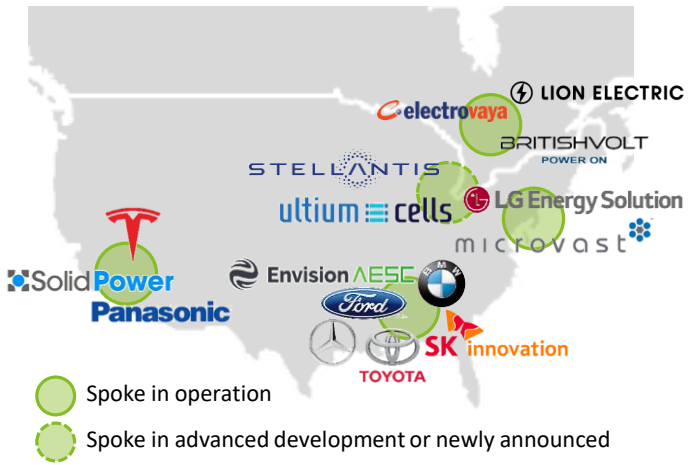
Sound recycling network and innovative and environment-friendly recycling technology promote sustainable, high-quality development

Li-Cycle, founded in 2016, is a in lithium-ion battery resources recycling leader in North America. At present, its primary business includes recycling Li-batteries and producing battery-grade materials. By adopting advanced battery recycling technologies and providing economically-feasible critical battery metals recovery solutions, Li-Cycle offers sustainable products to support the global transition toward electrification

KSF 1: Recycling network building around resource channels

- **Advanced planning:** Company's current business growth strategy focuses on North America and Europe, keeping abreast of the increasing demands of leading existing and potential customers of global industrial chain
- **Deepen cooperation:** According to the geographical distribution of each recycling plant, Li-cycle has forged key strategic partnerships across the value chain and completed long-term commercial agreements for in-take and off-take of essential battery materials in each region to further stabilize the recycling and sales channels

Li-Cycle North America recycling network



KSF 2: Environmental-friendly, innovative, differentiated technology

Despite the challenges of intensified market competition and increasingly stringent environmental regulations, the environmental benefits of Li-Cycle's proprietary technology can still meet clients' requirements for products quality and sustainability, appealing to ESG devoted clients

Environmental benefits of raw materials

Environmental benefits comparison for production of 1 tonne of battery materials[1]

74% CO_2 emission reduction	97% Water usage reduction
92% NO_x emission reduction	92% SO_x emission reduction

Environmentally sound solutions

"Low GHG + No PFAS"

Compared with pyrometallurgy, Li-Cycle's technology significantly reduces GHG emissions and avoids the issue of per-fluorinated and poly-fluoroalkyl substances (PFAS) pollution

Environmentally-friendly

Compared with other hydrometallurgy, Li-Cycle's hydro approach allows for safe processing without any water and landfill waste, minimal waste effluents production and exhaust emission

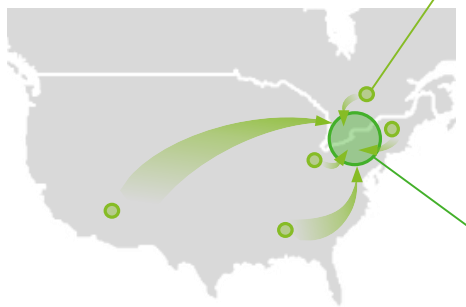
Source: company website, company annual report, public information, Deloitte analysis
Remarks: 1. Compared with direct extraction and refining of natural resources

Third-party Battery Recyclers: Li-Cycle (2/2)

Li-Cycle equipped the closed-loop recycling technology from end-of-life batteries to renewable materials and accelerates the improvement of recovery capacity to achieve vertical integration of resources

Segmented business plan to cover full battery recycle process

Li-Cycle recycles end-of-life batteries to achieve battery full life-cycle coverage through the "Spoke & Hub" network, provides customers with sustainable solutions for lithium-ion batteries, and creates the path to a closed-loop supply chain to support the secondary supply of key battery materials



Spoke: Flexible battery processing facility

- Recycle and handle the preliminary processing of end-of-life batteries through shredding, separation and other mechanical processes to produce black mass that creates major economic value
- The Spoke is a **decentralized and flexible-planning** facility that processes batteries close to the supply source

Hub: Centralized hydrometallurgical processing center

- Recover black mass into battery-grade raw materials through hydrometallurgical process for reuse in Li-battery production, including lithium, nickel, cobalt and more
- The Hub is a **centralized facility for large-scale production** of specialty materials that achieve economies of scale in recycling but with a high initial investment and environmental control cost

Capacity milestones reached for regional recycling

Type	Completion	Location	Status	Capacity (Tonnes)*
Spoke	2019	Kingston, ON	In operation	5,000
Spoke	2020	Rochester, NY	In operation	5,000
Spoke	2021	Gilbert, AZ	In operation	10,000
Spoke	2022	Tuscaloosa, AL	In construction	10,000
Hub	2023	Rochester, NY	In construction	90,000
Spoke	TBD	Norway	Planned	10,000
Spoke	TBD	Germany	Planned	10,000
Spoke	TBD	Warren, OH	Planned	15,000

* Recycling capacity: tonnes of Li-battery equivalent per year

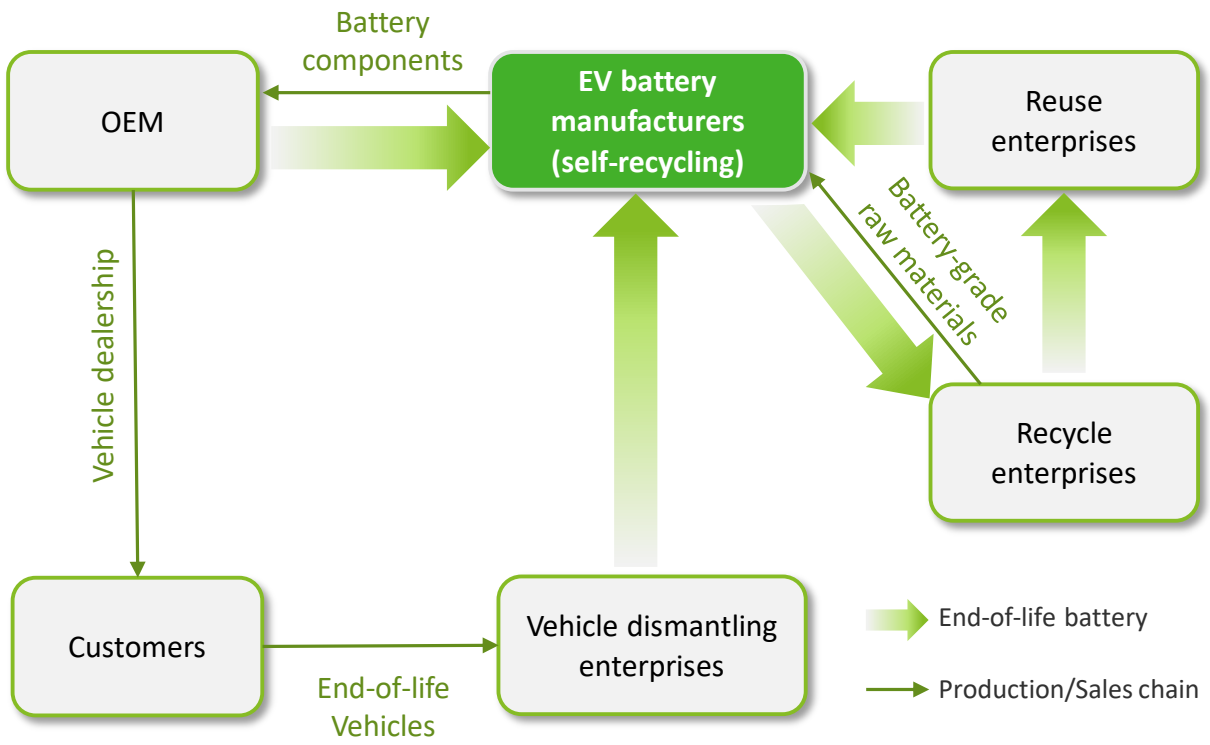
- Li-Cycle is actively investing in and building the Spoke and Hub facilities to improve the scale of the battery recycling business. Li-Cycle is expected to have up to 20 Spoke facilities, 3 ternary lithium battery Hub facilities and 1 LFP lithium battery Hub facility by 2025. The first Hub facility in Rochester, New York, is projected to have a battery materials processing capacity equivalent to 225,000 EVs every year

Source: company website, company annual report, public information, Deloitte analysis

Business Model: Battery Manufacturer as Recycler

Battery manufacturers, as the primary recycler of EV batteries, use their channel advantages to create an industrial closed-loop within the battery life cycle, from collecting and recycling to remanufacturing

Illustration of battery manufacturer recycling



Business model analysis

Model features

Battery manufacturers, as the primary recycler of EV batteries, have arranged the recycling network by establishing subsidiaries, acquiring recycling enterprises, industrial cooperation, etc. to form circular recycling of EV batteries, realize the cost reduction of recycling, and mitigate the bargaining power of upstream raw material suppliers

Pros

Diversified recycling and resale channels are critical factors for battery manufacturers to effectively control the directional circulation of end-of-life batteries and reduce the recycling and reproduction costs of EV batteries

Cons

Technical restrictions on self-recycling. Due to the dependence of crucial recycling technologies on recycling enterprises, the operation efficiency of the model is usually low, which further hinders the formation of the scale effect

Key players

CATL 宁德时代 · 国轩高科 GUOXUAN HIGH-TECH · northvolt

Source: CITIC Securities, Everbright Securities, Tianfeng Securities, public information, Deloitte analysis

Battery Manufacturers Recycling: CATL (1/2)

In recent years, CATL has further improved the strategic planning of the company in the lithium battery and new energy industry, give play to the advantages of industrial synergy, and prospectively arranged the recycling business to secure the company's battery materials supply and resources reserve

Prospective planning and industrial cooperation to enhance supply chain security

Contemporary Amperex Technology Co., Limited (CATL) is a global leading provider of innovative new energy technologies. CATL specializes in manufacturing lithium-ion batteries and is committed to providing efficient energy storage solutions for international green-energy applications by leveraging its advanced battery technology. Since 2015, the company has made prospective planning in battery recycling and regenerating. Over the years, CATL has participated in recycling technology development and investment in the battery recycling industry by building facilities and cooperating with enterprises, aiming to reduce dependence on upstream resources, ensure the stability of the supply chain, and achieve cost reduction in production

2011 – Establishment

Established in 2011, as ATL spun off its EV battery operations into the new company CATL

2015 – Engaged in recycling by acquiring Brump

Acquired 52.88% of the shares of **Brunp Recycling**, and CATL has planned power battery recycling and regenerating in advance, creating a closed-loop battery industrial chain with complementary upstream-downstream advantages

September, 2021 – Explored global markets

Established a strategic partnership with BASF to expand the European recycling market and promote the recycling business's rapid development

October, 2021 – The strategic planning is taking shape

The company invested in developing Brunp integrated battery material industrial park in Yichang, Hubei. The park is an intensive and large-scale production base to support end-of-life battery material recycling, covering the whole battery life cycle, integrating "phosphate mine – raw material – precursor – cathode material – battery recycling" and more

2022 – Deepened global business operation

CATL signed a tri-party framework agreement with ANTAM and IBI to cooperate on the Indonesia EV battery whole industry chain integration project, which includes nickel laterites mining and processing, EV battery materials, EV battery recycling and remanufacturing

Introduction to Brunp Recycling

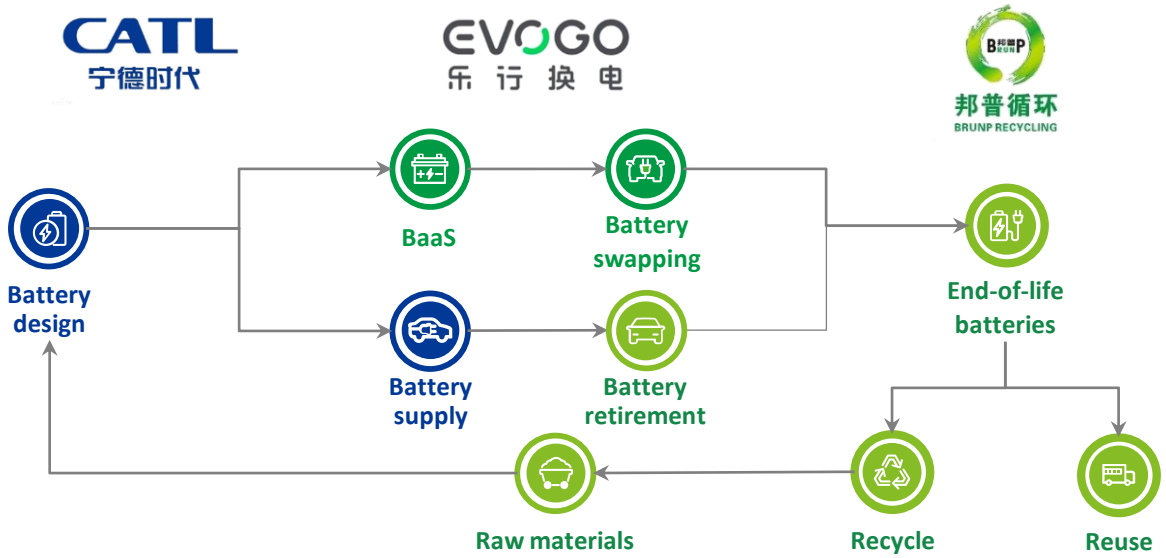
Guangdong Brunp is one of China's leading high-tech enterprises in the recycling and treatment of end-of-life lithium batteries and producing high-end battery materials in China. Headquartered in Foshan, Guangdong, Brunp Recycling has set up seven production bases domestic and out of China, including Foshan, Changsha, Pingnan, Fuding, Yichang in China, Morowali and Weda Bay in Indonesia

Source: company website, company annual report, public information, Deloitte analysis

Battery Manufacturers Recycling: CATL (2/2)

The industrial layout of "One core and Two extensions" of Brunp Recycling helps to form the internal regeneration and circulation of crucial battery materials within the value chain, resulting in the promotion of the sustainable development of CATL

Relying on the Brunp Recycling, forging a one-stop recycling industry for the reuse, recycling and remanufacturing of the EV batteries



- Brunp's "One core and Two extensions" boost CATL's circular business

Core — **Battery recycling:** helps to establish industrial ecological closed-loop

Extensions — **Resource business**: Provides CATL with upstream mineral resources and supports the security of the supply chain

Material business: Manufacturing of ternary precursor and other key materials for CATL battery production

- The existing resource recycling capacity and key metal recovery rate of Brunp Recycling stand among the top in Asia:

120,000 tonnes/year	99.3%	90%
Total battery recycling capacity	Recovery rate of Ni, Co and Mn	Recovery rate of Li

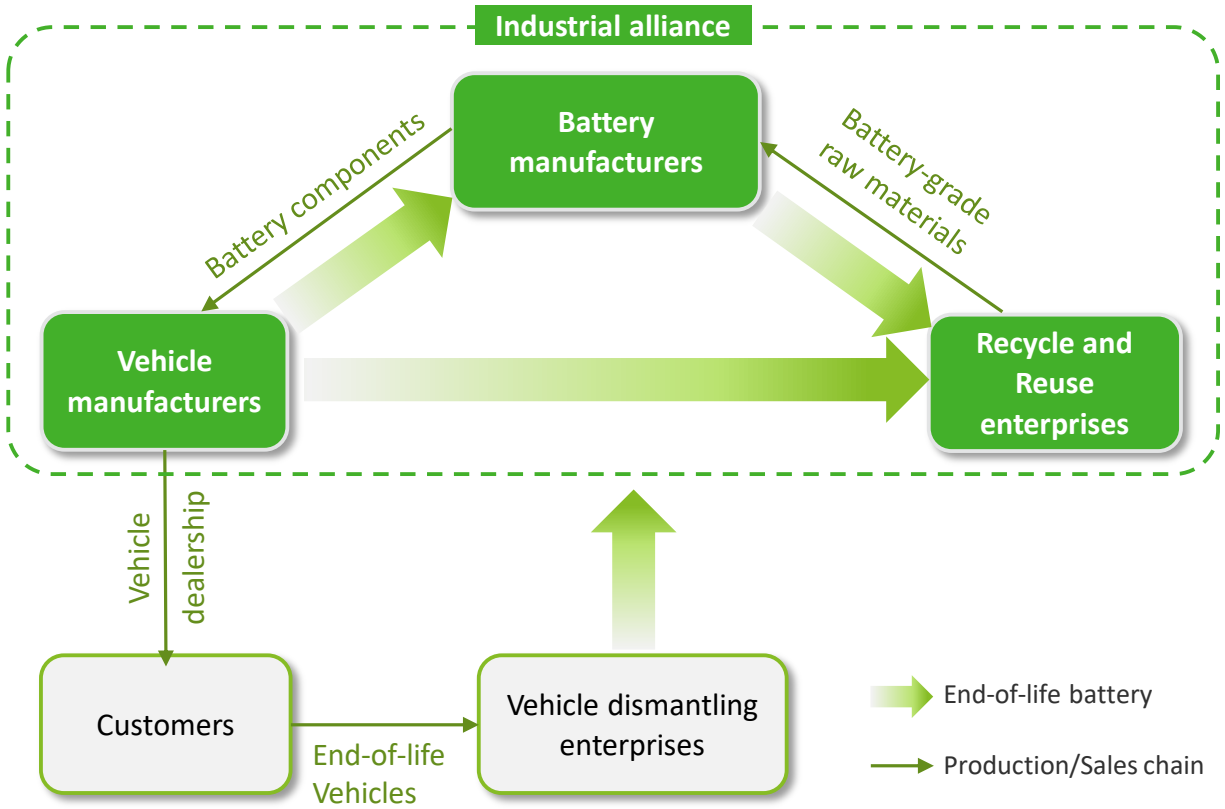
- According to the company's statistics, in the first quarter of 2022, a total of 21,300 tonnes of end-of-life batteries have been recycled and used to produce 18,000 tonnes of battery precursors, and the advantages of the internal circulation system will gradually create a marked effect.
- The establishment of Brunp integrated industrial park is conducive to further improve the CATL's strategic plan in new energy industry, giving full play to the advantages of industrial synergy and ensuring the supply of battery materials. It's estimated that after 2035, CATL will be able to meet a significant part of the demand for raw materials by recycling retired battery materials.

Source: company website, company annual report, public information, Deloitte analysis

Business Model: OEM-led Industrial Alliance as Recycler

The industrial alliance model could be an ideal business model and is led mainly by OEMs. By leveraging the distribution service network and recycling technology of the member enterprises in the industrial chain, the recycling alliance can achieve a cost-effective and scalable recycling business and reduce vicious competition in the market. However, this model is still in the initial trial stage of commercial operation, given that various stakeholders are involved

Illustration of industrial alliance recycling



Business model analysis

Model features

The industrial chain's upstream and downstream alliance members are the primary recycler of EV batteries. The alliance is the inevitable consequence of the Extended Producer Responsibility and the industrial collaborative cooperation mode driven by recycling economics. OEMs often adopt this mode to build a recycling network through alliances to form a closed loop of the industrial chain.

Pros

Extensive recycling channels and strong technical expertise. Through industrial collaboration, the vicious competition in the market, the cost of vehicle production, battery manufacturing and material recycling has been effectively reduced, and the overall recycling efficiency and mode operation efficiency have been improved

Cons

The negative impact of risk sharing is evident in this model. Members are bound by each other through industrial alliances. Enterprises need to bear the potential risks that other members of the battery recycling chain may bring, like uneven expertise.

Key players

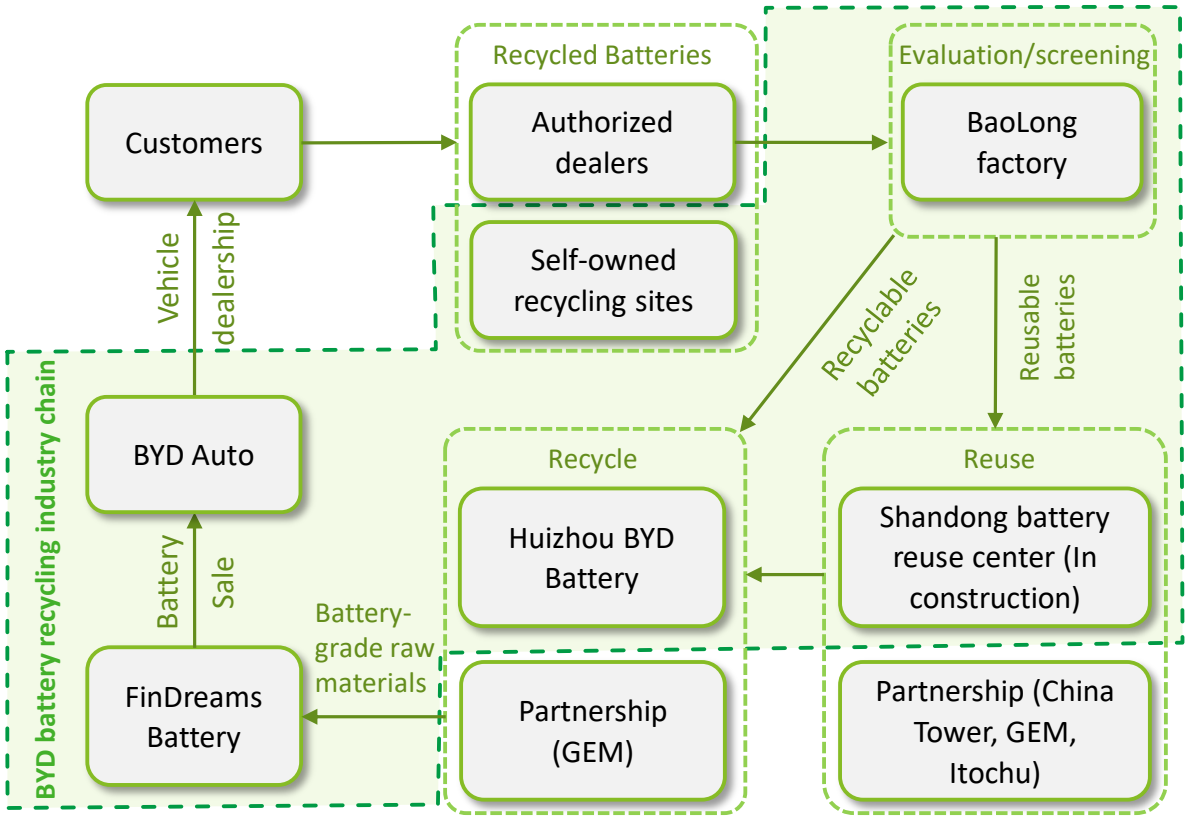
GHTECH 光华科技 · 北汽集团 BAIC GROUP · CHINA TOWER 中国铁塔 · northvolt · umicore

Source: CITIC Securities, Everbright Securities, Tianfeng Securities, public information, Deloitte analysis

Automotive OEMs Recycling: BYD

Relying on the advantages of core battery technology and battery installation scale, BYD has built its own key industrial chain sectors for battery recycling to complete the closed loop of the industrial chain

BYD recycling model illustration



BYD core competitive advantages

Scale of battery recycling

- Relying on the dramatic increase in sales of self-branded NEV, BYD's EV battery installation is steadily climbing, and **its retired battery recycling can reach a certain scale in the future**

Sales volume and battery installation of BYD (2022Q1)	432%	10.5GWh	Top3
	Year-on-year growth rate of new energy passenger vehicle sales	EV battery installation (including export)	Global ranking of total EV battery installation

Closed-loop industrial chain

- BYD has created a **complete, end-to-end, and closed-loop industry chain within the industrial ecology** of "battery manufacturing - vehicle manufacturing - battery recycling - evaluation and screening - recycling"
  - For **recycling channels**, BYD has a nationwide recycling network of 51 specialized battery recycling sites and authorized dealers for retired EV batteries
  - For **evaluation and screening**, BYD's Baolong factory dismantles and evaluates retired batteries, and adopts suitable methods for batteries recycling
  - For **recycling**, BYD Huizhou is responsible for recycling cathode materials, and in addition, it reached a strategic collaboration with GEM in 2015 on recycling

Source: CITIC Securities, Everbright Securities, Tianfeng Securities, CPCA, CAICV, GGII, Deloitte analysis

Market challenges and business implications

Challenge-facing EV battery recycling industry

Technical challenges and market mechanism challenges coexist in the recycling industry. Thus, many problems are still to be solved in each sector of the EV battery recycling industry chain. The healthy development of the EV battery recycling market is in urgent need of the guidance of macro policies and the joint efforts of all individual parties in the industry chain

End-of-life battery supply

Difficulties in channel construction
Establishing a stable recycling channel is one of the recycling companies' most crucial success factors. The establishment problem of the recycling channel significantly exposed due to the asymmetric information between the upstream enterprises with battery resources and the downstream recycling companies

Recycling cost challenges
At present, pricing mechanisms for the recycled end-of-life batteries are lacking, and the poor transparency causes the new batteries materials purchasing prices to drop away from the resale prices of recycled materials

Evaluation/Screening

Lack of standards
Types of power batteries are varied, from battery materials to internal structures and assembly techniques. The lack of unified standards poses challenges to the evaluation of end-of-life batteries

Data source barriers
Third-party recyclers are challenging to obtain the data of end-of-life batteries from vehicle or battery manufacturers, which increases the difficulty of battery state estimation, remaining useful life prediction and safety assessment

Reuse

High cost of reintegration and utilization
Only after disassembly, screening, re-integration, and other processes can the end-of-life batteries that meet the standard be put into reuse. In addition, a series of costs such as battery management and logistics transportation lead to limited profit margins

Uncertain downstream demand due to security concerns
Subjected to the application scenarios and the application enterprise's concern about the potential safety hazard of secondary battery utilization, the reuse of end-of-life batteries is weaker than expected

Recycle

Technical challenges of battery diversity
The disassembly and recovery technology process directly affect the recovery rate of high-value metals. The diversity of batteries will also bring technical difficulties. Moreover, the company needs to address the energy consumption and the environmental impact of the process

Difficulty to scale up due to unstable recycling channels
The massive investment in capacity construction in the early stage requires the companies to reach a specific scale of recycling end-of-life batteries to avoid significant profit pressure

Remanufacturing

Price uncertainty of raw materials
The price of recycled materials is affected by the double influence of the cost of recycling end-of-life batteries and the cost generated from the recycling process. The frequent fluctuation of the price of metal raw materials will also affect the attractiveness of recycled materials, and the uncertainty of the price poses severe challenges to the downstream application of recycled materials

Source: Deloitte analysis

Impact of upstream lithium battery and NEV industry trends on EV battery recycling

As the upstream industry, the technology and market trend of lithium battery and NEV industry are closely interrelated to the EV battery recycling

Related Trends of the EV battery recycling upstream industry		Impact on EV battery recycling industry
Rising prices of raw materials	• The productivity growth of upstream metal resource exploitation is lower than that of downstream application industries, and the **mismatch between resource supply and demand is significant**, leading to metal price fluctuations	• The critical metals in battery manufacturing can be recycled from end-of-life batteries, effectively supplement the shortage of resources, and **promote the development of the recycling industry** from the demand side
Rapid iteration of battery chemistry	• High nickelization and low cobalt of ternary batteries and Li-battery alternatives, which correspondingly **reduce the dependence on precious elements** through material innovation, are global R&D hot topics. • **The installation of LFP battery increases rapidly** due to its cost and safety advantages	• The fast innovation of battery technology and the diversity of specifications raise **the difficulty of battery disassembly and recycling** • The cost reduction trend of batteries may bring challenges to **the profitability of the recycling industry,** promote recycling companies to develop **more efficient recycling technologies and models**
Upgrading battery pack and vehicle manufacturing technology	• **Battery pack technologies** such as module-free design (CTP) and battery chassis integration technology (CTC) improve space utilization and mileage range and achieve high efficiency and cost reduction • Groundswell of the opinion of EV and **battery pack standardization**, but standardization itself is proceeding slowly.	• Highly integrated and structural batteries have **increased the difficulty of battery disassembly and technical barriers to recovery.** The vehicle companies and their partners will take on greater responsibility for recycling • The standardization of battery packs will benefit the automatic disassembly process of batteries, **promoting the standardization process of battery recycling**
Accelerated battery service and ecological construction	• Battery Bank (BaaS) and other **on-demand battery replacement service** provide centralized full life-cycle operation management such as battery leasing, charging, maintenance and swapping	• The rise of battery services has led to a **more centralized recycling channel, making it easy to create a scale effect** • Battery banks, charging stations are conducive to strengthening **the information traceability and management** of the battery life cycle, accurately predicting battery retirement, **improving the battery recycling efficiency and values**

Source: public information, Deloitte analysis

Business Implications for Battery Recycling Companies

Leading battery recycling companies should carefully consider the following issues from a strategic perspective:

Overall strategic planning (Where to play)

- Which sectors of the recycling business should the company invest in? Does the main business involve reuse or recycling?
- What business model should the company adopt? What are the core advantages and key points to profitability?
- Does the company consider the extension or closed-loop construction along the up and downstream, or specialization in recycling?

Capabilities development and Industrial synergy (How to win)

Capabilities development:

- **Channels** - How to construct and distribute self-owned recycling networks to ensure adequate resources and stable recycling channels? Through M&A integration, strategic alliance or exchange agreements?
- **Technology** - Which recycling process route to choose? How to improve the recovery rate and reduce recycling costs through technological innovation?
- **Capacity** - How to plan on recycling capacity improvement in the next 3-5 years to achieve scale effect?

Industrial synergy:

- **Upstream** - How to react to the rapid technological change and market trends in the upstream lithium battery and NEV industry? How to cooperate with battery manufacturers and OEMs who enjoy channel advantages?
- **Downstream** - Does the company need to extend to the reuse, regenerating or remanufacturing and develop the capacity of battery raw materials production such as precursors? How to compete with metal raw material suppliers such as Li-salt production companies?

Business Implications for Lithium and Battery Companies

Leading lithium companies and battery manufacturers should carefully consider the following issues from a strategic perspective:

Overall strategic planning (Where to play)

- Does the company consider expanding into recycling business? Based on what background, should the company get involved in battery recycling? What is the core business objective?
- If entering the recycling field, which industry sectors should the company plan to engage in? How can the company take advantage of the original battery business?
- What business model should the company adopt? Is it to do independent recycling capability R&D or seek industrial collaborations up and downstream based on the original business?

Capabilities development and Industrial synergy (How to win)

Capabilities development:

- **Channel** - How does the company leverage its sales network to build a reverse logistics recycling channel and form a closed-loop utilization of end-of-life batteries?
- **Technology** - How to make use of existing battery manufacturing technology for recycling technology transformation? Independent R&D of innovative recycling technology or technique patent purchase to improve recycling efficiency?
- **Capacity** - How to plan on recycling capacity improvement in the next 3-5 years, and realize industrialization to support its original business?

Industrial synergy:

- **Upstream -** How does the company supplement resources through recycling to mitigate the bargaining power against upstream resource suppliers?
- **Downstream** - Should the company rely on supply or establish cooperative relationships with recycling enterprises? Or vertically integrate the recycling enterprises with technological advantages through M&A? How to cooperate with OEMs in recycling closed-loop supply chain construction?

Business Implications for Automotive OEMs

Leading automotive OEMs should carefully consider the following issues from a strategic perspective:

Overall strategic planning (Where to play)

- Based on the company's strategic consideration and its capability's current situation, should the company get involved in battery recycling?
- If entering the recycling field, does it involve reuse or recycling? How can the company take advantage of the technology of the original car manufacturing business?
- Which industry sectors should the company plan to engage in? What is the core business objective? Is it to do independent recycling capability R&D or seek industrial collaborations up and downstream based on the original business?

Capabilities development and Industrial synergy (How to win)

Capabilities development:

- **Channel** - How to improve the utilization of the existing sales network and establish a recycling channel for retired batteries with stable sources and guaranteed quality to avoid losing resources to other third-party channels?
- **Technology** - Assess the current status of its own capabilities, including gaps in battery recycling technology capabilities, and its supply of retired batteries, and determine the depth of its involvement in battery recycling?
- **Economic** - Based on the cost-effectiveness of possible business models, further decide how to achieve technical capacity building: self-R&D, partnership, or M&A?

Industrial synergy:

- **Upstream** - Is it possible that the supply constraints of upstream materials be alleviated through the recycling business? Whether and how do OEMs seek cooperation with upstream battery and material companies to obtain technical capabilities?
- **Downstream** - How do OEMs cooperate with downstream recycling companies to supplement the battery recycling network? Is it possible to cooperate with energy and power suppliers to expand the reuse scenario when the technology and business model are mature?

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