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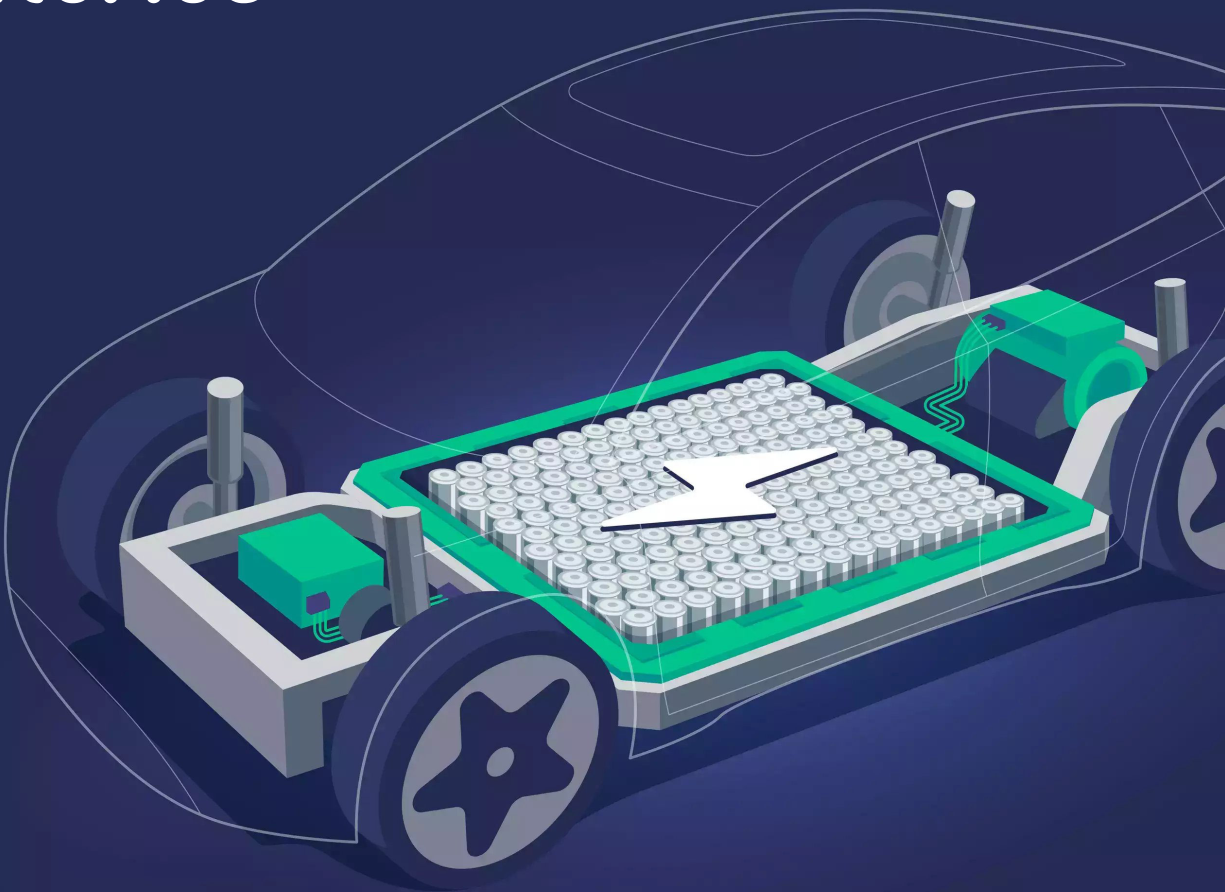
On behalf of:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

Agora Verkehrswende

International review on

Recycling Ecosystem of Electric Vehicle Batteries



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Agora Verkehrswende
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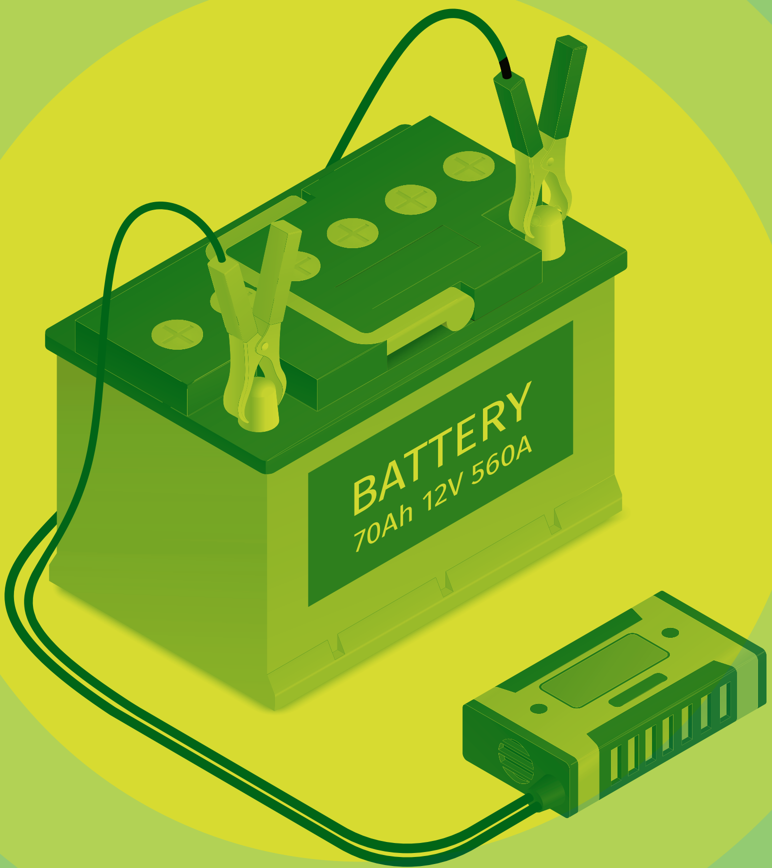
Abbreviations

ABS	Acrylonitrile butadiene styrene
CalEPA	California Environment Protection Agency
CDTFA	California dept of Tax and fee administration
DTSC	Department of Toxic Substance Control
EBA	European Battery Alliance
EoL	End of life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle
GWh	Gigawatt-hour
JBRC	Japan Portable Rechargeable Battery Recycling Center
kW	Kilowatt
kW/kWh	Kilowatt/ Kilowatt-hour
LAB	Lead Acid Battery
LIB	Lithium-ion battery
LPUR	Law for Promotion of Effective Utilization of Resources
MIIT	Ministry of Industry and Information Technology
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
NAAMSA	National Association of Automobile Manufacturers of South Africa
NDRC	National Development and Reform Commission
NEM: WA	National Environmental Management: Waste Act
NEV	New Energy Vehicle
NiMH	Nickel–metal Hydride Battery
OEM	Original Equipment Manufacturers
OSHA	Occupational Safety and Health Administration
PP	Polypropylene
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
SA	South Africa
SABS	South African Bureau of Standards
SLAB	Spent Lead Acid Battery
SMM	Sumitomo Metal Mining
SOC	State of Charge
SOH	State of Health
TSDF	Transfer, Storage and Disposal Facility
TWh	Terawatt-hour
VOC	Volatile organic compounds


BATTERY
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Introduction

Electric vehicles (EV) have seen a rapid growth with the global electric car stock hitting the 10 million in 2020[1]. This increasing shift in EV's would also mean an increase in battery demand. Lithium-ion batteries which currently power the EV's reached global manufacturing capacity of roughly 300 GWh per year and the production was around 160 GWh in 2020. Battery demand is set to increase significantly over the coming decade, reaching 1.6 TWh in the Stated Policies Scenario and 3.2 TWh in the Sustainable Development Scenario.

The envisaged projections in EV's and the subsequent battery demand raises important questions with regards to catering to the demand for the materials that will arise for manufacturing batteries, end-of-life (EoL) and waste management.

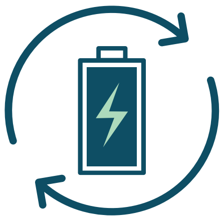
The increasing demand for battery materials necessitates the need for increased extraction of raw materials. However, reserves are limited in nature and the emissions that result from extraction, processing and transport would defeat its decarbonization goals. This therefore necessitates the need for a robust and efficient recycling infrastructure. It is important to note that recycling is crucial not only for securing the supply of key raw materials for the future but also for reducing the need for new mineral extraction, thereby lowering the environmental footprint manifold.

The life of an EV battery generally ranges between six to eight years and needs replacement when its capacity starts falling below 80%. There are three options post utilization of batteries for EV/ traction purposes:

01 Re-use/Repurpose the battery for secondary applications e.g., Stationary batteries for grid storage systems or standby use.

02 Recycle - Recover the materials in the battery such as Cobalt, Nickel, Iron, Copper etc.

03 Landfill Disposal



The collected lead, plastic, acid and other materials are then recycled separately.

Studies show that second life battery lifespan depends on its use, going from about 30 years in fast electric vehicle charge support applications to around 6 years in area regulation grid services[2]. Second life batteries start at 80% SOH (state of health) and its common EoL is 60% SOH. Once the second life battery reaches its EoL, the appropriate option would be to recycle the battery. The sheer volume of used battery packs ending in landfills is not an environmental conscious solution. Recycling process reintroduces the recovered materials back into use which reduces the consumption and mining of primary raw materials. This contributes to the economic cycle and forms a fundamental aspect to the circular economy. It also helps to avoid disposal of batteries in landfill. Recycling contributes to sustainability and circular economy and represents a viable option in managing the EV battery at its end stage.

Currently, the two widely used battery technologies for EV applications are:

- Lead acid batteries
- Lithium-Ion batteries

1 IEA, 2021. *Global EV Outlook,* s.l.: IEA.

2 Lluc Canals Casals, B. G. C., 2019. Second life batteries lifespan: Rest of useful life and environmental analysis. Journal of environmental management, Issue 232, pp. 354-363.

1.1 Lead Acid Batteries

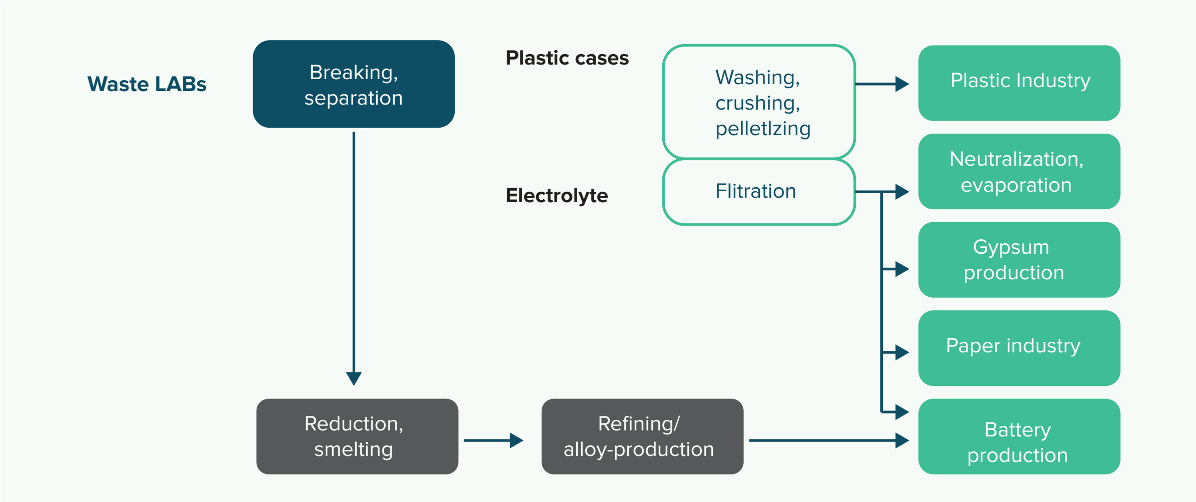


Figure 1 Lead acid battery recycling (Source: Öko-Institut e.V.)

The key steps for undertaking battery recycling in Lead Acid batteries are:

01 Lead Acid Batteries (LABs) undergo an automated process starting with a battery cutting machine with rotating hammers typically powered by an asynchronous motor.

02 The acid is released and collected, and the resulting mix is separated through a sink-float tank-type process, separating the lead and lead paste from the other materials (Polypropylene-PP, Polyvinyl chloride-PVC and Acrylonitrile butadiene styrene-ABS).

03 The lead and heavy materials fall to the bottom and the plastic floats.

04 The collected lead, plastic, acid and other materials are then recycled separately.

05 Plastic is washed, dried and melted together in the plastic recycler. The molten plastic is processed through a granulator that produces a uniform particle with a final size suitable for reuse.

06 Lead parts (lead grids, lead oxide and others) are cleaned and heated inside smelting furnaces at a temperature from 1,000 to 1,250°C. Sodium hydrogen carbonate can be added in liquid form for supplementary purification from metal residuals.

07 The molten lead is then poured into ingot moulds where the impurities float to the top and are scraped away. When the ingots cool, they are transported to battery manufacturers where they can be re-melted and used for new batteries.

08 Battery sulfuric acid can be neutralized or recycled. Neutralization is the process of turning the acid into water by using an industrial base compound. Recycling converts the acid to sodium sulphate, which can be used as white powder for laundry detergent and glass and textile production.

1.2 Lithium-Ion Batteries

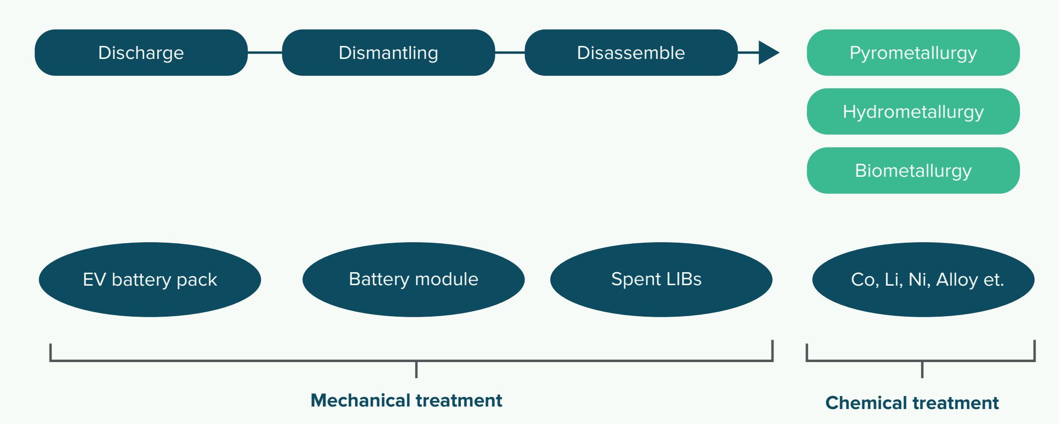


Figure 2 Lithium-ion battery recycling process (Source: IFRI, France)

The key steps for undertaking battery recycling in Lithium-ion batteries are:

I. The mechanical phase involves several steps: discharging the battery pack down to the level of the battery modules or battery cells.

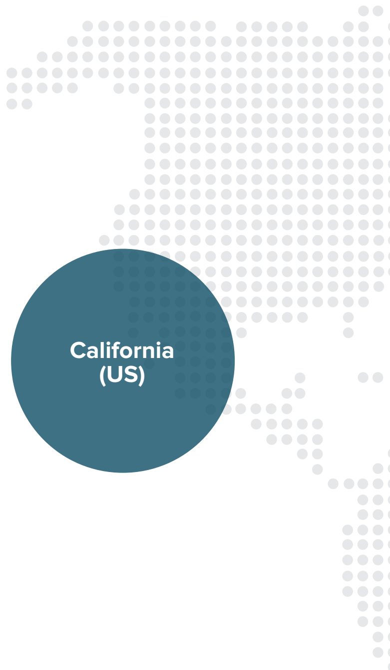
II. After that, two processes are possible:

- The **pyro process** is a melting process at very high temperatures in which organic components (the graphite anode, the organic electrolyte and polymers) are removed. The result is an intermediate alloy containing mainly copper, nickel and cobalt, which is then chemically treated. The process is criticized for its **high energy consumption**; however, it potentially still offers **significant efficiency potential** through energy recovery.
- The **hydro-process** includes a mechanical treatment for shredding and disassembling batteries. After that, they are put in an acid solution for the chemical separation of elements. Furthermore, there is a need for a **specific hydro-process for each type of battery**, in order to avoid negative chemical reactions. The shredding-dismantling phase **generates a loss of materials and raises safety issues** as well, depending on the remaining charge of the battery. If a battery is still charged, it can explode while being shredded.
- A **combined pyro-hydro process** may be preferable for two reasons. First, pyro treatment avoids the disadvantages linked to safety issues stemming from the different chemical composition of batteries, their constitution and their state of charge. Hydro-treatment can then logically be used in the separation and the treatment of the different materials recovered in slags, with different materials being susceptible to treatment, using different kinds of chemicals and acids.

> **The shredding-dismantling phase generates a loss of materials and raises safety issues as well, depending on the remaining charge of the battery.**

1.3 About this Study

The Nationally Determined Contribution – Transport Initiative for Asia (NDC-TIA) is a regional initiative funded by the International Climate Initiative (IKI) of German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). It is a joint project of seven organizations and with the engagement of China, India, and Vietnam. The organizations partnering with GIZ on this project are World Resources Institute (WRI), International Council on Clean Transportation (ICCT), International Transport Forum (ITF), Agora Verkehrswende, REN21 and SLOCAT. For the India component of the NDC-TIA project, the implementing partner is the National Institution for Transforming India (NITI Aayog).



Under the NDC-TIA India Component, the study "International review on Recycling Ecosystem of EV Batteries" was conducted jointly by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), Agora Verkehrswende, and Indian Institute of Technology Bombay (IIT Bombay).

The increasing adoption of electric mobility, as a response to decarbonising the transport sector, has seen rapid growth with the global electric car stock hitting 10 million in 2020. This increasing adoption necessitates an increase in battery demand. Battery demand is set to increase significantly over the coming decade, reaching 1.6 TWh in the Stated Policies Scenario and 3.2 TWh in the Sustainable Development Scenario[3].

The envisaged projections in EVs and subsequent battery demand raises important questions on meeting the high demand. This demand in turn necessitates the need for increased extraction of raw materials. However, reserves are limited in nature and the emissions that result from extraction, processing and transport would be counterproductive to its decarbonization goals. Recycling of battery, thus, becomes an important aspect in the entire supply chain. It is important to note that recycling is crucial not only for securing the supply of key raw materials for the future but also for reducing the need for new mineral extraction, thereby lowering the environmental footprint manifold.

This study thus focuses on the recycling ecosystem of batteries. Batteries up until recently were primarily used in electronic appliances. However, with the advent of EVs, batteries for traction applications have become synonymous with battery recycling and needs careful and in-depth study. This study looks into the policies and regulations currently in place for recycling of batteries, who the stakeholders are in the recycling ecosystem, supply chain, and major players for battery recycling in the international space.

3 IEA, 2021. *Global EV Outlook,* s.l.: IEA.

The review is conducted for:

1.4 About the report

This report documents the battery recycling ecosystem in Germany and rest of EU, California (US), China, Japan, and South Africa. The report documents the policies and regulations pertaining to recycling of batteries and the roles and responsibility of stakeholders involved in each country. The report also looks into the recycling ecosystem, supply chain for batteries, technology used for recycling, and the major market players in each country.

EU and Germany

2.1 Regulation

Compared to today, EU demand for lithium is anticipated to be 18 times higher by 2030 and 60 times higher by 2050. Cobalt demand is anticipated to be 5 times higher by 2030 and 15 times higher by 2050[4]. Currently, none of these materials are sourced within Europe in significant quantities. The EU is heavily dependent on raw material imports for battery production, including from sources where their extraction involves environmental degradation, the violation of labour standards, and local conflicts over natural resources. At the same time, reliance on recycled materials in EU battery manufacturing is low. Accordingly, there have been numerous calls for the development of competitive and resilient supply chains for battery production and recycling in the EU.

The EU and Germany have the political goal of enabling climate-neutral living by the middle of the century at the latest. As part of the Green Deal, the European Commission has formulated the goal of only allowing "the most environmentally friendly, most powerful and safest batteries" on the EU market and establishing the entire value chain for batteries in Europe. The negotiations on the European battery regulation began to set the legal framework for the practical implementation of this strategy.

The EU Parliament endorsed the European Commission's proposal for safe, circular, and sustainable battery supply chains in its January 2020 resolution on the European Green Deal. It stipulates that "Batteries placed on the EU market should become sustainable, high-performing and safe all along their entire life cycle. This means batteries that are produced with the lowest possible environmental impact, using materials obtained in full respect of human rights as well as social and ecological standards. Batteries have to be long-lasting and safe, and at the end of their life, they should be repurposed, remanufactured, or recycled, feeding valuable materials back into the economy."[5]

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Within the EU, the regulation of the recycling of LIB from end-of-life vehicles has so far been regulated by Directives: End of life vehicles directive, 2000/53/EC and Battery directive, 2006/66/EC.

Up to 2022, the applicable regulations were designed to minimise the negative impact of batteries and accumulators on the environment. The battery directive from 2006 applies to all batteries and accumulators and defines three categories: portable batteries and accumulators, industrial, and automotive batteries and accumulators.

Under this regulation Batteries and accumulators used in electrical vehicles are considered industrial batteries and accumulators. Various exemptions and amendments

4 EU Parliament 2021
5 EU Commission (2020) b

have to date been possible when implementing legislation at Member State level. The Member States must however ensure that appropriate collection schemes are in place for waste portable batteries and accumulators (WPBAs).

The directive further defined collection targets of 25% (2012) and 45% (2016) for portable batteries. For batteries, the following minimum recycling efficiencies apply depending on the cell chemistry:

a. recycling of 65% by average weight of lead-acid batteries and accumulators, including recycling of the lead content to the highest degree that is technically feasible while avoiding excessive costs
b. recycling of 75% by average weight of nickel-cadmium batteries and accumulators, including recycling of the cadmium content to the highest degree that is technically feasible while avoiding excessive costs; and
c. recycling of 50% by average weight of other waste batteries and accumulators (including lithium-ion batteries).

The overall responsibility lies with the producers of batteries and accumulators. They are responsible for the waste management of batteries and accumulators they place on the market. These regulations however, esp. collection targets, first and foremost address portable batteries, not EV batteries.

On national level in Germany battery recycling had been regulated to date by the German Battery Law (BattG). It implements EU Directive 2006/66/EC and regulates the sale, collection, and environmentally compatible disposal of batteries and accumulators.

To date three categories under the BattG apply:

1. Industrial Batteries: for commercial and agricultural purposes, and for vehicle propulsion.
2. Automotive Batteries: for starting and lighting vehicles.
3. Portable Batteries: neither industrial nor automotive, mainly suitable for portable equipment applications.

BattG applies to manufacturers that introduce batteries or accumulators to the market or offer them for sale. As the "initial distributor", the manufacturer is required to ensure collection and proper disposal of waste batteries from retailers and end users.

The law was already amended in 2021 with the passage of BattG2, however with current developments on European legislative level, further changes are anticipated from 2022 onward in line with the revision of the EU Battery Directive.

New requirements since January 2021:

1. The required minimum collection rate (for each collection system) was increased from 45 to 50%.
2. The manufacturers of automotive or industrial batteries must "maintain the financial and organizational resources" to ensure collection and recovery of batteries they have introduced to the market. The required recovery rates are 65% for lead-acid batteries and 75% for NiCd batteries.

In December 2020, European Commission proposed legislation to modernise the EU's regulatory framework for batteries in order to ensure the sustainability and competitiveness of battery supply chains. This legislation, which builds on the

> **The shredding-dismantling phase generates a loss of materials and raises safety issues as well, depending on the remaining charge of the battery.**

European Battery Alliance (2017) and the European Commission's Strategic Action Plan on Batteries (2018), is planned to be adopted early 2022. It revises the applicable regulations on LIB from end-of-life vehicles.

The EU battery regulation proposed by the EU commission would replace Directive 2006/66/EC and, once in force, will apply directly in all 27 EU Member States. It defines three interlinked objectives:

1. Establish common rules for a level playing field and thus strengthen the internal market
2. promote circular economies; and
3. reduce environmental and social impacts at all stages of the battery lifecycle.

It foresees stringent environmental and social standards with regard to material sourcing, production-related emissions, service lifespans, product safety, second use, and collection and recycling rates. Once adopted, this EU regulation will be immediately binding on all Member States.

Foreseen changes are as follows:

- Electric vehicle batteries are defined as a new battery category.
- It proclaims new requirements to minimise the carbon footprint of EV batteries and rechargeable industrial batteries:
  - Carbon footprint declaration requirement (starting 1 July 2024)
  - Classification in a carbon footprint performance category and related labelling (starting 1 January 2026)
  - Requirement to comply with maximum lifecycle carbon footprint thresholds (starting 1 July 2027)
- There is a future requirement on recycled content (starting 1 January 2027) for industrial batteries, EV batteries, and automotive batteries containing cobalt, lead, lithium, and/or nickel in active materials.
- It sets mandatory minimum recycled content quotas, which would come into effect in 2030 and 2035:
  - 12%/20% for cobalt; 85% for lead; 4%/10% for lithium; and 4%/12% for nickel.
- It states minimum electrochemical performance and durability requirements for rechargeable industrial batteries (starting 1 January 2026).
- Supply chain due diligence obligations is stipulated for economic operators, that introduce rechargeable industrial batteries and EV batteries to the market.
- New targets are set for lithium-based batteries: 65% by 2025, 70% by 2030.
- As well as recovery targets: By 2025: 90% for cobalt, copper, lead and nickel and 35% for lithium. By 2030: 95 % for cobalt, copper, lead and nickel and 70 % for lithium.
- Mandatory repurposing and remanufacturing operations for second-life industrial and EV batteries are specified.
- New labelling and information requirements regarding performance, duration, and minimum requirements are defined.
- The proposal further contains an electronic exchange system for battery information, including creation of a battery passport by 2026.
- And lastly, minimum mandatory green public procurement criteria or targets are set.

In general, it can be stated that the cost of recycling is to be paid for by the distributor, which, in case of the transport sector, is the OEM.

When implemented, the EC's proposal for the EU Batteries Regulation is to be classified as a milestone in EU environmental policy and as an important component of the European Green Deal.

The market ramp-up of electromobility and the associated industrial policy of the EU (giga factories for battery cells) provide a new strategic perspective: it is not just about "waste", but about optimizing the entire life cycle of batteries, a safe and ethically justifiable supply of raw materials and support the climate goals of the EU.

2.2 Battery Recycling in Germany (LIB)

There are different process routes for lithium-ion battery recycling. What they all have in common in Germany, however, is that the battery packs first have to be collected at central locations and taken to the recycling plants. Due to the fire hazard of old battery cells, special safety precautions must be taken for transport.

In the recycling plants, the battery packs are first sorted by type (cell chemistry, cell format, application) and then dismantled to remove peripheral devices (Figure 3). The battery cells are then mechanically processed by crushing them under protective gas, or pyrolytically decomposed by intense heating. This allows the cells to be chemically deactivated.

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Raw materials can then be recovered by hydrometallurgical processes (wet chemical, at low temperatures) or pyrometallurgical processes (use of melting aggregates at high temperatures).

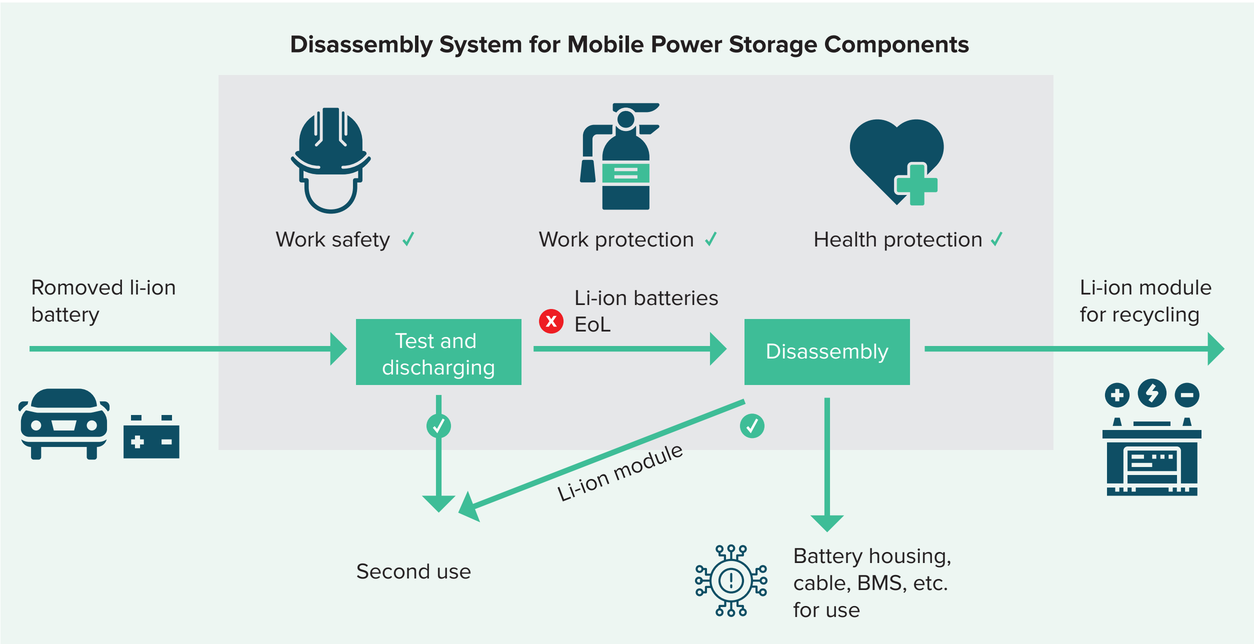


Figure 3 Disassembly system for Mobile Power Storage Components
(Source: Presentation Dr. Buchert, Öko-Institut, Batterieforum 2021)

2.3 Challenges and outlook/development

On the one hand, the existence of appropriate infrastructure, in particular collection systems (e.g. deposit systems), is decisive for the economic viability of recycling, since a large part of the costs of recycling are incurred in these preliminary activities. On the other hand, with the advent of e-mobility, additional costs arise for the separation/ dismantling of the batteries/vehicles, which can impede the economic efficiency of the treatment of such vehicles, for example costs for (re)training employees in dismantling, additional expenses for treatment of two battery technologies (lead-acid batteries and LIB), lack of broad customer structures for old LIB, challenges regarding storage, transport and logistics due to the risk of fire from LIB etc.

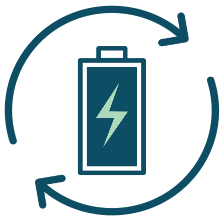
Overall, the major challenges in terms of ambitious and uniform standards at the EU level to date are:

- **Fire protection,**
- **Occupational safety,**
- **health protection,**
- **qualification of employees**
- **Lack of automation to date (lack of disassembly-friendly design, large variety of products, etc.)**

Beyond that, some indicators of battery raw material recycling (including recycling rates) within the EU are currently still relatively weak for LIB, and the EU recycling sector is still partially developing in the battery raw material area. This is particularly evident in the case of lithium and graphite and the extraction of raw materials from end products/ old scrap. Battery recycling is technically possible and there are technologies and pilot plants (on an industrial scale) for battery recycling. Rather, the obstacles to the recycling of batteries lie in the long service life as well as other economic (e.g. costs compared to primary raw material extraction), infrastructural (e.g. lack of collection systems) and technical (e.g. challenges related to storage and transport associated with fire hazards) factors.

The present reality is that the recycling of batteries from e-mobility applications will only be able to make a significant contribution to battery raw material supply in a few decades due to the typical material flow dynamic effects that result, among other things, from the long service life of the batteries.

Due to the increasing demand for battery raw materials, various consequences may arise in the future in the battery raw materials sector including short-term supply shortages, medium-term supplier markets and long-term ore degradation. In this regard, a general promotion of LIB recycling, as well as (environmentally friendly) recycling in all other application areas of battery raw materials (in particular promotion of nickel and cobalt recycling in their diverse application areas outside the LIB area), appears to be the logical response to help mitigate the negative effects of the rapid growth in the demand for raw materials for batteries. Recycling of batteries will contribute to an increased supply through secondary raw materials with lower environmental impact and greenhouse gas emissions. A local / regional recycling industry also provides green and future-proof jobs.



Recycling of batteries will contribute to an increased supply through secondary raw materials with lower environmental impact and greenhouse gas emissions.

Overall, a broad promotion of recycling seems advisable, which, in addition to batteries, also includes other areas of application of battery raw materials (outside the area of application of batteries) (general recycling of nickel, cobalt, etc., i.e. general battery raw material recycling). There are numerous starting points for implementing this funding. In general, the following starting points are possible:

- Adaptation of regulations (e.g. the EU battery regulation): recycling targets and recommended or mandatory minimum recycling (input) quotas
- Establishment or expansion of recycling-relevant infrastructures (collection systems, recycling plants, etc.) worldwide
- Further development of recycling technologies with the aim of increasing the number and quantity of recycled raw materials and increasing greenhouse gas savings
- Improving the exchange of information and cooperation between the actors involved.

Both e-mobility battery recycling and general battery feedstock recycling come with many trade-offs, limitations, and challenges, especially when the greenhouse gas emission reduction constraint is considered. In battery recycling, greenhouse gas emissions, yield and usability of the recovered materials in batteries depend on the recycling process chosen and the raw materials to be recovered, so general statements are difficult to make. Current technological and economic recycling frameworks favour nickel and cobalt, not lithium and graphite, but pilot plants for (industrial scale) lithium recovery exist. In general, future recycling technologies and also the current research and development efforts are decisive for the ecological advantages of recycling e-mobility batteries, since e-mobility battery recycling will only gain in significance in the future.[6]

2.4 Strategic approaches

European Battery Alliance (EBA) and European Commission

In October 2017, the European Commission set up the European Battery Alliance to support the scaling up of innovative solutions and manufacturing capacity in Europe. In May 2018, as part of the third 'Europe on the move' mobility package, it adopted a strategic action plan on batteries, with a range of measures covering raw materials extraction, sourcing and processing, battery materials, cell production, battery systems, re-use and recycling. It sets out a comprehensive framework of regulatory and non-regulatory measures to support all segments of the battery value chain and focuses on 6 priority areas given below.

1. Securing access to raw materials for batteries
2. Supporting European battery cell manufacturing and other investments
3. Strengthening industrial leadership through accelerated research and innovation programmes
4. Securing a highly skilled workforce along the whole value chain
5. Supporting a sustainable EU battery cell manufacturing industry
6. Ensuring consistency with broader frameworks

2.5 Major Market players

Germany has well established market for electric vehicles. As per the Batteries Act, all the business operators provide their services of collection, transport and reuse/recycling in well traced manner. Following are some major recycling and logistics associated firms with their basic operation strategies. It is evident from their businesses that Germany, as part of Europe, has economies stretched across borders. Logistic companies like Reneos and GRS batteries collect batteries from customers from various pickup locations with help of distributors in vicinity. These distributors are provided with collection containers from manufacturers. There after these containers are routed to manufacturers for reuse or recycling through proper traceable channel. Following is the overall procedure of recycling.

6 Agora Verkehrswende

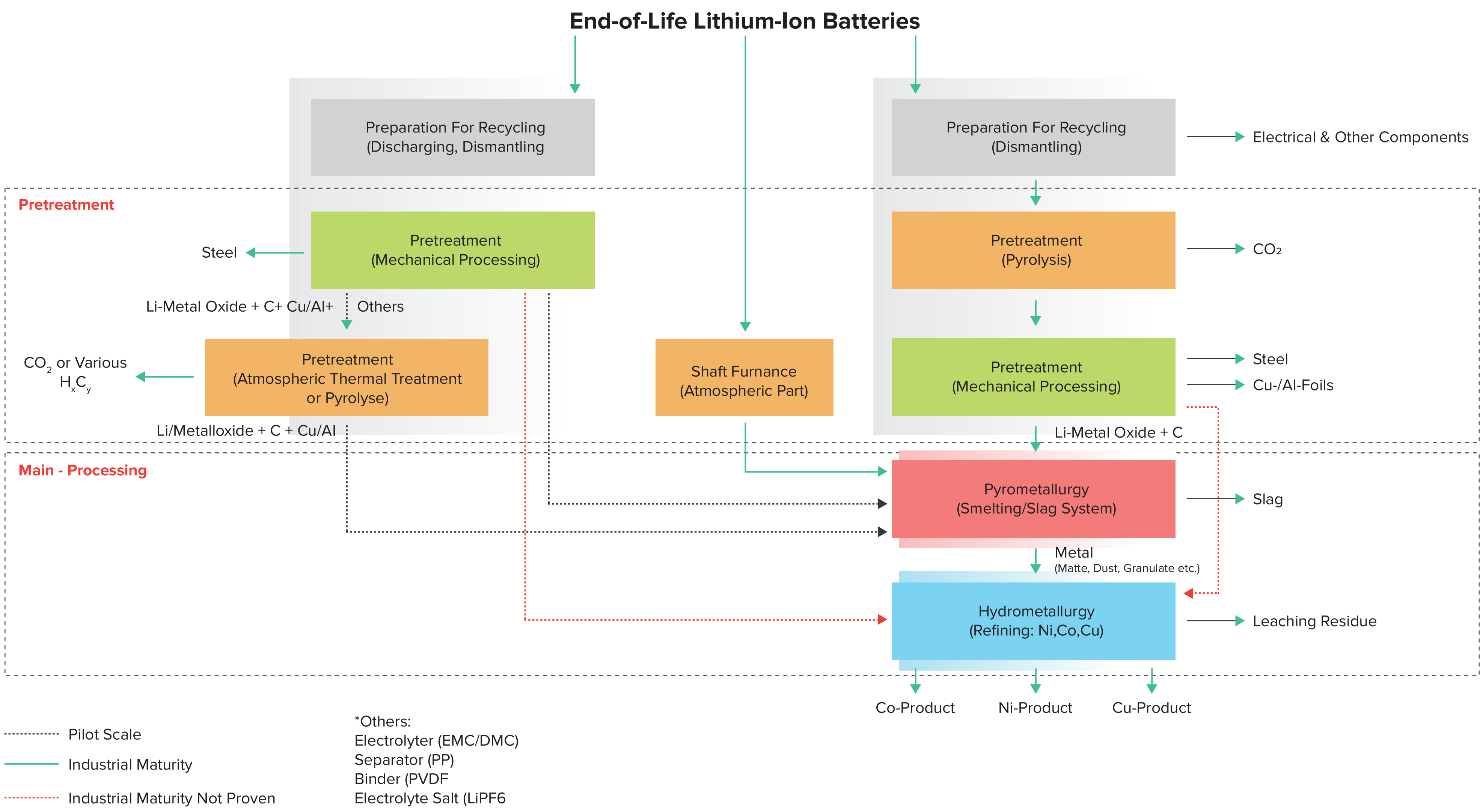


Figure 4 Overall procedure of recycling Li-Ion Batteries undertaken in Germany[7]

7 "Comparative study of Li-ion battery recycling processes," ACCUREC Recycling GmbH, Sept 2020

2.5.1 DUESENFELD GMBH

Duesenfeld[8,9] separates metals and elements form Lithium-Ion Battery in the form that can be used for manufacturing of new batteries' cathode material. Material suppliers are Car Manufacturers, OEMs and Battery Manufacturers.

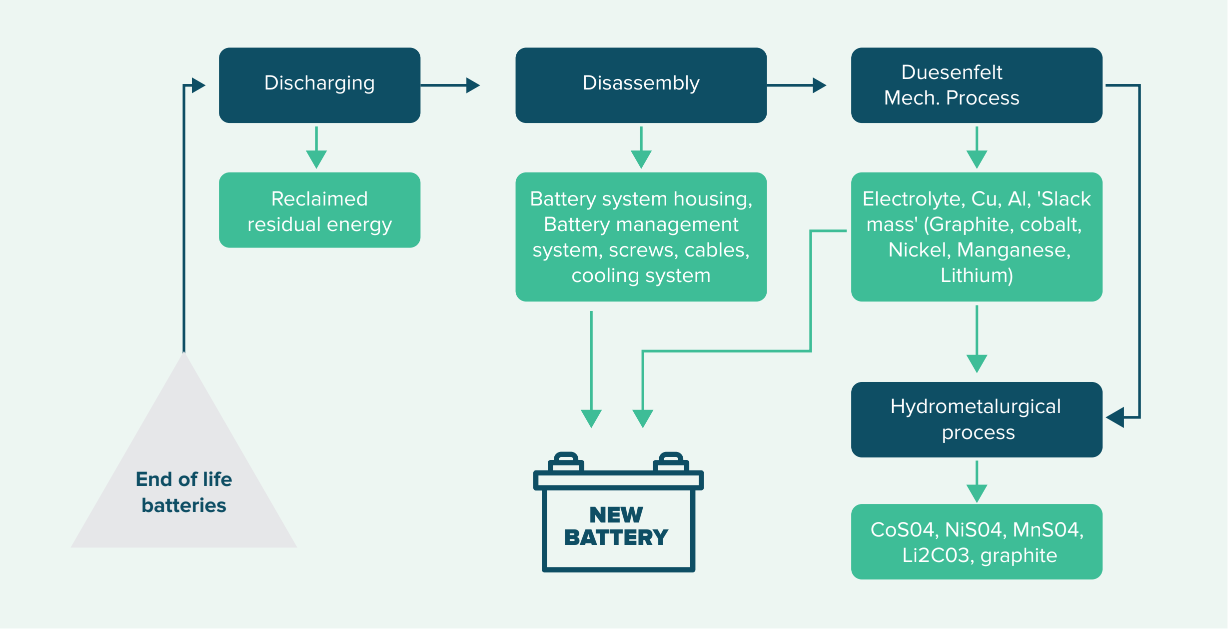


Figure 5 **End of life of Lithium-Ion batteries in Duesenfeld**

Mostly available battery containers are deployed with gasoline powered cars that are converted to EV. So as far as design goes, it's difficult to define any single shape of battery container section. By the time the cars are specifically designed with EV technology so there it has better design for EV battery storage so it's easier to dismantle them.

The possibility of ignition due to presence of electrolyte in battery has been a challenge in battery recycling. Electric, chemical, and burning dangers can be prevented by using mechanized atmosphere.

At the discharging station for further process, the batteries must be discharged completely for safety to zero volts. There are four discharge stations (summing up to 50 kW). The energy from the batteries is stored in them and fed back to grid so that it can be reused in the recycling process. This helps them to finish their first stage work without any external energy addition.

8 "Comparative study of Li-ion battery recycling processes," ACCUREC Recycling GmbH, Sept 2020
9 "Recycling of Batteries from Electric Vehicles," Green energy and technology: Behaviour of Lithium-Ion Batteries in Electric Vehicles, 2018

Procedure

1. Discharge the battery. Use that battery energy to run the process partly.
2. Shredding batteries in Nitrogen atmosphere so that batteries may not ignite
3. Mix the crushed parts in vacuum mixer
4. Evaporate the electrolyte at lower temperature so that Hydrofluride components can be avoided to be formed. Care is taken to keep Fluoride out of contact/reaction with other battery components. Recondensation of electrolyte is done to regain the electrolyte and dry mixture of other materials

Separation here is based on physical processes like, Magnetic separation, density difference, buoyancy difference etc. While smelting (pyrometallurgy) to reobtain nickel and copper is not done here. Pre-incinerate the battery to get rid of electrolyte and graphite (partly).

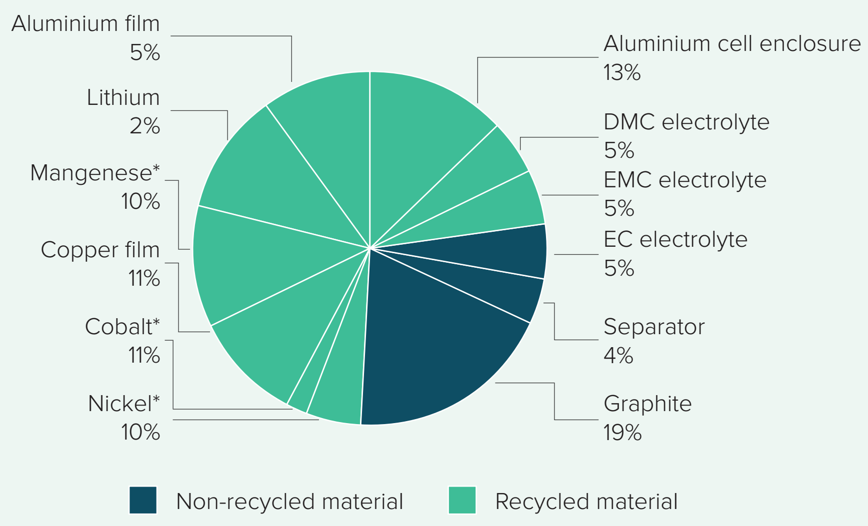


Figure 6 Duesenfeld Li-ion Battery recycling efficiency (Efficiency-72%)

Graphite, cobalt can be recycled via hydrometallurgical process. Cobalt has high carbon footprint, but recycling reduces that. 5 tons of CO_2 is saved by recycling 1 ton of Li-Ion battery. The company is keeping itself ready for saturated market scenario wherein all the material (elements) required to build the battery can hardly be mined. Keeping in mind the economies of scale, the firm has adopted sophisticated methodology to arrive at higher efficiency rate. Currently, the processes here can recycle 91% of battery including graphite and excluding it roughly it goes to 70%.

In hydrometallurgical method all the disintegrated material is treated in acid bath. Then in the liquid phase those are separated. They are reobtained in form of carbonates and sulphates in solid form. The components recovered include Cobalt and Nickel sulphate, Lithium Carbonate and Lithium Hydroxide with high purity. To separate the materials like Nickel and Cobalt which have similar properties, some additional processes are designed. To avoid the risk of fluorine that may form conducting salts by action of hydro fluoric acid, this component is separated in first step of hydrometallurgy so that further steps are risk free.

Metals can be easily recycled. Plastics with specially designed surfaces, some trace elements are added to improve material properties. From thermodynamic point of view, it is difficult to capture all losses. Also, economic trade-offs are evident. Currently the company is operating on very little economic margin. In future the targeted areas will be the car manufacturing hubs were in battery scrap will be their raw material to recycle.

2.5.2 UMICORE

Umicore[10] N.V. based in Brussels, Belgium, is an international material processing company. Energy Materials, Performance Materials, Catalysis, and Recycling are just a few of the company's divisions. A battery recycling pilot facility was tested in Hofers, Sweden in 2011, and was then scaled up and deployed in Hoboken, Belgium (known as subsidiary Umicore Battery Recycling H.Q.). In the Hoboken plant, an authorised capacity of 7000 tons/annum for Li-ion batteries has been declared. Smelting (in a shaft furnace) and subsequent hydrometallurgical treatment stages make up the majority of the Umicore process (see flowchart). Li-ion and NiMH batteries, as well as production trash, are fed directly into the smelter without any pre-treatment. Large industrial batteries, which are first dismantled to a tiny size, are the only ones that are prepared (e.g. cell level). Besides batteries, additives such as coke, sand and limestone (slag formers) are fed into the smelting furnace.

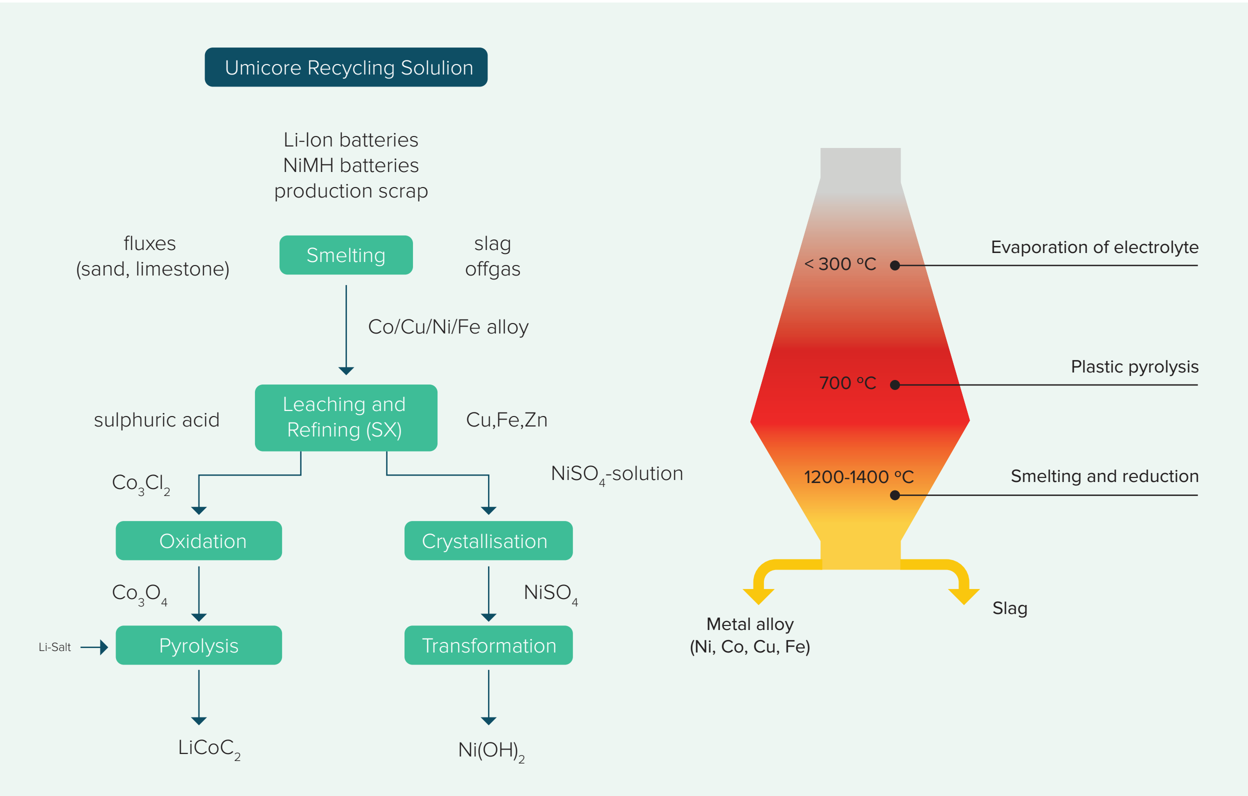


Figure 7 Umicore Recycling and smelting process

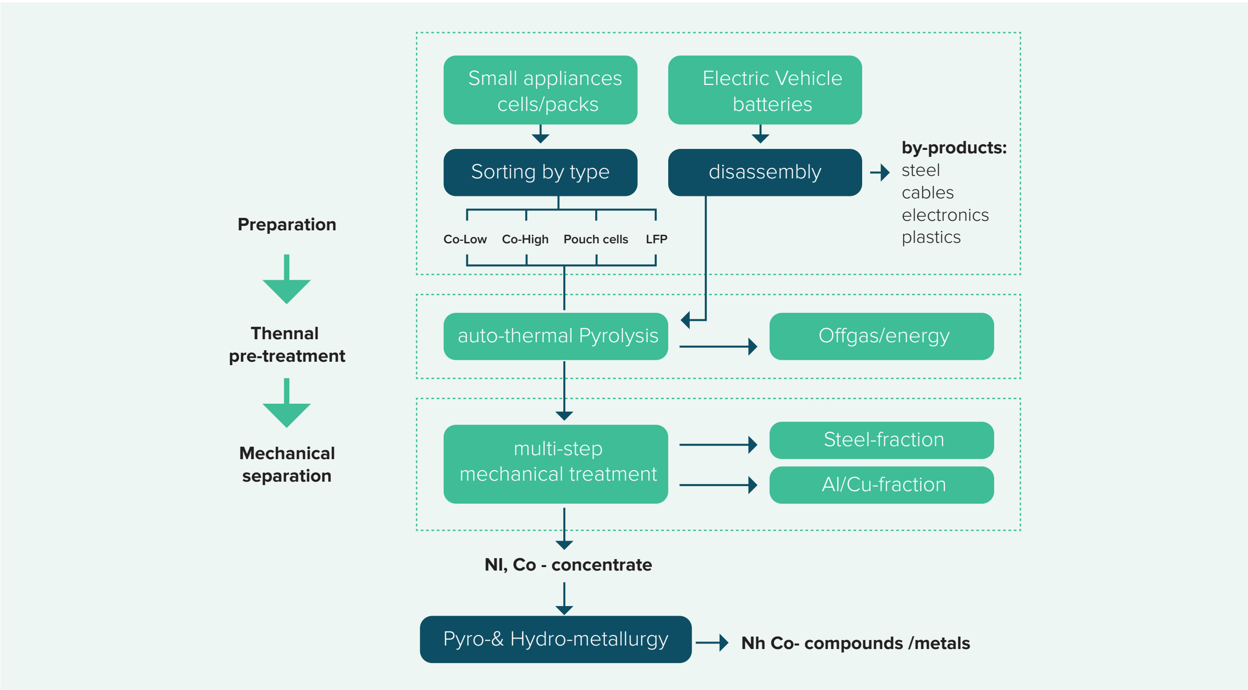
10 "Battery recycling," Umicore, [Online]. Available: https://csm.umicore.com/en/battery-recycling/. [Accessed May 2021]

The smelter can be divided into three zones based on the reactions that occur as a result of the gradual temperature increase in the smelting process: upper zone (300°C), where electrolytes are evaporated, middle zone (700°C), where plastics are pyrolyzed, and bottom zone (1200-1450°C), where smelting and reduction take place. Combustible compounds and reducing agents for metal oxides are organics (electrolyte solvents and plastic housings) and graphite, which account for 25-50 wt% (depending on battery pack structure) of batteries. According to legend, the energy released during these reduction reactions is enough to heat up the smelter. To ensure that no dangerous dioxins or volatile organic compounds (VOCs) are created, a gas cleaning system ("UHT technology") has been installed. In the flue dust, fluorine is captured.

2.5.3 ACCUREC (GERMANY)

Accurec Recycling GmbH[11], is a specialised battery recycling firm situated in Germany that recycles all types of modern rechargeable batteries. It was formed in 1995. It recycles batteries through the Thermal, Mechanical, Pyro, and Hydro routes. Li-ion batteries can be recycled at Accurec for both portable and industrial uses, including car batteries. Accurec launched a new dedicated Li-ion recycling centre in Krefeld, Germany, in 2016. In 2021, Accurec reached a Li-ion battery treatment capacity of 4300 tons/annum. Accurec recycles Li-ion batteries via thermal pre-treatment and mechanical separation, as described in the previous categories. Batteries must first be prepared, which includes sorting, disassembly, and discharge (depending on needs). After that, Accurec cracks and pyrolyzes the organic components using thermal treatment (in a rotating kiln, currently via external service). To avoid oxidation of certain unnoble metals like Al, the temperature in this rotary kiln treatment is limited to 600°C. Afterburner and quenching system clean the off-gas, and the extra energy from the burning of organic components is converted to high-pressure steam and used in industrial processes. After that, Accurec' s in-house multi-step mechanical separation plant screens, crushes,

Figure 8:
Accurec Recycling process



11 "Battery recycling Accurec," Accurec, [Online]. Available: https://accurec.de/. [Accessed May 2021]

and sorts the pyrolyzed battery cells. Steel fraction, Cu/Al fraction, and Co- and Ni-rich electrode powder are output products. The steel and Cu/Al fractions can be transported to metal smelting facilities for metal recovery, while the CoNi concentrate can be sent to pyrometallurgy and subsequent hydrometallurgy plants for the final recovery of Co- and Ni-salts or -metals. With the advancement of technology, Accurec is now developing and installing new equipment, which will be operational at the company's Li-ion battery recycling centre at Krefeld from 2022. In addition to nickel, cobalt, and copper, lithium and graphite will be recovered in the future.

2.5.4 NICKELHÜTTE AUE (GERMANY)

Nickelhütte Aue GmbH[12] (NHA) is a pyrometallurgical works and recycling company that was founded in 1635 in Aue, Germany. NHA is a company that specialises in the recycling of non-ferrous metal-containing garbage. Nickel, Copper, Cobalt, Vanadium, Molybdenum, and precious metal containing wasted catalysts from chemical and pharmaceutical industries, as well as petrochemical industries and hydrogenation operations of oils and fats, are of particular interest to the facility. They can also treat various types of residues, such as ashes, dusts, grindings, liquids, and slurries, as long as they include one or more of the metals listed above.[13 14].

NHA has been working in the recycling of Li-ion batteries since 2011. Thermal pre-treatment, pyrometallurgy, and hydrometallurgy are the primary components of the recycling process. The batteries can be melted in a short drum furnace (batch-wise furnace) to produce NiCoCu-Matte during the pyro-treatment stage. In addition, the company uses a rotating kiln to thermally pre-treat the batteries in part. There is currently no more comprehensive information available concerning the final hydrometallurgy treatments. Using a thermal rotary kiln for pre-treatment, the process capacity is estimated to be 7000 tons/annum.

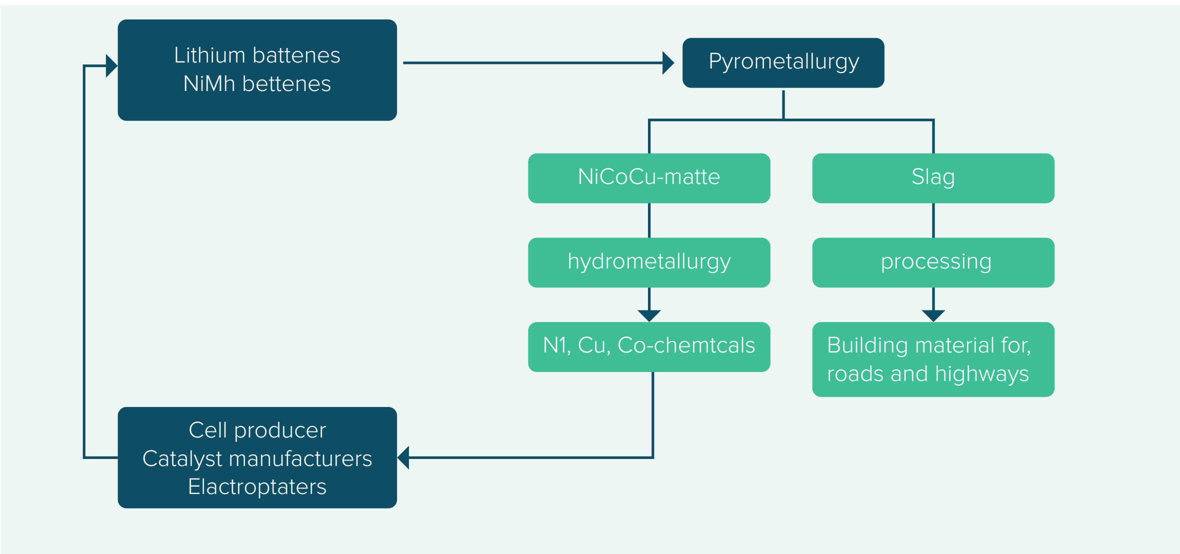


Figure 9: Nickelhütte Aue recycling process

12 "Comparative study of Li-ion battery recycling processes," ACCUREC Recycling GmbH, Sept 2020.
13 "Batteries Act," Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2015. [Online]. Available: https://www.bmu.de/en/law/batteries-act/. [Accessed May 2021]
14 "Gesetz über das Inverkehrbringen, die Rücknahme und die umweltverträgliche Entsorgung von Batterienund Akkumulatoren (Batteriegesetz- BattG)," Jan 2021. [Online]. Available: https://www.gesetze-iminternet.de/battg/BattG.pdf. [Accessed June 2021]

2.5.5 RENEOS

Reneos[15] provides a full variety of services for old car batteries, including legal compliance, shipping, storage, recycling, secondary life, and more. They collaborate with each country's current consumer compliance organisation. Customers can also select a partner from their existing network. They offer an online tool that allows customers to pick up their batteries and track their progress. The company works in following way:

- A producer and Reneos agree to work together for any number of countries in Europe and may be beyond.
- A car producer chooses which services he wants (just logistics or added recycling or added dismantling or not) and national network members he prefers
- To request an EV battery collection, dealers and car dismantlers in each country go to Reneos' website in their native language. Reneos is at ease using any other existing online payment platform.
- Reneos distributes the collection request to the client's chosen network members, such as GRS, Cobat, Bebat, Batteriretur, Stibat, etc.
- The National network member collects and handles the EV battery in accordance with the car manufacturer's instructions, adhering to all applicable regulations, and stores and delivers the EV battery to agreed-upon recyclers or performs agreed-upon extra services such as ship for diagnosis or ship for second life.
- All stakeholders, including dealers, car manufacturers, network members, recyclers, and others, can track the status of collections and deliveries, but only for their own relevant content.
- Post recycling, manufacturers will decide about the battery reuse, recycle or should be given a second life.

2.5.6 GRS BATTERIES GmbH

As a take-back system, GRS Batteries[16] fulfil complete product responsibility for a manufacturer or distributor of device batteries or industrial batteries in accordance with the Battery Act. As a non-profit organization, GRS Batteries follow the principle of equal treatment, pass cost advantages on to customers and are committed to protecting the environment. On this basis, safe and efficient product responsibility from users is taken.

GRS Service GmbH is a 100% subsidiary of the GRS Batteries Foundation. The foundation's operational take-back system is operated and efficient and safe solutions for the sustainable fulfilment of the statutory product responsibility of battery manufacturers and distributors is offered: from registration with the Federal Environment Agency through collection and recycling to assuming information obligations. The GRS return system for portable batteries and the GRS industry return

15 "Tailor-made solutions for end-of-life Li-ion batteries across Europe," Reneos, [Online]. Available: https://www.reneos.eu/. [Accessed May 2021]

16 "Stiftung GRS Batterien," [Online]. Available: https://www.grs-batterien.de/index/. [Accessed May 2021]

systems[17] for industrial batteries are based on the solidarity principle and are the simple, efficient and transparent solution for fulfilling product responsibility. When collecting, storing and transporting batteries, the GRS collection containers ensure maximum safety. With information and qualification program, all those involved and responsible - manufacturers, distributors, collection partners, consumers - receive comprehensive instructions to handle batteries. The role of the firm is listed below:

- Take care of the registration with the responsible authority for manufacturers of batteries or their authorized representatives.
- On behalf of manufacturers or their authorized representatives, distributors and treatment facilities are offered a reasonable and free option of taking them back. As part of industry solutions and at the customer's request, collection containers are made available and dispose of all batteries collected by the collection points for proper recycling is processed.
- Distributors are obliged to take back old batteries from the end user. For the free return of batteries in the retail business or in the immediate vicinity, distributors are equipped with collection containers as part of our industry solutions or at the customer's request and collect filled containers in order to send the recorded batteries for recycling.
- Properly guaranteeing the recycling of battery with efficient methods.
- On behalf of the manufacturers or their authorized representatives, distributors with information and communication tools that are suitable for informing end users in a legally compliant manner.

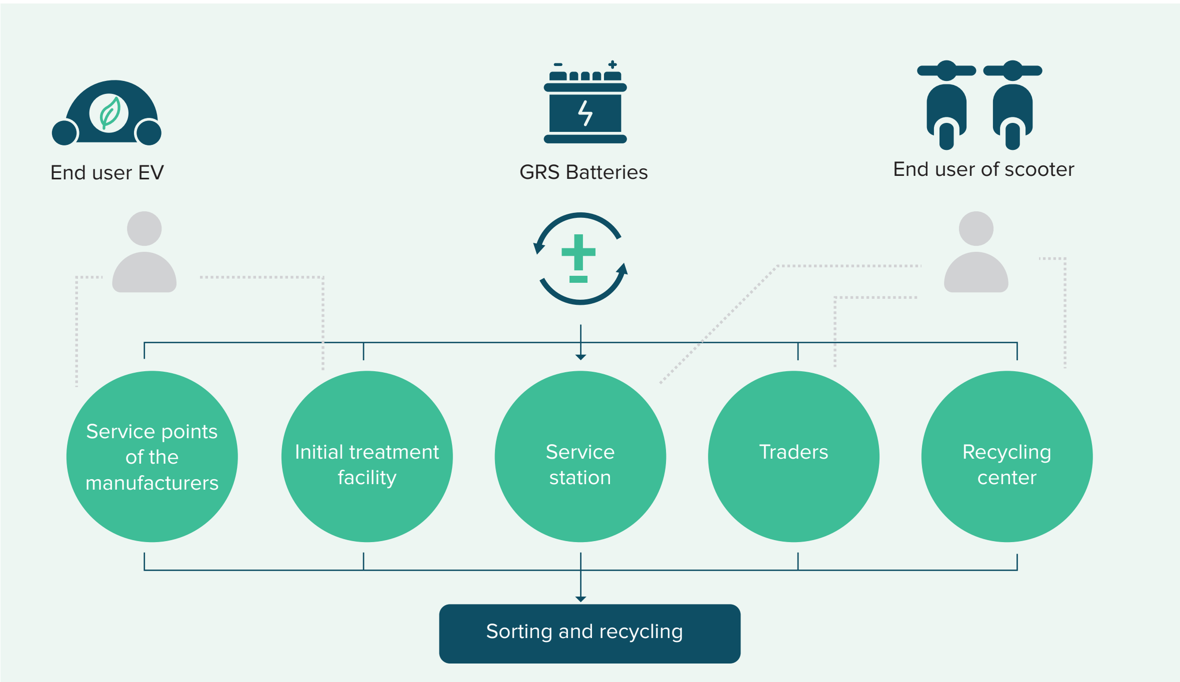


Figure 10 GRS batteries- partnership map

17 "Solution for all-rounders," GRS Batteries, [Online]. Available: https://w43ab56c4i3sje6sgzpyyiebhiac4c6men2g7xr2a-www-grs-batterien-de.translate.goog/hersteller-und-vertreiber/industriebatterien/. [Accessed May 2021]

2.6 Conclusion

A significant number of national and international activities in LIB recycling have been launched by the corporate and public sectors in the last decade, along with the rise of xEVs. Although general trends in various domains related to traction battery recycling may be observed, the high dynamics and fresh advancements in this new market have created unavoidable uncertainty. In terms of legislation, there are currently no explicit rules in place for traction batteries in the major markets. Furthermore, there are considerable differences in the legislation for the management of waste batteries in general. Some laws still allow landfilling, whereas others have tight recycling procedures and criteria. Currently, EU legislation appear to be the best fit for ensuring organised battery recycling, while particular regulations for xEVs and traction batteries are lacking. Regardless of this, the adoption of the new EU Battery Regulation, which is still likely for 2022, can be expected to significantly improve the framework conditions here.

A landfill ban, the expanded producer's responsibility principle, and recycling efficiencies are all important components. The EU and the PRC are presently working on special legislation in light of the rising return flows. The rest of the world is anticipated to follow suit. All recycling routes begin with the removal of the battery from the EOL vehicle, which is then disassembled down to the module/cell level. This enables the diverse material fractions of the battery infrastructure, which account for around 40% of Li-Ion battery weight and 65% of lead acid battery weight, to be directed to specific recycling procedures. At the moment, processes can recover 70% of components from Li-Ion batteries and 98% from lead-acid batteries. Two recycling approaches have been designed in theory and partially executed. The first method is similar to the previously discussed co-processing with pyrometallurgy and hydrometallurgy. In terms of logistics, an optimum strategy is used for the positioning of distributors in the market for the purpose of collecting. The batteries are then processed for reuse/recycling according to customer demand in a well-tracked way.

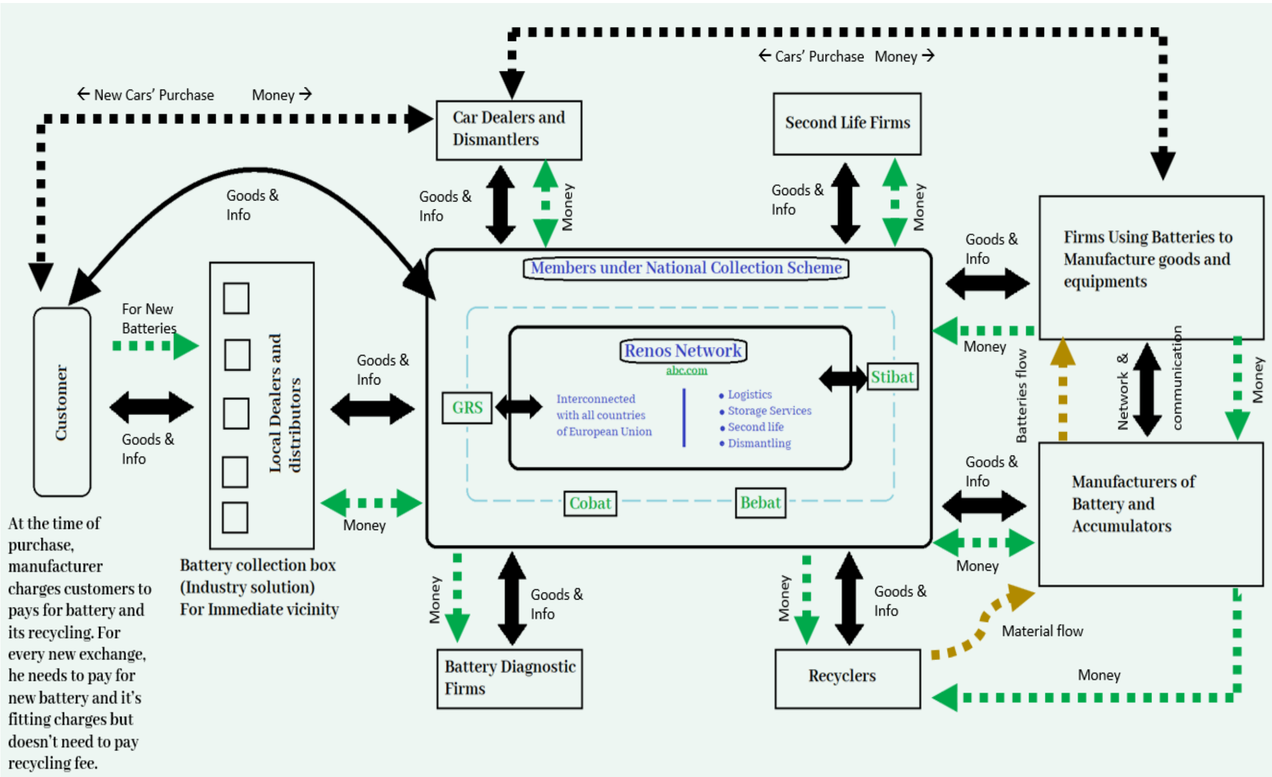
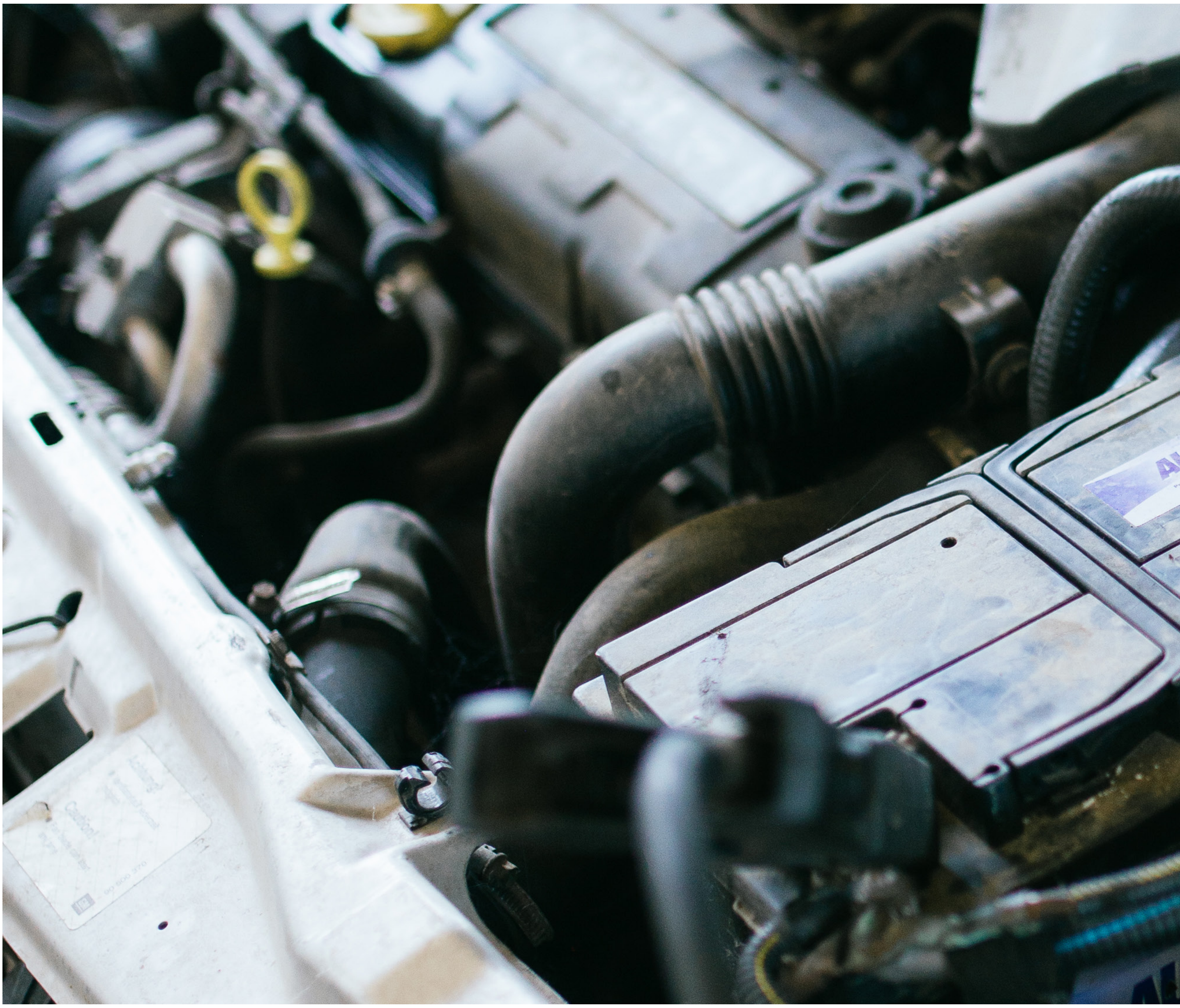


Figure 11 Overall understanding of battery flow process

There exists wide network for logistics (e.g. Renos) which has its network setup in various countries of Europe. As per National Collection scheme, there are registered battery collection logistic services (e.g. GRS) which have freedom to operate within the boundaries of a specific country in Europe. They may have their own website to monitor the flow of batteries as well as payment settlement or may register with Reneos (Common logistics firm all over Europe). Reneos has capability to integrate other online platforms also. All other stake holders are supposed to get registered with this online platform. When customers come with old battery to be swapped with new battery at local dealer, the dealer replaces the old battery for a new battery without any fee based on cost advantage and equal treatment policy to customers. Customers have to pay for new batteries and their fitting but no recycling charge. Distributors can dispose the batteries themselves or return them to the manufacturers free of charge. Manufacturers should finance the costs of collecting to logistics, treating and recycling all collected batteries and accumulators minus the profit made by selling the material recovered. However, under certain circumstances the application of de minimis rules to small producers could be justified.



Second life firms for batteries have their own ecosystem wherein they receive old used batteries dismantled from dismantlers and hence they can retrofit to make new battery for other low power density functions. Those second life batteries are sold to Power generation and ancillary system firms. After their retirement, these batteries again follow same logistic route and this time straight to recyclers.

There are some Battery diagnostic firms which help these firms to further route the batteries. In former case, battery diagnostic firms are paid by manufacturers and in later case, second life battery manufacturer firm pays. No money is charged from the customer in any case for recycling.

California (United States)

3.1 Overview

Waste batteries are just categorized as hazardous waste and no other rule of law existed in this regard. AB 1125 (the Rechargeable Battery Recycling Act of 2006) was approved in California in 2005, prohibiting the disposal of all household batteries in landfills and requiring merchants to accept rechargeable batteries for recycling at no cost to consumers. It does, however, address the proper disposal of batteries by providing a location for consumers to recycle rechargeable batteries. The laws regarding rechargeable batteries are outdated in terms of technology. In 2006, the recycling of batteries marked a very low score i.e. only some Lithium (0.55% of 507,259,000 batteries sold in California in the year 2001), was recycled and added to market again. The reasons may be that the batteries were still in use, or they are kept unutilized or improper disposal of batteries might have taken place due to the costly affair of recycling. The recycling technique was quite unpopular due to fire hazard noticed in public as well as recycling facilities. Such reasons were the main reason to ask for the shut-down of newly opened firms. So far, the history of battery recycling technology in Li-Ion Recycling, developments can be traced back to 1994, when Toxco brought hydrometallurgy into use. The main cause of the fire is the reactive nature of lithium. Due to accidental contact (short-circuiting) of cathode and anode in the battery while dismantling or disintegrating it, the separating layer i.e., micro-perforated plastic ruptures. This is all due to bad design. This accidental contact causes heat production. Lithium beyond 400 ▯ vaporizes exerting pressure on battery casings. This causes electrode deformity and thereafter battery becomes more prone to short-circuiting. During recycling also this problem is evident as it is difficult to know all the design standards of battery manufacturing. Fire in the recycling facility is a cause of shut down of many facilities. Therefore, without permission of the Department of Toxic Substance Control (2007) [DTSC], no firm can treat, store, dispose-off hazardous waste batteries. Apart from all these issues, there is a need to foster a rapid recycling program of Li-Ion Batteries due to EVs. The prices of precious metals are rising exponentially due to their limited resources and so does the cost of batteries.

3.2 Policy overview

3.2.1 LEAD ACID BATTERY

As per Lead Acid Battery Recycling Act[18] (Sept 2016), Lead acid batteries must not be disposed in Solid waste facility, land, surface, water courses, marine water, etc. but can be disposed in special facility made for this purpose only. Dealer is obliged to collect the used lead acid battery in exchange for new lead acid battery purchased by customer. It will be treated as misdemeanour if dealer fails to do so. At point of transfer, dealer is prohibited to charge any fee to accept used lead acid batteries of specified type from customer if used batteries, of same type and size, are available for exchange. If customer is unable to produce used battery at the time of purchase of new battery, there is provision of refundable deposit to be paid by customer towards dealer. If customer can submit used lead acid battery within 45 days after the purchase of new battery, the amount will be refunded by dealer to customer. For this purpose,

18 C. Garcia, "The Lead-Acid Battery Recycling Act of 2016," California Legislative Information, California, 2016

Customer will be provided with notice or additional attachment with the receipt of new purchased battery by dealer mentioning these norms of 45 days refundable deposit policy. Failure in submission of batteries by customer in the stipulated time allows the dealer to keep charged money with him. If the notice or additional attachment is not provided in this regard by dealer, there is provision of 60 days civil penalty system on the person involved. The penalty shall not exceed $1,000 per day, but if the violation is intentional, knowing, or reckless, the penalty may go up to $10,000 per day. Under this penalty following people are excluded:

- People who are not involved in direct sales of lead acid batteries
- People who are there to just replace the batteries in automotive (like garages that just replace batteries and don't sell it)
- Roadside service for battery replacements

Replaced new battery will possess a recycling symbol on it. This symbol will be placed by dealer at the time of sales.

From 1st April 2017 to 31st March 2022, there is mandatory provision to charge $1 per battery in the name of California battery fee by dealer. Dealer can keep 1.5% of the amount obtained in this case ($1) as his expanses towards getting the fee and putting it in to the channel (in Battery clean-up fund as the provision mentioned in the bill). The three purposes of this clean up funds are:

- Any area of the state that is reasonably suspected to have been contaminated by the operation of a lead-acid battery recycling factory is subject to an investigation, site review, cleanup, remedial action, removal, monitoring, or other responsive actions.
- Management of the Lead-Acid Battery Cleanup Fund, as well as the administration and implementation of this article by the department.
- Repayment of the loan (The measure would compel the board to borrow $1,200,000 from the California Tire Recycling Management Fund to implement the collection of the California battery fee and the manufacturer battery fee, with the loan to be repaid by October 1, 2017.)

After 1st April 2022, the fee will be $2 per battery. Manufacturers of lead Acid battery are required to pay $1 per battery manufactured, under Manufacturer battery fee from 1st April 2017 to 31st March 2022, sold to retailer/ wholesale distributor/ dealer/ person). After 31st March 2022 the fee may be revised.

3.2.2 LITHIUM-ION BATTERY FOR AUTOMOTIVE

[19]Every retailer, as specified by the Rechargeable Battery Recycling Act of 2006, must have a system in place for accepting and collecting spent rechargeable batteries for reuse, recycling, or proper disposal. Existing law mandates that the system for accepting and collecting used rechargeable batteries contain, at a minimum, certain components,

19 Dahle, "Recycling: lithium-ion vehicle batteries: advisory group," California Legislative Information, California, 2018

such as the free return of a used rechargeable battery of the type or brand that the store sells or previously supplied to the consumer.

This bill would require the Secretary of Environmental Protection to convene the Lithium-Ion Car Battery Recycling Advisory Group on or before April 1, 2019, to review and advise the Legislature on policies pertaining to the recovery and recycling of lithium-ion batteries sold with motor vehicles in the state, and to appoint members to the committee from specified departments, vocations, and organisations. The bill would require the advisory group to consult with specified entities and submit policy recommendations to the Legislature on or before April 1, 2022, aimed at ensuring that as many lithium-ion batteries as possible are reused or recycled in a safe and cost-effective manner at end-of-life. The law would make it mandatory for policy proposals to take into account certain factors. On January 1, 2027, the bill would abolish these provisions.

3.2.3 LITHIUM-ION CAR BATTERY ADVISORY GROUP (18TH NOV 2019)

Intention: To provide a background to the science, uses, and regulations related to the disposal of lithium-ion batteries, especially those used in electric vehicles. Here, background means to educate and inform the reader/ stakeholder who will serve as the secretary of California Environment Protection Agency's (CalEPA) Li-ion Car battery recycling advisory group.

Stakeholders:[20] Environment Protection Community, Auto dismantlers, Public & Private Manufacturers, firms associated with Collection, transport, processing and recycling of Batteries, DTSC, CalEPA and CalRecycle, California Energy Commission, Californians Against Waste, Earthworks, Occupational Knowledge International, Honda Trading America, Ford Motor Company, Alliance of Automobile Manufacturers, California New Car Dealers Association, Umicore USA, Surplus Service, SA Recycling, Kinsbursky Brothers International, The Rechargeable Battery Association, Sustainable Energy Solutions, Central Contra Costa Sanitary District, Southern California Association of Governments.

Barriers:

- Cost feasibility
- Success in the recovery of all metals. Pilot projects were undertaken
- Battery design standardization
- Costly and hazardous manual disassembly
- Collection and subsequent transportation go costly and tedious
- Energy-intensive procedure
- Problems in incorporating changes in battery manufacturing technology in near future.

20 "Lithium-ion Car Battery Recycling Advisory Group," CalEPA, 2019. [Online]. Available: https://calepa.ca.gov/climate/lithium-ion-car-battery-recycling-advisory-group/. [Accessed May 2021]

- Risk in business feasibility for recycling batteries as cobalt will be replaced with proper cheaper abundant substitute causing less return value for products recovered and more expanse on energy-intensive procedures.
- No standard way to test battery life
- Performance guarantee from outdated batteries

This meeting laid down presented probable future challenges in this area of EV battery recycling. To target the barriers, a planned policy layout was needed. Hence Advisory group drew a work plan on Dec 14th, 2020.

3.2.4 DRAFT PLAN OF ADVISORY GROUP

Period - Dec 2020 to March 2022

Aim - To develop policy recommendations for California Legislature ensuring nearly 100% participation of Li-Ion batteries of the state into recycling or recycled with safe and cost-effective end-of-life scenario.

Policy recommendations shall reflect - Possibilities and obstacles for repurposing the batteries into energy storage devices after they've been removed from the vehicle. Best management concerns for those batteries that have reached the end of their useful life. The overall impact of management methods on the environment and individual health.

Proposed subgroups - To bring this aim under the working umbrella, total work was subdivided into three parts.

1. **Reuse** - This refers to the reuse of a battery in another vehicle or for another purpose like stationary energy storage.
2. **Recycling** - This refers to material recovery via mechanical separation, Pyrometallurgical or Hydrometallurgical recycling purpose
3. **Logistics** - This encompasses removal of the battery from the vehicle, testing to determine and appreciate second usage possibilities and value, collection & sorting, transport and tracking.

Proposed timeline

1. Dec 2020: Create subgroups and define the scope
2. Jan 2021: Finalize subgroup assignments
3. Phase I: Jan – March 2021
    a. Identify opportunities and barriers
    b. March 2021 - present the draft report outline including opportunities and barriers
4. Phase II: March – July 2021
    a. Identify policy options to incentivize opportunities and overcome barriers
    b. July 2021- Draft policy options summary and present to Advisory group
5. Phase III: July to Dec 2021- Complete draft for the final report
6. Phase IV: March 2022- Complete final report

Workplan details

Phase I: Identification of Barriers and opportunities (Jan – March 2021)

Goals

1. Get a complete understanding of laws in California as they currently stand. All allowable and non-allowable activities must be considered.
2. Based on federal and state laws, what kind of program should be applicable in California. Should the facility be located/based in California? All the barriers to starting the facilities in California
3. Total capacity required (in terms of investment and manpower). Approximate date of plant erection and commissioning. Tentative date of operation in 100 % Potential capacity of the facility.

Phase II: Options to address barriers

Here policy solutions will be made to existing barriers that could help achieve nearly 100% reuse/ recycling of Li-Ion batteries circulated in the state. The support is taken from the University of California, Davis (UCD)

Goals

1. Search for the options that address barriers in incentivizing the reuse of batteries with enough safety ensured.
2. Search for the options that address barriers and recycling of batteries causing minimum environmental and economic costs while recovering key materials
3. Search for the options with safe and efficient logistics to support reuse and recycling.

Phase III: Compile and a complete draft of the final report (July – December 2021)

Phase IV: Report will be edited by the Advisory Group and presented in March 2022.

3.3 EPR guideline

3.3.1 LEAD ACID BATTERIES[21]

CalRecycle defines extended responsibility (EPR) as a strategy that places a shared responsibility for end-of-life product management on producers and all entities involved in the product chain, rather than the general public, while encouraging product design changes that have the least negative impact on human health and the environment at every stage of the product's lifecycle. This permits treatment and disposal expenses to be factored into the overall cost of a product. It places the major duty for design and marketing decisions on the producer, or brand owner. It also creates an environment in which markets arise that accurately reflect a product's environmental implications, and to which producers and consumers respond. EPR provides an incentive to eliminate waste and pollution through product design modifications by moving the costs and responsibilities of product disposal to producers and others who benefit directly.

21 C. Garcia, "ASSEMBLY COMMITTEE ON ENVIRONMENTAL SAFETY AND TOXIC MATERIALS- Lead-Acid Battery Recovery and Recycling Act," 2016. [Online]. Available: http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_2151-2200/ab_2153_cfa_20160408_163951_asm_comm.html. [Accessed April 2021]

3.3.2 LI-ION BATTERY[22]

In the case of Li-Ion batteries, the EPR is unclear, but the battery passport may be a viable alternative.

3.4 Technology used for recycling

3.4.1 LEAD ACID BATTERY[23]

There are two types of lead recovery technology. Specifically, the pyro and hydrometallurgical routes. Electrowinning processes are used in the hydrometallurgical route. Pyrometallurgical lead recovery procedures include several thermal smelting approaches, which involve heating waste in a variety of furnaces to remove lead (Pb). In terms of material efficiency, 100 percent recycling can be accomplished by optimising the process. The thermal method is suited for lead acid battery metallic components. Hydrometallurgical followed by electrowinning procedures are preferable for recovering lead from lead salts because they avoid the necessity for smelting non-metallic lead components at high temperatures. Dissolving lead from non-metallic battery components such as lead sulphate and lead oxide from battery sludge is done using hydrometallurgical and electrowinning processes. After obtaining soluble species, electrowinning is employed to extract metallic lead from solution. Electrochemical reactions deposit lead at the cathode in this procedure.

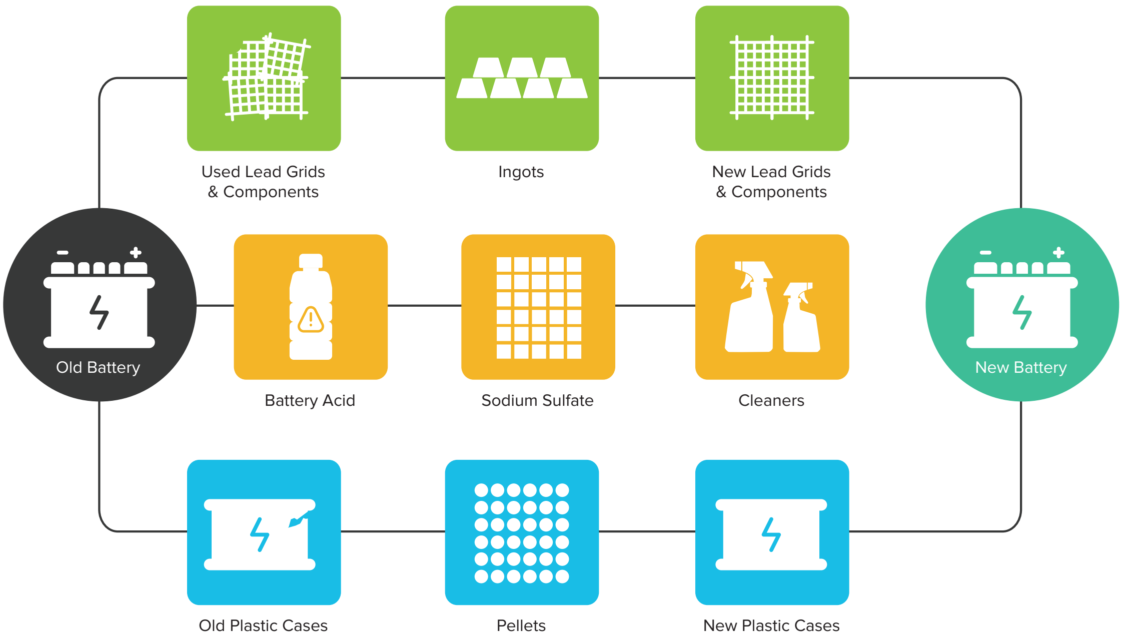


Figure 12 Lead Acid Battery Recycling technique

22 "Lithium-ion Car Battery Recycling Advisory Group Meeting #5 Draft Minutes October 13, 2020," [Online]. Available: https://calepa.ca.gov/climate/lithium-ion-car-battery-recycling-advisory-group/meeting-minutes-for-10-13-20-lithium ion-car-battery-recycling-advisory-group/. [Accessed May 2021]

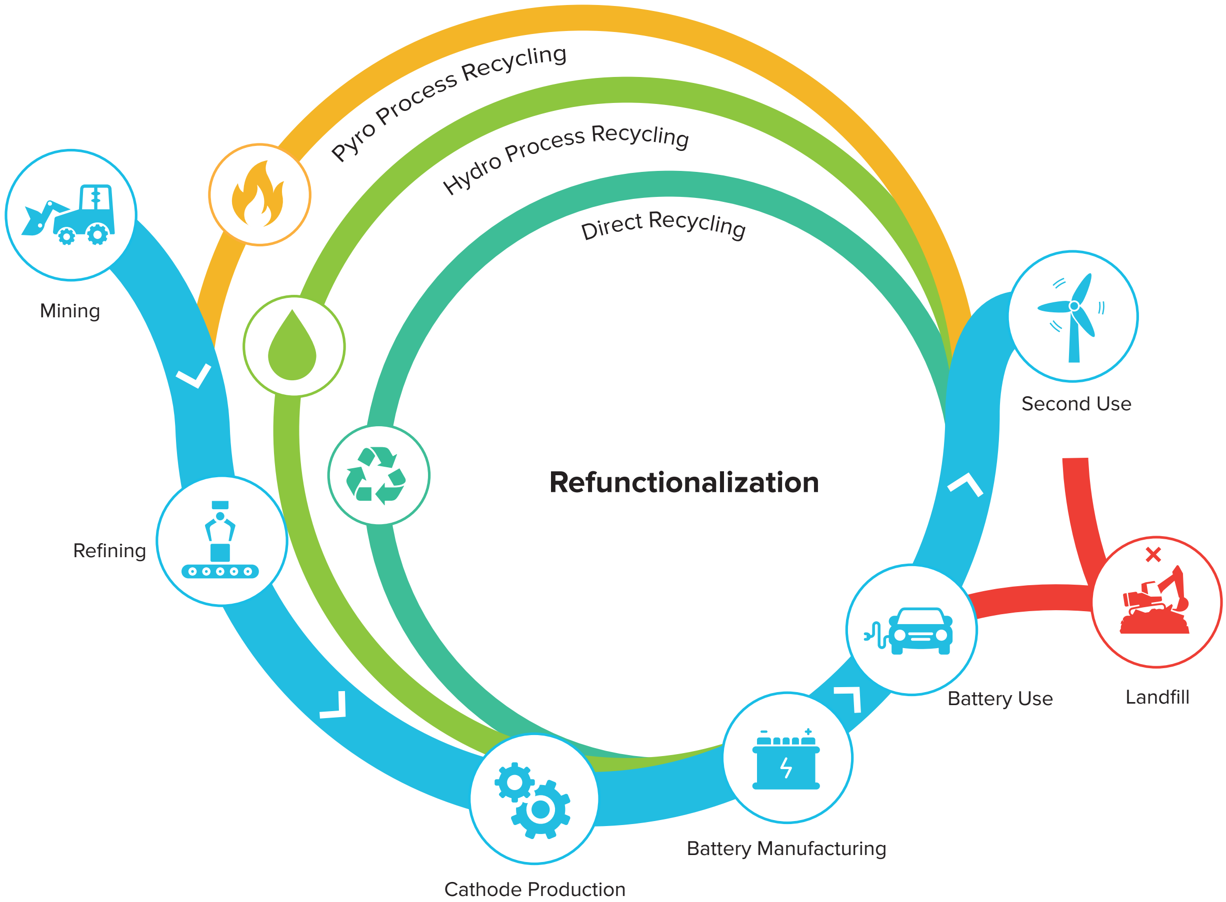
23 R. J. C. H. Laura Vimmerstedt, "Impact of Increased Electric Vehicle Use on Battery Recycling Infrastructure," https://www.osti.gov/servlets/purl/414298, 1996

3.4.2 LI-ION BATTERY[24,25]

In California, not many Li-Ion battery recyclers are in function. The method used as shown in below figures explain about three routs viz. Pyrometallurgy, Hydrometallurgy and Direct method. Pyrometallurgy is easier to implement but yields less material output. Hydrometallurgy route is bit efficient but expensive. Hence a trade-off is balanced between both the processes. Companies try various permutation and combinations with some external technology addition to reduce energy intensive nature of extraction. Those processes are made prior to metallurgical process and are physical in nature like magnetic separation and buoyancy. As the battery is available to recycling firm after its end-of-life usage, they are shredded into pieces followed by electrolyte extraction by vacuum distillation at slightly elevated temperature. These shredded pieces contain cathode, anode materials, aluminium, steel, copper, cobalt Nickel, plastic, etc. Some places involve electrolyte recovery prior to shredding as an advancement and method to prevent from fires. After this phase metallurgical phase starts. This stage gives out useful metals in their pure compound form. Under normal circumstances, Lithium was not recoverable, but Retriev technologies have the method to obtain Lithium in form of carbonate. Thereafter materials are reused to manufacture new battery and they are ready for the deployment in to EVs.

24 S. G. Jeff Spangenberger, "ReCell Advanced Battery Recycling Center: First Quarter Progress Report 2021," The ReCell Center, U.S. Department of Energy's (DOE), 2021

25 D. H. Ambrose, "Reuse and Recycling of Lithium-ion Batteries for Motor Vehicles: Background information for the
California Lithium-ion Battery Recycling Advisory Group," Union of Concerned Scientists. University of California, Davis, California, Jan 2020



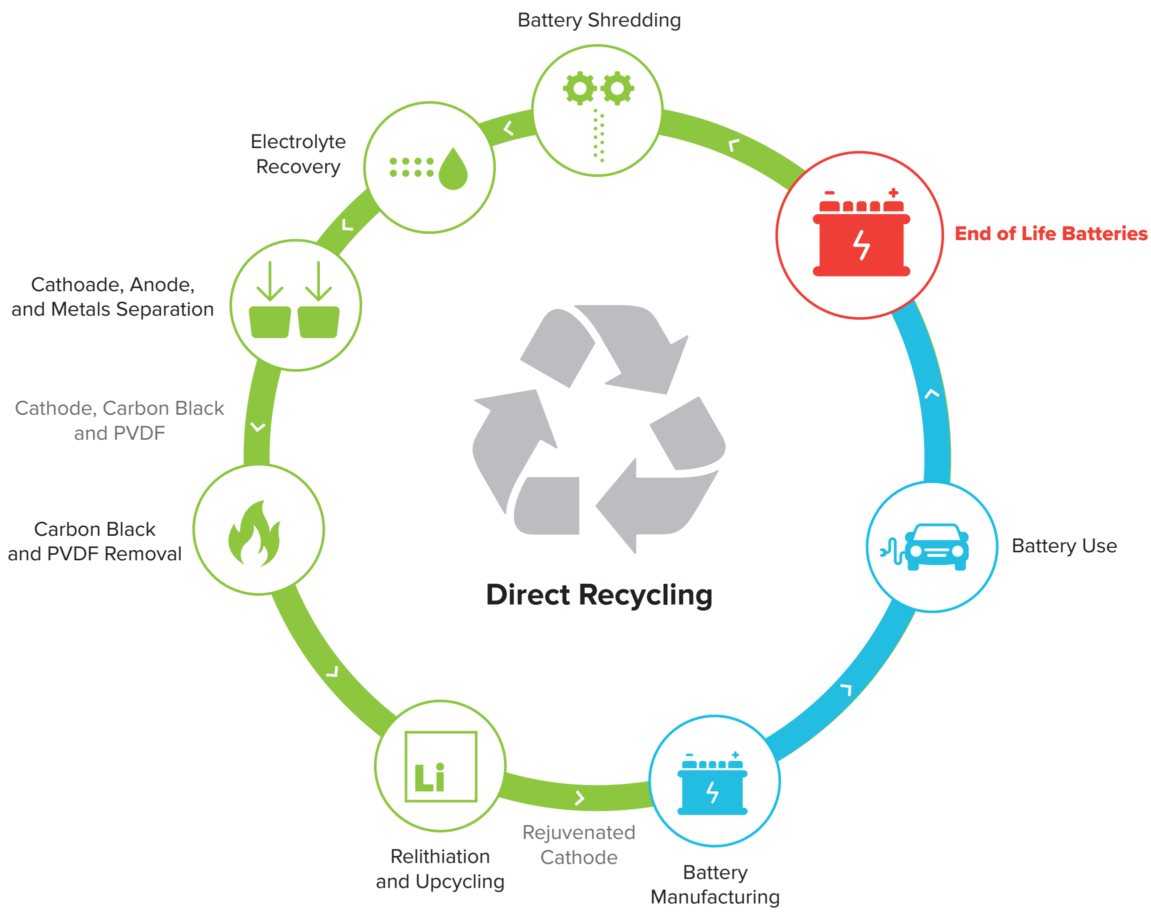


Figure 13 **General Recycling Methodology of Li-Ion Battery in California**

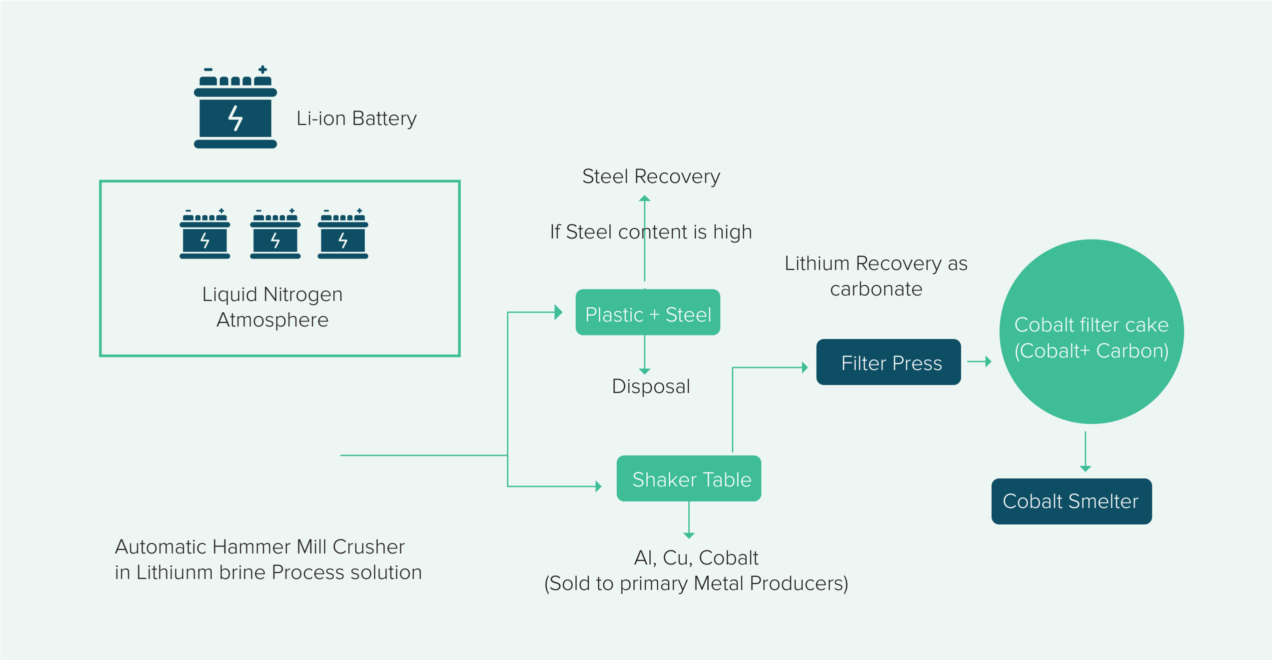


Figure 14 Useful material obtained in Li-Ion Battery recycling

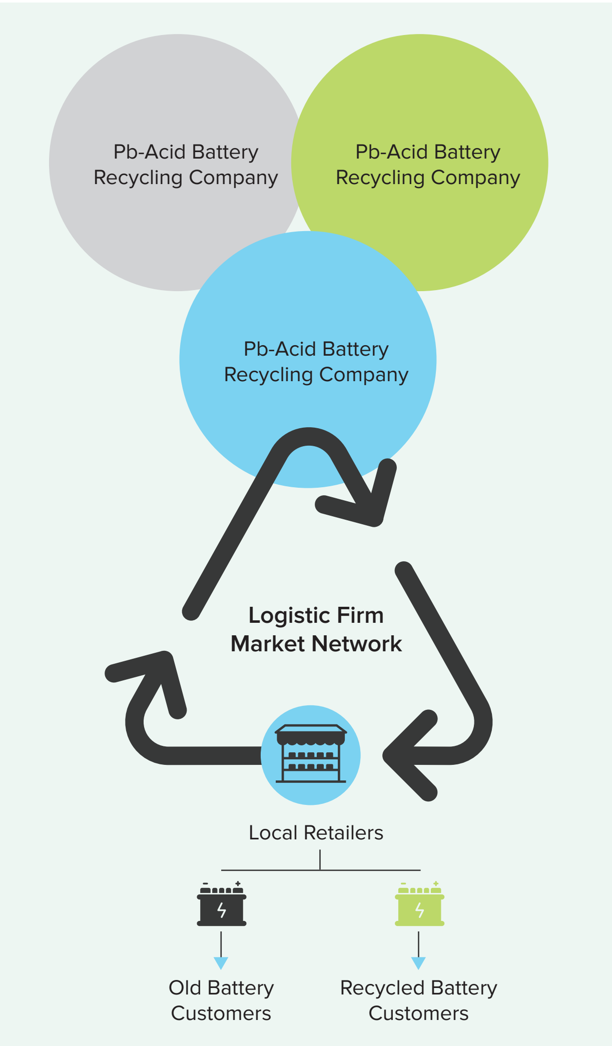


Figure 15 Value Chain for Lead Acid Batteries

3.5 Value Chain

3.5.1 LEAD ACID BATTERIES

In California, customers are allowed to choose any local battery dealer to place the battery for recycling. The battery will be recycled with some marginal charges. These charges are variable due to variable pickup location for logistic companies to get the order. Then these batteries are pushed to recycling companies where in reclamation of internal components like, lead, battery casing, electrolytes are done. New battery is formed out of these materials and sent back to logistic company. Then logistic company makes that battery available to customer at local shop. Whole process is trackable once booked. One such company is Batteries + Bulbs.[26]

The Big Green Box[27] is another example. As it is a recycling firm, it has framework which takes care of battery from door of customer to recycling firm and back to customer door. Lead Acid batteries primarily consist of lead metal and plastic casings, both of which are captured when recycled through the Big Green Box. This big green box is ready feature box which includes a U.N. approved, PG II, pre-labelled container, pre-paid shipping to and from permitted recycling facility, and includes all recycling fees.

26 "Batteries + Bulbs Recycling services," [Online]. Available: https://www.batteriesplus.com/t/recycling. [Accessed May 2021]
27 "The big green box: how it works," [Online]. Available: https://biggreenbox.com/pages/how-it-works. [Accessed April 2021].

Once this container is full, simply sealing and shipping it using a pre-paid mailing label. The container will be received at the nearest recycling facility and recycle everything inside. This program allows Certificate of Acceptance & Recycling to be mailed to consumer mentioning the weight of battery sent. It provides packaging instructions that can be easily followed to ensure package batteries in a safe and legally compliant manner. In addition, plastic bags for batteries are provided to be placed into, which provides proper insulation for the batteries and prevents unintentional discharges or short-circuiting during transit.

The Big Green Box, Clarios and many other such firms use the specific compliant boxes for used battery transport. Call2Recycle is apex stewardship program that looks after proper routing of used batteries to recyclers from customers. As the market of lead acid battery is quite big, Call2recycle needs local Stewards to manage and help Call2recycle to move used batteries towards recyclers with technically feasible chain. So Call2recycle team verifies the eligibility of industries applying for stewardship role in given locality. Upon successful fulfilment of criterions, local stewards are appointed that look after the collection of used batteries from public and private agencies as well as look after the health of area that may disturb due to improper handling of Lead Acid Batteries. California dept of Tax and fee administration (CDTFA)[28] along with Department of Toxic substance control (DTSC) are responsible for the administration of the lead-acid battery fees. Customers and Manufacturers are allowed to deposit $1 per battery for efficient working of this program. This fee is managed by CDTFA.

The reverse logistics of battery happens in three steps, which are collection, sorting and recycling. Post recycling these batteries are sent to manufacturing company for labelling and other formalities. Thereafter it follows usual route to retailer for sales. Customers are allowed to exchange their old Lead acid battery in place of new one without any recycling charge to be paid to dealer for the cause of recycling. With the purchase of new battery, $5 is relaxed for customer if he is available with old battery else this $5 become non-refundable. Apart from automobile Lead Acid Batteries (Starting and deep cycle) this program also covers other types of batteries as per chemistry but those are portable batteries.

28 K. Environmental, "Kelleher Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles," Sept 2019

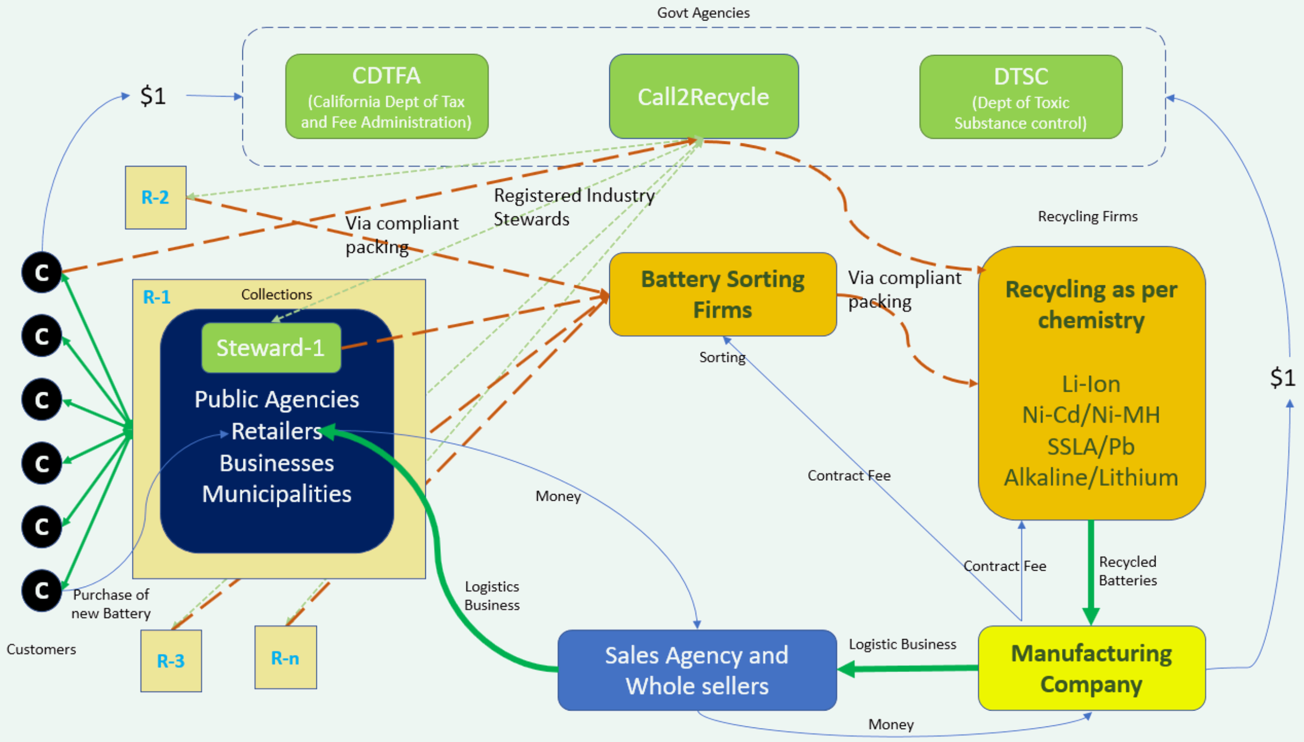


Figure 16 Lead Acid Battery Value Chain with stakeholders

3.5.2 LI-ION BATTERIES

Any Li-Ion battery has its lifetime of 6-8 years

It is not very sure how the used Li-Ion batteries, removed from car, are routed to recycling facilities. Any Li-Ion battery has its lifetime of 6-8 years. The advent of EV in California has happened 4-5 years back so the issue of bulk recycling of EV Batteries are not evident except those which are separated from manufacturing process due to defect, scrap generated in manufacturing or batteries recovered from EV accident.

Customer has to go to a retail outlet with battery swapping facility or especially available battery swapping firms. Usually below 80% State of Charge (SOC) the batteries are treated as of no first phase use i.e., for use in EV and hence their second life usage opportunities are looked upon. If that is also not possible then it is sent for recycling. For Battery dismantling Tesla is working with series of vendors in North America. Tesla operates presently with Kinsbursky Brothers Inc. in North America.[29] Tesla had undergone in a start-up with better space, but it failed. Companies have struggled to make swapping profitable. Despite raising $850 million in venture capital, Better Place (name of a firm) closed its doors in May 2013.

29 K. Kelty, "Tesla's Closed Loop Battery Recycling Program," Tesla, 2011. [Online]. Available: https://www.tesla.cn/en/blog/teslas-closed-loop-battery-recycling-program. [Accessed May 2021]

Musk claimed in June 2015 that buyers were not interested in replacing their batteries. Ample is now attempting to emerge for the same reason. The Ample station can determine the exact location of each battery module to be swapped using a mix of computer vision and secure wireless communication with the car. Once the battery modules have been removed from the vehicle, they are stored on shelves to be charged and ready for the next vehicle. Ample has its own Modular batteries. Ample is working with several Auto manufacturers to get the design of modular batteries in various countries. The compatibility issue is their prime focus that they won't ask car manufacturers to change their design.[30]

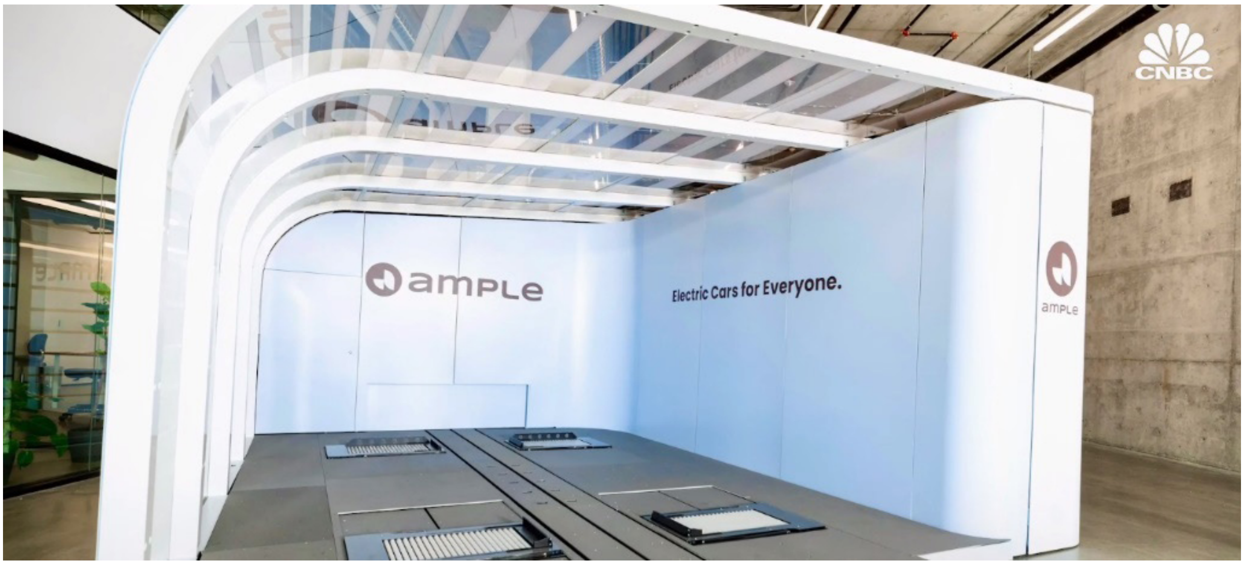


Figure 17 Ample portable EV Battery swapping infrastructure

It is difficult to trace the afterlife of batteries that Ample is considering best for their business. Uber is under their prime customer list that uses various EVs like Nissan, Kia, etc. Tesla is out of this business methodology and rather believes in its own collection and routing philosophy. The battery is removed at tesla retail shop and then it's sent for dismantling to various vendors (third parties like Toxco, Kinsbursky bros, Umicore, etc). Thereafter for recycling, all the dismantled material is sent to Kinsbursky Brothers Inc for recycling and then it follows usual path to Tesla for battery manufacturing. Global Tesla manufacturing is shouldered with the partners at Giga factory Redwood (Recycling expert) and Panasonic (Battery Manufacturing).

The materials for new batteries are mined in Australia, Indonesia, Africa, etc. there after they are sent to China for refining. Post refining, they are sent to Tesla Giga factory at Nevada. Panasonic manufactures new batteries for them there.

30 S. Doll, "Battery startup Ample announces autonomous swapping stations," electrek, March 2021. [Online]. Available: https://electrek.co/2021/03/03/battery-startup-ample-announces-autonomous-swapping-stations/. [Accessed April 2021]

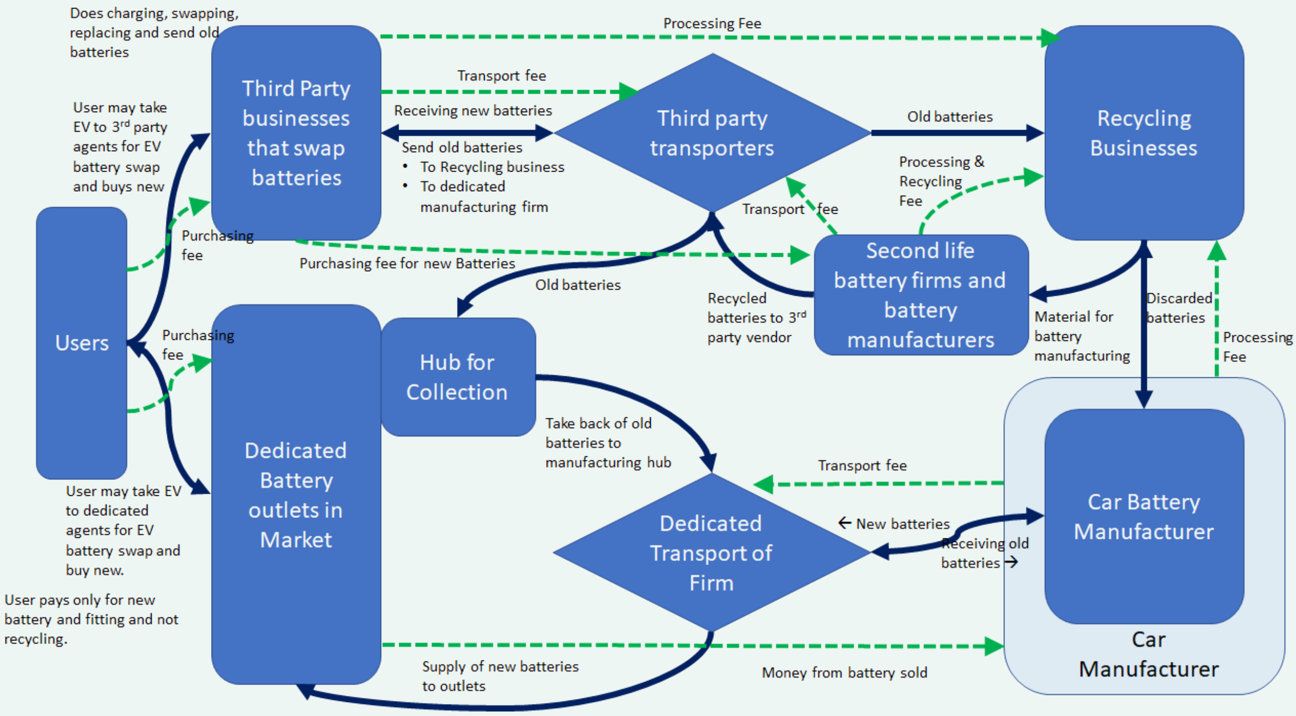


Figure 18 Understood Lithium-Ion Battery recycling ecosystem

For old batteries, California has its gates open for both dedicated and third-party vendors to operate in market. Presently the EV market has not expanded much hence there are mostly dedicated transport facilities from company and very few independent transporters exist. User can exchange his battery at dedicated or complying third-party vendor to swap his old battery. No recycling charge is to be given. New batteries are purchased and fitted. Now here starts back journey of batteries. Vendors collect old batteries to be sent back to original manufacturer (if exists) or to recycling firm if managed by third party. It is the responsibility of manufacturing hubs to look after processing and transporting fee. Third party businesses exist because of economy of extra recycled material and hence they can get equal competitive prices as that of original vendors. In third party cases, both third party firm and second life battery firm take collective responsibility of expenses.

3.6 Major Players in Recycling and their operation strategies

1. **Battery Recycle (Logistic cum Recycling firm):** Has recycling facility for nearly all types of batteries
2. **The Big Green Box (Logistic cum Recycling firm):** Recycles Lead acid and Li-Ion batteries at Lancaster and Ohio.
3. **Retriev Technologies (TOXCO):** A recycling firm that has its facilities for recycling of almost all kinds of batteries (including Pb-acid and Li-Ion) at Lancaster, Baltimore in US and Trail in Canada.
4. **Kinsbursky Brothers Inc.:** A logistic cum recycling firm based on TOXCO methodologies in recycling.
5. **American Manganese Inc.** is a critical metals company focused on the recycling of lithium-ion batteries with the RecycLiCo™ Patented Process.
6. **Aqua Metals**: Lead acid battery recycling company

3.6.1 RETRIEV TECHNOLOGIES (TOXCO)

Retriev is one of North America's largest EV battery recyclers, accepting all types of EV batteries and chemistries and routing them to one of its facilities based on geography and capacity. Battery recycling is a growth opportunity for the organisation, which has a corporate goal of being the finest battery recycler in North America. This firm also finds itself suitable to carter future requirements due to shift in battery technology.

The procedures are chosen based on the structure, form-factor, and recoverable components of each battery type. Automated hydrometallurgical operations, pyrometallurgical processes, and even hands-on mechanical disassembly are all part of the overall process. Retriev's factory processes alkaline, nickel-cadmium, nickel-metal hydride, lead acid, lithium-ion, primary lithium, silver oxide, and mercury batteries.

Retriev is a Resource Conservation and Recovery Act (RCRA) Permitted Part B Transfer, Storage and Disposal Facility (TSDF). They follow the US EPA Code of Federal Regulations and the Ohio Administrative Code. With IMS policy into picture, they maintain wastewater and Air pollution control permits as an integral part of the facility operations along with health safety rules in facility to be very strict. For this purpose, they train staff to current OSHA and EPA standards.

Table 1 Facilities at Retriev Technologies

Retriev Facility	Battery Chemistries and Services	Recycling Lines	Notes
Lancaster, Ohio, USA	Processes NiCd, NiMH and lead acid chemistries. Recover nickel, lanthanum and yttrium from NiMH.	For large-format batteries. 4,000 tonne capacity	Output is sold to rare earth, stainless steel or specialty alloy companies, e.g., aerospace applications with superior corrosion resistance

Retriev Facility	Battery Chemistries and Services	Recycling Lines	Notes
Trail, British Columbia, Canada	Processes lithium chemistries (rechargeable and non-rechargeable) and scrap from lithium battery manufacturing	All consumer and large-format batteries. 4,500 tonne capacity	Recycling only – no reuse is done
Baltimore, Ohio, US	Sorts and segregates alkaline, NiCd, NiMH, lead acid, lithium and less common battery types for further processing	Sorts, identifies, packages, and ships all battery types prior to recycling	

At the Trail, BC facility, Li-ion batteries are processed using a proprietary blend of manual and fully automated hydrometallurgical and materials separation procedures. Retriev had handled over 25 million pounds of lithium batteries by the end of 2018. The process for large-format battery packs from HEVs, PHEVs, and BEVs begins with manual disassembly of the battery packs to the cell or module level122 by experienced technicians. To avoid any disasters, safety training emphasises the use of correct equipment. Retriev notes that "some EV battery packs are designed in such a way as they cannot be disassembled."[31] Welded casings and mechanical fasteners that can't be opened are among the design aspects that make dismantling difficult, and some battery cells are welded together or potted and can't be dismantled.

Separated cells and smaller packs (e.g., laptop, power tool, and cell phone) are fed to an automated hammer mill crusher in the mechanical phase. To eliminate fugitive emissions and limit the reactivity of processed batteries, the crusher uses a lithium brine process solution. Electrolyte and lithium salts are dissolved. The li-ion "fluff," which is a mixture of polymers and steel, is subsequently removed from the process stream. If there is enough steel in the fluff, it is sent for steel recovery; otherwise, it is discarded. Depending on the input, the steel content can reach 65 percent. The copper cobalt product is subsequently produced by passing the process stream through a shaker table (a mixture of copper, aluminium and cobalt). Primary metal producers buy this product. After that, the slurry is put into a mix tank and/or a holding tank. The slurry is filtered to generate a cobalt filter cake (a mixture of cobalt and carbon), which is then shipped to a cobalt smelter, usually Glencore in Sudbury, Ontario, which is North America's only cobalt smelter. These water-based lines produce no effluents or discharges; all process water is re-circulated and cleansed. The residual slurry is transferred to the primary process line, where lithium carbonate is recovered. Only lithium primary processes undergo cryo-milling (low-temperature processing). Some batteries are chilled in liquid nitrogen to reduce their reactivity during the shredding process. If necessary, the acidic cathode components are neutralised with sodium hydroxide. Lithium is precipitated from solution as lithium carbonate after debris and carbon have been removed. There is no freezing in Retriev's li-ion process. Four output streams are produced:

31 K. Environmental, "Kelleher Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles," Sept 2019

- Copper cobalt product (copper, aluminum, and cobalt)
- Cobalt filter cake (cobalt and carbon)
- Li-ion 'fluff' (mix of plastics and some steel)
- Lithium brine (dissolved electrolytes and lithium salts)

The technical-grade lithium carbonate produced at the Trail, BC facility (>99 percent purity) is often sold to a steel mill. Depending on the batteries treated, the predicted recycling efficiency rate through the process ranges from 65 percent to 80 percent of the incoming battery weight.

For first analysis, Retriev usually receives a battery pack from a source or manufacturer. The processes and time it takes to disassemble the pack down to the cell level are detailed in a report produced at Retriev's Trail, BC facility. Retriev performs a comprehensive study on each cell to establish the metal values contained within, which are then employed in the valuation procedure. It is then assessed whether a tipping fee (also known as a gate fee or charge) must be levied to the battery owner or whether a credit is owed to account for the fact that the material revenues covered the recycling expenses, based on metal content and current metal market values. Because of today's cheap nickel and cobalt prices, most li-ion batteries now have a tipping fee, whereas in the past, these batteries were sometimes processed for a credit, with the generator being paid for the metal value minus a processing fee.

3.6.2 TOXCO

Toxco (in 1994) was the first firm in the word to jump into the business of Li-Ion battery recycling. Based on the method of hydrometallurgy and present time resources, Toxco carried its work in this direction.

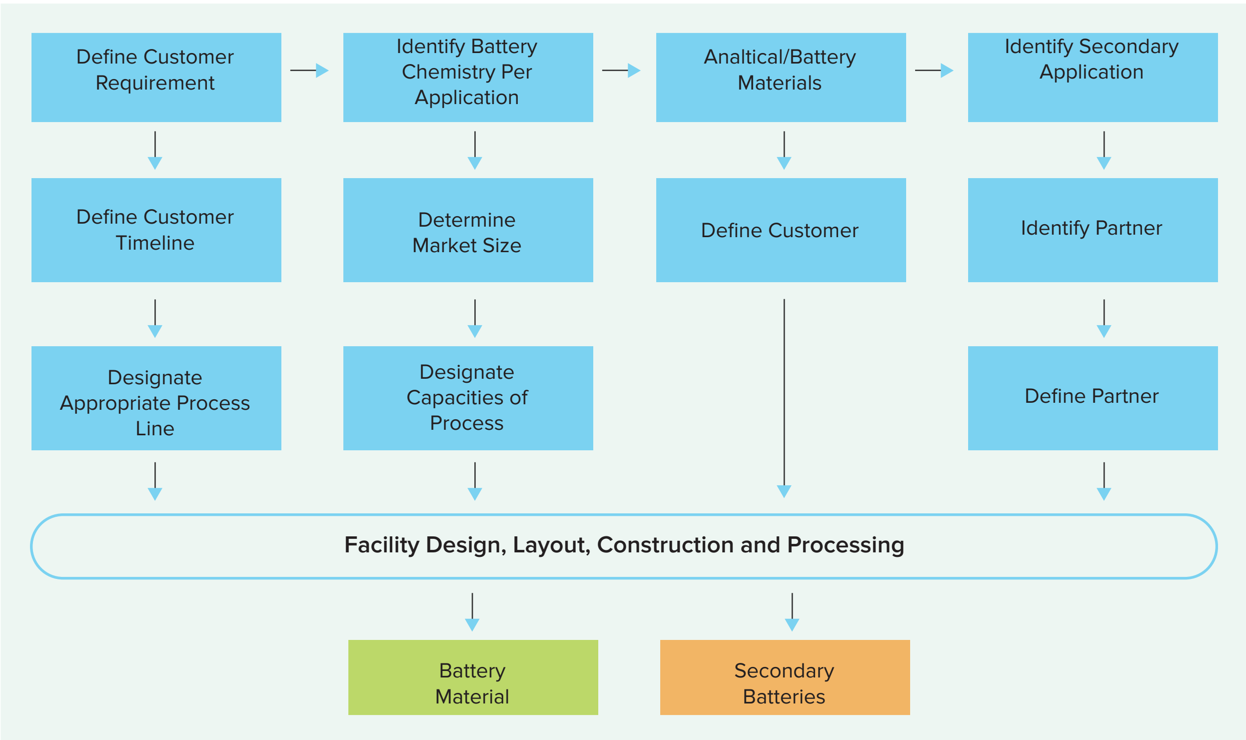


Figure 19 **Working Methodology of Toxco**

Toxco dominated in hydro metallurgy and hence the route map that it made consist of both recycle and reuse methods. Optimally figuring out each working stage finally facility design is moulded to obtain battery materials and secondary use batteries. Secondary batteries are made through reintegration of various cells, found useful after primary disintegration of unused batteries. Customer when sends in the battery also sends the requirements what in the end he wants. Logistics team also collect the information od time in which the battery is to be returned back as per reclamation request. Battery chemistry is decided to analyse what are the materials required to make it refurbished. Some part of it could also be taken in secondary application. Here it identifies partners who can mutually agree to help them with cells and technical support for making secondary batteries. This depicts deep involvement of resource sharing when it comes to secondary battery market. Partners may be consultants or firms like logistic, dismantling firm. After knowing the customer demands and price offered to/from customer, defining market size for finished products, acknowledging self-capacities and partner demands, the facility design, layout and processing was supposed to be initiated. After optimized work, two final goods i.e., secondary battery and Recycled battery material is ready for respective dispatches. Methodology used by Toxco is as given below.[32]

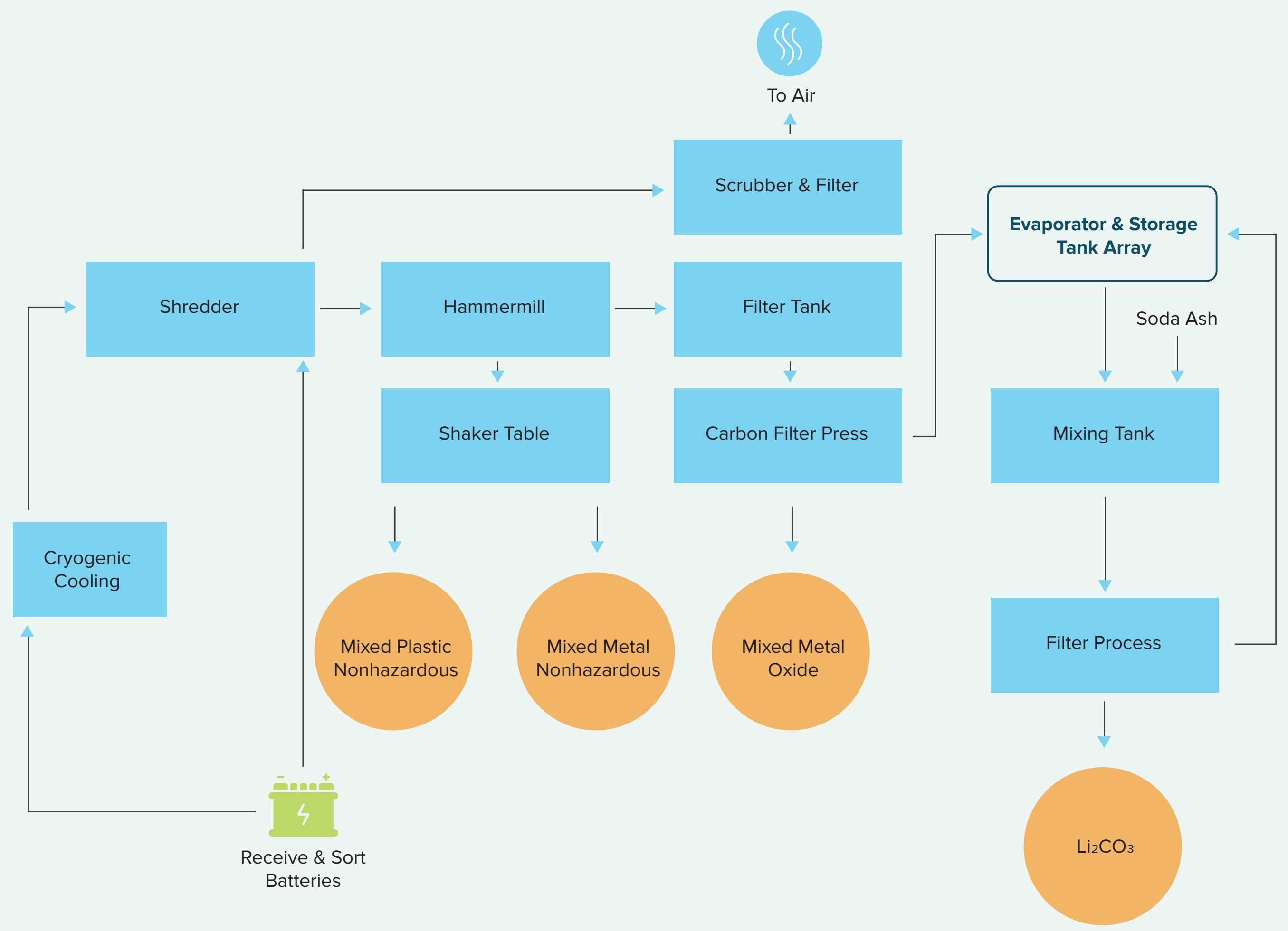


Figure 20 Toxco LIB Recycling mechanism

For safety considerations, the battery pack was first depleted, and the propylene glycol in the cooling tubes was retrieved. The control circuits were taken out and tested to see if they could be reused. The wires and a few other metals were taken out to be recycled.

32 J. S. A. B. I. B. Linda Gaines, "Life-Cycle Analysis for Lithium-Ion Battery Production and Recycling," y UChicago Argonne, LLC, Operator of Argonne National Laboratory ("Argonne"). Argonne, a U.S. Department of Energy Office of Science laboratory, 2010

The packs were disassembled, and the cell components were reduced in size using a series of mechanical operations. Fluff, copper cobalt (which yields saleable metals such cobalt, aluminium, nickel, and copper), and cobalt filter cake were the three end products (reused in appliance coatings). To precipitate out the lithium carbonate, soda ash was added to the resultant process solution. The recycling process is primarily mechanical and chemical, resulting in low emissions. Energy consumption is reduced since no high-temperature processing is required. About 60% of the materials in the pack can be recycled, with the remaining 10% being repurposed. The fluff, which makes up roughly a quarter of the package, will be thrown away at first, but the plastic will be recovered once the amount is sufficient to justify the effort.

Apart from these companies some other companies that shoulder logistics and battery recycling are Kinsbursky Brothers Inc.[33] which operate on similar collection, reuse and recycling model. KBI is fully permitted pursuant to California state and federal regulations to safely receive, store and process hazardous waste batteries[34] and catalytic converters.

American Manganese Inc. is a critical metals company focused on the recycling of lithium-ion batteries with the RecycLiCo™ Patented Process[35]. With minimal processing steps, the technique achieves high extraction of cathode metals such as lithium, cobalt, nickel, manganese, and aluminium at battery grade purity. American Manganese Inc. wants to commercialise its ground-breaking RecycLiCo Patented Process and become the market leader in recycling lithium-ion battery cathode materials.

3.7 Conclusion

Lead acid battery policy initiatives and infrastructure are deployed in strength but Lithium-ion battery recycling for EV is under process. As per Lithium-Ion battery recycling Advisory group, in upcoming month, July 2021, policy draft will be available in rough manner.

Various technological evolutions are happening in design of car batteries, chemistry and implementation infrastructure. Under recycling technology, Firms have their own method of recycling methodologies that suit the raw material infeed and population. Presently collaborations are evident in California for Lithium-Ion Battery value chain. Lead acid batteries are availed by firm support structure in market.

In coming days, Technology majors like Tesla and Ample will come up with their own method of battery replacements. Tesla, with its Mega factory 1 in Nevada, claims to have 100% material recovery in recycling process.

33 "Kinsbursky Brothers: Battery Preparation and Packaging," Kinsbursky Brothers, [Online]. Available: http://www.batterypoweronline.com/images/PDFs_articles_whitepaper_appros/Kinsbursky%20Brothers.pdf. [Accessed April 2021].

34 "KBI Battery recycling," [Online]. Available: https://www.kbirecycling.com/battery-recycling. [Accessed April 2021]

35 "Company Business Plan," 2019. [Online]. Available: https://americanmanganeseinc.com/wp content/uploads/2019/10/AMY_BP-8_28_2019.pdf. [Accessed April 2021]

China

4.1 Overview

In China, the number of New Energy Vehicle (NEV) reached 5.51 million in March 2021. Sales for 2021 reached 3.3 million units[36] and the market will significantly grow in the coming years. With the NEV market further growing and the life span of NEV batteries usually being about 6 to 8 years, a large number of batteries will need to be sustainably recycled or further utilized. China's decommissioned NEV batteries reached a total of about 200,000 metric tons by the end of 2020 (about 25 GWh, up from about 3 GWh in 2017) with a market size of EUR 1.3 billion. By 2025, a peak in NEV battery replacement is expected with 780,000 tons of batteries (about 116 GWh) to go offline by that time with a market size of about EUR 5 billion.

Driven by the pure volumes and thus the urgent need for sustainable recycling and after life solutions (cascade utilization e.g., as storage units in the renewable energy business) but also due to increasing (global) raw material supply pressure, this comes along with the need to establish and strengthen battery after life management systems.

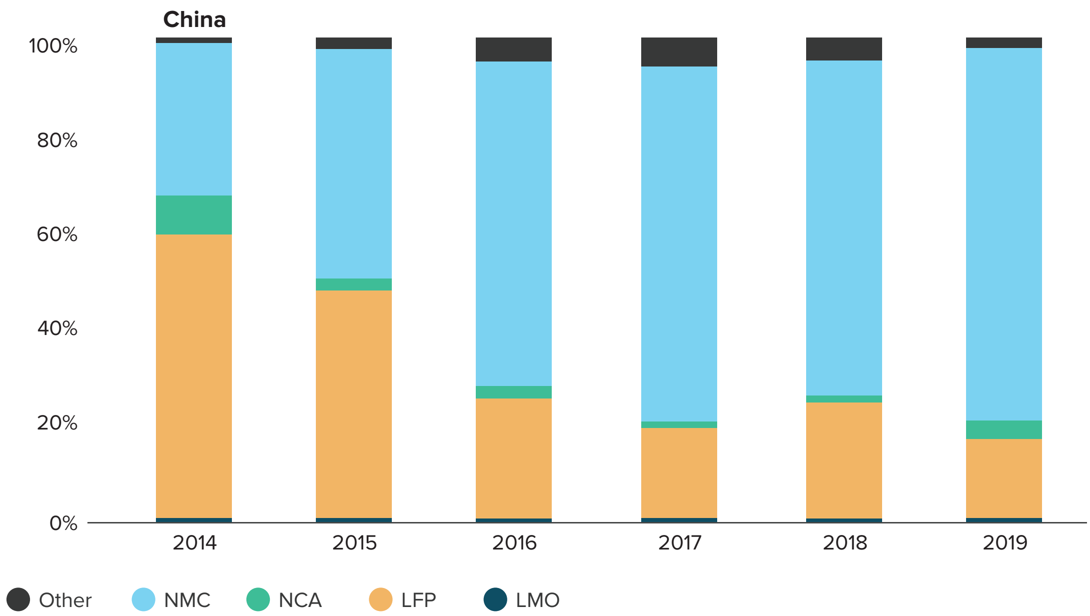


Figure 21 Share of new light duty EV sales by battery chemistry

In 2018, China mandated automakers to set up a national network of service stations where car owners can discard or exchange old batteries. Herein, the auto-manufacturers & battery makers bear full responsibility to track every battery pack.

Under this initiative, the following battery recycling efficiency target were setup:

1. Through Hydro processes: 98% recovery of nickel, cobalt, manganese
2. Through Pyro processes: 97% recovery of nickel, & rare earths.

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4.2 Policy Ecosystem

The Chinese government released relevant policies and regulation on battery recycling starting already in 2006 followed by targeted policies starting in 2015:

- **2006:** Guidance document "Automotive Product Recycling Technology Policy" - the regulations declares that the so-called new energy automobile manufacturers are responsible for the recycling and utilization of used batteries
- **2015:** Electric Vehicle Power Battery Recycling Technology Policy
- **2017:** MIIT released an action plan ("Promotion Plan for Extended Producer Responsibility System") promoting the development of the NEV battery industry
- **February 2018:** Interim measures on traction battery recycling
- **July 2018:** Interim Provisions on The Traceability Management of Power Battery Recovery and Utilization of New Energy Vehicles by MIIT – requiring that the comprehensive management platform for national monitoring and power battery recovery and utilization traceability of new energy vehicles must be established to carry out traceability management for the whole process of power battery production, sales, use, scrap, recovery, and utilization.[37] Hence starting from 2018: a unique code had been assigned to each battery produced or imported for New Energy Vehicles (NEV) for the purpose of reuse and recycling.
- **July 2018:** First Pilot Scheme started in Beijing, Shanghai, Jiangsu and further regions (Notice on the Pilot Work of Power Battery Recycling of New Energy Vehicles by MIIT)
- **2019:** Guide to the Construction and Operation of New Energy Vehicle Power Battery Recycling Service Outlets - NEV production and step utilization companies need to build or authorize recycling service outlets
- **March 2021 -** The Government Work Report outlines the efforts needed to accelerate the establishment of the NEV battery recycling system
- **July 2021 –** National Development and Reform Commission (NDRC) released a notice on its circular economy development plan during the 14th Five-Year Plan period (2021-25) outlining that the government will enhance the regulatory mechanism for NEV battery tracking (New Energy Vehicle Industrial Development Plan)
- **August 2021 -** MIIT issued a directive, "management measures for the gradual utilisation of NEV power batteries". The directive focuses on cascade utilization of NEV batteries (incl. reusing retired NEV batteries in other facilities, to encourage cooperation between NEV manufacturers, battery producers and recyclers)
- Local governments have started to promote the NEV battery recycling sector (e. g. Jiangsu province has set up 907 NEV battery recycling centres, Shanghai initiated a full life cycle tracking and regulation system for NEV batteries)
- **Dec 2021:** Interim Measures for the Management of New Energy Vehicle Power Battery Recycling by MIIT

After the first dedicated battery recycling regulation in 2015, a pilot scheme was implemented in 2018 wherein 17 cities and regions were selected. The government undertook various measures in 2018 to address the issue concerning battery reuse and recycling. The Interim Measures on Traction Battery Recycling was issued in February which placed responsibility on the EV manufacturers for setting up facilities to collect

China's decommissioned NEV batteries reached a total of about 200,000 metric tons by the end of 2020 (about 25 GWh, up from about 3 GWh in 2017) with a market size of EUR 1.3 billion.

37 Sun et al. (2021): Management status of waste lithium-ion batteries in China and a complete closed-circuit recycling process. Science of the Total Environment 776 (2021) 145913.

and recycle spent batteries, establish a maintenance service network which allows members of public to repair or exchange their old batteries. The carmakers were also encouraged to adopt standardised battery designs that allowed easy dismantling to help automate the recycling process. An interim administrative measure on the "traceability of traction battery recycling" was set up in July of the same year to enable a traceability system to identify owners of discarded batteries. Additionally, a whitelist consisting of five recycling companies were commissioned for the recycling of batteries for NEV. The enterprises met the requirements of "Standard Requirements for the Comprehensive Utilization of Decommissioned NEV Power Batteries". This list of companies has now increased to 47 companies[38].

4.2.1 2006: GUIDANCE DOCUMENT "AUTOMOTIVE PRODUCT RECYCLING TECHNOLOGY POLICY"

So called New energy automobile manufacturers are responsible for the recycling and utilization of used batteries.

4.2.2 2015: ELECTRIC VEHICLE POWER BATTERY RECYCLING TECHNOLOGY POLICY AND 2017: "PROMOTION PLAN FOR EXTENDED PRODUCER RESPONSIBILITY SYSTEM"

These initiatives proposed the establishment of an electric vehicle power battery recycling system based on the implementation of the extended producer responsibility system. Starting from 2018, a unique code had been assigned to each battery produced or imported for New Energy Vehicles (NEV) for the purpose of reuse and recycling.

4.2.3 2019: "GUIDE TO THE CONSTRUCTION AND OPERATION OF NEW ENERGY VEHICLE POWER BATTERY RECYCLING SERVICE OUTLETS"

In 2019, China notified the New energy vehicle power battery recycling service outlets Construction and operation guide. The initiative required NEV production and step utilization companies to build or authorize recycling service outlets.

Key features of the guide are as following:

- Batteries "should" be handed over to comprehensive utilization enterprises for cascaded use or recycling
- Recycling Service Outlets to record in detail battery code, battery type, battery product type, battery relevant information such as quantity, battery source, battery destination, etc., and to keep records for three years
- Regulation provides construction requirements as well as operational conditions (temperature, space, etc.) and equipment
- Location of the centralized storage recycling service network to be in line with the urban and rural areas planning regulations
- Safety and environmental protection requirements set as well as for occupational safety

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- Foresees the improvement of power battery recycling systems, cascade utilization and resource usage
- Encourages the construction of shared recycling channels
- Foresees the establishment and improvement of management system of power battery transportation and storage, repair and maintenance, safety inspection, decommissioning and withdrawal, recycling and utilization, and strengthen the supervision of the whole life cycle based on tended system of producer responsibility
- Optimization of the layout of the recycling industry
- Promotion of efficient extraction of valuable elements from discarded power batteries.

A snapshot of the battery recycling ecosystem prevalent in China has been given. Current policies prioritize second life EV batteries and promote marketization improving information transparency, recycling efficiency and R&D for recycling technologies.

4.2.4 2021: CHINA'S NEW ENERGY VEHICLE INDUSTRIAL DEVELOPMENT PLAN FOR 2021 TO 2035

The plan follows the Energy-Saving and New Energy Vehicle Industry Plan for 2012 to 2020 and aims to build a green, robust, and internationally competitive auto industry. It sets a target of an approximately 20% share for new energy vehicles (NEVs) in new vehicle sales by 2025 and other development targets for the NEV industry[39].

The set development plan intends to accelerate the roll out of the legislation of power battery recycling as well. It foresees the improvement of power battery recycling systems, a cascade utilization and resource usage. It further encourages the construction of shared recycling channels.

Through the establishment and improvement of a management system of power battery transportation as well as storage, repair and maintenance, safety inspection, decommissioning and withdrawal, recycling and utilization, a system for battery recycling is designed which also intends to strengthen the supervision of the whole life cycle through increased producer responsibility. "In particular, it is encouraged to form coalitions among vehicle integration, components production, internet, and the electronic information and communication industries, to cooperate to improve the safety, reliability, and convenience of vehicle operating system."[40]

The plan set five strategic tasks, which need to be met to fulfil its vision. These are

1. Improving capacity for technology innovation – to enhance the Research and Development landscape and cooperation among stakeholders.
2. Building an NEV Industry ecosystem – stepping up from the production of key components to a systematic approach of an industrial ecosystem for the entire NEV life cycle
3. Advancement of Industrial integration and development – describing the integration of NEV industry with three core fields: energy, transportation, and Information/Communication Industries

39 ICCT 2021-1
40 ICCT 2021-2

4. Building a sound infrastructure system – to scale up charging and battery swapping networks for NEV and overall deployment of intelligent transport systems
5. Increasing openness and deepen international cooperation – the task which aims at a green, robust, and internationally competitive NEV industry, encouraging the expansion of Chinese corporate cooperation with foreign firms and institutes.

Under task 2, reference is made to the importance of battery recycling, as the task requires the establishment of "an efficient battery recycling system by implementing the extended producer responsibility policy, building up a battery traceability management platform, and improving technologies and industry deployment for the reuse, recycle, and disposal of spent batteries from NEV.

Already in the previous plan four ministries had been responsible for the realisation of objectives: the Ministry of Industry and Information Technology (MIIT), the National Development and Reform Commission (NDRC), the Ministry of Science and Technology (MOST), and the Ministry of Finance (MOF). The Plan for 2021–2035 further foresees the engagement of the Ministry of Public Security, Ministry of Ecology and Environment, State Taxation Administration, China Banking and Insurance Regulatory Commission, National Energy Administration, and 11 other departments. This depicts the complexity of the plan.

Latest regulation is the "Interim Measures for the Management of New Energy Vehicle Power Battery Recycling**"** released in December 2021 by MIIT. This foresees the implementation of a management system for the tracking of batteries along the entire life cycle. Pilot project have been set up in Beijing, Tianjin, Hebei and 17 regions.

4.3 Recycling Methodology in China

China pursues a second-life strategy for the batteries of Electric vehicles, whereas recycling consists of two stages or paths: **Cascade utilization and resource recycling**.

"Cascade utilization is mainly aimed at lithium-ion batteries with 60–80% residual capacity after its retirement from electric vehicles. After re-testing and analysis, they can be used in other areas where the operating conditions are relatively simple and the battery performance requirements are relatively low such as renewable energy installations in buildings, fast EV charge stations energy storage applications, portable power generators, E-Bike application" (Sun et al. 2021)

It is regarded that electric vehicle batteries are in use for four to six years, after which they have less than 70 to 80 percent capacity. This means that they can typically be used in second-use applications for another two to four years before finally being sent for recycling. This approach is still in the demonstration stage, although successful applications have been presented.

Resource Recycling consists of disassembling and recycling of batteries to extract valuable materials to be used as raw materials for the re-manufacture of lithium-ion batteries. The processes do not differ from recycling processes in other countries and can be mainly divided into physical methods and chemical methods. In China "a great deal of research on resource recovery of waste LIBs focused on chemical methods, among which pyrometallurgy and hydrometallurgy account for 16.79% and 57.25% respectively in all recovery technologies." (ib.)

Some key aspects of the EV Battery Recycling System in China:

- EV batteries categorized as "Power battery": Battery that provides energy for the power system of new energy vehicles, including lithium ion, metal hydride nickel power batteries, etc., do not include lead acid batteries
- The category NEV (New Energy Vehicles), which is frequently used for Electric cars, includes all-battery electric, hybrid electric, plug-in hybrid, and hydrogen fuel cell vehicles, all using a range of different battery sizes and types.
- "Recycling" comprises of collection, classification, storage, and transportation of waste power batteries.
- All regulations depict the requirement of "professional transportation" without further elaboration and definition
- Manufacturers of EV's and related enterprises (Distributor, Battery OEM) are responsible for battery recycling and required to establish recycling service outlets – these service outlets are then responsible for collection, sorting, storage and packaging of waste power
- Automobile manufacturers should establish a green supply chain management system and incorporate the concept of green supply chain management into the corporate development strategy plan.
- It is regulated, that batteries "should" be handed over to comprehensive utilization enterprises for cascaded use or recycling
- Recycling Service Outlets are to record in detail battery code, battery type, battery product type, battery relevant information such as quantity, battery source, battery destination, etc., and to keep records for three years
- Regulation provides construction requirements as well as operational conditions (temperature, space, etc.) and equipment
- Location of the centralized storage recycling service network has to be in line with the urban and rural areas planning regulations

Safety and environmental protection requirements are set as well as for occupational safety

China accounts for 77% of the EV battery recycling capacities in Asia

4.4 Use cases

China accounts for 77% of the EV battery recycling capacities in Asia[41]. The EV Battery Recycling Industry in China is reported to growing annually by 78.4%. Currently, over 15,000 companies in China are engaged in EV battery recycling activities with over 9,000 being newly registered this year[42]. The uptake of EV battery recycling in the local governments have begun. For instance, in Jiangsu 907 EV battery recycling centres have been deployed while Shanghai has initiated a full life cycle tracking and regulation system for NEV batteries.

The city of Shenzhen started providing subsidies for NEV battery recycling in 2018 (roll out since January 2019) under the "Financial Support Policy for Promotion and Application of New Energy Vehicles". All firms that legally sell NEV products in Shenzhen could receive such subsidy based on kWh of their products sold. Still to date this is a novel action at subnational level.

4.5 Learnings from the Chinese Battery Recycling Policies

4.5.1 GOOD PRACTICES AS PER THE CHINESE BATTERY RECYCLING POLICIES

- Penalization of registered Battery Recyclers not confirming to required standards for battery recycling
- Circular Economy Promotion Law
- Pollution control technical specifications on treatment of waste lead-acid batteries
- Enterprises which utilize recycled hazardous wastes in the production raw materials, obtain 50% of VAT rebates.
- New energy vehicle products (EVs), including imported new energy vehicles have to mandatorily include product certification to implement traceability management
- To improve traceability and data management:
- Implementation of traceability management of battery products being sent for secondary use.
- Each enterprise should upload traceability information in the traceability management platform.
- Automobile manufacturers should upload the information of recycling service outlets in the traceability management platform.
- The seller should report the record information to the vehicle manufacturer in a timely manner after the sale of the vehicle and inform the vehicle owner of the requirements and procedures for updating the record information when the information is changed.
- Recycling data also to be incorporated by Recyclers and automotive manufacturers and dealerships
- Industry and information technology departments in charge of the same level with the relevant departments of the region to monitor and inspect the implementation of the relevant enterprise traceability responsibilities.

41 Eric Ng, 2021 "EV battery: China powers Asia in race to ramp up recycling capacity as industry tests new method to overcome pollution problems | South China Morning Post (scmp.com)"
42 Subhash Nair, 2021 "China's EV Battery Recycling Industry Is Growing Annually (dsf.my)"

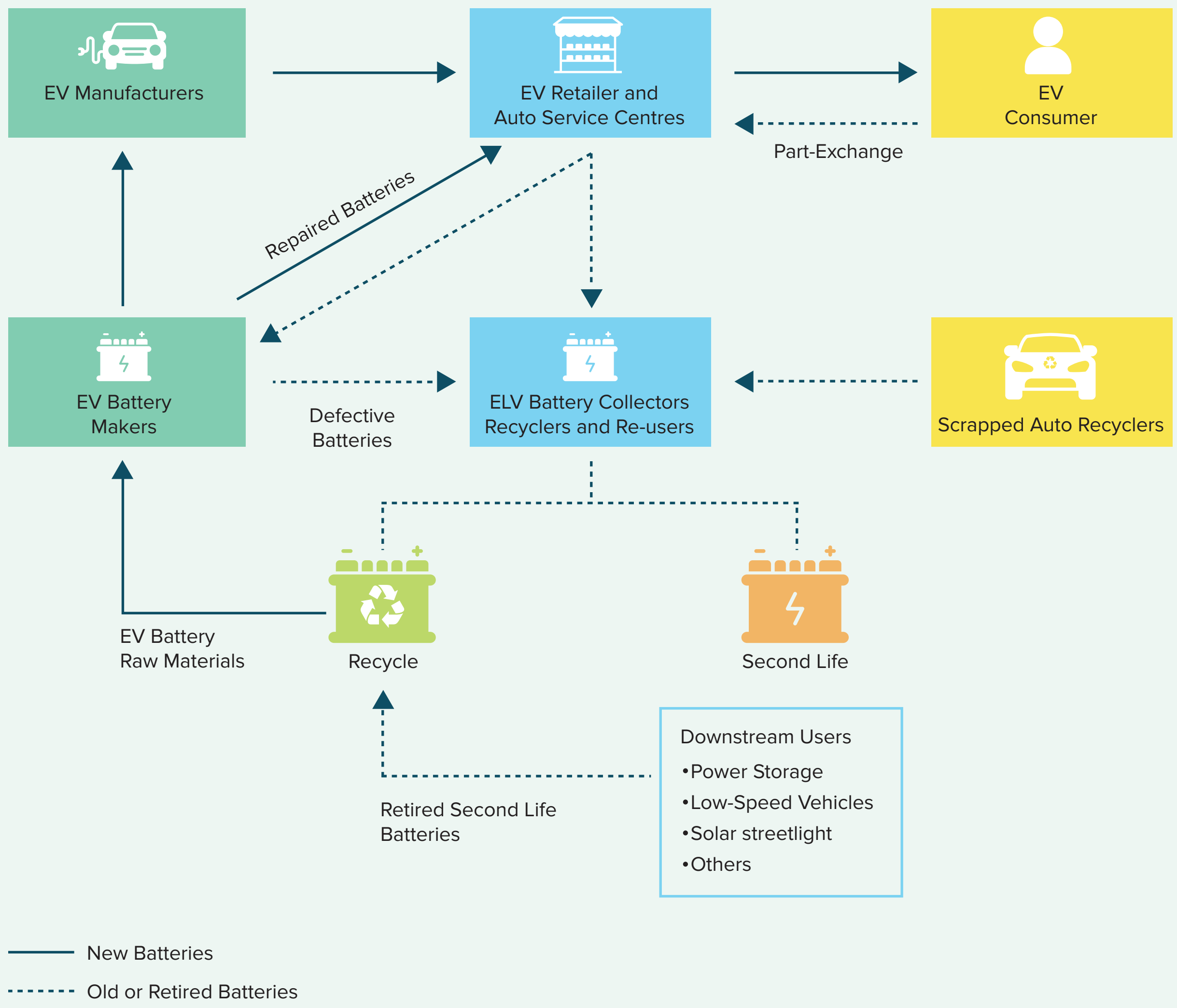

Figure 22 Battery recycling ecosystem in China

4.5.2 DISADVANTAGES OF CHINESE BATTERY RECYCLING POLICIES

- **Legal provisions confusion**: Battery recycling is managed by several departments, the business sector manages the recycling, industrial sector manages the use, and the environmental protection sector manages treatment. Coordinate relations between these sectors are not formed, leading to chaotic management system.
- **Lack of systematic extended producer responsibility system**: In the existing legal system of resources and the environment, the contents of the extended producer responsibility system are scattered in more than a dozen laws, regulations or policies, a complete and unified standard does not form. In addition, lacks correlation and coordination in related contents, which are mostly general requirements, lacking details of the terms.
- **Great difficulty in small smelter rectification**: Due to old age technology usage and low capital infusion capability of the small smelters
- **Lack of economic incentive system**: In waste battery recycling industry, China lacks appropriate economic incentive system. In the overall work of the waste

battery recycling, there is no benefit/ profitability can be seen in the short term, leading to low sense of responsibility and enthusiasm of entities.

Given below is a snapshot of the timeline of the various waste battery related regulations that were notified in China.

Laws and regulations	Year	Major regulations on battery recycling
Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution	1995	Waste batteries are dangerous solid wastes and need to be recycled separately
Technical Policy for the Prevention and Control of Hazardous Waste Pollution	2001	Phase-out batteries containing mercury and cadmium
Policy on Pollution Prevention Techniques from Waste Batteries	2003	Battery industries should take responsibility for collecting waste batteries and for proper labeling
National Hazardous Waste List	2008	Lead-acid batteries are dangerous solid wastes that need to be collected and treated separately
Administrative Measures on the Collection and Using of Waste Electrical and Electronic Product Treat Fund	2012	Manufacturers or importers are responsible for the fund collection
Directory of Waste Electrical and Electronic Equipment Treatment (2014)	2015	Waste LIBs were officially added to the scope of the Fund
Technology Policy for the Recycling of Power Battery (2015 edition)	2016	Provisions on the recycling and utilization of waste EV batteries
Policy on Pollution Prevention Techniques of Waste Batteries	2016	The pollution prevention and control technologies of waste UBs
The Implementation Plan of the Extended Producer Responsibility System	2016	Implement the extended producer responsibility system for batteries
The Interim Measures for The Management of Power Battery Recovery and Utilization of New Energy Vehicles	2018	Automobile manufacturers should shoulder the primary responsibility for power battery recovery
The Interim Provisions on The Traceability Management of Power Battery Recovery and Utilization of New Energy Vehicles	2018	The comprehensive management platform for national monitoring and power battery recovery and utilization traceability of new energy vehicles must be established
The Notice on the Pilot Work of Power Battery Recycling of New Energy Vehicles	2018	Confirmed some pilot regions and pilot enterprises to carry out the pilot work of power battery recycling
The Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution (2020 edition)	2020	The estalblishment of a credit record system for the prevention and control of solid waste (including waste UBs) pollution
The Notice on Matters Related to the Total Ban on Solid Waste Import	2020	The import of solid waste in any way is prohibited

Figure 23 Timeline and key feature of Waste battery regulations in China

Japan

5.1 Overview

Japan was one of the first countries to mandate e-waste recycling, enacting the Basic Act on Establishing a Sound Material-Cycle Society in 2000. Sound material-cycle society, a concept similar to circular economy, aims to create a society in which natural resource consumption is conserved and environmental burden is reduced to the greatest extent possible, by preventing or reducing the generation of wastes, etc. from products, etc., by promoting proper cyclical use of products, etc. when these products, etc. have become circular resources, and by ensuring proper disposal of circular resources (i.e., disposal as wastes).

There are numerous recycling acts/laws in Japan, each having a particular set of products and/or materials as targets. When it comes to batteries, however, there is no battery recycling law in place. In early 1994, retail retailers in Japan began recycling batteries. An Act on the Promotion of Effective Utilization of Resources was published in 1991 to ensure the effective utilisation of resources by taking the necessary steps to reduce the generation of Used Products and By-Products and promote the use of Recyclable Resources and Reusable Parts in order to contribute to waste reduction and environmental preservation, as well as to the sound development of the national economy.

Japan was one of the first countries to mandate e-waste recycling, enacting the Basic Act on Establishing a Sound Material-Cycle Society in 2000.

After its revision in 2000, Law for Promotion of Effective Utilization of Resources (LPUR) was enforced in April 2001. Under the law, two types of products were stipulated as “specified resources-recycled products,” for which the producers are required to promote self-collection and recycling.

1. Compact rechargeable batteries (sealed lead acid batteries, sealed nickel-cadmium batteries, sealed nickel-metal-hydride batteries, lithium batteries)
2. Personal computers (including CRTs and liquid crystal displays)

The aim of this rule is to encourage producers to voluntarily collect and recycle products that are recyclable and need to be recycled. Other basic batteries, such as manganese cells and alkaline batteries, are not covered by any legal framework. In April 2013, the Law to Promote the Recycling of Small Used Electronic Equipment (abbreviated as “the Small Home Appliance Recycling Law”) went into effect. A Cabinet Order issued under this law identifies target small household appliances in 28 categories, including mobile phones and PCs. Depending on their circumstances, each town chooses specific items to collect and recycle from the list of target items. As a result, the actual target goods differ by municipality. The predecessor, Home Appliance Recycling Law 2001, covered only 4 home appliances and obligated manufacturers to recycle these items, and consumers to bear the cost.

Manufacturers, merchants, customers, processing businesses, and the government all have roles and responsibilities in this process, according to the Small Home Appliance Recycling Law. It gives municipalities the freedom to choose whether or not to participate in the programme and which things to collect. As a result, the new law is sometimes referred to as a voluntary participation programme, as opposed to the Home Appliance Recycling Law, which imposes responsibilities on the parties involved. As per the targets set by the act, the term Recycling is defined as the turning of waste compact rechargeable batteries into iron, lead, nickel, cobalt, cadmium, and other recyclable resources which can be used further. Energy recovery is not the part of recycling.

In Japan, Battery waste recycling is carried by businesses like 4R Energy Corp. (a joint initiative between Nissan and Sumitomo corp.), Toyota, Sumitomo Metal Mining (SMM) etc. In case of lead acid batteries, Japan has recovered from the recycled resource problem by making it mandatory to use recycled lead primarily to manufacture lead acid batteries[43].

5.2 The Act on the Promotion of Effective Utilization of Resources (1991) and the Treatment of Specified Resources-recycled Products

The purpose of this act is to ensure effective resource utilisation and to take necessary measures to reduce the generation of Used Products, etc., and By-Products, as well as to promote the use of Recyclable Resources and Reusable Parts, in order to contribute to waste reduction and environmental preservation, as well as to the sound development of the national economy.

Business operators are encouraged to conduct independent and autonomous collection and recycling activities.[44,45] Place to place and time to time the situations may change which will again require amendments to loosen up the law. It's better that business operators must design their own route themselves. Its unorganized sector as per Japanese govt. The manufacturers, etc. of products using batteries should conduct the self-collection of waste sealed batteries by designating self-collection points, installing collection boxes, or taking other measures needed for self-collection.

The ministerial ordinance (March 2001) provides the matters to be judgement criteria concerning voluntary take-back and resources reconversion of "used sealed storage batteries" by a person who operates a business of manufacturing, etc. of sealed storage batteries and a person who operates a business of manufacturing, etc. of products using sealed storage batteries, in accordance with paragraph 1 of Article 26 of the Law for Promotion of Effective Utilization of Resources. As per the ordinance, battery manufacturing and battery utilizing entity have the responsibility to collect the used rechargeable batteries. However, they can deny the collection with a justified reason. They can even ask for assistance from repairing, selling and processing agent for collection and voluntary takeback scheme. If this collection and takeback work is offered to any third-party agency in terms of contract, collection of periodic development report is must.

If battery using company is sending any request to battery manufacturing company for any battery collection scheme, then without any compensation this work is to be carried out by battery manufacturing companies.

> **As per the targets set by the act, the term Recycling is defined as the turning of waste compact rechargeable batteries into iron, lead, nickel, cobalt, cadmium, and other recyclable resources which can be used further. Energy recovery is not the part of recycling.**

43 Abe, A. (2015). *Current Situation of Waste Lead Acid Battery Recycling in Japan*. https://wedocs.unep.org/20.500.11822/30429.

44 "Act on the Promotion of Effective Utilization of Resources (Act No. 48 of 1991)," 2006. [Online]. Available: https://www.meti.go.jp/policy/recycle/main/english/pamphlets/pdf/cReEffectLe_2006.pdf

45 N. I. o. E. S. J. Dr. Tomohiro Tasaki, "The Recycling Scheme for Compact Rechargeable Batteries in Japan- under the Act on the Promotion of Effective Utilization of Resources," Organization for Economic Co-operation and Development, Jan 2014. [Online]. Available: https://www.oecd.org/environment/waste/EPR_Japan_battery.pdf. [Accessed April 2021].

Battery manufacturing companies must define places for collection scheme to be run. They must also advice procedure for collection revised annually.

Article 2 of this ordinance mentions that business entities shall provide target ratio to total weight of utilizable resource (like iron, cobalt, lithium, lead, etc) from batteries. The ratio of that kind of battery collected must not go below the ratio listed.

Table 2 Ratio of minimum battery material to be recycled by weight to battery weight

Sealed Batteries	Ratio of material to battery (wt/wt)
Lead Acid	50/100
Ni-Cd	60/100
Ni-H2	55/100
Li storage batteries	30/100

5.3 Recycling ecosystem in Japan

5.3.1 BATTERY COLLECTION BY JBRC

Figure 24 Pail can for Li-Ion battery for collection

For small rechargeable battery manufacturers, equipment manufacturers using the same batteries, and their importers, it was obligatory to collect and recycle small rechargeable batteries. Japan Portable Rechargeable Battery Recycling Center (JBRC)[46], a producer responsibility organization, started in April 2001 as an organization that makes these manufacturers JBRC members and jointly carries out recycling activities for members' small rechargeable batteries. Retailers which sell compact rechargeable batteries have to register with Japan Portable Rechargeable Battery Recycling Center (JBRC)[47].

Method of registration involves filling up of membership form sent to Business holders (battery manufacturers, manufacturers of equipment using the batteries, or importers of these batteries) post confirmation of membership conditions. The JBRC secretariat sends a membership application by email. The collection is handled safely by JBRC in a pail can. Pail packaging was introduced from July 1, 2018. While inserting multiple types of batteries into a pail can, it is advised to put the battery type name in a plastic bag. Bags inside pail cans can be of 10-20 kg each. Pail cans are lent free of charge from JBRC. Along with the pail cans, JBRC also provides boxes.

5.3.2 COLLECTION AND RECYCLING SCHEME

In partnership shops, collection boxes for trash compact rechargeable batteries have been installed for recycling. Consumers are able to collect their waste batteries in segregated containers at these shops, either in their own plastic bags or in JBRC-provided boxes/pails. When the collecting boxes are full of used rechargeable batteries (about 7-8 kg), cooperation stores request that the JBRC take them up for recycling. Waste commercial rechargeable batteries are collected for recycling in large quantities

46 N. I. o. E. S. J. Dr. Tomohiro Tasaki, "The Recycling Scheme for Compact Rechargeable Batteries in Japan- under the Act on the Promotion of Effective Utilization of Resources," Organisation for Economic Co-operation and Development, Jan 2014. [Online]. Available: https://www.oecd.org/environment/waste/EPR_Japan_battery.pdf. [Accessed April 2021]

47 "New "JBRC member" registration," JBRC, [Online]. Available: https://www.jbrc.com/member/new_member/. [Accessed April 2021]

and for commercial reasons by cooperative businesses (there by bypassing JBRC). Construction enterprises that replace rechargeable batteries, businesses that sell rechargeable batteries, and businesses that use huge quantities of rechargeable batteries are all sources of commercial waste rechargeable batteries.

Outsourcing is done by JBRC to perform transportation of waste batteries to recyclers. JBRC pays contract fee to collection and transportation business. Planning of logistics is not managed by JBRC. It is left with contract companies alone. At recycling center, manual sorting of batteries is done before they are routed to different recycling processes. Recyclers after recycling are left with waste crushed residue and useful resources obtained from physical reuse and hydrometallurgical recycling. Recyclers earn from selling useful material but have to spend for disposal fee to final disposal businesses. There after this disposal may enter into other economy. JBRC also pays contract fees to these recycling businesses. Post recycling, the reports of results of recycling are to be submitted to JBRC so that they can update this to Manufacturers of batteries and products using batteries.

5.3.3 ROLE OF STAKE HOLDERS IN COLLECTION AND RECYCLING

Table 3 Obligations of stakeholders

<table>
<tr><th colspan="2" rowspan="2">Obligations</th><th colspan="2">Stake holders</th></tr>
<tr><th>Battery Manufacturers</th><th>Manufacturers of products using batteries</th></tr>
<tr><td>Collection of waste rechargeable batteries</td><td rowspan="4">Specified resources-recycled products</td><td>✔</td><td>✔</td></tr>
<tr><td>Recycling of waste rechargeable batteries</td><td>✔</td><td></td></tr>
<tr><td>Provision of information</td><td>✔</td><td>✔</td></tr>
<tr><td>Cooperation with municipal govt for collection</td><td>✔</td><td></td></tr>
<tr><td>Labeling of rechargeable batteries</td><td>Specified labeled products</td><td>✔</td><td></td></tr>
<tr><td>Equipment design that makes it easy to remove rechargeable batteries</td><td>Specified reuse promoted products</td><td></td><td>✔</td></tr>
</table>

Manufacturers of products using batteries are supposed to collect battery waste and handover it to battery manufacturers. Each year they are supposed to disclose the info about collection. Instead of collecting the waste from consumers, the retail shopkeepers are supposed to assist the rechargeable battery collection, thus cooperating the chain. Consumers are expected to cooperate with business operators, etc. in the collection and recycling activities under the scheme and promote the utilization of recyclable resources and reusable parts. Commercial facilities that generate waste rechargeable batteries, are expected to cooperate with manufacturers, etc. in the collection of batteries as businesses cooperating for recycling.

5.4 Supply chain

5.4.1 LEAD ACID BATTERY RECYCLING VALUE CHAIN

Below shown supply chain for lead acid batteries in Japan[48] start from users, exchanging their old vehicle Lead Acid battery against new one. Cost of new battery is to be borne at lower prices. The old batteries move from users to Lead acid battery manufacturers back in the supply chain. Trade in denotes the exchange of money in place of old batteries. Then a contract entrustment is released by Battery manufacturers and logistics companies to deliver their waste safely to disposal firms for clean recovery of lead and other valuable products. Entrustment fee includes contract fee to disposal businesses and delivery businesses. As the materials are recovered, re manufacturing of goods take place and is sent back to consumer via mentioned route. Customers have to pay discounted price if they purchase new lead acid batteries.

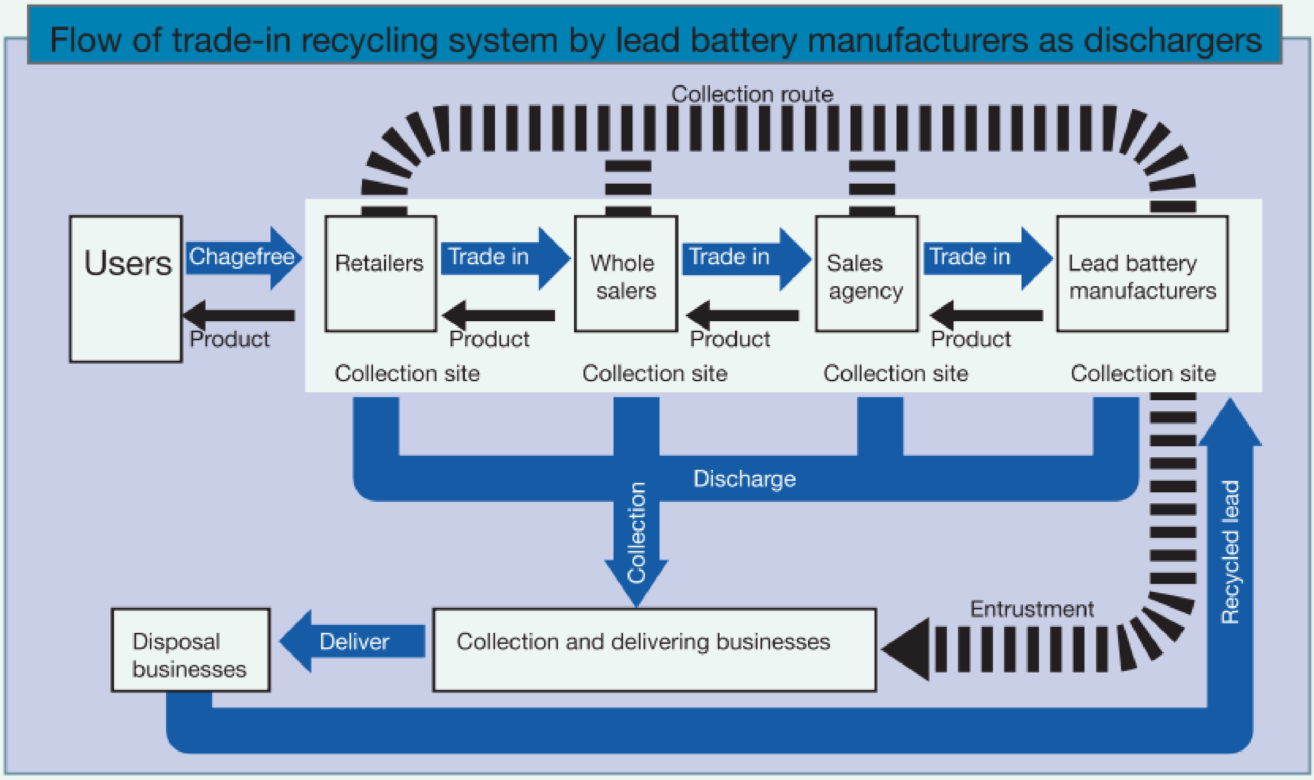

Figure 25 Value chain for Lead Acid Battery Recycling

A contemporary automotive battery recycling system has been established. Battery makers who are members of the Battery Association of Japan buy recycled lead batteries and return them to be recycled, with 20 million lead batteries projected to

48 "Towards 3R oriented Sustainable Society: Legislation and Trends 2007," Industrial Science and Technology Policy and Environment Bureau, Ministry of Economic Trade and Industry, Japan, 2007. [Online]. Available: https://www.meti.go.jp/policy/recycle/main/data/pamphlet/pdf/handbook2007_eng.pdf.
[Accessed April 2021]

be returned annually. Despite the fact that this system was effective and functional, there was concern that collection of batteries would stagnate due to an increase in the number of imported vehicle batteries, some of which did not meet recycling requirements, and the possibility that disused batteries would become chargeable if the market price of lead had dropped significantly. In light of these circumstances, the reports are gathered and sorted at the Central Environment Council's joint meeting in order to ensure the effectiveness of imported battery collection and recycling, as well as to establish a continuous and stable system that is less susceptible to market trends in the lead market.

5.5 Use Cases: Major Players

Japan has collaborative value chain in place. As per the act on promotion of effective utilization of resources, firms are supposed to handle the collection scheme as per their flexibility, various companies as per their initial capacity have come up to tackle this issue. Auto manufacturing companies have collaborated with logistic and metal refining companies to set the value chain into position.

5.5.1 HONDA, JAPAN METALS & CHEMICALS CO., LTD., AND MATSUDA SANGYO CO., LTD.

Honda, an automaker, Matsuda Sangyo, a recycling expert, and Japan Metals & Chemicals, a metal alloys company, have joined forces to combine their specific disciplines and fully benefit on their distinct assets.

The goal had been to extract the nickel and cobalt[49] from the batteries as a material could be used. Realistic recycling process was difficult to find. It was challenging to establish a realistic recycling procedure. Instead, they began with an approach that took advantage of their respective firms' distinct qualities as an automobile maker and an alloy manufacturer, and then worked backwards from there. This gave rise to the notion of obtaining nickel and cobalt as an alloy rather than removing them separately. This will shorten the metals separation process and also reduce labour and cost.

Battery pack consists of control components along with four sets of cells called modules. Inside every module are twelve cells. And inside each cell is a cathode containing nickel and cobalt. First step ends with extraction of the cathode.

The process follows multiple steps of disassembly from pack to module to cell and ends with extracting the cathode from each cell. While that happens, substances inside the cell must be safely and properly dealt because that become toxic from the reaction of water and air, as well as that are flammable and volatile.

The process of opening the cell, which contains flammable, volatile compounds as well as substances that become hazardous as a result of the chemical reaction of air and water, is the major hurdle to safely and quickly disassembling batteries for future scaled production.

49 "A shared dream for a circular economy: Collaboration with the alloy experts, Japan Metals & Chemicals," HONDA, 2018. [Online]. Available: https://global.honda/about/sustainability/environment/face/case84/02.html. [Accessed April 2021].

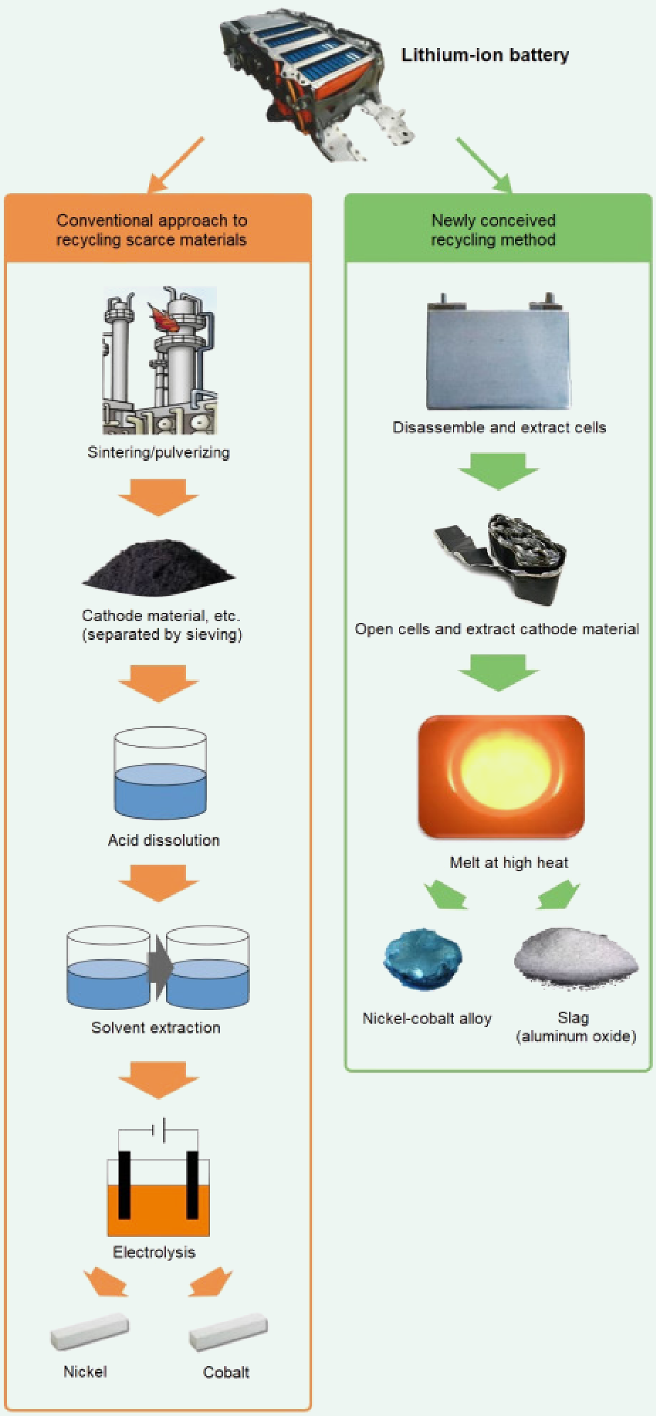

Figure 26 Honda conceived methodology over trivial Battery recycling

The first issue that Yokoyama and the combined project team had to deal with was copper. To avoid electric shock or the cell igniting, remaining electricity must be drained while opening a lithium-ion cell. When the remaining voltage in the cell falls below 0.6 volts, the copper in the cell dissolves, rendering the nickel-cobalt alloy worthless as a raw material for creating the hydrogen-absorbing alloy. Hence, they had to satisfy two conditions at once to extract the cathode, a requirement for first step: securing safety, and maintaining enough voltage to keep the copper from dissolving.

A chemical that creates hydrofluoric acid is found in the electrolyte inside the cell. Because hydrofluoric acid is extremely corrosive, the electrolyte must be completely emptied from the cell before it can be opened. The team created their own mechanism from the ground up that drains the electrolyte in a sealed state and replaces it with a cleaning solution to rinse the inside of the cell. This electrolyte is being studied for its ability to extract lithium.

There after the extraction of cathode material is a challenge. The purpose of not dismantling cell/ battery so obtained is to get proper recovery of cobalt and Nickel. It is because Nickel and cobalt are in the form of black powder sprayed over an aluminium foil. This foil is compactly rolled and fitted in the cell. This rolled foil is nothing but cathode for the cell. Its tedious to design a system that separates out this packed foil without damage. JMC has joined with Honda to come up with the solution to extract this cathode material safely. They had planned to establish satellite facilities across Japan that will disassemble batteries and ship only the extracted cathodes to JMC's factory.

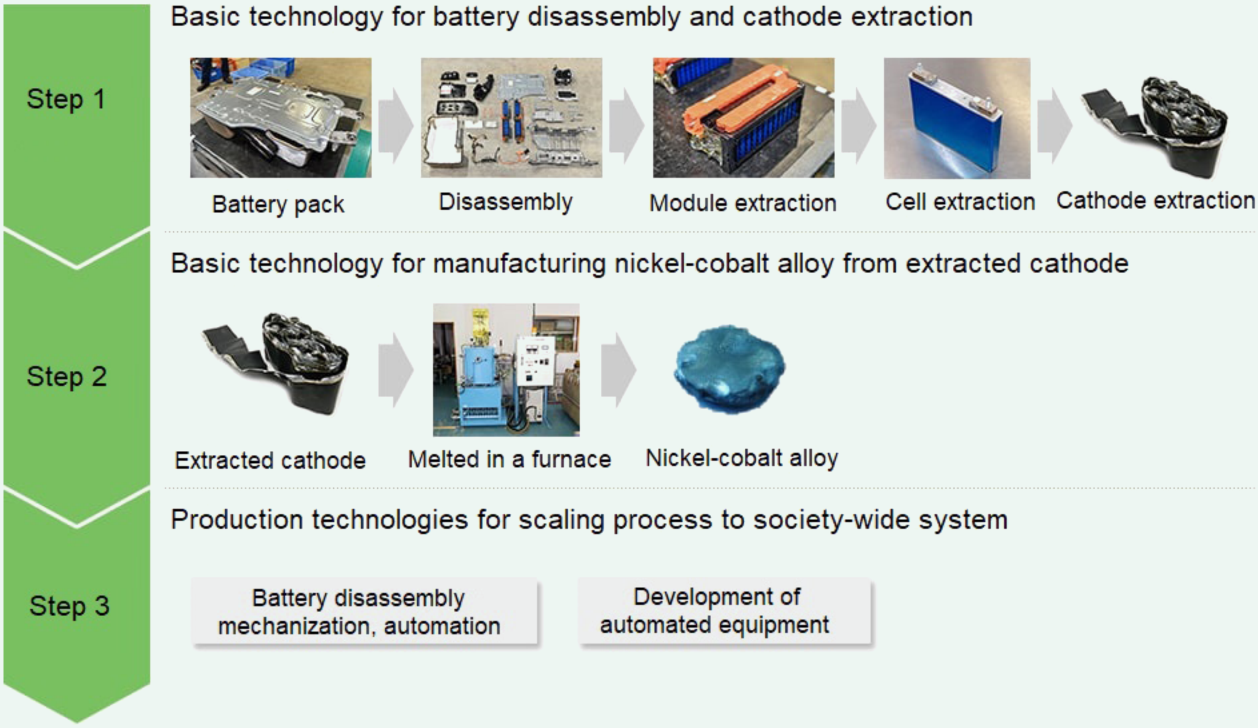

Figure 27 Steps involved in Recycling

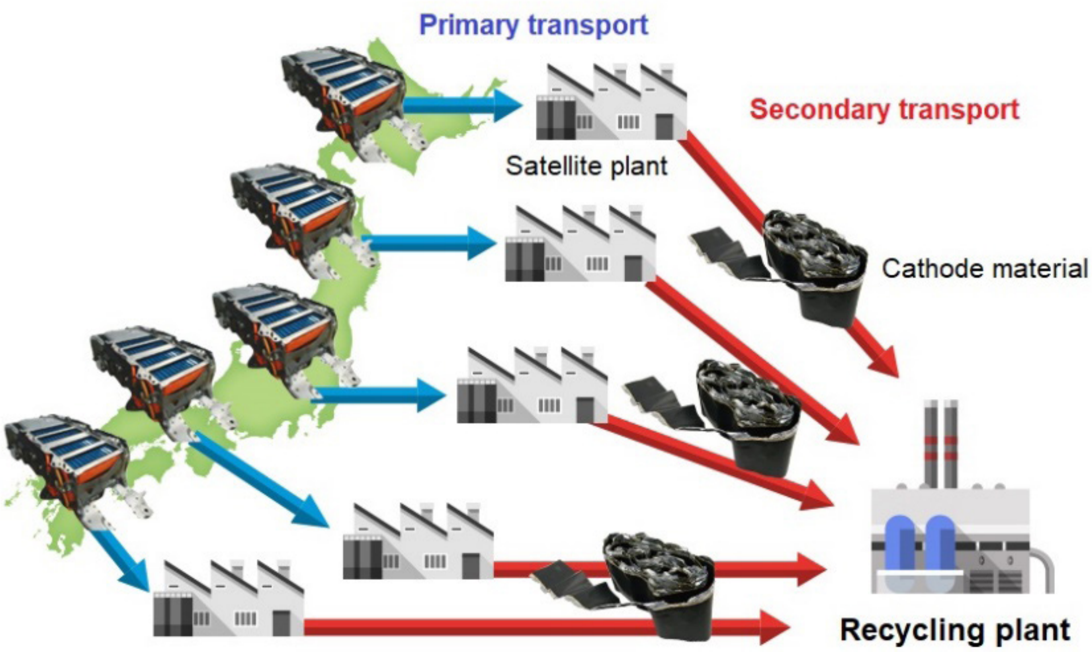

Figure 28 Various facility in sully chain for recycling

5.5.2 TOYOTA

In October 2010, Toyota[50] started the world's first 'battery-to-battery' recycling operation in partnership with other related companies (Sumitomo metal mining and Prime earth EV energy). It extracts nickel from used nickel-metal hydride batteries and recycles it as a raw material for batteries. In other words, complete recycling of rare metals has moved into the final validation phase.

Figure 29 Toyota battery recycling concept

First, the hybrid battery is removed from the hybrid vehicle taken over by sales office and Reunion companies nationwide. Toyota has setup one stop reception center for its batteries and accepts pickup request on internet. The batteries will be recovered from the dismantling companies and will be sent to the recycling companies. There are 34 collection centers in the country. The dismantled batteries are recovered and sent to recycling center. The battery delivered to the recycling plant is processed into raw material under safe and reliable processing. Dismantled batteries will be halved in the reduction path. Then they are sent to crusher and cut into pieces. Further they are sent to the cleaning process. Recycled material separated in the recycling process are source of battery raw materials. Those are shipped in barrels. Impurities are removed from the recycled material here to produce high purity sulfuric acid, Nickel. Battery raw materials are then sent to manufacturing plant. High quality recycled material helps for manufacturing new batteries. Nickel recovered will finally enter into hybrid battery in the battery manufacturing process.

The raw material mainly composed of Nickel hydroxide is cut into a shape and processed into positive electrode plate. A battery cell is completed by alternately compiling both anode and cathode. Then cell is inserted in resin base and thus the battery module is completed by attaching the vehicle casing. This casing is specific according to vehicle make and model. The completed battery pack will be sent to the vehicle production process after clearing the inspection process. Then batteries are delivered to the production line.

5.5.3 SUMITOMO METAL MINING CO. LTD. (SMM)

Sumitomo[51] has discovered a method for recovering and recycling cobalt, copper, and nickel from spent lithium-ion batteries and the intermediates used in their manufacture.

50 Toyota, "Vehicle Recycling," Environmental Affairs Division, Toyota, Japan, April 2017
51 L. Sumitomo Metal Mining Co., "Press Release," 28 March 2019. [Online]. Available: https://www.smm.co.jp/en/news/release/uploaded_files/20190328_E.pdf. [Accessed April 2021].

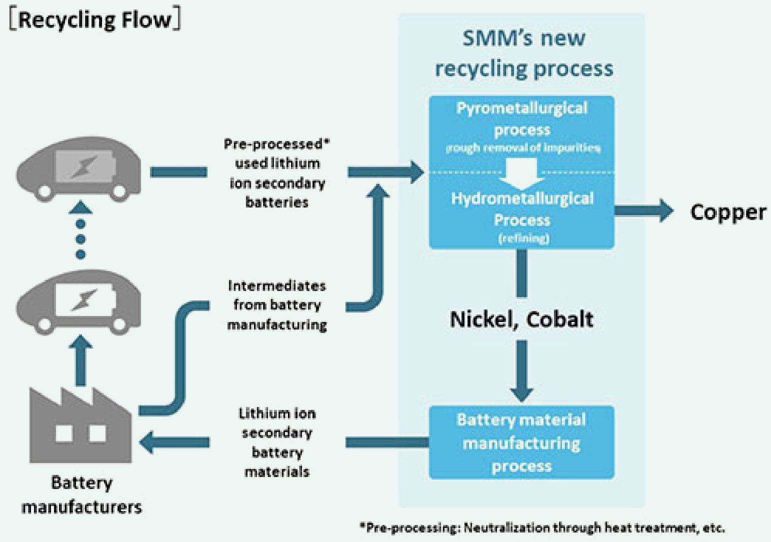

Figure 30 Sumitomo battery recycling methodology

In July 2017, SMM began smelting and refining copper and nickel from lithium-ion batteries at its Non-Ferrous Metals Division's Toyo Smelter & Refinery in Saijo City, Ehime prefecture, and its Niihama Nickel Refinery in Niihama City, Ehime prefecture.

Untreated LIBs are calcined at 1000 degrees Celsius, causing the cells to open and inflammable components like the plastic shell and organic solvent to burn off. Magnetic separation can be used to separate the residue, which consists of metallic and metal bits of iron, copper, and aluminium. Carbon powder and active cathode material (LiCoO2 and/or LiCoxNi(1-x) O2) make up the remaining fraction. By adopting a pyrometallurgical refining method that is independent of the existing procedure to extract most of the impurities from lithium-ion batteries, SMM has created a technology that selectively recovers nickel, cobalt, and copper as an alloy. The alloy is then leached and refined using a hydrometallurgical process to recover the nickel and cobalt for use as battery materials, while the copper is used to make electrolytic copper. Lithium is not targeted. Metallic wastes like as copper and stainless steel can be used as by-products, and high-quality cobalt oxide is recovered for use directly in the construction of new LIBs. Large batteries can be handled as well, but they must be pierced before being placed in the furnace.

SMM says it has built a pilot plant that uses these pyrometallurgical and hydrometallurgical refining processes in the city of Niihama to learn the feasibility of the recycling process and to scale it up to production level.

5.5.4 NISSAN, 4R ENERGY, SUMITOMO CORP.

Nissan[52] saw a need to utilize reusable lithium-ion batteries more effectively. In 2010, it launched 4R Energy Corp., a joint venture with Sumitomo Corp. This company has developed and tested to use EV batteries as part of a stationary energy storage system. The factory is Japan's first specializing in the reuse and recycling of used lithium-ion batteries from electric vehicles

52 "Zero Emmission," Nissan Motor Corp, [Online]. Available: https://www.nissan global.com/EN/ZEROEMISSION/APPROACH/COMPREHENSIVE/4RBUSINESS/. [Accessed May 2021].

The lithium-ion batteries used in Nissan's EVs retain their capacity much beyond the vehicle's useful life. The "4R" business model, which reuses, resells, refabricates, and recycles lithium-ion batteries, enabling them to be used for energy storage solutions in a variety of applications, resulting in a considerably more efficient battery energy cycle.

The company has developed a system that quickly measures the performance of used batteries and is applying this innovative technology to batteries collected from all over Japan at the Namie plant[53].

The batteries recycled and refabricated at the factory are used to offer the world's first exchangeable refabricated battery for electric vehicles, and also used in large-scale storage systems and electric forklifts.

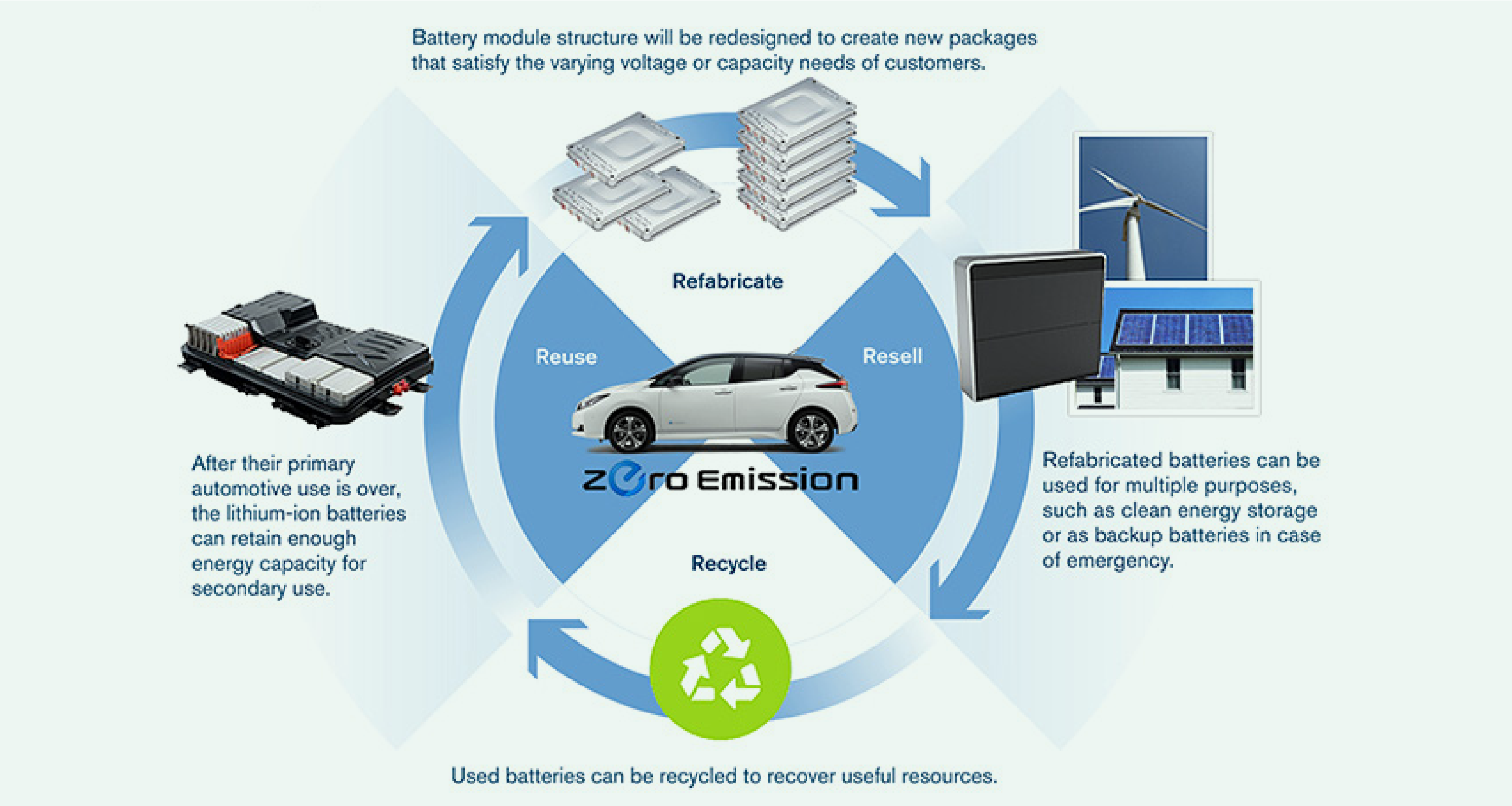

Figure 31 4-R concept by Nissan's 4-R Energy Corp

When one of Electric Vehicle battery packs is delivered to 4R Energy for recycling, it's initially analyzed and graded[54]. Those with as excellent as new components receive an A grade and can be utilised in new EV battery packs. When components obtain a B grade, they are regarded capable of powering industrial machinery and big stationary energy storage devices, such as those that can store electricity produced by solar panels during the day and utilise it to power the building at night.

The lowest grade given to exhausted battery components is C, although even those with this grade are employed in backup power units that provide power when the traditional electric grid fails. For instance, at grocery shops, there are devices that

53 P. Release, "Nissan, Sumitomo Corp. and 4R set up plant to recycle electric-car batteries," Nissan Motor Corp., Namie, Japan, 2018.
54 "Nissan gives EV batteries a second life," Nissan Motor Corp, Jan 2021. [Online]. Available: https://global.nissanstories.com/en/releases/4r. [Accessed May 2021]

power refrigerators and provide emergency lighting in the event of a power loss. After segregation into different categories post dismantling, based on customer demand, the batteries are refabricated depending on application. These new packages satisfy various voltage ranges and capacity need of customers. These batteries are then made ready to be delivered to customers (sold).

4R Energy had been actively developing a range of storage devices based on Nissan LEAF lithium-ion batteries that had been used previously. In November 2015, it increased its activities by initiating a power system stabiliser test in Satsumasendai, Kagoshima Prefecture, in addition to an existing experiment with a large-capacity storage system in Osaka's Konohana Ward since 2014. It also put a small-capacity storage system to the test in a commercial facility in Okinawa Prefecture, fine-tuning its performance evaluation for used module units and selecting standard technologies. The Nissan Advanced Technology Center deployed an energy management system made up of 24 Nissan LEAF batteries in July 2015.

Post use in various applications, batteries are brought for recycling. Recycling business is shouldered by Sumitomo by their technology to recover useful resources (as mentioned in previous section).

5.6 Conclusion

Japan is liberal in context of battery recycling infrastructure. For all kind of batteries, Japan has the act of promotion and effective utilization of resources (1991), which motivates firms for voluntary collection and recycling scheme into picture. Ordinance that extends the responsibilities of this act for the stake holders develop minimum mandatory recycling material ratio for various kind of batteries. To look after small portable batteries of all the types, JBRC has set a mechanism with specified supply chain. Various firms. As per their capacity and changing economies, get into collaboration to look after the value chain and recycling technological adjustments from time to time to time.

South Africa

6.1 Overview

South Africa is trailing behind the worldwide EV market, which is expected to reach five million units in 2019. Despite these policies, the South African (SA) EV market is well behind other markets, which are increasingly appreciating the additional features of electric vehicles. According to Brian Hastie, chairperson of the EV subcommittee at the National Association of Automobile Manufacturers of South Africa (NAAMSA), South Africa is falling behind due to a lack of model options. "Consumer prices are unattractive, EV business cases for OEMs/importers are unfavourable, and the country is expected to grow at only 3.7 percent by 2025 as a result of this poor growth.".[55] This shows that inclusion of EV is very new to South African Market. The growth and End of life scenarios of EV predict that South Africa will have to wait for some 5-6 years. It is therefore the EV battery recycling market has not yet flourished in SA. All the industrial and commercial grade batteries are collected at various collection centers of Automobile manufacturers as well as third parties and are shipped to France for their recycling treatment.[56]

Lead acid battery recycling business is well established in SA and delivers efficiency more than 90%. All the battery recycling practices are followed under guidelines mentioned under Atmospheric pollution prevention Act 1965 and National Environmental Management: Waste act 2008. There is no specific law in picture for battery recycling and treatment, but Lithium battery Recycling is a project (of public Private partnership) to bring up EV battery recycling opportunities in South Africa. It is funded by the Green Fund (Department of Environmental Affairs, SA)

Lead acid battery recycling business is well established in SA and delivers efficiency more than 90%.

6.2 Policy Guidelines

6.2.1 ATMOSPHERIC POLLUTION PREVENTION ACT 1965

In the second schedule, mentioned in the Act, last amended in March 1997, under section 23, information about lead (Pb) and its associated processes are mentioned. All the mentioned rules are equally applicable to all processes and so to Lead. Lead processing are mentioned as follows-

- Process in which by the application of heat, lead is melted or extracted for any material containing lead or its compounds
- Process in which compounds of lead are manufactured from metallic lead or its compounds by methods that give rise to noxious or offensive gases
- Process by which lead or any material containing lead, or its compounds are used or handled in such a way as giving rise to noxious or offensive gases.

55 "What's putting the brakes on EV adoption in South Africa?" Smart Energy International, April 2021. [Online]. Available: https://www.smart-energy.com/industry-sectors/electricvehicles/whats-putting-the-brakes-on-ev-adoption-in-south-africa/. [Accessed May 2021]

56 F. S. Benjamin D.H. Knights, "Lithium Battery Recycling: A Research and Policy development to advance a green economy in South Africa," Department of Environmental Affairs Republic of South Africa, 2015

6.2.2 NATIONAL ENVIRONMENTAL MANAGEMENT: WASTE ACT 59 OF 2008 (NEM: WA)

Amended by National Environmental Management: Waste Amendment Act 26 of 2014, this act promotes the law regulating waste management. Used batteries are treated or termed as waste and are treated according to Waste Act as per the document. Key insights on reduction, reuse, recycling and recovery of waste, are as follows-

- The recycling, reuse and reducing (processing) work must use lesser natural resources than disposal of such waste
- All the processing work done on given waste must have lesser impact on the environment than the disposal of such waste.
- There is provision for minimum determined material production after processing work of given entity by person or group of persons in charge.

6.2.3 EPR GUIDELINES

Before deciding any EPR guideline, the relevant ministry must -

- Must consult the affect producers of the waste/entity
- Consider country's obligations in terms of any applicable international agreement.
- Consider relevant scientific Information

6.2.4 MAIN EPR GUIDELINES

After consultation with the minister of trade and Industry, the Act asks minister to identify products or class of products that will be covered by the EPR guidelines, specify EPR guidelines for product and identify people who are supposed to extend their responsibilities towards such products.

Relevant ministry may specify:

- Requirements
- Financial arrangements (with concurrence of the minister of finance)
- Institutional arrangements for administration
- Minimum percentage of products or material to be recovered post processing
- Labelling requirements
- Producer must carry out Life Cycle Analysis of product/class of product after the processing phase with acceptable standards
- While redesigning the product after processing phase-
    - Clean production measures in design are to be implemented
    - Composition, volume or weight must have restriction (same as standard available product)
    - Packing must be designed so that it can be recycled/reused further.

6.3 Recycling Ecosystem in South Africa

6.3.1 LITHIUM BATTERY RECYCLING

The project Lithium battery recycling[57] is carried out by CM Solutions (A metallurgical Consultancy and Labs) with particular focus on recycling EV Li-Ion batteries. The project was funded through the Green Fund by the Department of Environmental Affairs, under the administration of the Development bank of South Africa.

With the aim of having LIB manufacturing plant in South Africa, this project aimed at recycling of lithium batteries to recover the lithium for further battery manufacture. Since lithium batteries contain several different value components other than lithium, a process was needed which would provide an acceptable disposal route for all the battery components. Increasing the economic viability and sustainability of the process for recycling is also one among the objectives of the project. Any waste streams generated should be benign and be disposed of with minimal environmental impact. Based on the economic viability following research objectives were generated.

- Being flexible enough to treat a wide range of Lithium-Ion Battery types
- Generate a final product which can be traded on the metal market or used in Li-Ion Battery manufacturing
- Have minimum capital expenditure
- To have value chain with established flow of money
- To have positive impact on policies of battery import, production and sales

The document has in-depth technical analysis of Li-Ion battery recycling process with its Life Cycle Analysis done and analysed. Based on the data collected from market about prices of battery ingredients and manufacturing, a forecasting model was set to recycle batteries. The results depicted no-positive economy in standalone mode i.e. without recycling fee from people to recycle the battery, it is not possible to bring monthly revenue generation above the cost incurred to run and setup. To achieve positive economy in this case, levy of less than 3 % of the battery cost would ensure breakeven in 5 years.

Key policy remarks

As a stand-alone process, lithium battery recycling does not appear to be financially viable. To cover roughly half of the costs of the recycling process, a recycling fee would need to be imposed. The final feed may differ depending on the results of a more thorough financial analysis. This tax might be applied to all batteries imported into the country as a levy. It might also be used to stimulate the adoption of electric vehicles by incorporating a battery recycling charge in the petrol and diesel fuel levy, for example. The Trash Act already has a structure for fees related to waste disposal.. "Extended Producer Responsibility" (EPR) is incorporated into the act as a regulatory mechanism to integrate the environmental costs associated with the life cycle of a product into the overall cost of that product. The proposed battery levy may be well catered for within the EPR mechanism.

57 F. S. Benjamin D.H. Knights, "Lithium Battery Recycling: A Research and Policy development to advance a green economy in South Africa," Department of Environmental Affairs Republic of South Africa, 2015

6.3.2 LEAD ACID BATTERY RECYCLING

The formation of $PbSO_4$ on electrodes of lead acid battery is main reason for end-of-life processes in Lead Acid Batteries. This layer inhibits any further ion exchange from electrolyte to electrode and vice versa.

The National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN No. R. 635 of August 23, 2013) and the National Norms and Standards for the Disposal of Waste to Landfill (GN No. R. 626 of August 23, 2013) were promulgated alongside the Regulations.[58] The former specifies a procedure for assessing waste for landfill disposal, implying that if disposal is a viable option for the waste residue generated during the Spent Lead Acid Batteries recycling process, the waste must be assessed in accordance with this procedure to determine the type of landfill in which it will be disposed. The latter prohibits the disposal of lead acid batteries in landfills immediately.

Currently, there are three sets of developed National Norms and Standards which may be relevant to the management of Spent Lead Acid Batteries:

- Standards for Scrapping or Recovery of Motor Vehicles (GN No. 925 of 29 November 2013)[59]
- Norms and Standards for the Storage of Waste (GN No. 926 of 29 November 2013)[60]
- Norms and Standards for the Remediation of Contaminated Land and Soil Quality (GN No. 331 of 02 May 2014)[61]

The above-mentioned licence requirements may apply to SLAB recyclers (i.e. secondary lead smelters), those who are temporarily storing SLABs, and those who are allegedly draining the acid on the ground, based on the criteria established in these Notices.

Aside from the laws stated above, there is an E-Waste management law. It's worth noting that batteries are classified separately from e-waste in South Africa (NEMWA, No. 59 of 2008, Regulation, 2012). The reason for this is that there are many different types of batteries, and not all of them are found in e-waste devices. Lead-acid batteries, for example, are mostly utilised in automobiles and hence do not qualify as e-waste. Batteries such as lithium-ion or nickel-cadmium batteries, on the other hand, are commonly found in e-waste devices and would unavoidably wind up in the same waste stream as e-waste. Although batteries are not readily accepted by E-waste collectors and therefore, they are routed through some other take back schemes[62]. It is healthy

58 "National Waste Classification and Management Regulations," 2013. [Online]. Available: https://www.environment.gov.za/sites/default/files/legislations/nemwa59of2008_wasteclassification.pdf. [Accessed May 2021]

59 "National Standards for scrapping or Recovery of Motor Vehicles," Nov 2013. [Online]. Available: http://www.iwmsa.co.za/sites/default/files/downloads/National%20standards%20for%20the%20scrapping%20or%20recovery%20of%20motor%20vehicles.pdf. [Accessed May 2021]

60 "National Environmental Management: Waste Act 59 of 2008," Amendment 2014. [Online]. Available: https://cer.org.za/wp-content/uploads/2010/03/NEMWAlatest.pdf. [Accessed May 2021].

61 "Norms and Standards for the remediation of Contaminated Land and Soil Quality," May 2014. [Online]. Available: https://cer.org.za/wp-content/uploads/2014/02/natl-norms-and-stds-for-remediation-of-contaminated-land-and-soil-quality.pdf. [Accessed May 2021].

62 Z. Sadan, "Exploring the potential for local endprocessing of e-waste in South Africa," Minerals to Metals Initiative, Dept of Chemistry, University of Cape Town, Cape Town, South Africa, Jan 2019.

to note the processes involved in treatment of such wastes. It matches the treatment of waste End-of-Life batteries. Due to this feature, it may be beneficial to note the value chain of these goods from End-of-Life phase to primary minerals which are further sent to manufacturing industries.

6.4 Supply Chain

6.4.1 LEAD ACID BATTERIES

The majority of spent lead acid batteries (SLABs) are recycled. The economic value connected with the lead component in SLABs is a major driving force towards their recycling. In 1942, the battery business was required by law to implement a battery collection system described as a "scrap deposit" by the industry but technically recognised as a "one-for-one returns scheme" by the government. The method was created with the goal of collecting and recovering as many lead plates as possible for secondary lead processing. Since then, South African battery makers have maintained a collection scheme for SLABs.

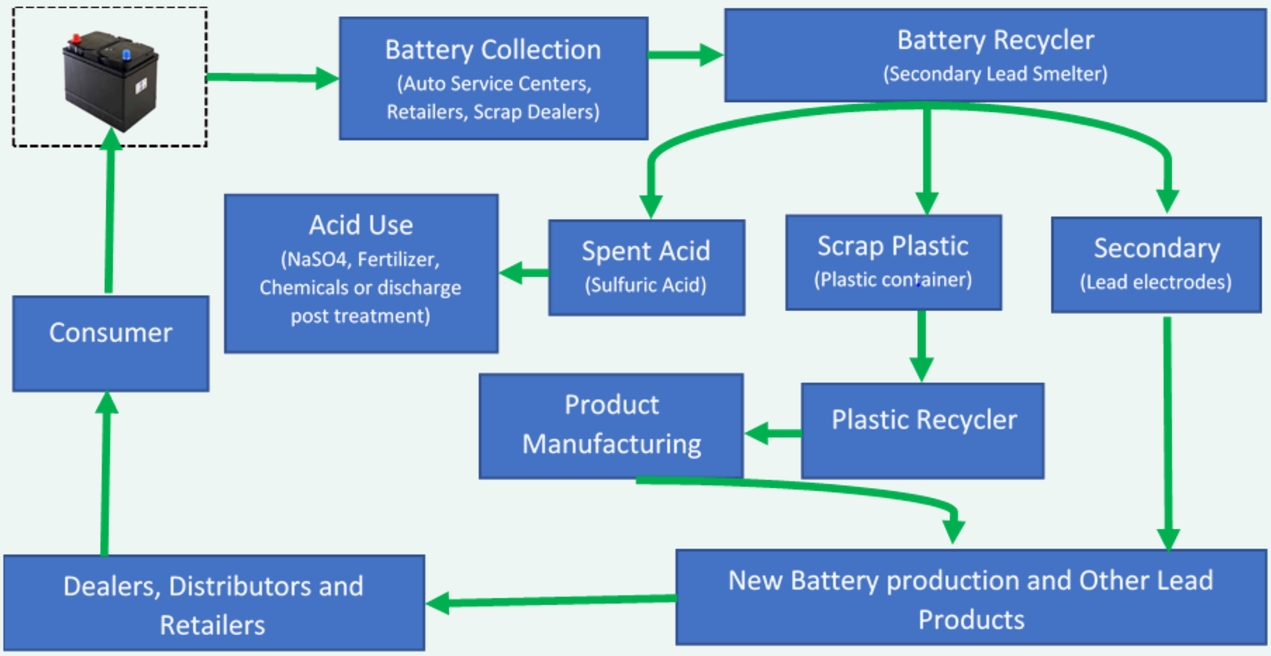

Figure 32 Standard Lead Acid Battery Recycling process in South Africa

- **Collection:** Manufacturers, distributors, retailers, wholesalers, service stations, and any other retailing points that sell a new Lead Acid Battery while also providing a service of retaining an old one employ the one-for-one returns method. When distributors are distributing new Lead Acid Batteries, they collect the Spent Lead Acid Batteries that have been retained. SLABs are collected and taken to secondary lead smelters for recycling. All SLABs that escape the one-for-one return system are sold on the free market, where individuals, particularly refuse pickers, gather and sell them to scrap metal dealers. Scrap metal merchants either sell them to local secondary lead smelters or ship them for recycling to other countries. Secondary lead smelters also accept Spent Lead Acid Batteries from individuals.

- **Spent Lead Acid Batteries Receiving Bay:** The receiving bay is a storage place for Spent Lead Acid Batteries that are collected through the one-for-one scheme or from other enterprises across the country, with some imported from other countries. Spent Lead Acid Batteries are received and stored on site on an impermeable floor to minimise the entry of leaking acid into the soil and hence potential groundwater pollution. Forklifts commonly load spent lead acid batteries onto the conveyor system that carries them to the Spent Lead Acid Batteries processing facility.

- **Spent Lead Acid Batteries Processing Component:** The battery breaker is the main module of the SLABs processing component, and it breaks and pulverises the battery into little coin-shaped bits. These fragments are placed in settling tanks and separated based on density variations - heavier pieces, such as lead, sink and settle at the bottom of the sump, whilst lighter particles, such as rubber (ebonite) and plastic, float. Polypropylene and Polyethylene are the two forms of plastics found in a laboratory. Polypropylene plastics are delivered to a plastic recycling facility to be reprocessed, whereas polyethylene plastics are burned in a furnace to recover energy and remove carbon from the process. Lead is sent to a smelting facility for separating metallic lead from a mixture of various substances whilst the acid is drained to effluent management plant for neutralization.

- **Lead Smelting Component:** Furnaces are used to melt scrap lead at extreme heat in order to extract metallic lead from a mixture of other compounds in this component. Metallic lead, lead oxide (PbO), lead sulphate (PbSO4), and other metals such as calcium (Ca), copper (Cu), antimony (Sb), arsenic (As), tin (Sn), and occasionally silver make up the scrap mixture from the breaking process (Ag). Hard or antimonial lead is the name given to the metallic lead generated in this process, which is packaged in the form of lead ingots. The furnaces are connected to a series of scrubbers that control air emissions as part of a pollution abatement system.

- **Lead Refining Component:** The antimonial lead produced in the lead smelting facility is refined further in this component to produce what is known as soft lead. Because the soft lead standard allows no more than 10g per tonne of these metals, the primary goal of the refining process is to remove practically all Cu, Sb, As, and Sn.

- **Blending Component:** A blending kettle is the most important part of a blending facility since it is used to make specialty lead alloys. In this department, highly sophisticated engineering equipment is used to cast pure lead into various alloys needed for the production of many sorts of LABs. Refined soft lead, D-alloy, 6 percent Sb alloy, positive calcium alloy, negative calcium alloy, and W-alloy are among the alloys created. These alloys are manufactured in complete accordance with the applicable SANS. SABS inspectors visit the site on a regular basis to ensure that these criteria are being followed. To distinguish between the manufactured alloys, the produced alloys are packaged in the form of lead bullions and colour tagged.

- **Plastic Recycling Facility:** Plastic recycling facility basically reprocesses the shredded plastics (polypropylene) into palletized briquettes. The produced briquettes are reused in the battery manufacturing process for producing new battery casings.

- **Acid Effluent Plant:** The acid effluent plant is a wastewater treatment facility that neutralises acidic effluent before it is discharged into the municipal sewerage system. Before being released, the water from the plant is tested in a lab to see if it passes the municipality's effluent discharge regulations. On a monthly basis, the municipality verifies the quality of tested water to verify compliance with the stipulated effluent requirements. During site visits to SLAB's recycling facilities, it was discovered that, while it is possible to regenerate battery acid, it is often not economically viable because it must be topped up with concentrated acids in order to be reused, which necessitates a significant amount of energy. Furthermore, because the battery acid is usually too low to regenerate, it is only regulated on-site through neutralisation. Even if it could be regenerated, its usage would be restricted to the battery manufacturing business, and it could not be utilised for any other industrial purposes because the acid is already contaminated with lead sulphates. However, there are methods that can manufacture lead-free acid, which may then be processed and transformed into sodium sulphate (Na2SO4) and supplied to the laundry detergent, glass, and textile production industries.

Customer related information of Lead Acid Battery collection

- When purchasing a new Lead Acid Battery whilst returning an old one (SLAB) to the retailer, customer get a "scrap discount" of about Rand 171 (as of 2015) on the original price of a new LAB.
- Customer can also trade their old battery without necessarily purchasing a new one. The payments for an old battery in these cases vary depending on the price of lead scrap as determined by Scrap Index.com and sometimes the London Metal Exchange but are typically about Rand 50 per SLAB (as of 2015).
- When customer purchase a new Lead Acid Battery without returning an old used one, a Rand 50 incentive is charged on customer as a levy. However, the levy does not apply to Lead Acid Batteries sold to vehicle assembly plants for use in new vehicles or where Lead Acid Batteries are purchased as original equipment, e.g., Lead Acid Battery purchase for a new burglar alarm. The levy does also not apply when Lead Acid Batteries are exported.

6.4.2 LI-ION BATTERY

There is no Li-Ion Battery recycling facility in South Africa. All the collected material is collected by retailers including Woolworths and Pick 'n Pay. There after these batteries are routed France for their further processing. The project study conducted by CM Materials in South Africa plan for Li-Ion Battery manufacturing and recycling facility. This study has covered all important players in this area (e.g. UMICORE, TOXCO, INMETCO). Recupyl is South African based firm that has run its pilot study in France. Their patented technology[63] describes pathway of Li-Ion Battery. the process is described in Major players Section.

6.5 Use Case: Major Players

South Africa lags in EV promotion and hence not many commercial scaled Li-Ion battery users are available here. Instead Lead Acid battery is prominently used here. Recycling methodology is well established here.

6.5.1 LEAD ACID BATTERY RECYCLING

First National Battery

Scrap Battery, a part of First National Battery's[64] , is in charge of collecting discarded lead acid batteries in South Africa. Scrap Battery also offers a collection service for huge amounts of batteries, while Battery Centre franchises operate as drop-off places for obsolete batteries. At First National Battery's recycling facility in Benoni, scrap batteries are treated to the point where the bulk of the components can be used to make new vehicle batteries.

BHG Recycling Process[65]

As per typical Lead acid battery recycling procedure, BHG processes its batteries in three parallel paths. Namely, Plastic path, Lead smelting path, and two paths for Electrolyte.

Plastic crushed pallets are injection moulded to form new containers for reuse. Lead recycled is available in form of Ingots which is further used for making lead and lead Oxide electrodes. Based on the choice or requirement, used acid can be converted to sodium sulphate and can be sold to glass industries or it can be treated chemically for either reuse in battery or for discharge in environment.

63 J.-C. F. Farouk Tedjar, "METHOD FOR THE MIXED RECYCLING OF LITHIUM-BASED ANODE BATTERIES AND CELLS". Domene (FR) Patent US 7820317B2, 26 Oct 2010

64 "Recycling Process," First National Battery, [Online]. Available: https://www.battery.co.za/recycling/recycling-process/. [Accessed 2021]

65 "Battery Recycling," BHG, [Online]. Available: https://bhgpower.co.za/battery-recycling/. [Accessed May 2021]

01

Batteries are collected through Battery Centre franchises and other sources around the country.

02

Scrap batteries are transported to the smelter in Benoni.

03

Batteries are processed through a battery breaker, seperating lead, plastic and acid.

04

The acid is neutralised and processed through the effluent plant before being disposed of in accordance with envirorvnental regulations.

05

The plastic components are washed and convened into pellets to be re-used in the manufacturing of new battery container and covers by Fim National Battery.

06

The battery plates, terminals and other lead pieces an! stoclcpiled for refining and blending with other materials to produce lead alloys for new batteries.

04

Any elements of the scrap batteries that can't be reclaimed are disposed of in a compressed cake form in a Class 1 dump.

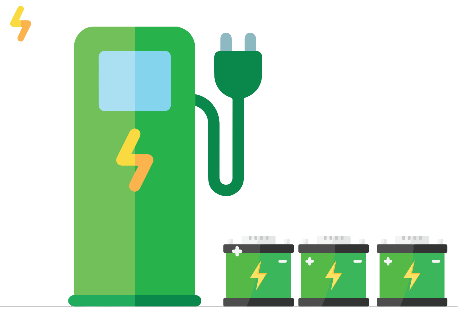

Figure 33 **First National Battery recycling chain**

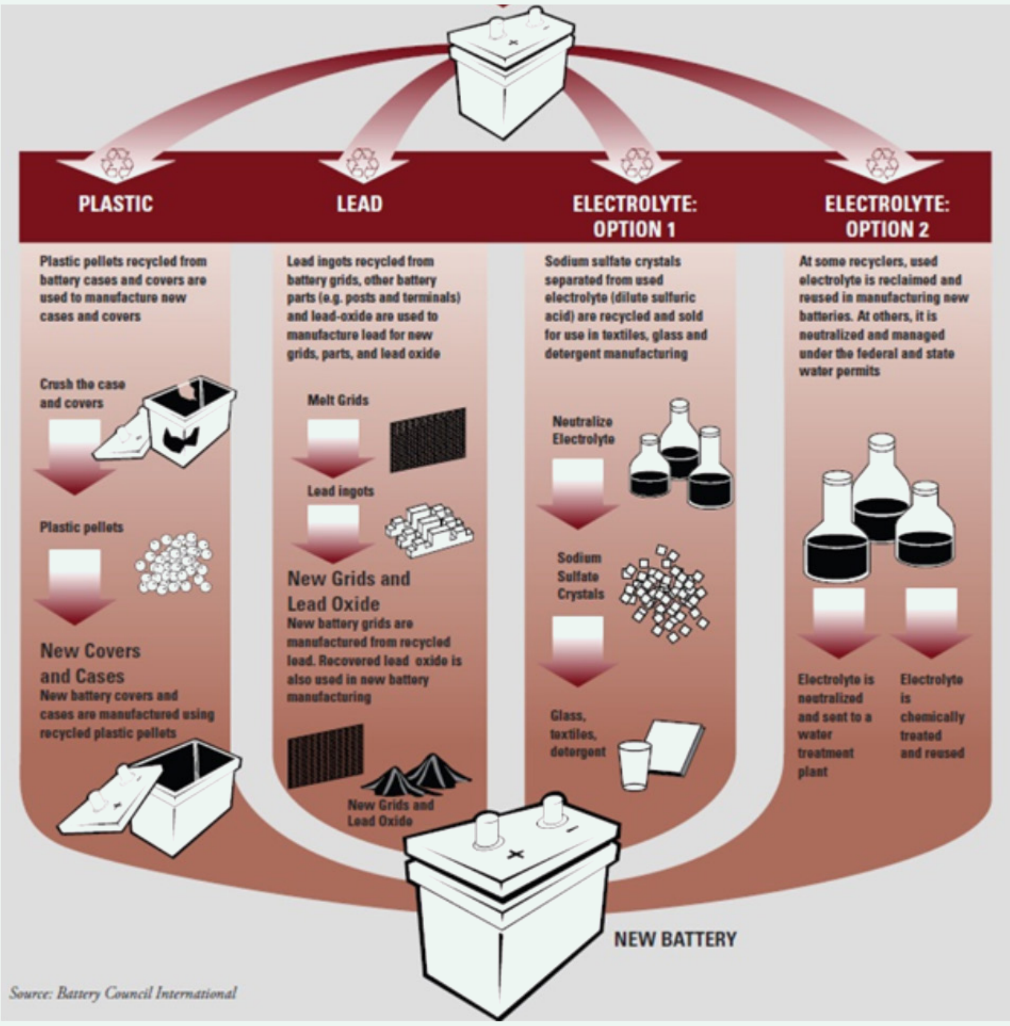

Figure 34: **BHG Battery recycling process**

6.5.2 LI-ION BATTERY RECYCLING

Recupyl

The Recupyl SA invented the Recupyl procedure, which was tested in France and adopted in Singapore. The technique is capable of treating 110 TPA of lithium batteries, both primary and secondary. Lithium carbonate is produced by a mixture of physical and chemical treatment procedures. Crushing, magnetic separation, and density separation are used to turn the battery scrap into a fine powder. The powder is then fed through a hydrometallurgical process that includes processes like as hydrolysis, leaching, and precipitation. Cobalt is recovered as cobalt hydroxide (Co(OH)2) while lithium is recovered as lithium carbonate (Li_2CO_3). The patent explains the processing processes in detail. Battery crushing is a two-step procedure that takes place in a rotating shredder. The crusher runs in a CO_2 and 10-35 percent argon environment. Any elemental lithium interacts with CO_2 to produce Li_2CO_3, which is less reactive than elemental lithium. A physical separation procedure is used to separate the crushed batteries. An inert atmosphere is created above the hydrolysis reaction using some of the remaining gas from the crushing step. The rest of the gas is used in the lithium precipitation process, where CO_2 combines with LiOH in solution to produce insoluble Li_2CO_3. Screening, magnetic separation, and gravity (densiometric) separation are used to separate the components of crushed battery scrap. Vibrating screens with a mesh size of 3 mm and a length of 500 m are utilised in the screening process. Metal oxides and carbons are found in the -3 mm fraction. This is then screened again on the 500 m screen, yielding a cobalt-rich -500 m fraction. This percentage contains lithium as well. Copper is abundant in the +500 m fraction. The copper-rich fraction is sold alongside steel, while the cobalt-rich fraction is transferred to hydrometallurgical treatment. Magnetic separation is used to address the +3 mm fraction. The steel from the battery casings is found in the magnetic fraction. A densiometric table is used to separate the non-magnetic portion. Paper and plastics are found in the low-density, non-magnetic fraction. Non-ferrous metals belong to the non-magnetic, high-density portion. Each of these fractions is available for purchase. Hydrolysis is used to handle the fine material left over from the physical separation procedure. Water is added to the substance. To attain a pH of 12-13, a solution of lithium hydroxide is applied. Lithium from the electrodes dissolves in solution to form lithium salts. Hydrogen is produced during the hydrolysis reaction, and inert gas from the crushing step is used to safely purge the hydrogen. The metal oxides and carbon are suspended in a solution and are filtered out. A lithium precipitation process is used with the lithium-containing solution. Lithium is precipitated from an alkaline leach solution as $Li2CO3$ or $Li3PO4$ using $CO2$ gas or phosphoric acid, respectively. The off-gas from the crushing stage is the source of $CO2$. At a pH of 9, precipitation occurs. Because the pH of the hydrolysis solution is 12–13, acid is added to lower it. The precipitate is washed and dried at 105°C in a $CO2$-saturated solution. At a pH of 3 and a temperature of 80°C, the stream containing residual suspended solids from the hydrolysis process is leached in sulfuric acid. The metal oxides disintegrate, leaving carbon behind. Prior to cobalt precipitation, the leach product is filtered and the solution is purified. Copper and iron are removed from the solution during the purification process. The inclusion of steel shot helps to cement out the copper. In order to precipitate iron, soda is used to raise the pH to 3.85. Cobalt precipitation is fed a copper- and iron-free solution. Electrolysis or precipitation as $Co(OH)3$ with the addition of sodium hypochlorite are both used to recover cobalt from solution. The leftover solution is passed to the lithium precipitation phase because it contains lithium.

Following diagram explains about the steps involved in Recupyl process.

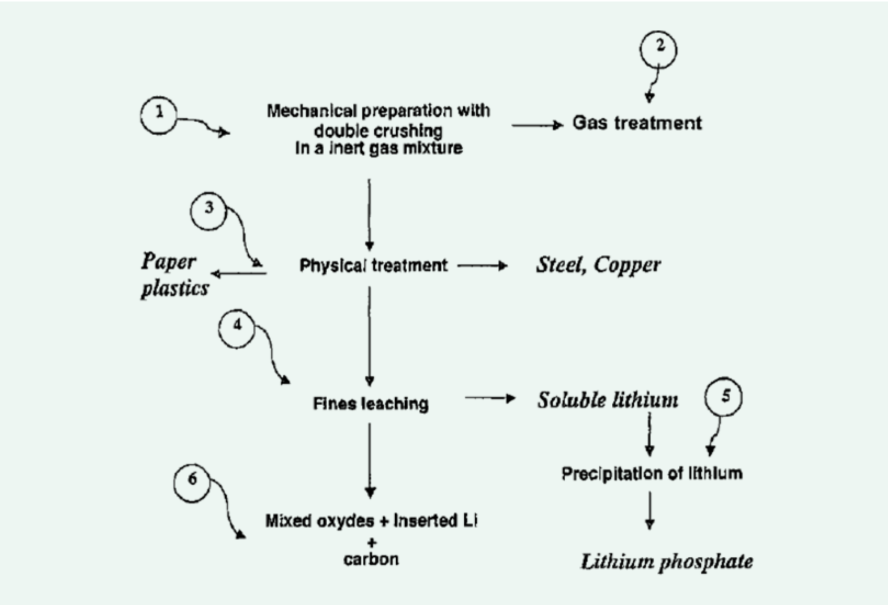

Figure 35 Patented Recupyl LIB Recycling Process

6.6 Conclusion

South Africa will have to wait for some years for EV infrastructure developed with them. Powering the vehicles using Lead Acid battery will continue. No specific Battery recycling policy but having superseding policy into picture, South Africa is responsibly executing recycling/reusing opportunities on Batteries. There is no fixed EPR laid down as the rules talk about waste in common but there is provision of EPR guidelines in policy which are equally applicable to any kind of battery recycling infrastructure in South Africa present today or upcoming tomorrow. Li-Ion battery recycling will not be standalone industry. Report shows, to support it, levy of 3% of total battery cost is to be shouldered by customer. Guideline also ask for setting minimum recycling efficiency of the process towards intended entity. In practice, companies follow world renowned techniques for Lead acid battery recycling yielding efficiency of 90% and above.

Supply chain seems obvious, in comparison to other countries, that customer will interact with local distributers and there after battery will be processed in traceable format for both Lead acid as well as Li-Ion battery. Studies are going on to set up an ecosystem of Li-Ion Battery. It is probable that motivation could be drawn from already existing EV manufacturers and their supply chain, existing E-Waste treatment policy and supply chain and existing Lead acid supply chain.

Conclusion

With the envisaged increase in EV adoption in the coming years, the increase in battery demand is imminent. This increase will lead to faster exhaustion of minerals required to produce batteries. In this regard, battery recycling undoubtedly holds an important role in the efficient use and re-extraction of the resources ensuring a stable supply chain and thereby contributing to the circular economy. However, the scale at which battery recycling can contribute significantly has not been achieved yet owing to many reasons. Efficient battery waste management policies and regulations are the need of the hour to encourage participation from the industry and the entire ecosystem.

This report has documented the policy and regulations for battery recycling in the countries: Germany and EU, China, California (US), Japan and South Africa. The stakeholders involved as well as their roles and responsibilities, the recycling ecosystem, and the major players in the market of the countries are documented. The benefits of recycling batteries have been established and the policies in each country may undergo further deliberations to establish a holistic and thriving battery recycling ecosystem to harness its full potential.

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Battery recycling undoubtedly holds an important role in the efficient use and re-extraction of the resources ensuring a stable supply chain and thereby contributing to the circular economy.

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