In Collaboration with Pure Earth, the International Lead Association and Responsible Battery Coalition

GLOBAL BATTERY ALLIANCE

BATTERIES POWERING SUSTAINABLE DEVELOPMENT

in partnership with the World Economic Forum

Consequences of a Mobile Future: Creating an Environmentally Conscious Life Cycle for Lead-Acid Batteries

WHITE PAPER

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Cover: Getty Images

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Foreword

This paper offers recommendations for policy-makers and describes best practices for the safe management of lead battery recycling.

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The need for urgent and more intensive action against climate change is broadly recognized. In its September 2019 report, the Global Battery Alliance (GBA) sets forth a profound goal, expressed in the publication's title: *A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation*. In it, the GBA states that a circular, responsible and just battery value chain is one of the major near-term drivers to realize the Paris Agreement goal of limiting the global temperature increase to below 2°C in the transport and power sectors. This lays out a course towards achieving the 1.5°C goal if complemented with other technologies and collaborative efforts.

As stated in the report, "[A] vision of the battery value chain is incomplete without providing a perspective of the other large battery market segment: lead-acid batteries (LAB). In 2018, approximately 72% of the world rechargeable battery capacity (in GWh) was provided by LABs."[1]

This White Paper, a follow up to that report, addresses the safe and environmentally responsible management of LAB recycling. Unfortunately, the mismanagement of LAB recycling around the world has dire consequences, despite evidence in North America and Europe that the risks can be managed by adopting effective control measures that limit lead exposures. A July 2020 report by the non-profit organizations Pure Earth and UNICEF, titled *The Toxic Truth: Children's Exposure to Lead Pollution Undermines a Generation of Future Potential*, reveals that lead poisoning is affecting children on a massive and previously unknown scale. Approximately one in three children – up to 800 million globally – have blood lead levels at or above 5 micrograms per decilitre (µg/dL), a level the report says requires an urgent international response.[2]

LABs are valued for their affordability and high recycling rate. Nearly all materials used to build LABs can be recycled to create new batteries of equal value. With growing concerns over resource extraction and waste, LABs present one of the best potential examples of a closed-loop circular economy. However, technical and regulatory challenges to recycling LABs in low- and middle-income countries exist, resulting in unsafe recycling practices. In these countries, used lead-acid batteries (ULABs) are often recycled in facilities without adequate pollution and workplace controls, or in the informal economy, where pollution controls are non-existent and severe pollution is common.

This paper provides a series of recommendations for policy-makers and describes best practices for the safe management of lead battery recycling. It highlights the economic and health benefits of fostering the adoption of these practices globally. The challenges presented by the improper recycling of ULABs can only be addressed through collaborative efforts between governments, the private sector and civil society. This paper aims to contribute to work undertaken in the context of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (the Basel Convention). One specific opportunity is to inform whether the 2003 "Technical Guidelines for the Environmentally Sound Management of Waste Lead-acid Batteries" should be updated.

This Global Battery Alliance White Paper was written in collaboration with Pure Earth, the Responsible Battery Coalition and the International Lead Association. It builds on the global leadership of the Basel Convention Secretariat and United Nations Environment Programme, which have championed the need to introduce global standards in LAB recycling for many years.

Executive summary

Used lead-acid batteries need to be managed and recycled in a manner that prevents lead pollution, protecting workers and public health.

“ In 2018, approximately 72% of the world rechargeable battery capacity (in GWh) was provided by LABs. … LABs will be employed in cars, including [electric vehicles], for many years and the global market for them is expected to further grow.

Modern economies depend on the ability to transfer and store energy. The demand for batteries for both mobile storable energy and connectivity continues to grow.

As noted in the Global Battery Alliance (GBA) report *A Vision for a Sustainable Battery Value Chain in 2030*: “[A] vision of the battery value chain is incomplete without providing a perspective of the other large battery market segment: lead-acid batteries (LAB). In 2018, approximately 72% of the world rechargeable battery capacity (in GWh) was provided by LABs. … LABs will be employed in cars, including [electric vehicles], for many years and the global market for them is expected to further grow … LABs are, therefore, an integral part of the global battery market and will continue to be so for a long time.”[3]

Approximately 65% of the global demand for lead-acid batteries (LABs) is currently driven by automotive applications, with nearly every vehicle on the road requiring a LAB for starter, light and ignition functions. The remainder of uses are as industrial batteries, with lead-based batteries popular for off-grid energy renewable storage. They are used especially in developing countries as a key enabling technology to deliver on Sustainable Development Goal 7: affordable and clean energy for all.

LABs are valued because they are affordable and highly recyclable. Nearly all materials used to construct LABs can be recycled to create new batteries of equal value. When the lead is contained within a manufactured battery, it presents no risk of exposure to the user. And properly managed recycling and manufacturing facilities present little risk of exposure to workers, bystanders or the environment. When considering the growing concerns over resource extraction and waste, LABs are a potential example of a closed-loop economy.

However, technical and regulatory challenges to recycling LABs in low- and middle-income countries exist. In these countries, used lead-acid batteries (ULABs) are often recycled in facilities without adequate pollution and workplace controls, or in the informal economy, where pollution controls are non-existent and severe pollution is common.

The primary threat from unsound ULAB recycling is the release of lead dust and the subsequent exposure of workers and the public, particularly children, to lead. Lead is a well-studied neurotoxicant. The World Health Organization states that no concentration of lead in children’s blood is safe, noting that, “It is now quite clear that there are adverse neurodevelopmental effects at the lowest blood lead concentrations yet studied. ...There appears to be no threshold level below which lead causes no injury to the developing human brain.”[4] Children exposed to lead face permanent adverse health effects, including impaired brain development and nervous system damage that can be observed as measured decrements in IQ.

The July 2020 report by the non-profit organizations Pure Earth and UNICEF, *The Toxic Truth: Children’s Exposure to Lead Pollution Undermines a Generation of Future Potential*, reveals that lead poisoning is affecting children on a massive and previously unknown scale. Approximately one in three children – up to 800 million globally – have blood lead levels at or above 5 micrograms per decilitre (μg/dL), a level the report says requires urgent action.[5]

Lead comprises approximately 60% of a LAB’s weight. ULABs need to be managed and recycled in a manner that prevents lead pollution, protecting workers and public health. They must be recycled in well-regulated facilities with prescribed design and safety equipment, worker health and safety procedures, and pollution controls. These requirements preclude the involvement of the informal sector in many activities such as metal smelting. However, efforts to simply shut down informal recyclers can be counterproductive, as these operations can easily move and reopen, creating additional contamination hotspots.

Even formal recycling operations can pose significant health risks to employees and local communities if safety and environmental protection standards are not adequate. The development of a safe, profitable and efficient ULAB recycling economy requires a coordinated approach to ensure that appropriate regulations, enforcement activities, technical assistance, market and tax incentives, as well as infrastructure are all in place and working to keep ULABs out of the informal recycling sector. Such an approach promotes environmentally sound recycling by enabling regulated operations that take the necessary steps to reduce potential exposures to lead.

Informal sector
Addressing the informal sector's role in ULAB recycling must ensure the economic and social implications are fully considered. The informal sector has inherent strengths when activities are restricted to battery collection. Its high collection frequency solves the storage problem faced by the retailers, one of the major causes of non-compliance.

Informal sector collectors can often pay higher prices for ULABs than formal sector recyclers can pay because their operating costs are lower, including lower wages and no environmental or overhead costs. The regrettable consequence of this trade, however, is that these batteries are often then sent to informal smelters, ultimately the major sources of the environmental pollution. The recycled lead resulting from this process is finally sold to local battery manufacturers, assemblers and reconditioners.

The price disadvantage in sourcing used batteries is a significant factor in formalized (licensed) recyclers and smelters having an inadequate supply of ULABs to operate competitively.

Cleaning up contamination
The enormity of the contamination from informal or otherwise unsound ULAB recycling that has already occurred highlights the obligation to couple a transition to environmentally sound ULAB recycling with the remediation of previously contaminated sites.

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Communities that are already contaminated by poor-performing smelters will remain contaminated without adequate remediation. This will create exposures for generations to come, perpetuating a cycle of intergenerational poverty.

Lead remediation projects in both low- and middle-income countries, which include long-term monitoring and oversight to ensure that these areas are not disturbed in the future, have been shown not only to reduce exposures to lead and decrease the associated blood lead levels, but have also proven cost-effective using World Health Organization metrics.

Solutions to these challenges exist and are described in this document. Indeed, industry and policy-makers can take straightforward, affordable and profitable steps right now.

Optimizing battery usage
Around the world, people use LABs for tasks they were not designed to perform. For example, in some low- and middle-income countries, as many as 40% of the automotive LABs in circulation are used for domestic power storage. An automotive battery will typically last two years in the home. Alternatively, deep discharge LABs are designed specifically for such use and can provide 5 to 15 years of service in the home. The selection of the appropriate battery for the task at hand can reduce

the turnover of LABs and consequently the total volume that is recycled annually. Other alternatives are also possible, such as second-use electric vehicle lithium-ion (Li-ion) batteries or other battery chemistries designed and deployed for affordable battery applications in mini-grid and off-grid solutions in low- and middle-income countries in areas so far lacking access to electricity.

Key recommendations include:

1. Assess existing national ULAB recycling markets to understand their scope, roles, incentives and impacts on the economy, and to facilitate the design of a tailored national response.

2. Develop and implement national policy and regulatory drivers that ensure that battery producers are given significant responsibility – financial and/or physical – for the treatment, recycling or disposal of ULABs.

3. Create economic and social policies aimed at shifting the market forces to ensure used batteries stay in the formal supply chain. These include battery deposit systems and taxes/subsidies to influence the market for ULABs.

4. Consider an appropriate division of labour between the informal and formal sectors so that certain non-smelting activities may be conducted by the informal sector, such as waste collection and sorting, while other activities, such as battery breaking and smelting, are limited to the formal sector.

5. Require informal recyclers to relocate to industrial estates and upgrade their operations to join the formal economy and adhere to regulatory standards, or enforce regulation to close them down and remediate any contaminated land.

6. Establish an effective regulatory framework that ensures that formal ULAB recycling facilities are licensed and operate to acceptable environmental and health and safety standards. Sites should be audited and permits only issued when the standards can be achieved. Licensing or permit conditions must stipulate what the facility should do to mitigate fugitive and point source lead emissions, as well as workplace exposures, and a regular monitoring process should be agreed and followed to ensure that the site continues to meet any pre-agreed limits. In addition, adopting regulations prohibiting the bulk sale of ULABs to recyclers other than those with a valid license or permit is needed.

7. Establish regulatory requirements for battery manufacturers to encourage the adoption of responsible sourcing practices, so that any lead-containing raw materials they require are only procured from recyclers who meet acceptable environmental and health and safety standards.

8. In low- and middle-income countries where formal recyclers are unable to compete with informal recyclers, address the competitive disadvantage of formal smelters by reducing the tax on ULABs. It is also necessary to establish a refundable tax on manufacturers so the price paid for ULABs to formal recyclers is greater than that paid to the informal sector. Finally, the importation of lead, along with a rigorous regulatory system, to increase the use of formal smelters, should be permitted.

9. Promote in-country recycling in countries with existing national standards that ensure environmentally sound recycling consistent with the Basel Convention. This enables the profitability of responsible local recyclers, rather than encouraging exports to other countries. It is critical to support the formalization of recycling rather than encouraging the informal sector to collect, break and sell the ULABs to foreign interests.

10. Establish a dedicated funding mechanism to identify and remediate former ULAB recycling sites that are contaminated with lead, focusing on sites adjacent to residential areas.

11. Educate communities about how to select appropriate batteries for energy access and how to return used batteries safely and responsibly.

Below: Pure Earth

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Closed loop recycling: Benefits and known challenges

The LAB is the gold standard for a circular economy as nearly all its spent materials can be used to manufacture new batteries.

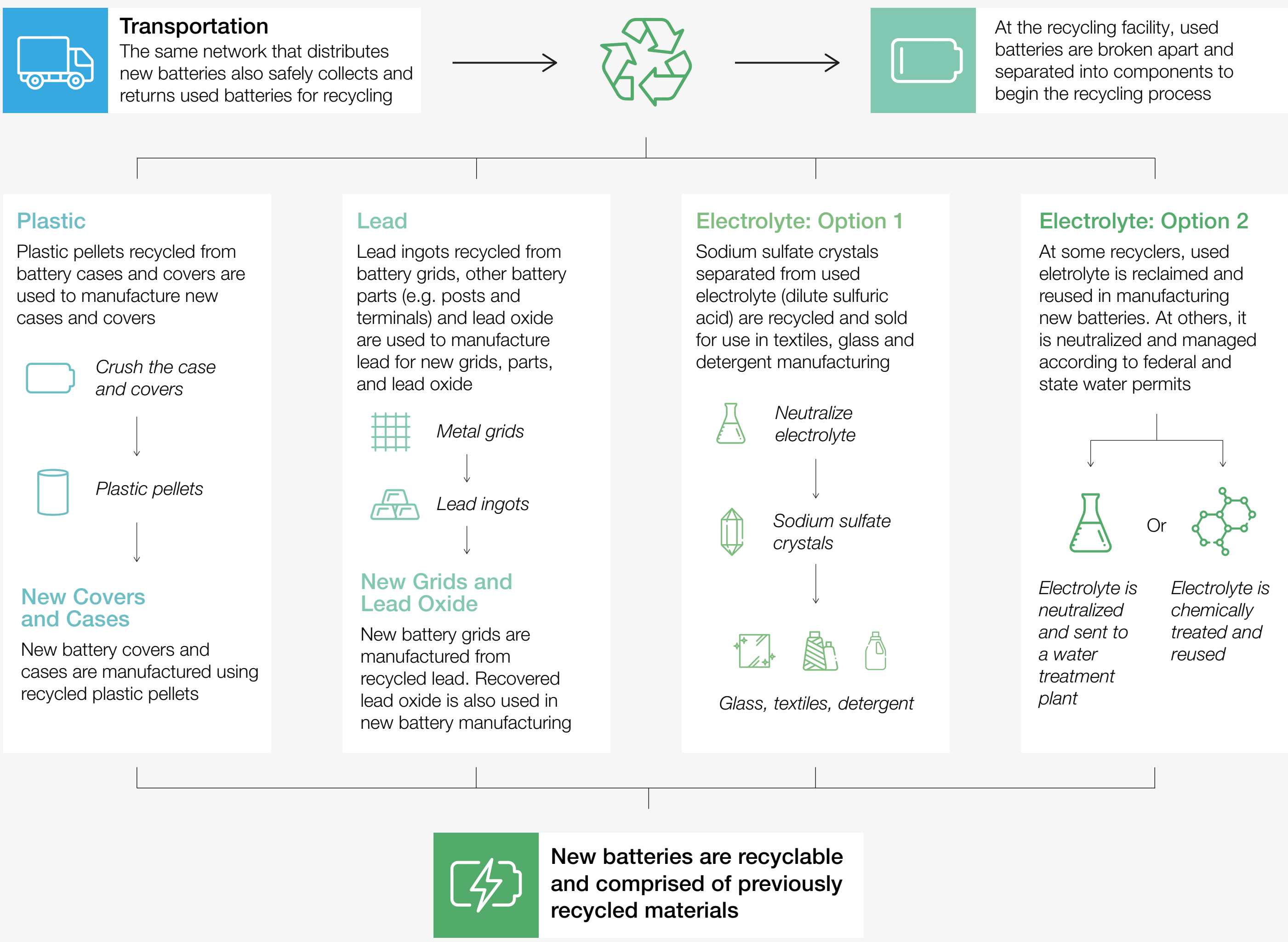
The Basel Convention Secretariat's technical guidance on LAB recycling states that, "… lead can be infinitely recycled, rendering a LAB an outstanding candidate for a sustainable product".[6] As a circular economy is one where products are recycled to new products while minimizing waste across the renewal process, management systems for LABs have optimized this circular model through the closed-loop system. Old batteries efficiently and economically become new batteries to be used and eventually recycled again.

One of the greatest advantages of LAB technology over competing chemistries, besides cost, is its high degree of recyclability with an efficient infrastructure capable of capturing and recycling the batteries at the end of their useful life. Compared to other battery chemistries, LABs are straightforward, consisting of lead-based cathodes and anodes and a sulphuric acid electrolyte housed in a polypropylene case. This simplicity has allowed a high degree of standardization within the industry and enables the batteries to be fully recycled to produce new raw materials that have applications in several industries.

A major benefit to recycling LABs is their economic efficiency. The use of recycled materials reduces the ecological impact of lead battery production by nearly 50%.[7] The LAB is the gold standard for a circular economy as nearly all the materials recovered from spent batteries (lead metal and lead compounds, plastics and acid) can be used to manufacture new batteries. In many regions, an extensive network of companies performing high-quality collection and recycling exists, ensuring that nearly all batteries are collected at the end of their life. The closed loop recycling process reduces cradle-to-gate battery production energy and greenhouse gas emissions as fewer virgin raw materials are needed.[8]

As part of their recommendation to the European Commission, the Öko-Institut and Fraunhofer Institute concluded, "Under the strict legal framework and long-term industry application, the environmental impact associated with [the] life cycle of lead-acid batteries can be considered very low. … At least in the industrialized countries, a proper collection and recycling system enabling a high collection and recycling rate of lead from these batteries is in place."[9]

FIGURE 1 **Brief overview of recycled products from lead-acid batteries**



Source: Based on Battery Council International, "How a Lead Battery Is Recycled", 2020, https://batterycouncil.org/page/Battery_Recycling (accessed 24 November 2020).

> **Lead can be infinitely recycled, rendering a lead-acid battery an outstanding candidate for a sustainable product.**
>
> Basel Convention Training Manual: National Management Plans for Used Lead Acid Batteries, 2004

The success of these collection programmes hinges on lead's intrinsic economic value, coupled with an effective regulatory framework that ensures that workers and the environment are protected from the metal's adverse effects. As a result, the Basel Convention concluded that the economic viability of recycling systems will depend on the following:

- The market price of the recycled versus unrecycled lead
- The availability of sufficient ULABs to supply a recycling centre
- The cost of collecting and storing ULABs
- The cost of transporting ULABs to the recycling centre.

These economic dynamics work well when they are supported by necessary legislative controls that establish clear requirements for operations employed in all the life-cycle stages of the lead battery. Used lead battery collection, transportation, breaking and recycling must be regulated. This ensures that the economic advantages incorporate necessary environmental and occupational exposure controls that acknowledge the toxicity of lead.

Lead is a valuable commodity for which there is significant demand but, in low- and middle-income countries without strong regulatory controls, a large number of ULABs are being handled in informal or illegal recycling operations, leading to a significant degree of environmental degradation and lead poisoning in workers and surrounding populations. In these countries, also, even licensed operators may fail to adopt the necessary environmental and human health exposure controls, due to ineffectual site permitting and licensing by regulatory authorities.

In addition to realizing the value that ULAB recycling adds to a country's economy, the benefits of developing a closed-loop system for ULAB recycling becomes particularly clear when the full health, economic and environmental impacts of unsound and informal recycling are understood. To create such a closed-loop system, policy and technical action must be taken.

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2 Health and economic impacts from informal and unsound ULAB recycling

It is not uncommon for children living close to informal ULAB recycling sites to have high blood lead levels.

> “Overall, the economic loss from childhood lead exposures in low- and middle-income countries was already estimated to be $977 billion or 1.2% of global GDP in 2011.

Lead has long been recognized as a developmental and cumulative toxicant that affects the central nervous system, especially the developing brain, which makes children particularly at risk. At high levels of exposure, lead can cause comas, convulsions and even death. At lower levels, lead can affect children’s brain development, resulting in reduced intelligence and negative behavioural changes. The World Health Organization has concluded that no level of lead in the blood of children is safe.

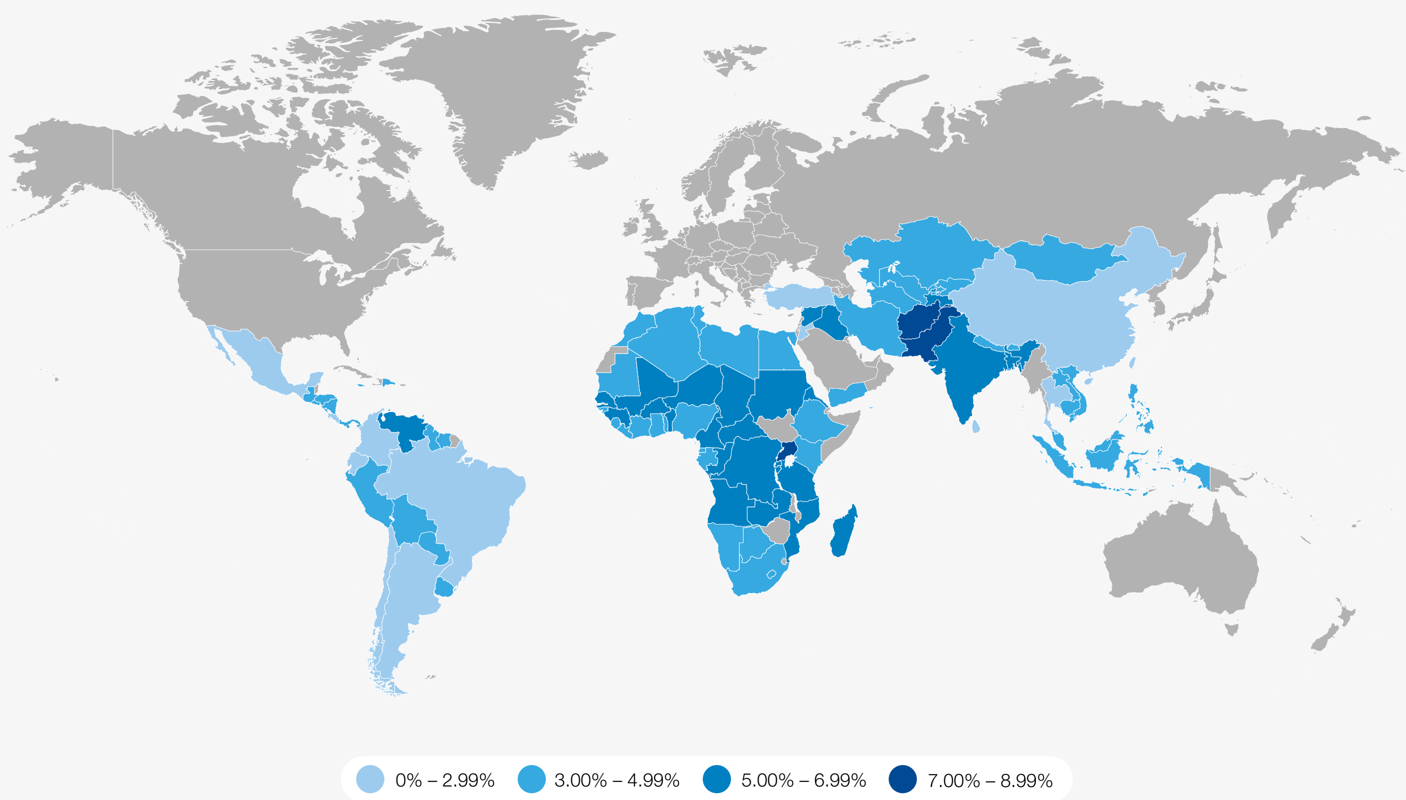
No universally agreed threshold for what constitutes “lead poisoning” exists. In the United States, the Centers for Disease Control and Prevention recommends that children with the highest 2.5% of blood lead levels in the nation receive exposure intervention and case management to identify and mitigate lead’s negative effects. In the United States, that currently equates to a blood lead level “reference value” of 5 µg/dL.[10]

A recent assessment by the Institute for Health Metrics and Evaluation (IHME), drawing on the data set of their 2019 Global Burden of Disease study, estimates that, on a global basis, approximately one-third of all children (815 million children) have blood lead levels above 5 µg/dL.[11] This estimate is substantiated by a second independent analysis of blood lead levels among children in low- and middle-income countries that finds 631 million children in these countries have blood lead levels above 5 µg/dL.[12]

It is not uncommon for children living close to informal ULAB recycling sites to have blood lead levels that are 10 times higher than the US threshold for intervention.

Overall, the economic loss from childhood lead exposures in low- and middle-income countries was already estimated to be $977 billion or 1.2% of global GDP in 2011. In Africa, the GDP loss is estimated to be more than 4%.[13] This estimate only captures productivity losses and does not account for other costs, such as healthcare spending on associated diseases or lost tax revenue from untaxed informal recyclers. While these economic costs are not all associated with battery recycling, the fact that informal ULAB recycling is a significant contributor to these underlying exposures is well established.

FIGURE 2 **Economic impacts from lead exposures by GDP loss**



Source: New York University, NYU Grossman School of Medicine, “Economic Costs of Childhood Lead Exposure in Low- & Middle-Income Countries”, 2013.

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Mitigating negative impacts from informal lead-acid battery recycling

The number of informal ULAB recycling sites has been estimated to be between 10,000 and 30,000 globally.

❝ **The waste streams generated by informal ULAB recyclers present a range of hazards. From a human health perspective, the dominant hazard is the lead itself.**

The terms “informal sector” and “informal economy” are used to describe the unregulated, unlicensed and often illegal economic activity within an economy. The informal sector includes undocumented labourers, street hawkers, sellers of banned produces, and other small to medium-scale industries operating outside of the law. At present, the informal sector is estimated to account for about 20% of global GDP and about 30% of global employment.[14]

While informal economies provide valuable opportunities for low-income and marginalized populations, ULAB recycling is simply too dangerous for it to be conducted outside of licensed, regulated and environmentally responsible facilities. The equipment, sanitary controls, standardized processes and monitoring necessary to prevent occupational and public exposures to lead are not available in informal operations; they are typically simple, clandestine operations that use crude processes and equipment.

The demand for LABs has grown rapidly in the 21st century as vehicle ownership and power storage needs have expanded. Today, as many as half of the ULABs used in low- and middle-income countries are recycled in the informal sector. As the demand for batteries increases, the number of informal recyclers likely increases at the same pace.

The number of informal ULAB recycling sites has conservatively been estimated to be between 10,000 and 30,000 globally.[15] Informal ULAB recycling usually takes place in residential backyards, rural lots or unplanned and unregulated industrialized areas. The typical informal recycling process is as follows: the used battery cases are broken open using a machete or axe. The electrolyte is dumped on the ground or into a drainage canal or sewer. The lead plates are removed by hand and also dumped on the ground. Separators are thrown into a pile and are later either disposed of in unofficial dumpsites or taken to a municipal landfill. The lead plates are placed in a hole and melted using a heat source, such as a propane torch. Impurities are scraped from the top of the molten lead, which is then scooped out and poured into moulds to be sold to refiners and battery makers.

The waste streams generated by informal ULAB recyclers present a range of hazards. From a human health perspective, the dominant hazard is the lead itself. Lead dust is released on-site through the breaking and separating of the battery components and is released into the air when the lead components are melted. Lead dust released directly on-site migrates to nearby communities on workers’ clothes, in hair, on shoes, on vehicle tyres, through storm water run-off, by the wind and by the off-site disposal of contaminated waste. Lead dust and vapours released during melting rises into the air and generally falls back on the ground within several hundred metres of the source.

The electrolyte, which in LABs is sulphuric acid and is also contaminated with lead, is typically disposed of on-site in the manner described above, posing the risk of groundwater contamination. The lead-contaminated separators have no immediate value and are generally either crudely incinerated on-site (such as in a metal barrel). This process produces significant smoke and lead emissions. If not incinerated, they are disposed of in informal dumping grounds or municipal landfills.

In more efficient operations, the dividers are washed to recover the lead on them. But they are often washed by hand, presenting opportunities for further lead exposures.

Image: Pure Earth

Where informal recycling operations have been closed down or informal recyclers have had to move them quickly to evade detection, the contaminated separators are often left on-site in a pile, along with lead-contaminated soil.

Before designing national policies and interventions aimed at restructuring the ULAB collection and recycling market, it is recommended that governments first conduct an assessment of the scale, roles, processes and relationships that exist and drive the ULAB marketplace. Recommendations for how to conduct such an assessment are described in detail in the "Training Manual for the preparation of national used lead acid batteries environmentally sound management plans in the context of the Implementation of the Basel Convention", published by the Secretariat of the Basel Convention and the United Nations Environment Programme.[16]

After such an assessment is made, policy-makers and industry can begin taking distinct steps to create safer and more formalized ULAB recycling industries. These steps are to:

Step 1: Create alternative livelihoods for informal ULAB recyclers

The potential loss of livelihoods from the ULAB recycling market's increased formalization could create stiff resistance among informal operators, making it difficult to implement or enforce proposed changes. A potential loss of livelihood could incentivize them to take additional steps to hide their work. For this reason, creating an attractive alternative to informal recycling will likely increase the acceptance of new systems.

One strategy to engage the informal sector and take advantage of its strengths is to encourage informal operators to collect used batteries and to facilitate their work, particularly in areas that lack formal collection processes and centres. This could be particularly beneficial in remote areas or areas far from formal sector recyclers. Care should be taken to ensure that collected batteries are returned to formal sector recyclers/smelters. In many countries, the informal sector already serves as the primary channel through which batteries are collected. This is the case in Bangladesh, where urban scrap collectors known as *feriwallas* collect and sell used batteries.

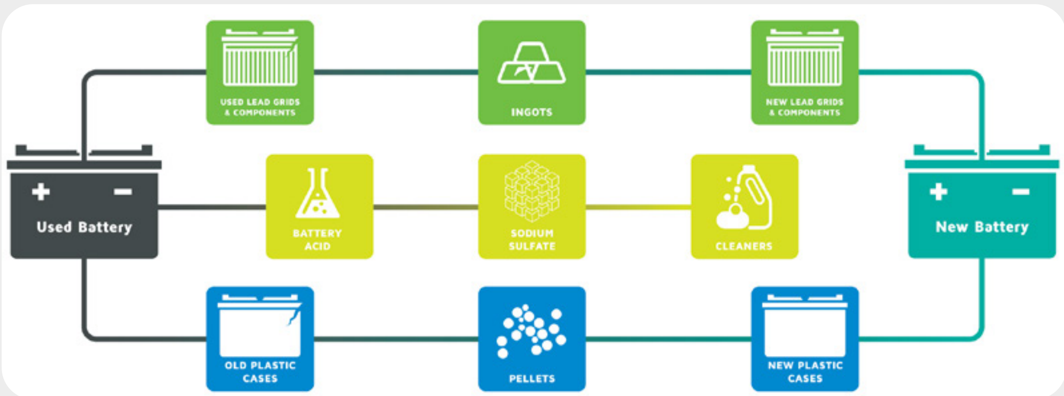
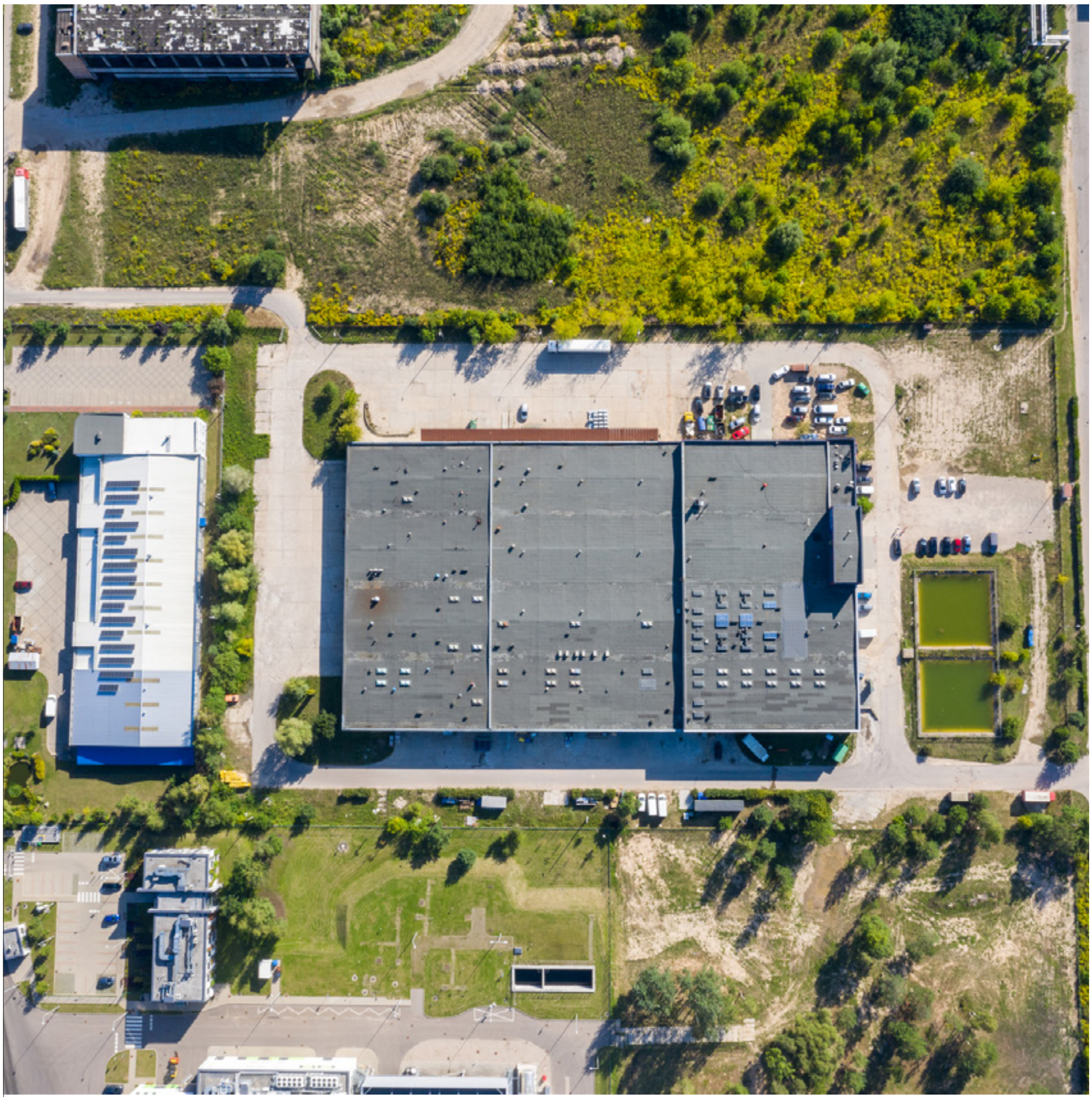


Image: Responsible Battery Coalition

Step 2: Relocate informal ULAB recyclers to industrial estates and formalize operations

ULAB recyclers are often located within residential areas, presenting risks to area residents. In a few cases, governments have allocated industrial land for informal small-scale operators to cluster. This approach potentially mitigates the active contamination of residential environments by siting recyclers at an adequate distance from where people live. Once the industries are clustered, incremental improvements in the equipment and processes at the new site can and should be introduced to mitigate off-site contamination and improve worker safety.

Nevertheless, informal ULAB recycling is never safe. If a relocation strategy is implemented, it should only be viewed as a temporary risk-reduction measure on the path to more systemic changes that keep ULABs within the formal supply chain.



Step 3: Remediate contaminated sites

Contaminated sites need to be remediated or they will continue to poison local residents for many decades. Aerosols containing lead from ULAB smelting fall to the ground and can remain in the top 2.5 cm of soil indefinitely, creating exposures for generations to come and perpetuating a cycle of intergenerational poverty.

The perception, particularly in low- and middle-income countries, is that environmental remediation projects are prohibitively expensive and complex and are generally out of reach for resource-constrained governments. While this prohibitive cost may be accurate for some chemical contamination challenges, it is not necessarily the case regarding lead.

Lead risk-reduction projects have been completed in countries of all income levels around the world, using local materials, local equipment, local labourers and local managers, and with budgets that are appropriate for local municipal governments. Remediating lead contamination can be done well and inexpensively. In some circumstances, the remediation involves a cap, or impermeable surface, which leaves lead contamination below the cap protected. However, long-term protection is dependent on ensuring that a monitoring and oversight programme is in place to guarantee that these areas are not disturbed in the future, resulting in the reopening of exposure to the lead.

Lead remediation projects in low- and middle-income countries have been shown not only to reduce exposures to lead and lower associated blood lead levels, but have also proven to be cost-effective based on metrics developed by the World Health Organization.

The enormity of the contamination from informal or otherwise unsound ULAB recycling that has already occurred highlights the fact that transitioning to environmentally sound ULAB recycling will not be sufficient to eliminate the associated health impacts. Such efforts must also be coupled with work to remediate the many thousands of communities that are already contaminated and will stay contaminated for generations without proper interventions.

Below: Getty Images

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Policies and tools to increase formal recycling rates and reduce risks

The goal of battery collection and recycling should be to keep LAB recycling/smelting out of the informal sector.

The goal of structural reforms to battery collection and recycling systems should be to keep lead battery recycling/smelting out of the informal recycling sector as well as to improve the environmental and health and safety performances of formal/regulated recyclers. However, assistance to formalize the informal sector is important to transition workers to formal sector employment.

The relationship between the formal sector battery recyclers and the informal sector varies by country and region. It is influenced by local economic conditions, social frameworks, cultural norms, regulatory and enforcement mechanisms and other factors specific to the location. Nevertheless, there are sufficient similarities in the formal-informal relationship that certain policy tools are broadly applicable and practical in low- and middle-income countries worldwide.

Extended producer requirements for battery manufacturers

According to information published by the European Commission, "Extended producer responsibility (EPR) can be defined as 'an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle'. … [It is] a potential policy tool for increasing recycling in areas where market factors do not otherwise financially incentivize collection and recycling."[17] In practice, EPR implies that "producers take over the … responsibility for collecting or taking back used goods, for sorting them and for their eventual recycling".[18] Such responsibility may be merely financial or may involve organizational measures, such as the development of separate collection agencies.

These responsibilities are to ensure that the products are efficiently collected at the end of their life and returned to a licensed, high performing recycler, collecting the data necessary to determine collection rates and compliance with any EPR collection targets.

In the case of lead batteries, EPR schemes already operate efficiently in several regions, and recovery schemes are typically financed by revenues from recycled materials, meaning that no financial contribution from battery producers is needed.

Battery deposit and refund systems

To incentivize customers to return ULABs to retailers so they can be transferred to environmentally sound recyclers, many countries allow or require retailers to collect a deposit from customers when a new battery is purchased. This deposit is then refunded to the customers when they return a used battery, which is typically at the time of purchasing a replacement battery. In the United States, this deposit is typically between $5 and $15 per battery.

Many states have adopted model legislation created by the Battery Council International that requires retailers to collect a deposit of at least $10 on all batteries sold, which is refunded to customer if they return a ULAB within a certain time frame. The legislation also makes it illegal for consumers or retailers to dispose of a lead battery in a landfill, or to provide a used lead battery to informal

Image: Pure Earth

“ One potential tool to change this market dynamic is a battery fee imposed on buyers that is transferred to formal sector recyclers once they prove that they have purchased and safely recycled a ULAB.

collectors or recyclers. This has been the backbone of the 99% recovery level of ULABs, coupled with regulatory mandates requiring the direct responsibility of managing and transporting end-of-life batteries to licensed recyclers. These deposit systems are also used in European countries.

Employing battery fees to keep ULABs out of the informal sector

One of the primary challenges with reducing informal battery recycling is that informal recyclers can often afford to pay more for used batteries than formal sector operators. Formal sector battery recyclers have a host of costs that do not exist for informal operators, such as taxes; capital costs for equipment, pollution and employee health controls; higher wages; benefits; and other forms of overhead costs typical for a licensed and regulated company. Informal recycling operations, on the other hand, usually operate as unregistered businesses, employing unskilled labourers who use the most basic equipment in dangerous conditions, and have limited occupational health, safety or environmental abatement controls. Because of their low overhead costs, they can afford to pay more for ULABs from the retailers than the formal recyclers, while still making a profit.

One potential tool to change this market dynamic is a battery fee imposed on buyers that is transferred to formal sector recyclers once they prove that they have purchased and safely recycled a ULAB. The additional income from the receipt of this fee should, in theory, increase the amount that formal sector recyclers can pay for ULABs. This type of economic policy tool must be carefully structured to provide the appropriate level of incentive to the formal sector to bid more for ULABs. It should also be administered carefully so that formal sector operators only receive the income from the fee/tax if they actually purchase and safely recycle a ULAB.

Taxes must be introduced carefully to ensure that they encourage and support the formal high-performing recycler. For example, it has been found that the introduction of goods and services taxes (GSTs) or sales taxes on ULABs can inadvertently encourage sales to the informal sector. The removal of such a tax in Brazil has been seen as one of the main reasons why this country has been able to decrease reliance on informal recyclers in the lead battery value chain.

An emerging tool is battery traceability technology that can track each battery from sale to return to recycling. The Global Battery Alliance is developing a “battery passport” that aims to track batteries throughout their life cycles. China has recently established rules requiring battery tracking focused on ensuring compliance with end-of-life management requirements, eliminating the role of the informal sector.

BOX 1

GST collection on scrap lead-acid batteries

Abolishing the GST on the formal sector increases government revenues.

The formal sector, with its capacity to process used lead-acid batteries (ULABs) in a clean manner, is at a market disadvantage for buying scrap batteries, as it must pay a goods and services tax (GST). The informal sector does not pay this tax and can thus purchase scrap at higher rates. The consequences of this are enormous: more toxic lead released into the environment.

Removing the GST for ULABs would level the playing field. While at first glance it seems that this would deplete government coffers, it would in fact add to revenues. The end product, lead ingots, also avoid GST in the informal sector. If all ULABs were to go to the formal sector, which would pay GST on lead ingot sales alone, overall GST collections would rise.

Example: $10,000 of scrap batteries, processed into $15,000 of lead ingots. GST at 15%.

Current circumstance:

– Half of the ULABs go to the formal sector and half go to the informal sector.

– The tax is charged on both the purchase of ULABs and the sale of lead ingots, for the formal sector only.

GST collections:
Informal sector: $0
Formal sector: $5,000 x 15% + $7,500 x 15% = $1,875

New arrangement:

– No tax is levied on the purchase of ULABs, enabling 90% to go to the formal sector, thus shifting 90% of ingot production and sale to the formal sector (valued at $13,500).

– The tax on ingots remains.

GST collections:
Informal sector: $0
Formal sector: $9,500 x 0% + $13,500 x 15% = $2,025

Result: an 8% increase in GST.

Image: Pure Earth

Responsible sourcing practices

Battery manufacturers should be encouraged to adopt responsible sourcing practices to understand the provenance of any lead-containing raw materials purchased in their supply chain. These responsible sourcing practices should include undertaking appropriate due diligence enquiries to ensure that approved suppliers meet national legislative requirements and that any recycled battery materials procured have been produced and transported according to the Basel "Technical Guidelines for the Environmentally Sound Management of Waste Lead-acid Batteries".[19]

Manufacturers should use their influence to strengthen environmental and health and safety performances in their suppliers' operations with a focus on supporting efforts to minimize workplace lead exposures and any emissions into the environment. An audit or assurance programme should be established for key suppliers. Manufacturers should exit relationships with suppliers that continue to fail to meet agreed standards after reasonable efforts have been made to encourage improvement in their environmental and health and safety performances.

Discourage transboundary shipments of ULABs where existing national standards ensure environmentally sound recycling

The financial viability of environmentally sound national ULAB recycling schemes can be threatened where unrestricted transboundary shipments are permitted to other regions. Unrestricted transboundary trade in ULABs can both encourage the proliferation of informal recyclers and undercut the profitability of the formal, regulated sector in the country of origin.

In-country recycling should be promoted in countries with existing national standards that ensure environmentally sound recycling consistent with the Basel Convention. This enables the profitability of responsible local recyclers, rather than exporting to other countries. It is critical to support the formalization of recycling rather than encouraging the informal sector to collect, break and sell the ULABs to foreign interests. Regulatory and economic drivers should be developed to limit this practice so ULABs stay in the country of origin where the environmentally sound recyclers' national capacity is sufficient to meet demand.

Public education on alternatives for energy access applications

Around the world, people use LABs for tasks they were not designed to perform. For example, in some low- and middle-income countries, as many as 40% of the automotive LABs in circulation are used for domestic power storage. When used in the home, LABs are often discharged to zero charge. Automotive LABs are not designed to be discharged to zero, and doing so can shorten the useful life of the battery. For this reason, an automotive battery will typically last two years in the home.

Alternatively, deep-discharge LABs are designed specifically for home use and can provide 5 to 15 years of service in the home. The selection of the appropriate battery for the task at hand can reduce the turnover of LABs and consequently the total volume that is recycled annually.

Lead-free alternatives, such as second-use electric vehicle Li-ion batteries, may be suitable for servicing mini-grid and off-grid solutions in low- and middle-income countries in areas lacking access to electricity. However, care must be taken to ensure that safe and environmentally responsible routes for recycling these products are available; today such recycling facilities generally do not exist.

BOX 2 | National regulations on lead-acid batteries in Brazil

Before the development of Brazil's ULAB model, the majority of post-consumption LABs were improperly discarded and processed by illegal smelters, who possessed no license and had no legal authorization to perform such activity.

Processing by illegal smelters prevented major producers from recovering ULABs' lead components, and allowed smaller players to purchase lead back from illegal recyclers at a reduced price, affecting the market dynamics. This situation caused lead to cost less and be more readily available for small- to medium-sized industries, whose concerns with legal issues were not as strict as the larger players.

The implementation of Brazil's national regulations made it mandatory for all processes involving extraction, utilization and recovery of lead components to be controlled and reported by the battery manufacturer, leading to a more upgraded industry, greater control and significantly lower environmental impacts. These regulations also favoured the elimination of illegal smelters, transferring the lead reclaiming process exclusively to legal, controlled organizations. These national regulations instituted the limits for lead, cadmium and mercury in batteries produced or sold in the country, and defined the standards for LAB management and disposal.[i]

The implementation of the reverse logistics process (see Figure 3) made it mandatory for retailers to collect and send back all used LABs to distributors, and for distributors to divert ULABs to legal smelters appointed by the manufacturers.

The requirement for environmental licensing of ULABs' transportation activities was exempted, given that batteries kept their core and were handled only by trained drivers with the proper certification, which created the regulation for the transportation of hazardous materials. This made it viable to collect ULABs and cores all over the country and transport them through different states to the recycling facility without involving bureaucracies or added costs.

Manufacturers of LABs would only be allowed to process ULABs and/or purchase lead from recycling processes from legal, environmentally licensed smelters. It also determined that manufacturers would be responsible for annually reporting the volume of LABs produced, the volume returned from final customers, the volume of ULABs processed, and the lead recouped by the smelters.

Applicable taxes on ULAB cores/parts were exempted to promote the frictionless adoption of the intended recycling/reverse logistics programme. As higher volumes of LABs were produced or retailed due to the higher quantity and lower cost of reclaimed lead, the overall tax revenue increased.

Brazil's standardization institute (INMETRO) defined industry requirements, aligned with global standards, to assure that LABs were being produced, tested and certified, favouring the use of recycled lead in the process.[ii]

While the global secondary production of lead accounted for 54% of the refined lead production in 2007, in Brazil this number was close to 70% and was projected to reach up to 90% by 2020.[iii] This model staunched tax revenue loss due to the previously high volume of illegal activities, and it also eased government control on activities for lead's entire value chain as the obligation to report all steps of the process transferred over to the manufacturer.

[i] Government of Brazil, Ministry of the Environment, National Environment Council (CONAMA), Resolution 401/2008 of 4 November 2008.

[ii] Government of Brazil, Ministry of Development, Industry and Foreign Trade, National Institute of Metrology, Quality and Technology (INMETRO), Ordinance 299/2012 of 14 June 2012, "Conformity Assessment Requirements for Lead-Acid Batteries", http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC001843.pdf (accessed 27 November 2020).

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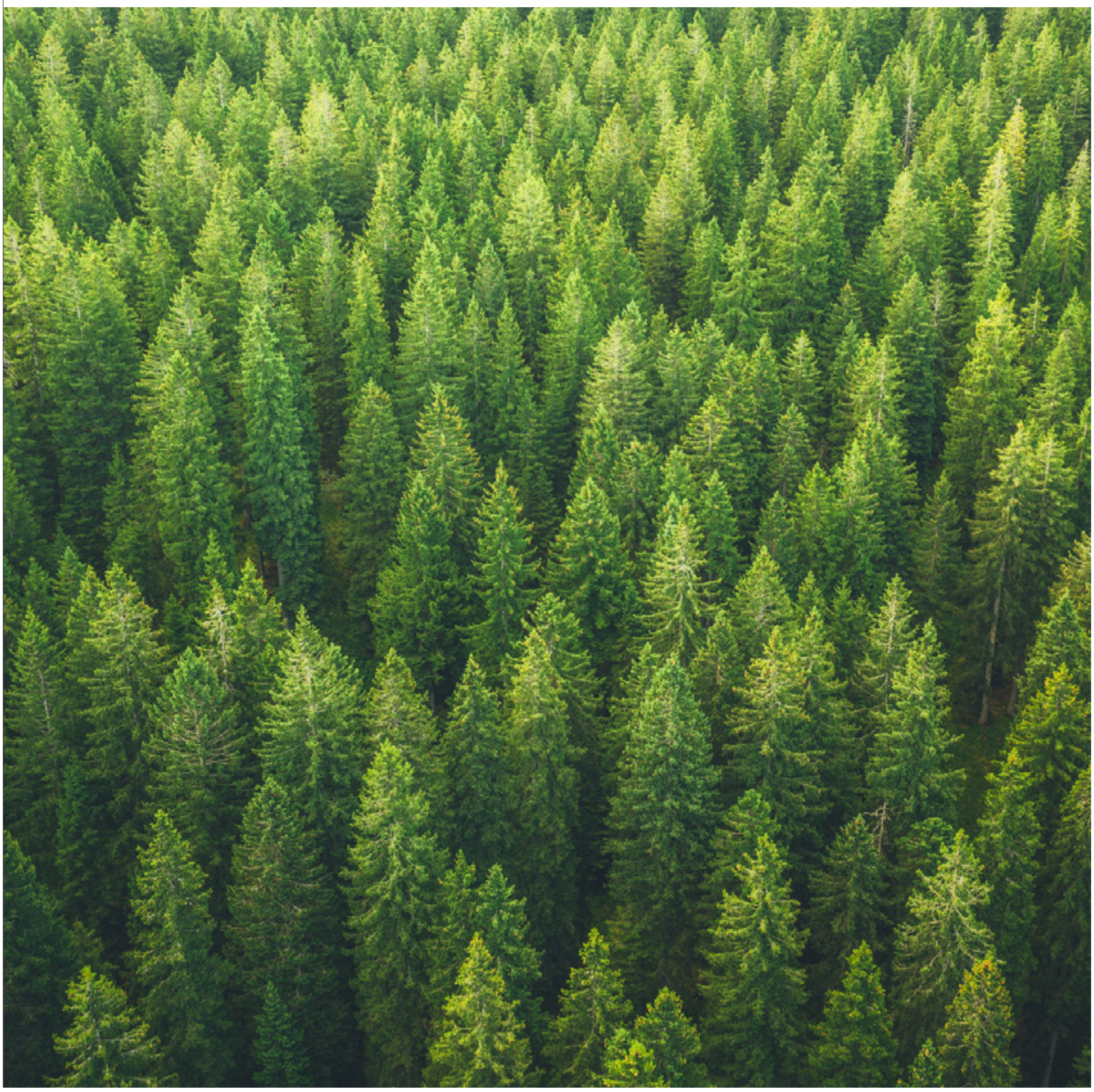
Below: Getty Images

5

Technical guidelines to improve formal ULAB recycling

An effective regulatory framework must ensure formal ULAB recycling facilities are licensed and operate at acceptable standards.

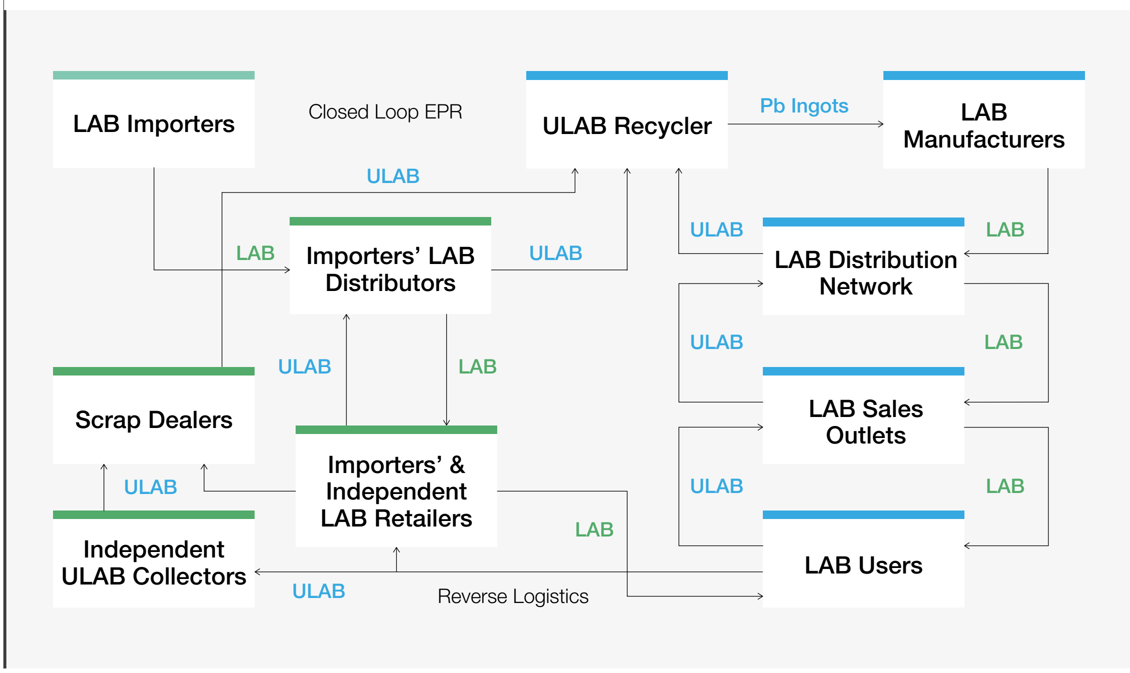


Even formal recycling operations can pose significant health risks to employees and local communities. Authorities must take responsibility for establishing an effective regulatory framework that ensures formal ULAB recycling facilities are licensed and operate at acceptable environmental, health and safety standards.

Sites should be audited by regulatory authorities and permits only issued when the standards can be achieved. Licensing or permit conditions must stipulate what the facility should do to mitigate fugitive and point source lead emissions. Workplace exposures and a regular monitoring process should be established, with follow-up to ensure that the site continues to meet any pre-agreed limits.

Reverse logistics for the retrieval of ULABs
The activity to guarantee the safe collection of ULABs is best orchestrated through the battery manufacturers themselves through reverse logistics. Manufacturers should anticipate their batteries being recycled and returned to them and should create pathways to allow for this process. This can be achieved by linking deposit refunds, regulatory mandates for safe management, and transport or effective EPR programmes. This process allows maximizing the benefits of the circular economy regardless of whether LABs are manufactured domestically or imported.

FIGURE 3 **Closed loop reverse logistics of used lead-acid batteries collection**



Source: Provided by Brian Wilson, International Lead Association

Notes:
LAB – lead-acid battery
ULAB – used lead-acid battery
EPR – extended producer responsibility
Pb – lead

Processing and separating the ULAB components

Well designed and operated ULAB breakers will separate the components and produce:

- Clean, washed polypropylene chips
- Clean, washed separators
- Battery paste that is not dry enough for the furnace, but not so wet that it is "soup"
- Clean battery grid metallics.

A Hammer Mill breaker is the most effective method of disassembling the ULAB. No other method of breaking a ULAB, either manually or using a battery saw, can provide the level of component separation obtained from a Hammer Mill breaker.

Air pollution control

As outlined in a Commission for Environmental Cooperation report, "All stages in the secondary lead recycling process can result in the release of gaseous or particulate emissions, either as point sources through stacks or as fugitive emissions":[20]

- Stack emissions: Exhaust gases from a smelting or treatment process, typically emitted from a smokestack
- Fugitive emissions: Untreated emissions that result from material handling, vehicular traffic, wind erosion from storage piles, storm water run-off and other uncontrolled sources.

Fortunately, with stack emissions, lead dust released from these sources can be scrubbed from the air and processed back into lead ingots. Different technologies known for effective air scrubbing are:[21]

- Fabric filter or baghouse systems
- Electrostatic precipitators (ESPs)
- Wet electrostatic precipitators (WESPs)
- Cyclones
- Ceramic filters
- Wet scrubbers

When properly fitted onto exhaust stacks, lead dust pollution can be significantly reduced or stopped altogether. To combat fugitive emissions, a few simple practices can be employed. These include regularly cleaning facility roadways, enclosing ULAB storage and breaking areas, enclosing furnace, refining and casting areas, and ensuring that material storage areas are wet for dust suppression and that vehicle wash stations are available at the exit.

Solid waste management at ULAB facilities: Slag, polypropylene and other solid wastes

As ULABs are processed, various solid wastes are created, from the slag produced through treatment in the furnace to the disposed personal protective equipment required to work in a facility. Although research is being conducted on this subject, most

> Exposure to lead dust and fumes in the workplace can result in adverse health outcomes including, but not restricted to, effects on the nervous system, kidneys, blood pressure, red blood cells, male fertility and female reproduction.

slag is not currently recyclable. However, other waste products, such as propylene plastics, cardboard and other small plastics can be fully recycled.

Money can be made also from the recyclable solid waste. Polypropylene plastic pellets sell for up to $500 per ton, once decontaminated from lead.[22] It may be in the economic interest of operators, or in the societal interest of policy-makers, to invest in ways to pelletize recycled ULAB polypropylene.

Treatment of the battery electrolyte
The neutralization of the battery electrolyte with a suitable alkali and its subsequent discharge from the site are unrecoverable costs and are not environmentally or economically sound solutions. Often it is not economical to recondition the battery electrolyte. The LAB uses commercial-grade sulphuric acid, and ULABs yield diluted sulphuric acid. Commercially, this acid is relatively cheap, especially when compared to reconditioning costs. A far better environmental and economic solution is to either recondition the battery electrolyte or to convert it into a saleable product.

Some examples of what battery electrolyte can be converted to are gypsum, ammonium sulphate and calcium sulphate (lime). These products have more extensive use in glass manufacturing, construction and agriculture.

It is critical that companies selling these products from the ULAB recycling process have adequate quality control processes in place to ensure that they do not contain harmful levels of lead.

Employee health and safety
Exposure to lead dust and fumes in the workplace can result in adverse health outcomes including, but not restricted to, effects on the nervous system, kidneys, blood pressure, red blood cells, male fertility and female reproduction. For these reasons, it is critical that “employers make a suitable and sufficient assessment of the risks to the health and safety of their employees” created by the work.[23] This evaluation should determine whether the exposure of any employees to lead is liable to be significant. It should then identify and implement the measures to prevent or adequately control that exposure, recording the significant findings of the assessment.

An effective programme to reduce employee lead exposure should include the following:

- Establishing occupational health standards, such as workplace air limits and biological limit values
- Providing training and education and enforcing personal hygiene practices
- Controlling airborne dust/fumes through effective engineering and administrative controls
- Using appropriate personal protective equipment, and facilities to clean and maintain all equipment issued to employees
- Maintaining a frequent and thorough housekeeping schedule for the facility
- Providing clean and lead-free welfare (e.g. showering) and canteen facilities
- Providing regular health surveillance and feedback of the results to employees
- Removing employees from exposure if blood lead levels approach a target value.

The International Lead Association has produced 10 Golden Rules that if followed will ensure reduced occupational lead exposure during lead battery manufacturing and recycling:[24]

1. Plant workers must wear the designated clothes, provided by their employer, in the workplace
2. Wear clean work-wear every day or shift, and change during the working day if necessary
3. Wear the appropriate fit tested and properly maintained respiratory equipment, and/or apply the correct ventilation
4. Always shower after every shift and whenever potential contamination risks have been high
5. Do not take work-wear home for washing or cleaning
6. Adopt work practices that minimize or mitigate occupational lead exposure
7. Segregate work areas from administrative offices and eating areas
8. Ensure that eating and drinking areas are always clean and lead free
9. Always wash hands and face and scrub nails prior to eating at the workplace
10. Never smoke at work.

6 Conclusion and future trends

Government action is needed to implement legislation and set and enforce standards that properly regulate LABs.

The problem of unsound LAB recycling practices in some low- and middle-income countries has been recognized for decades. Regrettably, the increased demand for energy storage solutions in these regions has only exacerbated the problem of environmental pollution, despite the resolution made at the third session of the United Nations Environment Assembly of the United Nations Environment Programme in December 2017 to promote the environmentally sound management of ULABs. The number of informal ULAB recycling sites has conservatively been estimated to be between 10,000 and 30,000 globally.

Recently, momentum to address lead exposures resulting from unsound ULAB recycling has increased in the global community. The 2020 report, *The Toxic Truth: Children's Exposure to Lead Pollution Undermines a Generation of Future Potential*, published by Pure Earth and UNICEF, has shed new light on the vast scale of the problem and on proven strategies to reduce exposures.

The new initiative, Protecting Every Child's Potential, was announced in October 2020 by Pure Earth, UNICEF and the foundation of the world's largest LAB maker and recycler, Clarios, to create a collaborative platform to mobilize international action and prevent children's exposures to lead from unsound LAB manufacturing and smelting as well as other goods that contain lead. The partnership capitalizes on the three organizations' complementary expertise: the assessment of lead exposures and rehabilitation of contaminated sites, the promotion of children's health and rights, and the safe manufacturing and responsible recycling of LABs.

A key aim of the partnership is to mobilize support from the private, public and non-profit sectors to accelerate action. This partnership represents a promising step forward and could serve as an entry point for other actors to meaningfully engage in solutions to this challenge.

The task of addressing this global crisis poses a formidable challenge that will not be met overnight. Actions and interventions may need to occur incrementally, and always with the awareness of local conditions and a concern for livelihoods. However, lessons learned from other regions of the world where the safe recycling of lead batteries forms part of a functioning circular economy can be transferred. To make this sustainable, government action is needed to implement legislation and set and enforce standards that properly regulate the safe manufacture, usage and, most importantly, smelting of LABs.

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