gaia

25TH ANNIVERSARY
2000-2025

# Q&A

## QUESTIONS & ANSWERS:

# ELECTRIC VEHICLE (EV) BATTERY RECYCLING

March 2025

www.no-burn.org/batteries/#ev

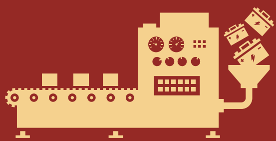
## Questions & Answers:

# Electric Vehicle (EV) Battery Recycling

## CONTENTS:

## Why is EV battery recycling important?

According to the Intergovernmental Panel on Climate Change (IPCC), in 2019, the transport sector accounted for about 15% of total GHG emissions and 23% of global energy-related $CO_2$ emissions, with road vehicles generating 70% of direct transport emissions.



Shifting the transport sector from fossil fuel dependence to electrification is understood as a necessary and crucial step for countries to reduce greenhouse gas emissions (GHGs). This confidence is reflected in increasing government, private, and development finance investments worldwide in transport sector electrification, and an increasingly competitive market for electric vehicles (EVs), including trains, buses, passenger cars, two- and three-wheelers, electric bicycles, and more. Transport electrification is causing skyrocketing demand for transition (also called "critical") mineral extraction, processing, and refining. Plus, the battery manufacturing capacity significantly exceeds projected demand at least until 2030.

Increased mineral demand and battery manufacturing come with the potential for toxic and climate emissions, human rights abuses, and ecological impacts concentrated in certain geographies in the Global South and often on Indigenous lands, and risk setting a path to exceed planetary boundaries. Batteries at end-of-life expose communities, workers and waste pickers to hazardous waste, fire and explosion risks.

Given geopolitical considerations, end-of-life management through mineral recovery – especially EV battery recycling – is seen by governments, industry and many civil society groups as a solution to meet the demand for transition minerals and national battery production targets. The promise of battery recycling includes lower GHG emissions, land and water use, and other environmental impacts than primary mineral extraction and refining. Recycling is one step in a broader zero waste solutions framework to conserve materials and reduce GHG emissions.

The first step is to rethink and redesign the systems and products, to avoid battery overproduction and battery material footprints, while extending EV battery lifetimes (and reducing total embedded GHG emissions) through repair and repurposing, and ensuring that materials can be safely recycled and recovered as feedstock for new EV batteries.

## What happens to EV batteries once they are removed from a vehicle?


(c) Electric Scooter Insider

Most of the EV batteries made are still on the road today. This will begin to change around 2030 as a large volume of EV batteries begin to reach end-of-life. At the moment, there is little known about the fate of used batteries once they are removed from an EV. Most of the information shared today in the news and reports about what happens to EV batteries at their end of life is based on recycling manufacturing scrap (a homogenous and predictable feedstock) or with consumer electronics, and speculation on what could happen in the future at a commercial-scale operation.

A few references claim that less than 5% of lithium-ion EV batteries are being recycled globally, but this data is challenging to verify for many reasons. For example, in China, statistics are limited to those reported by the relatively few Chinese government-approved (or white-listed) recyclers, and excludes the batteries collected and stockpiled for later processing by the possibly thousands of so-called wildcat recyclers.

The massive battery packs weighing about 1,000 lbs (~450 kg) used in EVs are said to be taken out of the vehicle once the battery capacity drops below 80 percent of its initial capacity, typically after 10 to 20 years of use, based on current technologies. This estimated lifespan is based on current battery chemistries, which are changing rapidly and may lead to significantly longer lifespans in the future. When removed from a vehicle, EV batteries that meet certain quality and design criteria can be repurposed for a second life as stationary storage, lasting another 10+ years. Almost no data is available on how many are reused or repurposed for a second life, and what the ultimate fate of the battery is. More transparency is needed on the chain of custody of a battery across its full life cycle: from manufacturing, to the vehicle, to a second-life, to recycling and disposal.

## What does effective EV battery recycling look like?

An effective EV battery recycling process will safely treat and convert all components, only when all other uses have been exhausted, to reusable material in the same or equivalent industrial uses. This process avoids the use of intense hazardous chemicals, battery burning, and adverse environmental impacts, especially toxic air emissions and hazardous waste byproducts

# Environmental Justice Criteria to Assess EV Battery Recycling

GAIA developed the following questions to assess the effectiveness of proposed EV battery recycling processes, maximizing each of the positive indicator and minimizing the negative criteria:

## RECOVERY OF MATERIALS & ENERGY INTENSITY

- What are the **actual recovery rates** of all materials (not only transition minerals) recycled from the end-of-life EV battery?
- What is the **fate of all materials** (mass balance) that enter the recycling stream, including what is burned, landfilled or otherwise disposed of?
- What is the **emissions intensity** and energy use of the collection, logistics, and recycling process, including the embedded emissions of inputs (for example, to produce the acids and chemicals used in recycling processes)?

## AIR, WATER & TOXICITY HAZARDS

- What are the **toxicity hazards of air pollutant emissions** **and impacts** to frontline communities and lands from the entirety of the collection and recycling process?
- What are the **water effluents and contamination risks** to frontline communities?
- What is the **water use intensity and wastewater burden** of different recycling options? What happens to the wastewater: what quantities are treated in what manner and disposed of where? and where does it go?

## MANUFACTURER RESPONSIBILITY

- What is the energy use, environmental impact, and cost of the **logistics system to collect and transport** the spent batteries from the place they were removed from the vehicle to the recycling processing plant? Who bears the responsibility for its functioning and cost?

- To what extent are the batteries **designed** for safe and effective recycling? How can battery manufacturers be incentivized to design batteries for the longest possible use of materials?

## BENEFIT-SHARING

- What **benefits are created for communities and marginalized sectors** involved in the value chain of recycling EV batteries? What is the process for establishing those benefits, and how can they be maximized, while minimizing risks and burdens for communities?

## WASTE TRADE

- What systems and **safeguards are in place on exports of spent batteries** to ensure responsible end-of-life battery waste management, including safe and effective recycling?

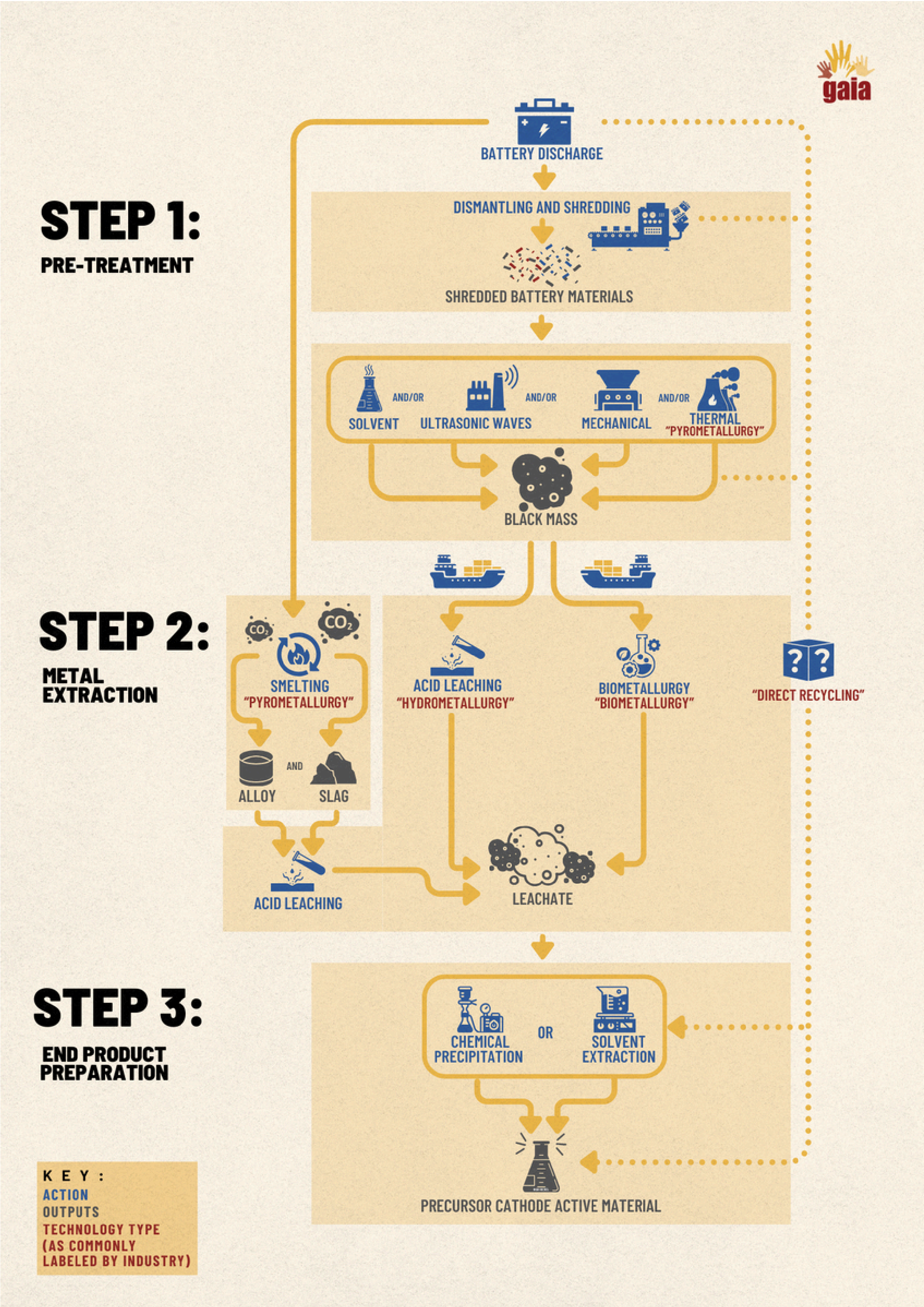
# What are the current proposed pathways for EV battery recycling?

The field of battery recycling is changing rapidly, and there are many different proposed recycling processes that combine steps in different ways, often using inconsistent terminology.

The motors in EVs use traction batteries, and the most widespread type is lithium-ion batteries (LIBs), which are complemented with lead-acid batteries (LABs) in most vehicles. Lithium-ion batteries come in a variety of different battery chemistries including lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), and lithium iron phosphate (LFP), among others, which affect recovery strategies and value of end-of-life lithium-ion batteries. Not all of the pathways below are viable options for all lithium-ion EV battery chemistries.

With an aim to provide a general guide, some of the most prevalent pathways for recycling lithium-ion batteries (typically with cobalt and/or nickel-rich cathodes) can be explained as a multi-step process as follows:

## Steps in Proposed Pathways for EV Battery Recycling



## Step 1 - Pre-treatment

In this step, the batteries are discharged and dismantled. Next, to remove the separator, electrolyte, and fluorinated glues, processes such as mechanical disassembly, wet and dry shredding/crushing, solvent dissolution, ultrasonic-assisted separation, and thermal treatments at temperatures 400 to 700°C (such as pyrolysis or calcination) are applied. The pre-treatment step will produce black mass, which is then further processed in a second step. Pre-treatment may be skipped when battery materials are burned or smelted.

## Step 2 - Metal extraction

There are several ways to extract metals from battery materials:

SMELTING

High-temperature processes of burning or smelting (often referred to as **pyrometallurgy**, which encompasses a wide range of thermal treatments) of spent lithium-ion batteries or mixed battery materials at temperatures from 1400 to 1700°C produce an alloy. The resulting alloy is subsequently treated with a hydrometallurgical process.

ACID LEACHING

Acid-leaching (known as **hydrometallurgy**) is currently the most favored option for leaching metals from black mass or alloy, with huge quantities of toxic acids and solvents being used; this process produces leachate (liquid containing metals).

BIOMETALLURGY

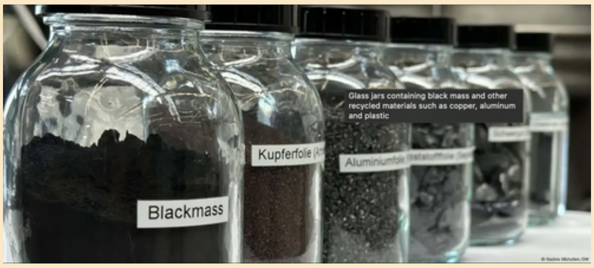
Newer proposals such as leaching with inorganic or organic acids (known as **biometallurgy**) or using electricity as the catalyst to help separate and extract the valuable materials from the batteries (known as **electrometallurgy**); this process produces leachate.

Any combination and sequence of the above and others under development.

## Step 3 - End product preparation

This step aims to separate metals from the leachate into battery-grade materials, including precursor cathode active material and anode material. This process can use solvent extraction, flotation, crystallization, or chemical precipitation, etc. End product preparation is complicated and may be costly.

### BLACK MASS




(c) Nadine Michollek/DW

Black mass is an intermediary product of some battery recycling pathways created by shredding lithium-ion batteries, as shown in Step 1 (Pre-treatment) in the diagram above.

There is no standardized definition of what constitutes black mass, and the exact composition varies depending on the batteries treated and the treatment process employed. It is a black powder containing a mixture of battery materials including graphite, lithium, nickel, cobalt, inorganic fluorine compounds, and halogenated organic solvents.

Many of the compounds in black mass, including inorganic fluorine compounds and halogenated organic solvents, are listed as hazardous wastes under international conventions and harmful to human health. However, black mass may not always be classified as hazardous waste due to economic and political considerations, with an attempt to ease import regulations. Black mass is often produced in one country and exported to another for further processing, such as China or South Korea.

## DIRECT RECYCLING OF EV BATTERIES

Direct recycling is the recovery, regeneration, and reuse of various battery components, such as individual cells and electrolytes, without breaking down the chemical structure. Newer proposals emerged, such as leaching with inorganic or organic acids (known as biometallurgy) or using electricity as the catalyst to help separate and extract the valuable materials from the batteries (known as electrometallurgy); these processes produce leachate. This recycling pathway is less studied and less mature, even though it could offer many advantages: highest material recovery rates for all materials; lower costs; reduced carbon emissions and energy intensity; and fewer risks of toxic impacts on frontline communities. While this process remains under development, current proposals suggest it can include shredding, magnetic separation, froth flotation, precipitation in water-based solution, ultrasonic waves, thermal treatment, and relithiation to revive degraded cathode active materials.

?

# How do pyrometallurgy, hydrometallurgy, and direct recycling compare?

Much of the literature today aims to classify EV battery recycling proposals into three discrete categories: pyrometallurgy, hydrometallurgy and direct recycling.

As described above, the reality is more complex, with most processes utilizing multiple thermal and solvent-based steps.

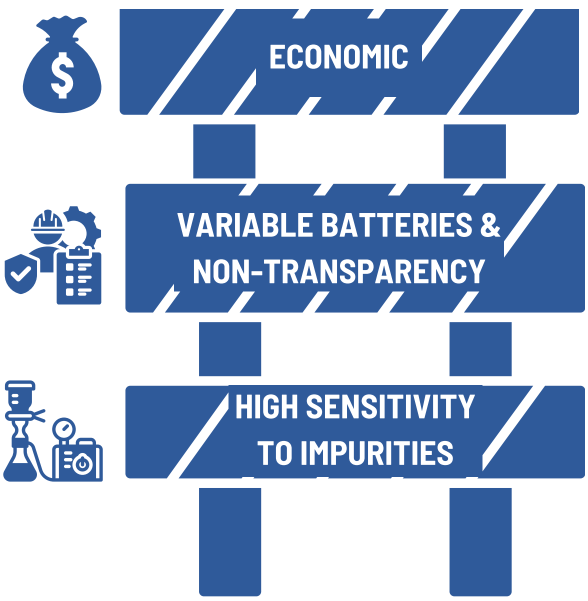
The following reasons make it challenging and a bit misleading to try to compare these processes:

> These terms are not uniformly defined and lead to much confusion. For example, while "pyrometallurgy" is traditionally a term considered synonymous with smelting, it also often refers to a wide range of high heat thermal treatments beyond smelting. This means that some pre-treatment processes for the hydrometallurgy pathway – such as calcination – can be considered a type of pyrometallurgy.
>
> What is more, as the three steps above show, pyrometallurgy" and "hydrometallurgy" are closely interconnected. Recycling most often involves both pyrometallurgy and hydrometallurgy; Umicore is one of many examples of such combined recycling techniques.
>
> Other than smelting, most of the hydrometallurgy recycling pathways are technologies that are still maturing, requiring further optimization to reach a commercial scale. Direct recycling largely remains in the research and development stage.

# What are the barriers to scaling up new EV battery recycling technologies?

Little evidence is available to show actual processing capacity, recovery rates, cost-effectiveness, and ability to treat both manufacturing scrap and post-consumer EV batteries beyond a small volume. A range of technical and economic barriers have yet to be addressed to transition successfully from a pilot or lab-scale lithium-ion battery recycling process operating under optimal conditions to a high-volume commercial scale one. Most of the proposed recycling pathways also focus primarily on extracting a few valuable components, with risks of most of the mass balance going to waste.

Some of the barriers to scaling up are:




## ECONOMIC

Recycling for recovery of materials beyond high-value ones such as cobalt and nickel is expensive. New proposed recycling pathways will likely require price premiums, toll-based mechanisms, and revenue-sharing for recyclers or subsidies in order to be economically feasible.

The costs of material recovery processing may be higher than the economic value, especially for lithium, graphite, and manganese in the cathode active materials and in the anode.

While high lithium recovery rates have been achieved in a lab under optimal conditions, it is challenging to do so due to thermodynamic reasons and so, economically unfavorable.

Due to market conditions, it can remain cheaper to buy mined rather than recycled materials; low market prices for metals (especially lithium, graphite, and manganese) make recovering battery-grade materials from recycling unprofitable.

Recycling facilities that require high market prices to operate profitably may discontinue operations. For example, in 2023, Chinese battery recyclers went bankrupt due to low lithium prices.

## VARIABLE BATTERIES & NON-TRANSPARENCY

Due to a lack of disclosure and labeling of highly variable battery configurations and chemistries, it is challenging to safely sort and optimize conditions for reuse, repurposing and recycling. The recycling feedstock—all types of aged batteries with different configurations and chemical composition from dozens of manufacturers—will be highly variable and unpredictable. Regulation has so far failed to mandate disclosure with strict labeling requirements, making sorting for next best use and recycling of highly complex batteries very challenging.

### SMELTING

(c) Oeko-Institut

Smelting is a technology that can recycle many different lithium battery chemistries, such as Umicore's battery recycling plant in Belgium. However, it is not a new recycling technology, and largely only suitable for cobalt- or nickel-rich batteries. While smelting followed by hydrometallurgy effectively recovers cobalt, nickel, copper, and iron in amounts very near to their initial battery concentration, this rather cheap and crude method has very high energy requirements, produces toxic dust, fly ash, and gasses, and burns off most of the battery mass such as the graphite, binders, and electrolyte.

## HIGH SENSITIVITY TO IMPURITIES

The effectiveness of the emerging recycling pathways that include a hydrometallurgy step for battery recycling lies primarily in the thermal pre-treatment that is done to convert a spent battery into black mass.

Hydrometallurgical techniques are very sensitive to impurities. Unless these are cleaned out, contamination will lead to low yield, low quality product, or the use of more chemicals, energy, and processing stages. The often highly variable quality of black mass produces contaminated substances requiring significant treatment to be converted into battery-grade materials.

High quality hydrometallurgical outputs require lots of time, effort, resources, and a large plant footprint, all of which are directly related to the extent of pre-treatment.

If pre-treatment is not done well, then the impurities and contamination in the black mass make the metal extraction step much more technically and economically challenging. Chemical input ratios will likely need to be strongly adjusted upward, while extra contamination levels will require more inputs and resources to produce battery-grade materials.

## Beyond scaling up, what are other challenges for battery recycling?

**EV batteries pose safety risks for all handling, including recycling.**

EV batteries pose high fire risks in all handling operations - from collection to transportation, repair, disassembly, recycling and disposal. Lithium-ion cells carry a very high risk of fire due to thermal runaway. This occurs when heat builds up in the battery faster than it can be dissipated, causing the battery to off-gas or even explode. From China to France, Hungary, and the UK, and Missouri in the US, lithium-ion battery recycling facilities have had fires releasing thick plumes of smoke with toxic chemicals, resulting in at least one death and sometimes forcing residents to evacuate.

**The highly variable and proprietary configuration of EV batteries makes them challenging to disassemble.**

EV batteries are not standardized: more than a dozen manufacturers each have their own different battery sizes (from scooters to passenger vehicles to trucks) and shapes (e.g., cylinders, prisms, and pouches).

The battery cells, packs, and modules are then configured and welded together using various binders and in different casings. For example, while cell-module-pack construction is common, manufacturers are increasingly opting for cell-to-pack or cell-to-chassis configurations.These alternative configurations allow for less material use, weight and production time, but then make disassembly far more challenging and costly. In all, EV batteries are not designed with repairability, reusability, or recyclability in mind.

**EV batteries have different chemistries, with the market share of each constantly changing, and so, varying recyclability.**

Most EV batteries today are lithium-ion batteries, but there are many different battery chemistries within this category, and the market share of each is always changing. While lithium nickel manganese cobalt oxide (NMC) remains the dominant chemistry globally, the share of less expensive batteries that do not have high-value cobalt and nickel (such as lithium-iron phosphate, LFP) is rapidly rising to more than 40% globally, with most of that concentrated in China. This represents a high proportion of batteries that lack high-value materials that typically pay for recycling.

Moreover, lead-acid batteries (LABs) remain common in Global South countries in, for example, two- and three-wheeler EVs, most of which come from China. Looking forward, there are important longer-term shifts in the types of lithium-ion batteries, whether it is moving away from graphite-based to silicon-based anodes, different cathode chemistries, or moving away from lithium-ion batteries entirely to sodium-ion or solid-state batteries.

## There is a lack of standards and narrow performance goals for materials recovery, GHG emissions, and energy balances of battery recycling.

Most discussion of battery recycling is concentrated on recovering transition minerals such as cobalt, copper, nickel, lithium, graphite, and manganese. This focus is too limited; recycling goals should instead look at a full mass balance analysis and energy balance analysis that includes embedded emissions. The mass balance analysis should use standardized metrics and extend to all components of EV batteries, including plastic casing, electrolyte and fluorinated binders, electronic components, and metals such as aluminum, copper, and steel in the foils and more.

## Batteries and black mass are inherently toxic.

Black mass contains high concentrations of hazardous substances, such as nickel and cobalt oxides, $PM_{2.5}$, fluorine, arsenic, tin, and cadmium. Processing it in a hydrometallurgical process can result in emissions of hydrogen sulfide ($H_2S$), sulfur oxides, carbon monoxide (CO), hydrogen chloride, and fluoride-containing gasses.

Among a host of toxic air emissions, wastewater, and other byproducts that can be generated from a battery recycling process, per- and polyfluoroalkyl substances (PFAS) present a distinct concern as they persist permanently in the environment and human bodies once introduced. Research shows that thermal treatment during the pre-treatment phase to create black mass (before hydrometallurgical processing) may lead to an incomplete breakdown of PFAS, in addition to the production and release of new and persistent fluorinated substances.

## Informal workers are excluded from the recycling boom and disproportionately harmed by the uptick in battery waste.

The informal economy sectors are largely excluded from the lithium-ion battery recycling boom. This causes harm especially in Global South countries where wastepickers and waste workers will have to bear the brunt of the uptick of EV battery waste in the absence of end-of-life waste management infrastructure. There are already well-developed informal recycling ecosystems for lithium-ion batteries in many countries, where workers have to operate with no formal protections or grievance mechanisms while performing dangerous labor.

### Recycling steps are outsourced to multiple companies.

All steps of battery recycling - from collection, to pre-treatment, to metal extraction, and precursor material preparation - must be assessed as a whole in order to determine the merit or value of one of them, because they are interdependent.

This is very challenging, because the steps are typically outsourced to different companies, over multiple sites, and often involve international shipment.

### Collection and transportation logistics costs for battery recycling are high.

The cost of collection and transportation of EV batteries removed from a vehicle can make up an estimated 40% of the recycling costs. Moreover, EV batteries can present a fire risk when improperly dismantled, therefore requiring more strenuous packaging and capacity standards for shipment across the country.

## Will EV battery recycling reduce primary mining?

It is incorrect to simply assume that all recycled material will displace primary (or virgin) mineral extraction for battery production. In order for recycling to reduce mining, the process must be a closed loop, that is, it must produce recyclates that are battery-grade material that can compete with primary mineral extraction for battery production.

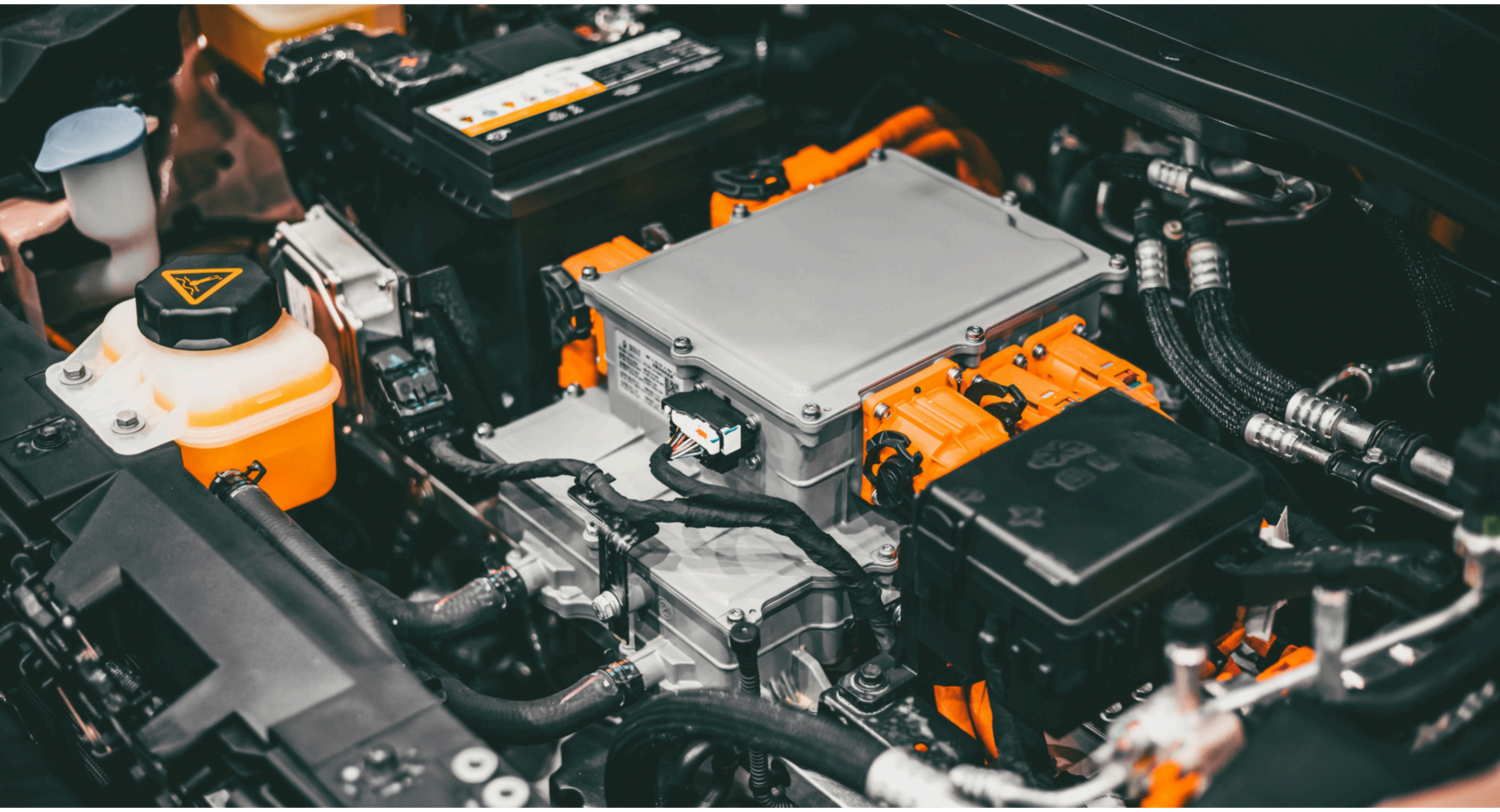
Even though certain reports claim high battery recovery rates will reduce mineral demand and battery production, these analyses appear to be based on undisclosed or unavailable industry data and assumptions that the challenges highlighted above will be successfully resolved.

It is not yet known if the barriers to scaling up can be overcome in a way that

1. maintains the very high lab-scale recovery rates,
2. does so in a way that produces a battery-grade recyclate that is cost-competitive enough to displace primary mineral extraction and new battery production, and
3. avoids causing significant harm to communities and ecosystems.

While recycling has lower GHG and toxic emissions, and less land use and environmental degradation than primary mineral extraction and mineral refining, recycling remains costly to the environment in terms of carbon and toxic emissions from collection and transportation, energy, water, and toxic material inputs for the processing, and land use for battery recycling plants. Those pressures on the environment can only be redeemed if it is an effective recycling process that displaces primary mineral extraction and new battery production. We have laid out the many challenges to realizing that circularity above. Credible data—that is today not yet disclosed or available—is needed to verify industry claims that EV battery recycling is technically and economically possible at commercial-scale, that it will displace primary mineral extraction and new battery production, and on what time scale this will happen.

Strategies that focus, for example, on avoiding overproduction and reducing material footprint (vehicle and battery sizes) can have far greater impact to reduce mineral demand than recycling, as discussed in our recommendations.



## What are GAIA's recommendations for the way forward?

- Examine battery recycling through a critical lens.
- Prioritize material conservation and environmental protection strategies in accordance with the zero waste hierarchy.
- Minimize social and environmental costs by reducing waste and toxicity in EV batteries.
- Incentivize reuse and repurposing of EV batteries once removed from a vehicle.

### EXAMINE BATTERY RECYCLING THROUGH A CRITICAL LENS

It is important that in this period of innovation and opportunity, the promise of battery recycling to reduce primary mineral demand and battery production be examined through a critical lens.

Lessons from the recycling of plastics show that industry often makes overly optimistic claims and markets the promise of new pilot technologies, only to have those technologies then fail to mature to deliver technically and economically at commercial scale.

### GAIA proposes the following policy recommendations on EV battery recycling:

**Exclude processes that destroy materials.** Avoid including battery burning as "recycling" in legislation. Circularity and circular economy policies must exclude processes that destroy materials.

**Regulation and funding must be scaled up for battery design for safe recycling.** The most fundamental characteristic affecting the efficacy of battery recycling is made not in tweaking any of the recycling processes in a sophisticated high-tech treatment suite, but rather in the design, configuration, and chemical composition of the battery when manufactured.

Design improvements are essential to enable ease of disassembly and effective recovery of battery materials, which could be enhanced by **extended producer responsibility** (EPR) schemes. Public and private funding today is heavily skewed towards battery recycling, and this should be shifted towards rethinking energy and transportation systems, including battery design.

**Hold battery manufacturers and automakers accountable** through mandatory EPR for the robust and effective **collection, recycling, and disposal** of batteries across their full life cycle (removal from a vehicle, to reuse and repurposing, to recycling and disposal) and all related **costs**, including the recovery of lower-value materials.

**Industry must disclose data.** Ensure transparency and access to data by requiring battery manufacturers, automakers, and battery recyclers to disclose comprehensive battery data to a public or independent reporting body. This includes data and other information about the battery itself by battery manufacturers and automakers, including but not limited to detailed chemical composition, hazardous substances, replacement parts, instructions for safe handling and dismantling, and repair manuals, battery state of health (original capacity, level of degradation, remaining capacity), battery history of use, negative events and chain of custody. Battery recyclers must disclose data on material recovery mass balance (inputs and outputs, prioritizing minerals but not only limited to), energy, water, and toxic emissions (including by toxin and effects).

**Scaled-up and intensified R&D in safer recycling processes**, such as direct recycling, that offer the highest material recovery rates of all materials with lower costs, reduced carbon emissions and energy intensity, and fewer risks of toxic impacts on frontline communities. Such investments should also consider the social costs of transition and embed safeguards to ensure frontline workers have available and accessible mechanisms to prevent further harm.

## EXTENDED PRODUCER RESPONSIBILITY (EPR)

Extended Producer Responsibility (EPR) is a policy tool intended to shift the cost of waste management of and pollution from specific products from the taxpayer to the producers, importers and distributors and incentivize eco-design. It seeks to improve the environmental and social performance of products by holding producers and brand owners accountable for the entire lifecycle of their products. Whether or not EPR schemes deliver on these aims depends on their setup and implementation.

Therefore, the EPR scheme requires government oversight, stakeholder participation in decision-making (including all potentially affected communities), and careful considerations to limit conflicts of interest. The EPR scheme also needs dedicated human and material resources to ensure that prevention, collection, and recycling targets are met, and that the legal framework is complied with - including governance rules (For more information: GAIA (2023). The Pros and Cons of EPR: Lessons from France).

## PRIORITIZE MATERIAL CONSERVATION AND ENVIRONMENTAL PROTECTION STRATEGIES IN ACCORDANCE WITH THE ZERO WASTE HIERARCHY

Given the many challenges to battery recycling, now is the time to prioritize material conservation strategies that have long been proven to be more effective than recycling, namely reduction, repair, reuse and repurposing, which rank higher on the zero waste hierarchy for batteries.

Reforming transport and energy systems in the short- and medium-term is the most impactful measure according to the zero waste hierarchy for batteries, as a means to center sufficiency and reduce global energy consumption and resource use. This involves a wide range of measures including limiting battery manufacturing overproduction and following binding material footprint reduction targets, such as smaller vehicles and batteries.

Reducing the average vehicle battery size of light-duty battery electric vehicles is one of the most immediate and effective ways to reduce raw material demand. Policy measures such as (implementing) energy efficiency standards, tailoring EV purchasing tax incentives to vehicle weight (removing incentives for super-sized passenger vehicles and SUVs exceeding a certain weight) and (expanding) charging networks can help to spur this shift towards smaller batteries and so, reduce carbon emissions.

## PREVENT SOCIAL AND ENVIRONMENTAL COSTS BY REDUCING WASTE AND TOXICITY IN EV BATTERIES

The best way to deal with waste is to prevent it at the source. **Waste prevention measures** should be considered early on in the design phase of EPR schemes, especially for reduced material footprint (smaller batteries).

Mandatory EPR schemes should penalize battery configurations and materials that are less durable or environmentally-friendly, and reward the use of those which improve durability, reduce toxicity, and are better for the environment.

This can be done using clearly defined **eco-modulation criteria** and strong associated fees. Such criteria could include, for example, smaller batteries, disassembly-friendly battery configurations, reduced levels of toxic materials (such as PFAS), fair and equitable access to battery data and analytics, etc.

These criteria should be defined and selected to have a real impact on prevention: the modulated fees (the primes and penalties) must be high enough to guide producer choices.

Cost coverage of EPR schemes should be extended as far as possible to upstream costs, in addition to all end-of-life, prevention and reuse costs.

Regulation must also set and enforce stringent safety and quality inspection standards on waste battery exports. Countries like Egypt and Bhutan have already begun to loosen import restrictions for used EVs, introducing used batteries into their end-of-life ecosystems.

## INCENTIVIZE REUSE AND REPURPOSING OF EV BATTERIES ONCE REMOVED FROM A VEHICLE

Regulation should not only ensure that all relevant right to repair laws apply to EV batteries, but also include mandatory EPR schemes that define processes and targets for reuse and repurposing of EV batteries once removed from a vehicle. Upon removal from a vehicle and in all cases before an EV battery is recycled, it must be inspected and tested for a second-life, such as reuse, remanufacturing, or repurposing. Policy measures to address the many proprietary technology and software barriers to provide fair and equitable access to battery information, state of health and analytics will play a critical role in enabling EV batteries to be reused or repurposed when removed from a vehicle at 70-80% of its initial capacity, thereby extending their life for 6 to 30 years for different second-life applications.

# Glossary

**Anode** - A major component in lithium cells, the anode is the negatively charged electrode by which the electrons leave a device.

**Biometallurgy** - In biometallurgical processes, inorganic and organic acids produced by microbial activities promote the leaching of metals from spent lithium-ion batteries.

**Black mass** - A powder containing valuable battery metals such as lithium, nickel, and cobalt sourced from shredded EV batteries.

**Calcination** - The process of heating solids at a higher temperature of about 400 to 700°C to remove volatile substances or oxidize a specific amount of mass.

**Cathode** - A major component in lithium cells, the cathode is the positively charged electrode by which the electrons enter a device.

**Direct recycling** - Process involves the recovery, regeneration, and reuse of various battery components directly without breaking down the chemical structure. Direct recycling methods may include: physical separation, relithiation, magnetic separation, sieving, froth flotation, precipitation in water-based solution, thermal treatment and ultrasonic waves.

**Electrolyte** - Serves as the medium that enables the movement of only lithium ions between the cathode and anode. For the electrolyte, materials with high ionic conductivity are mainly used so that lithium ions move back and forth easily.

**Hydrometallurgy** - Also called acid-leaching, this process uses chemical-treated water, usually heated, to extract certain metals from a feedstock, such as an alloy pro from smelting or black mass.

**Incineration** - Process involves thermal decomposition and rapid oxidation of waste material at temperatures ranging up to 1200 Celsius, with the addition of air or oxygen at sub-stoichiometric to excess levels. All materials are burned and transformed into cinders and ash, some of which is fly ash coming out as air emissions and some of which falls to the bottom as bottom ash. Incineration sometimes uses the resulting heat to generate electricity from so-called waste-to-energy incineration.

**Lithium-ion batteries** - Lithium-ion batteries consist of largely four main components: a cathode, an anode, electrolyte, and a separator. A lithium-ion battery generates electricity through chemical reactions of lithium, which is inserted into the cathode.

**Manufacturing Scrap** - Byproducts and wastes generated during manufacturing and assembly, in addition to batteries that are defective or rejected at quality control stages of battery production.

**Pyrolysis** – Process of heating waste at temperatures of 200 to 550°C in the absence of oxygen to produce a liquid or gas fuel. Pyrolysis is a type of chemical recycling.

**Pyrometallurgy** - While traditionally a term considered synonymous with smelting, pyrometallurgy recycling processes refers to a wide range of high-heat thermal treatments beyond smelting, such as pyrolysis, incineration, calcination, or torrefaction. The pyrometallurgy process recovers select metal alloys while burning off plastics, organic solvents and other materials.

**Relithiation** - A process used in direct recycling to regenerate and restore cycled, degraded cathode active particles (LCO, LMO, NCM, NCA, and their mixtures) to revive their high electrochemical performance. Proposed relithiation techniques include ionothermal, hydrothermal, chemical, and electrochemical relithiation, as well as solid-state sintering.

**Separator** - A microporous layer consisting of either a polymeric membrane or a non-woven fabric mat that separates the anode and cathode to prevent a short circuit. Lithium-ion battery separators are generally created from polyolefin, predominantly polyethene (PE) or polypropylene (PP) or their composite membrane such as (PP/PE/PP). Modern separator technology also contributes to a cell's thermal stability and safety. Separators impact several battery performance parameters, including cycle life, energy and power density, and safety.

**Smelting** - A process of extracting metal by applying heat and chemical reducing agent such as coke. It typically involves burning a large portion of the battery itself, needing very high temperatures in the range of 1400 to 1700 °C, and producing an alloy, slag, fly ash and gaseous emissions.

**Thermal treatment** – Any process involving high-temperature treatment: drying, gasification, pyrolysis, calcination, smelting, incineration, etc. Temperature ranges start at possibly 100°C. The Basel Convention determines "thermal treatment" but sets no specific temperature range with a lower boundary. Possibly a lower boundary of 200 when hydrocarbons start to break down.

## Authors:

Lien De Brouckere, Doun Moon, and Erica Jung

## Editors:

Claire Arkin and Agnes Mampusti

## Design and graphics:

Nadia Beatrice Cruz

## Reviewers and other contributors:

Miriam Azurin, Alida Cantor, Jefferson Chua, Sheila Davis, Raquel Dominguez, Jessica Dunn, Kenza Sara Elazkem, Perry Gottesfeld, Anthony Hackett, John Hadder, Maria Jensen, Nihan Karali, Yutack Kim, Eric Lau, Dustin Mulvaney, Yanina Rullo, Neil Tangri, and Monica Wilson

*We acknowledge Andrew N. Rollinson for his substantial research contributions to this publication.*


This publication has been made possible in part through funding from the 11th Hour Project, a program of the Schmidt Family Foundation. The views expressed in this publication do not necessarily reflect those of the 11th Hour Project.

**See GAIA's resources on electric vehicle batteries at: www.no-burn.org/batteries**