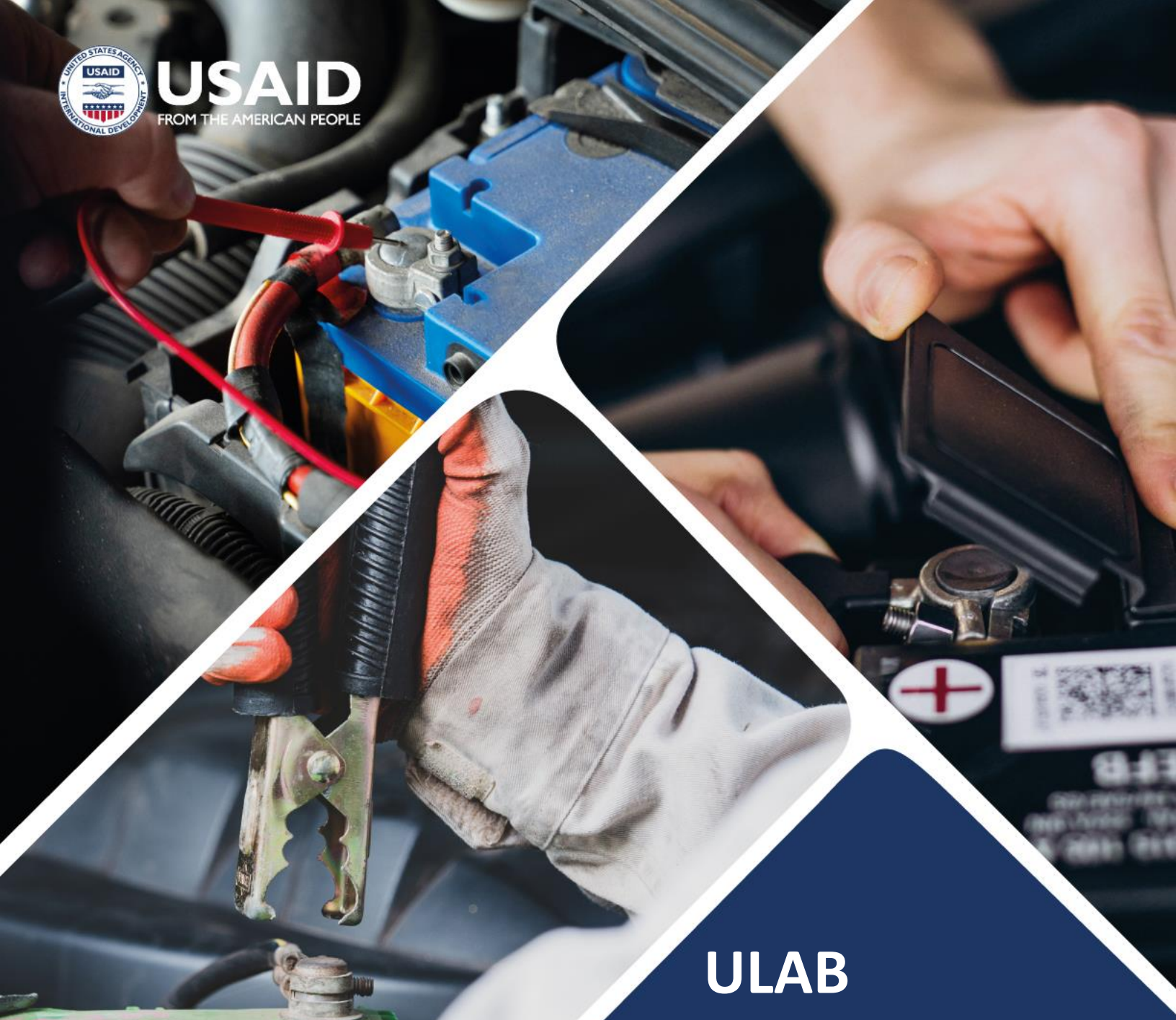


USAID
FROM THE AMERICAN PEOPLE

# ULAB RECYCLING ASSESSMENT REPORT

## POWERING A LEAD-SAFE FUTURE

**JULY 2024**

*This study is made possible by the support of the American people through the United States Agency for International Development (USAID.)* The contents of this study are the sole responsibility of Dalberg Advisors and do not necessarily reflect the views of USAID or the United States Government.

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# Table of Contents


EXECUTIVE SUMMARY 6

1. CALL TO ACTION | *Why should we support safe ULAB recycling* 11

2. THE ULAB RECYCLING SUPPLY CHAIN | *How can ULAB recycling be conducive to lead exposure* 14

3. THE CHALLENGE: *What contributes to unsafe ULAB recycling in LMICs* 21

4. THE PATH-FORWARD: *How can LMICs transition to sound ULAB recycling* 28

5. COUNTRY CASE STUDIES 39
   - 5.1. MEXICO 40
   - 5.2. INDIA 53
   - 5.3. NIGERIA 68

REFERENCES 79

# GLOSSARY

**ARBR** – Alliance for Responsible Battery Recycling

**BLL** – Blood Lead Level

**CEC** – Commission on Environmental Cooperation

**DALY** – Disability-Adjusted Life Years

**EPR** – Extended Producer Responsibility

**GDP** – Gross Domestic Product

**GST** – Goods and Services Tax

**HSN** – Harmonized System of Nomenclature

**LAB** – Lead-Acid Battery

**LMIC** – Low- and Middle-Income Countries

**MT** – Metric Tons

**MoEFCC** – The Ministry of Environment, Forest, and Climate Change

**NESREA** – National Environmental Standards and Regulations Enforcement Agency

**NGO** – Non-Governmental Organization

**NOM** – Norma Oficial Mexicana (Official Mexican Standard)

**OEM** – Original Equipment Manufacturer

**PEL** – Permissible Exposure Limit

**PPE** – Personal Protective Equipment

**PRO** – Producer Responsibility Organizations

**REAN** – Renewable Energy Association of Nigeria

**REDIN** – Recycling and Economic Development Initiative of Nigeria

**RETC** – Registro de Emisiones y Transferencias de Contaminantes (Pollutant Release and Transfer Register)

**RIASA** – Recicladora Industrial de Acumuladores

**SEMARNAT** – Secretaría de Medio Ambiente y Recursos Naturales (Ministry of Environment and Natural Resources in Mexico)

**SLI** – Starting, Lighting, and Ignition

**SMA** – Stationery Motive (Movable) Applications

**ULAB** – Used Lead-Acid Battery

**USAID** - United States Agency for International Development

**$** – United States Dollar

# EXECUTIVE SUMMARY

**Lead poisoning accounts for ~1 percent of the global disease burden,** affecting one-third of the world's children, mostly in low- and middle-income countries (LMICs). It is responsible for 5.5 million annual deaths, causes cognitive underdevelopment and increases risks of cardiovascular diseases and kidney failure, among other health issues. The economic costs of lead poisoning **amount to annual GDP losses of $1 trillion in LMICs** and a purchasing power parity loss of $5,000-$9,000 per capita.

Unsafe recycling of used lead-acid batteries (ULAB) is a significant source of lead exposure, exposing between 6 and 17 million people, especially workers and communities near smelters.

**Improvements to reduce exposure from ULAB recycling are urgent and cost-effective for society**. At a large scale (above 24 thousand metric tons annually), recycling of ULABs with adequate standards has a variable cost of $425~$500 USD per metric ton, with an initial capital investment often in the tens of millions of dollars. Variable costs for recyclers without these standards range from $350 to $410 per metric ton, with no significant initial investment. These recyclers achieve lower recovery and purity rates. The full social costs of recycling without adequate standards, accounting for resulting productivity losses, is an order of magnitude above the private cost of recycling. Unsafe ULAB recyclers do not internalize the societal cost of lead exposure. Thus, without government and societal pressures, unsafe practices are likely to continue.

While informal recycling will never be safe, **most formal sector facilities are also too small to afford adequate pollution controls to sufficiently reduce emissions and occupational exposures**. Many formal operators also operate with low safety standards that do not ensure the minimum engineering and administrative controls, nor protect their workers with medical screening programs or personal protective equipment (PPE). Such facilities are often located near densely populated neighborhoods. In these settings, ULABs are drained with the acid drained on the ground and broken manually rather than mechanically, with lead dust and fumes released in an uncontrolled manner during smelting, contaminating air, soil and nearby water sources.

**Large investments are needed to achieve minimum sufficient reductions in occupational and environmental exposures**. Even mid-sized facilities, which feature mechanized processes, proper ventilation systems, and industrial-scale equipment require elevated capital investments. Scale is needed to spread these investments and reduce unit costs, so more environmentally sound and sustainably viable recycling facilities often exceed an annual recycling capacity of 50 thousand metric tons. **Informal recyclers,** operating with rudimentary methods and no occupational exposures and environmental emissions measures, **and formal recyclers with low standards**, who

use basic and insufficient equipment and lack proper environmentally sound protocols, **can rarely, if ever, reach this scale,** as they lack financial capacity and technical capabilities and processes.

**The transition from mid-standard to high-standard recycling does not necessarily require substantial additional investment in equipment**. Instead, it involves implementing the appropriate, rigorous processes and protocols to further protect workers and communities. This includes regular blood lead monitoring for workers, frequent environmental emission checks, and stricter adherence to occupational safety standards throughout the recycling process.

The findings from this research study suggest that for each country, the priority approach for safer ULAB recycling depends on two factors

- **Domestic ULAB market size** – If a country's annual output of ULABs is below 50,000 metric tons, it should probably export ULABs, as adequate recycling plants will struggle to reach economies of scale and stay profitable. If annual output of ULABs exceeds this threshold, countries can develop environmentally sound recycling operations domestically, with appropriate regulations and enforcement.
- **Mix of recycling types** – If a country's ULAB recycling is highly atomized, with hundreds of informal and low-standards smelters and refiners, its priority should be to shift recycling to fewer, safer, larger recyclers. When the recycling industry has achieved mid-standards and sufficient consolidation, the focus should be to improve existing operations.

In LMICs, interventions can make ULAB recycling safer by either **shifting recycling from unsafe to relatively safer operations** or **improving existing operations** incrementally. These approaches are not mutually exclusive, but the priority will change depending on each country's characteristics. Shifting operations entails moving away from informal and low-standard operations to fewer, larger, and safer operations. Improving existing operations is a process of working with existing recyclers to gradually raise their occupational exposures and environmental emissions safety standards.

The public sector, private actors and civil society can use a wide range of interventions:

- **To shift recycling to safe operations**, countries can align economic incentives by pursuing a bundle of strategies, potentially including initiating takeback and refund fee programs; involving original equipment manufacturers (OEMs) and ULAB importers in extended producer responsibility (EPR) programs to create closed loops, procuring lead from responsible sources and producing more durable/lasting lead-acid batteries; favoring investments in ULAB recycling plants with higher standards and in reverse logistics for ULAB collection and transportation; and enforcing minimum standards to deter informal and low-standard recycling.

- **To improve existing operations**, interventions can build awareness among workers and employers and build capacity to improve work practices, recycling methods, pollution controls and performance monitoring.

We explored three large markets — Mexico, India, and Nigeria— as case studies in this report:

**Mexico** processes over 620,000 metric tons of ULABs annually. In most instances, this market benefits from vertical integrations and is highly concentrated with 18 recycling plants, the largest among them clustered in the state of Nuevo León. Mexico ULAB recycling could improve by developing comprehensive worker protection regulations, demanding third-party emission testing and verification, and conducting systematic blood lead level surveillance for workers, among others.

**India** produces between 1.2 and 1.7 million metric tons of ULABs annually, mostly recycled in-country. The Indian ULAB recycling sector is characterized by over 650 registered smelters, recycling ~70 percent of Indian ULABs, and an unknown number of informal smelters, accounting for an estimated 30 percent of the ULAB market. To promote environmentally sound ULAB recycling, stakeholders in India should shift recycling to fewer, larger recycling plants with improved pollution controls. Additionally, there is an opportunity to increase recycling capacity and OEMs' role in collection and recycling.

**Nigeria** produces nearly 190 thousand metric tons of ULAB annually. Around 90 percent of these ULABs are collected informally. These are then recycled informally or in low-standard formal settings, posing significant lead exposure risks. Safer, formal recyclers struggle competing with informal and low-standards recyclers. To revert the situation, Nigeria should shift recycling to safer operations by holding importers accountable for ULABs being recycled in Nigeria. Promising policies include setting minimum take-back prices and consolidating ULABS to facilitate investment in top-tier recycling facilities. Greater coordination between state-level and national authorities and capacity building efforts could improve regulatory enforcement.

# THE PATH FORWARD

Success in reducing lead exposure from ULAB recycling depends on the efforts of actors, including private sector firms, mostly LAB manufacturers and large ULAB recyclers, governments in LMICs, and institutional donors and philanthropies. The best strategy for environmentally sound ULAB recycling will vary from country to country. The following broad actions, nonetheless, are likely to help environmentally sound management across settings.



## Private Sector Actors

*Recommendations for LAB manufacturers and large ULAB recyclers*

- **Increase takeback rate** of ULABs by offering or raising deposit or refund fees and investing in reverse logistics for ULAB collection and transportation, potentially exploring joint investments with other LAB manufacturers.
- Bet on **higher quality** LABs, with longer useful lives, to reduce the number of ULABs generate annually, explore guarantee schemes, and educate consumers on the best batteries to meet their needs.
- **Invest** in large recycling plants in LMICs, with annual capacity above 50 thousand metric tons. Recent experiences in India show these investments are economically viable



## Governments in LMICs

- Align **pricing and economic incentives** for environmentally sound ULAB recycling in large recycling plants, meeting adequate standards (e.g., minimum take-back prices, deposit fees, competitive taxes).
- Mandate **minimum capacity for recycling plants to operate**, for economies of scale to make environmental investments affordable (i.e., at least between 24 and 50 thousand metric tons of annual capacity).
- Upgrade and enforce regulatory standards, including **blood lead level testing for workers and environmental testing of air, soil and water**, with third-party verification.



## Institutional Donors & Philanthropies

- Support **governments** in achieving regulatory changes, adapted to national priorities.
- Build **lead testing capacity**, either nationally or regionally, to enable appropriate monitoring and surveillance.
- Fund **local civil society organizations** conducting research, awareness and capacity building efforts. Estimated funding for lead exposure reduction is only ~$15 million, less than 0.01% of lead poisoning's impact on LMICs' economies. Greater funding for locally grounded organizations is thus likely to generate high social return.
- Identify or build a **blueprint** to ensure full and environmentally sound exporting of ULABs in LMICs generating less than ~50 thousand metric tons a year.
- Advocate for and build alliances with private sector to expand recycling capacity meeting adequate standards and gradually improving occupational safety conditions for workers and communities.



# 1. CALL TO ACTION

## Why is it important to support sound ULAB recycling?

*Unsafe ULAB recycling exposes workers and communities to lead emissions that can lead to lead poisoning. Without effective government and social pressures, market forces push towards unsafe ULAB recycling.*

**Lead exposure affects one in three of the world's children, 90 percent of who are in low- and middle-income countries (LMICs)** (UNICEF, 2022) (Pure Earth, n.d.)**.** There is no safe level of lead exposure. Children are at higher risk of lead poisoning because they absorb 40 percent to 50 percent of ingested lead (Jennifer Sample, 2024) - which can be higher in countries where children have poor nutrition - and their developing brains are more vulnerable to toxic effects. Additionally, they are more likely to be exposed to lead through frequent hand-to-mouth contact. Lead exposure in children results in numerous cognitive, social, and health issues. High levels of lead exposure can severely damage the brain and central nervous system of children, causing coma, convulsions, and even death. Although low levels of lead exposure show no obvious symptoms, they can impair brain development and cause behavioral changes such as reduced attention span and increased antisocial behavior in children (World Health Organization (WHO), 2023).

**Lead exposure also has significant health impacts on adults.** Adults suffer from health effects due to lead exposure as they absorb 10 percent to 15 percent (Jennifer Sample, 2024). This leads to

higher risks of high blood pressure, cardiovascular disease, and kidney failure (Pure Earth Mexico). Lead poisoning is now a major cause of cardiovascular disease in adults, leading to 5.5 million deaths annually (Larsen & Sánchez-Triana, 2023). Women with elevated lead levels during pregnancy may experience miscarriages, stillbirth, premature birth, and low birth weight in their babies ( Agency for Toxic Substances and Disease Registry, 2020). For instance, a study by Pure Earth and UNICEF found that over 900,000 premature deaths per year are attributed to lead exposure (UNICEF and Pure Earth, 2020). Lead exposure is also responsible for 21.7 million disability-adjusted life years (DALYs) globally due to its long-term health effects. This includes 30 percent of the global burden of unexplained intellectual disability, 4.6 percent of cardiovascular disease, and 3 percent of chronic kidney diseases (World Health Organization (WHO), 2023).

**The health impacts of lead exposure cause significant productivity and prosperity losses, resulting in annual GDP loss of ~ $1 trillion in LMICs.** Lead exposure results in productivity and prosperity losses by reducing physical well-being, cognitive capacity, and attention span, among other factors. These effects impact educational attainment and workforce productivity, ultimately causing significant economic losses. For instance, comparing children with lifetime average blood lead levels < 5 µg/dL, with children between 5 and 9.9 µg/dL, the latter group scored 4.9 points lower on Full-Scale IQ (Todd A. Jusko, 2008). The economic burden is profound: lead poisoning contributes to ~$1 trillion in annual GDP loss in LMICs alone (Attina & Trasande, 2013) and over $2 trillion globally (Tsai & Hatfield, 2011). Additionally, lead poisoning causes significant purchasing power parity losses, estimated at $5,000–9,000 per capita, due to the cumulative effects of lead exposure on communities (Champion, Khaliq, & Mihelcic, 2022). The global cost of lead exposure is estimated to be around $6 trillion (2019) (Larsen & Sánchez-Triana, 2023).

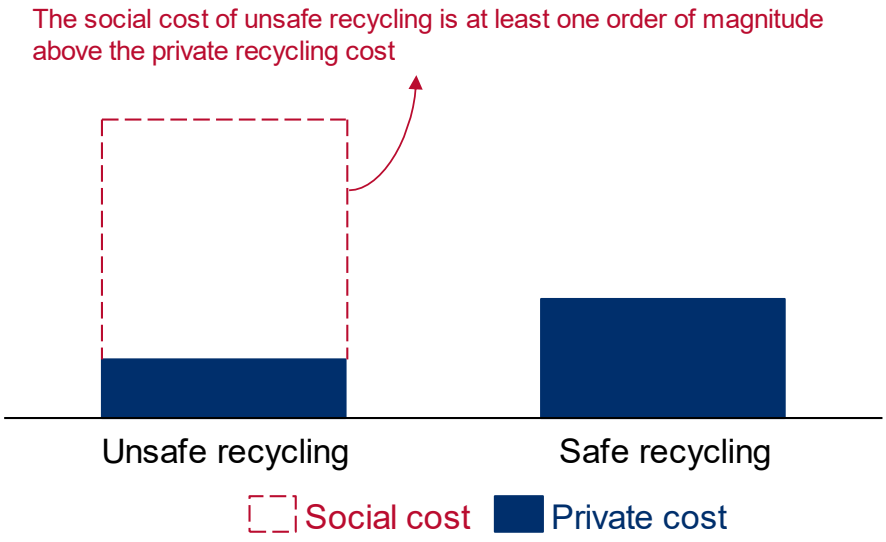
> *"Many of the effects of lead exposure can occur at low levels of exposure. Cumulative exposure over time, even if low, creates long-term outcomes. There is no known threshold for adverse effects"*
>
> *- Professor, University of Rochester -*

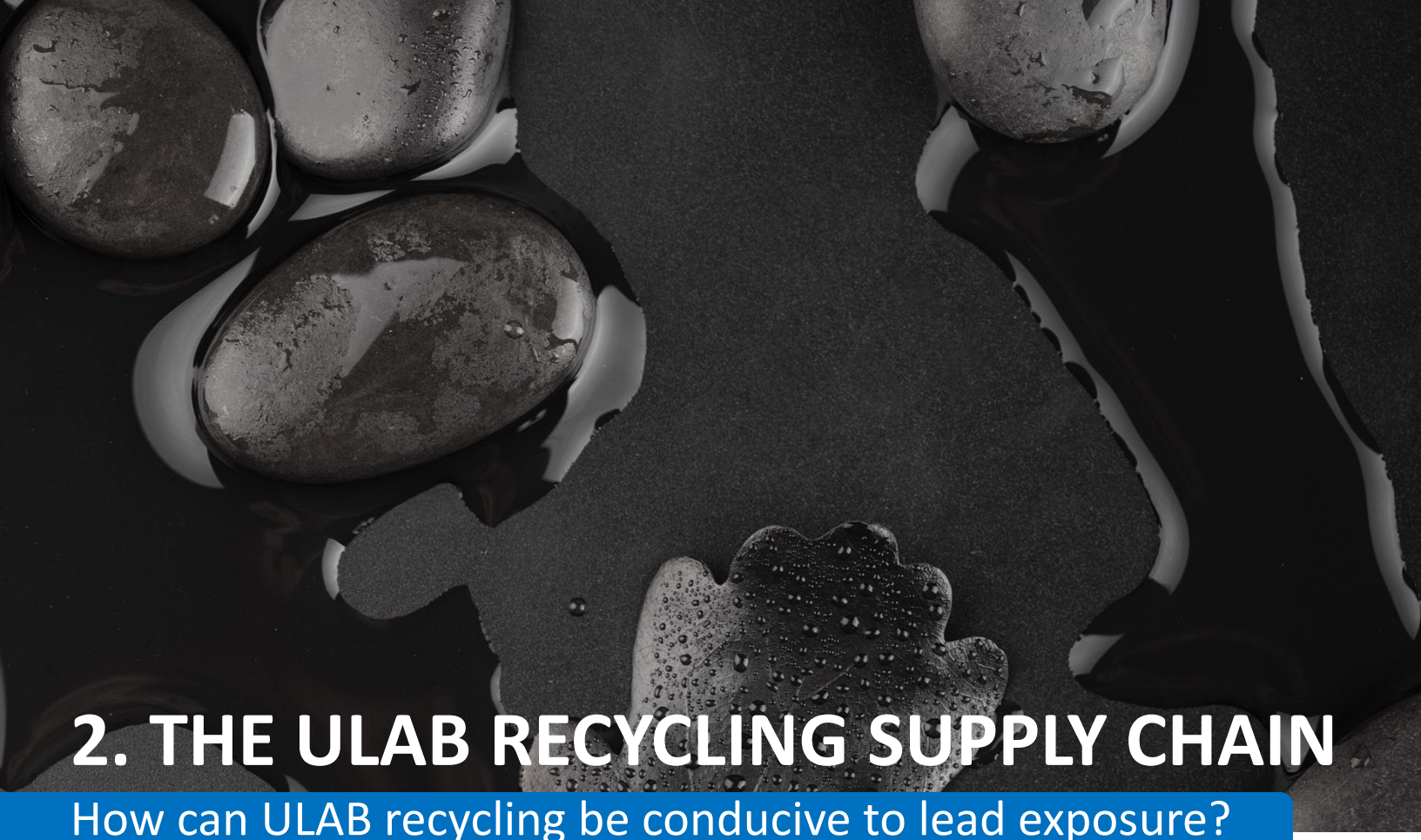
**Unsafe recycling of used lead acid batteries (ULABs) creates multiple pathways for lead exposure, affecting millions of people in LMICs.** Lead acid batteries (LABs) are extensively used in the automotive and industrial sectors. Recycled lead from these batteries is a profitable enterprise, supporting both formal and informal sectors. Globally, there are an estimated ~10,000 to 30,000 informal ULAB recycling sites (Global Battery Alliance in partnership with the World Economic Forum, 2020), with thousands of low-standard formal recycling sites that are sources of lead poisoning. Although recycling lead is an extremely hazardous industry in all countries, evidence suggests that emissions from these facilities are greater in LMICs. These unsafe sites create many pathways of lead exposure through the release of fume and lead particulates into the air, soil, water bodies, and onto other surfaces (Lavanchy). People are mostly exposed through airborne lead emissions and contaminated water. Children get most of their exposure from the

ingestion of lead-contaminated dust and soil. These pathways affect both workers and nearby communities. The number of people exposed to lead at informal smelting sites is a significant knowledge gap but is widely understood to be in the millions. One 2016 study estimated 6 to 17 million people were exposed through dump sites, smelters, and other lead-contaminated sites (Ericson, et al., 2016).

**Unsafe ULAB recyclers do not account for the social cost of their lead emissions, and thus have low economic incentives to improve operations.** The social cost of unsafe recycling far exceeds the private recycling cost by at least one order of magnitude. Without checks, market dynamics tend to drive a "**race to the bottom**," wherein minimizing operational and capital costs leads to increased social costs. This trend is particularly evident in countries where a large share of recycling occurs in informal or low-standard settings. Interventions to favor environmentally sound recycling must therefore change private sector incentives.

***Figure 1: Illustrative unit costs of ULAB recycling***





# 2. THE ULAB RECYCLING SUPPLY CHAIN

## How can ULAB recycling be conducive to lead exposure?

*The levels of occupational exposures and environmental emissions can vary greatly depending on the stage of used lead-acid battery recycling. When measures are not adequately safe lead exposure, recycling practices result in significant contamination and are a significant risk for both workers and nearby communities due to proximity to residential areas, inadequate engineering and administrative controls, or lack of worker protection.*

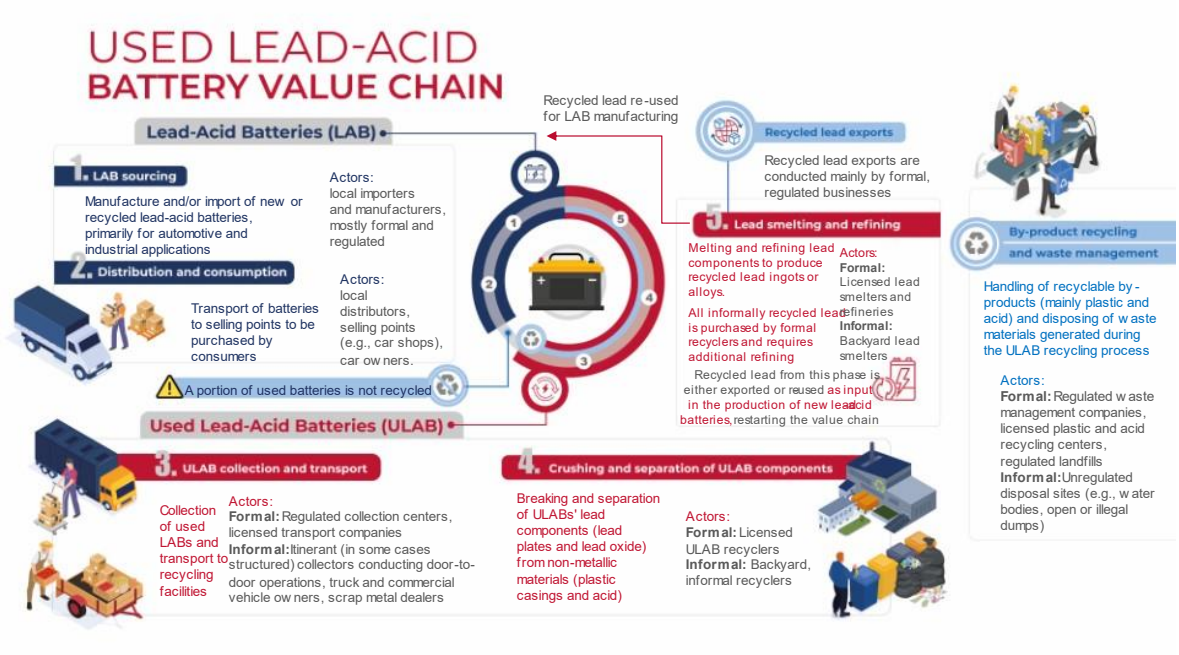
Stakeholders involved in ULAB recycling operate across five broad stages. Each stage features multiple sub-processes varying in sophistication, formality, and fragmentation.

1. **LAB sourcing,** encompassing the manufacture and/or import of new batteries or from refurbishing used lead acid batteries
2. **LAB distribution and consumption,** through which batteries reach consumers for use in vehicles, backup power suppliers, solar applications (especially in LMICs where they are a lower cost alternative to Li-ion batteries for home solar power systems), and industrial motive power

3. **ULAB collection and transport,** wherein retailers and collectors gather used batteries from consumers and businesses and transport them to recycling facilities
4. **Breaking and separation of ULAB components,** which involves the manual or mechanical breaking of used batteries into its components—mainly lead, acid (which is often dumped), and plastic—for further processing
5. **Lead smelting and refining,** wherein recovered lead is melted and refined to produce secondary lead, which is used in the production of new batteries and other products

The visual below summarizes this full process.

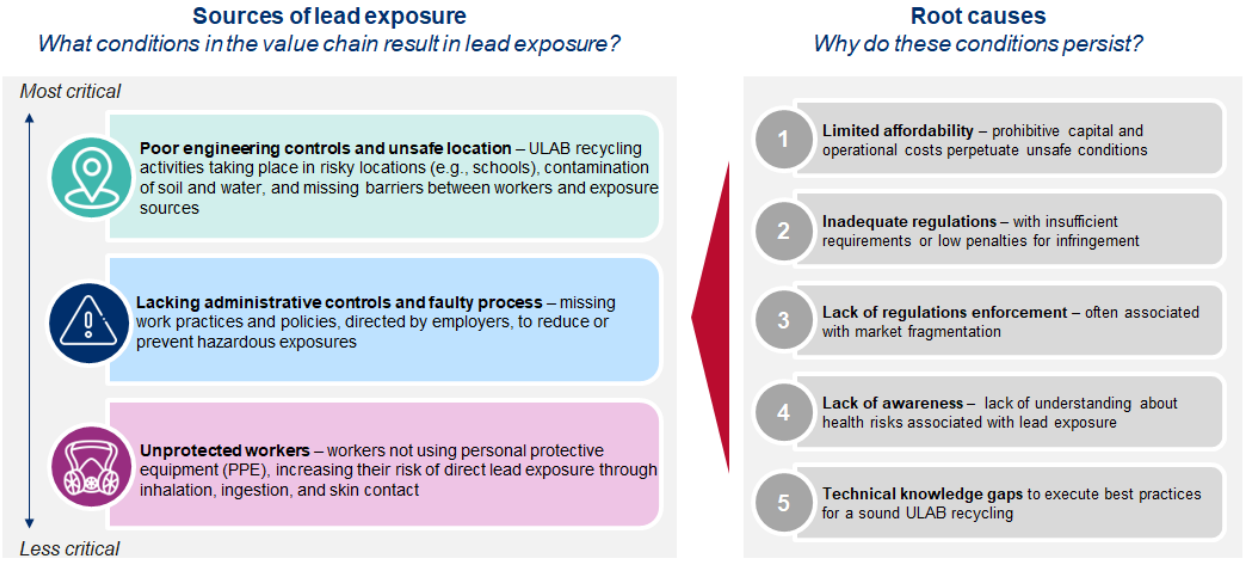
***Figure 2: Simplified ULAB recycling process***




**Lead exposure can occur in all ULAB stages due to poor facility location, inadequate engineering and administrative controls, or lack of worker protection.** When formal recycling facilities are located even within several kilometers from residential areas or in risky locations like flood plains or waste dumps, recycling activities can result in widespread community exposure through contaminated air, soil, and water, with the latter being minimal but still present. Communities located within 50 to 200 meters from informal sites are also at risk of lead exposure. Inadequate engineering and pollution controls such as poor ventilation and leakage control systems, and the lack of negative pressure enclosures release fugitive and stack emissions that contaminate large areas outside of recycling facilities. Lacking administrative controls, including appropriate policies and procedures for decontamination and hazard mitigation, can further expose workers carrying lead residues to their homes and families on their skin, hair, and contaminated apparel. This is a

common source of childhood lead poisoning. Workers operating without appropriate personal protective equipment (PPE) at collection points, during bulk transport, and recycling and smelting – especially in LMICs - can face direct lead exposure through inhalation and ingestion. These risks persist due to a combination of root causes: limited affordability of environmentally sound practices, inadequate regulations and enforcement, low knowledge and risk perception of health effects of lead exposure, and insufficient technical knowledge to implement environmentally sound practices. The figure below illustrates these sources of exposure and their underlying causes. Addressing engineering controls and zoning issues is the most effective measure to reduce lead exposure whereas offering PPE is the least effective in the hierarchy of controls.

***Figure 3: Hierarchy of controls***




- ## ULAB collection and transport

**The collection and transport of ULABs is the first stage of the ULAB recycling process that involves the collection and transport of ULABs from consumers to recycling sites.** Two main actors collect ULABs: formal retailers, frequently integrating collection with extended producer responsibility (EPR) programs, and informal scrap dealers, conducting itinerant collection. Formal retailers typically use take-back or buy-back programs and offer financial incentives such as discounts on new batteries to encourage consumers to return used batteries. These collected batteries are then stored on-site and transported to recycling facilities. When take-back is embedded into EPR programs, domestic battery manufacturers or importers bear responsibility for their collection. In contrast, itinerant collection is largely informal, involving scrap dealers (or networks of scrap dealers) collecting batteries from households and dumps, using their own

vehicles for transport. When these vehicles are used for other activities, such as transporting scrap metals, household goods, or construction materials, there is a risk of cross-contamination.

## Extended Producer Responsibility Programs

Extended Producer Responsibility (EPR) programs are policy approaches that place the responsibility of managing a product's lifecycle, including disposal and recycling, on the battery manufacturer. These programs make manufacturers accountable for the take-back, recycling, and final disposal of their batteries.

Countries like Germany, Japan, and Canada widely use EPR programs for collecting and recycling ULABs. These programs require battery manufacturers to establish systems for collecting and recycling batteries once they are no longer in used. Manufacturers collaborate with retailers and recycling companies to ensure convenient collection points for consumers. By making manufacturers responsible for end-of-life management, EPR programs promote sustainable practices and reduce the environmental impact of ULAB recycling.

**Used batteries collected by retail outlets often end up in informal recycling, especially in LMICs, prompting further exposure across the rest of the recycling process.** When facing limited storage capacities and infrequent pickups by formal transport services, formal retailers sometimes sell collected batteries to informal collectors to alleviate the constraints of formal transport services' limited storage capacity and infrequent pickups. Tax avoidance and upfront cash payments (rather than delayed or deferred payments from formal collection systems) further incentivize this diversion.

**To minimize lead exposure risks, collection sites must be equipped to store large volumes and safely handle leaky batteries, using secure, covered storage with spill containment systems and impermeable floors**. During transport, batteries should be secured to minimize movement and prevent acid leaks, often using specialized containers.[1] Leaky batteries must be placed in leak-proof containers and managed according to environmentally sound waste disposal protocols. The Basel Convention guidelines can help guide countries in enforcing the environmentally sound management and transport of ULABs. Even in informal contexts, environmentally sound practices such as carefully stacking ULABs to reduce movement during transport and placing cardboard layers between batteries to absorb leaks can reduce lead exposure. Additionally, vehicles transporting ULABs should display "hazardous chemical" decals, contact details and avoid carrying other items to prevent cross-contamination.

[1] For instance, UN 2794 Certified Leak Proof Containers

**Lead exposure, although minimal at this stage, occurs when these collection and transport safety provisions are neglected.** Mishandling leaky batteries, especially when poorly stacked and subjected to strong movement during collection, can contaminate surrounding items vehicles. Further, informal collectors frequently open the ULAB's plastic cases by hand and dump the battery acid to reduce weight and maximize transport capacity, as purchasers offer more money for drained batteries. This practice contaminates the environment and directly exposes collectors to hazardous materials.

## The Basel Convention

The Basel Convention is an international treaty that regulates the transboundary movements of hazardous waste, including Used Lead Acid Batteries (ULAB), to protect human health and the environment. **It requires exporters to obtain prior informed consent from importing countries before any shipment, ensuring all involved parties agree to the transport**. The convention mandates comprehensive documentation and tracking of ULAB shipment, stipulating that they must be handled, transported, and recycled or disposed of using environmentally sound management practices. By enforcing strict controls and promoting cooperation between countries, the Basel Convention helps mitigate the risks associated with the transport of ULABs.

- ### Breaking and separation of ULAB components

**In this stage, ULABs are broken apart to separate lead components–lead plates and lead oxide–from non-metallic components–the plastic cases and acid.** Actors operating at this stage exhibit significant variation in environmentally sound practices. In sophisticated and more industrialized facilities, automated systems mechanically break down batteries and sort components with limited human intervention. These setups frequently include conveyors, hammer mills, and machinery to separate lead and plastic components, and collect the acid for treatment. Less sophisticated methods involve using a power saw to open the plastic casing and then separate components. Low-standard operations frequently rely on manual methods, in which workers use basic tools to break open the battery cases and manually sort out materials, with the acid often dumped on the ground.

**To ensure environmentally sound breaking and separation, strict operational controls and practices must be followed by recyclers to minimize significant occupational exposures and fugitive emissions outside of facility boundaries.** Facilities should be located in a designated industrial zone and utilize generalized and localized ventilation and dust collection equipment to prevent fugitive and stack lead emissions. Areas of the facilities where battery breaking and

smelting occurs should be confined with negative pressure enclosures. Even facilities with adequate ventilation systems must require additional PPE, including respirators, protective clothing, and gloves for all personnel. Regular environmental monitoring for stack emissions and ambient air should be conducted routinely to ensure the effectiveness of safety measures. Moreover, workers should be in a routine medical surveillance program to monitor exposures with blood lead level testing and should be removed from working around lead (with pay) when they exceed designated levels. Operators in charge of these processes must also identify and separate any lithium-ion batteries recovered during collection, which can explode if introduced into a hammer mill.

**Lead exposure during breaking and separation is greater when these activities are performed manually.** When they are not performed safely, workers may inhale lead dust, and their skin may be directly exposed to lead-contaminated acid. The breaking of battery cases releases lead particles into the air, creating a significant inhalation hazard. Improper handling of acid electrolytes can result in skin exposure. In informal and low-standard recycling facilities, breakers separate components with axes, machetes, or hammers.

**Advancements in battery design and technological capabilities of recycling facilities can support safer practices at this stage.** For example, advanced battery designs may require more sophisticated separation techniques, potentially leaving manual ULAB breaking ill-equipped to handle newer ULAB types, hence discouraging informal and low-standard recycling.

- ## Lead smelting and refining

**In formal facilities, once lead components are separated, they are smelted in furnaces and then refined in kettles to achieve higher purities.** Smelting operations involve heating lead in a furnace to separate it from contaminants including other metals and slag. Smelting practices can vary greatly, from sophisticated smelting facilities, equipped with rotary or reverberatory furnaces conducting controlled and automated smelting, to high-risk operations conducted in open pit fires or open furnaces lacking any containment. The extracted lead can be further refined by adding chemicals such as sulfur to remove other metallic impurities, and by conducting oxidation or electrolysis to yield a high-purity lead ingot.

**These processes rely on the quality of the separation during the previous stage**. For instance, if a facility operates a hammer mill and can separate the grid metallics from the battery paste, smelting can be more energy-efficient, as grids require low melting temperatures and yield metallic alloys, whereas paste requires high melting temperatures and longer smelting times to produce high purity lead (99.7–99.9 percent pure). However, if separation is conducted manually, grid metallics and battery paste will enter this process jointly, yielding lower-purity ingots.

Similarly, the quality of refinement will depend on the sophistication of a recycling facility. Informal and low-standard recyclers frequently will do minimal refinement. Lead that has been processed by informal recyclers is often sold as scrap and must be smelted again and then refined before it can be used to make a new lead battery. Each time the lead melts, there is a loss to the environment.

**The smelting and refining stages present some of the highest risks of lead exposure in the ULAB recycling process.** These processes are associated with the highest exposures to lead fume generated during high-temperature operations. Extremely fine lead fume particulates of approximately 0.1 microns in size, are generated when lead temperature exceeds 500°C, and are readily absorbed into the lung and can travel directly to the brain. Since these fume particles are invisible to the naked eye, operators frequently have an incorrect risk perception of their working environment. Larger lead dust particulates, ranging from 0.8 to 500 microns, are generated throughout the recycling process. Without proper controls, these fume and dust particulates can spread, affecting not just workers but also surrounding communities. In settings where open smelting is common and protective measures absent, these dangers are significantly magnified.

**Environmentally sound smelting and refining operations require ventilation and pollution controls to reduce lead exposures for workers and minimize emissions to the environment.** Smelting and refining facilities must be located in designated industrial zones and employ emission control systems such as baghouses and scrubbers to capture lead fume and particulates. Temperature-resistant PPE is crucial for workers near furnaces. Like earlier process stages, effective ventilation, regular environmental monitoring, and stringent worker health surveillance remain essential.



# 3. THE CHALLENGE

## What contributes to unsafe ULAB recycling in LMICs?

*ULAB recycling practices vary substantially both across and within countries. The prevalence of different recycling types depends on both market-shaping conditions and the characteristics of private actors.*

### ULAB recycling operations can be classified into four types, with varying risks of lead exposure

**The four main ULAB recycling types in the world typically coexist within LMICs.** ULAB recycling practices vary substantially both across and within countries depending on **capacity** of employed labor, **scale** of recycling operations, **financing** needed for operations, **traceability** of lead from generation to recycled product, **lead recovery** percentage, and **safety** of recycling operations. The four types are: [a] **informal**, [b] **low-standard**, [c] **mid-standard**, and [d] **high-standard**:

- **Operations in the informal recycling type are rudimentary and hazardous at every stage, involving unskilled labor and inadequate safety measures.** These small-scale operations handle less than 1,000 metric tons of ULABs annually. From collection, batteries are

manually opened and the acid is dumped on the ground to reduce transport weight. Improper storage and transportation often cause cross-contamination. Components are manually broken down and separated, frequently at sites located within residential areas and without the use of any precautions, including appropriate PPE. Open-air smelting in backyards or on the side of a road, also conducted with unsafe equipment and no PPE, produces lead scrap with a low recovery rate of only 50–60 percent. The remaining lead escapes into the environment and settles in soil and dust. Operations of this type require minimal to no financing given the basic equipment and technology used. Workers in these settings are generally self-employed and make money by selling the lead scrap at a higher price than the lead battery. Since these activities proceed without registration or regulatory oversight, they are sometimes transient and untraceable. Consequently, informal recycling poses significant danger to workers, nearby communities, and the environment.

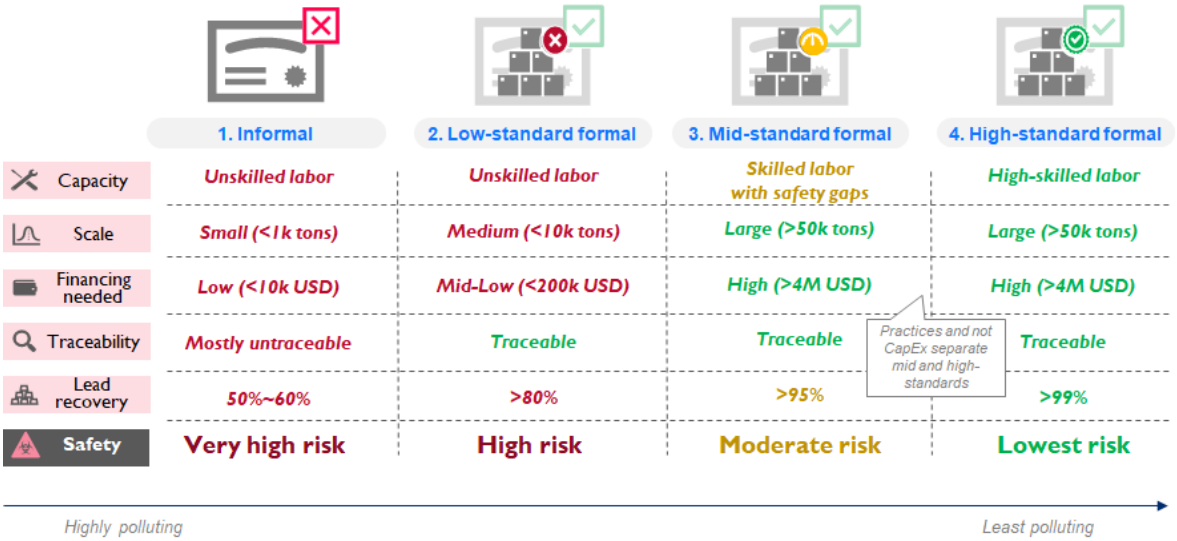
- **The low-standard formal recycling type, despite being formally registered and traceable, remains highly risky and results in excessive lead exposures to workers, surrounding communities, and the environment.** These operations can handle medium volumes, up to 10,000 metric tons of ULABs annually. Companies in this type employ unskilled labor to minimize costs, and despite equipment such as basic ventilation systems, their operations generally lack basic engineering and pollution controls. They operate without any worker protection measures such as periodic blood lead level (BLL) surveillance, and PPE or personal hygiene practices. Moreover, they do not conduct any periodic environmental lead monitoring, maintenance, and cleanups. Workers manually break batteries, dump the acid, and the smelting operations lack proper pollution controls and extraction ventilation systems. The use of slightly improved equipment increases the lead recovery rate to a maximum of 80 percent. These facilities need low capital investments—around $100,000–200,000 to cover furnace and minimum pollution controls investment. The formal registration of these companies obligates them to pay taxes, making them traceable. Despite this traceability, their operations remain hazardous, mirroring the risks of the informal recycling type.

- **The mid-standard formal recycling type carries moderate risk and traceable medium-scale industrial processes, achieving higher lead recovery compared to previous types due to improved furnaces.** Companies in this category employ a mixture of laborers and technically trained personnel with capacity to process at least 50,000 metric tons of ULABs. These operations are industrialized, utilizing a mixture of manual and mechanized processes for battery breaking and rotary furnaces for lead smelting. These plants generally have basic ventilation systems operating in some areas of the facility but often lack sufficient filtration for the exhaust. These improvements result in a high lead recovery

rate of over 95 percent, but also demand significant upfront investment due to their industrial nature—around 20 times as much upfront capital as low-standard formal operations need (a minimum of ~$4 million). While emissions associated with this type may be somewhat reduced compared to previous types due to baghouse filters on the furnace, workers and nearby communities are still subject to moderate fugitive emissions and stack emissions, as certain standards like regular BLL surveillance and thorough environmental lead cleanups are not always implemented. Moreover, air monitoring in the workplace and personal hygiene practices vary. However, companies in this type are traceable because they formally register with the government and comply with tax obligations.

- **The high-standard formal recycling type represents the lowest risk category, featuring large-scale, traceable industrial processes in companies that adhere to the highest standards.** These companies register formally and operate on a large scale, employing a mixture of laborers and highly skilled labor force and advanced equipment to recycle over 50,000 metric tons of ULABs and achieve over 99 percent recovery rates. Similar to the mid-standard type, their processes are fully industrial and automated, requiring large upfront investment. What sets high-standard formal recycling apart is their general and local ventilation and baghouse filters on all exhaust gases, high operating efficiency, and occupational health protection measures in place. Although these companies generally follow the highest standards, occasional non-compliance can still occur. Compared to the other three types, the high-standard formal type features the best safety, efficiency, and regulatory compliance, offering the best opportunity to improve operations sufficiently to protect workers and the environment.

*Figure 4: Recycling types in LMICs*




## Scale is a necessary condition for environmentally sound recycling, as economies of scale dilute the unit cost of such investments

**At the smelting stage, the four recycling types vary widely in fixed investments and unit cost of recycling; scale is a critical factor in diluting fixed costs and supporting the financial viability of mid- and high-standard recycling types.** Informal and low-standard operations achieve lower unit costs by avoiding occupational exposures and environmental emissions standards and investing minimal amounts, despite processing fewer ULABs. Conversely, mid-standard and high-standard operations incur higher initial costs for equipment and capital costs; they rely on scaling up operations to spread fixed costs and achieve financial viability. However, such plants will remain uncompetitive unless there are sufficient ULAB collection systems in place.

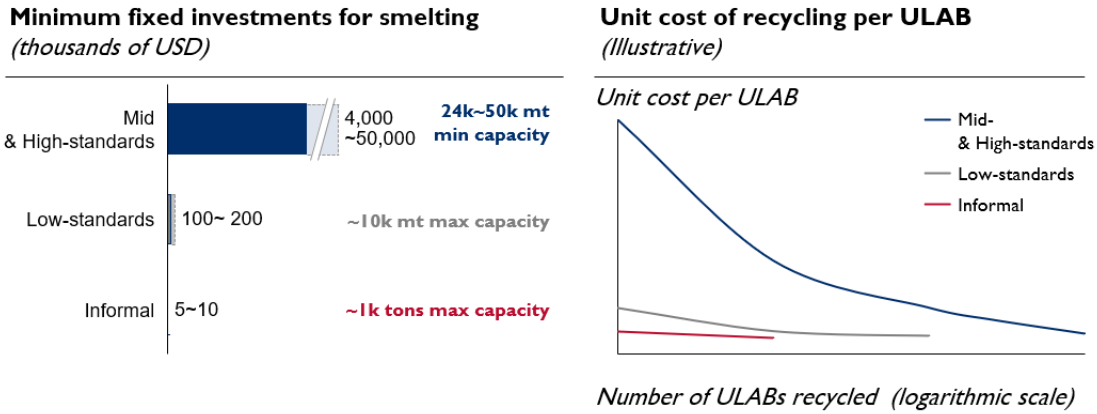
**A sharp increase in fixed investments and per-unit costs occur between the low-standards formal and mid-standard formal types.** The financial viability of environmentally sound recycling operations with the necessary ventilation and pollution controls to protect workers and the environment relies on a company's capacity to dilute these increased fixed costs, especially when operating at mid- and high standard.

**Informal and low-standard recycling operations achieve lower costs by investing minimally in ventilation and pollution control equipment.** Informal operations require minimal capital ($5,000–10,000) to process up to 1,000 metric tons of ULABs, while low-standard operations invest $100,000–200,000 to handle up to 10,000 metric tons. These types maintain considerably

lower unit costs even at their smaller volumes, due to their rudimentary equipment that are highly polluting and, in the case of informal operations, tax avoidance.

**Conversely, mid-standard and high-standard recycling types require substantial upfront investments.** These capital costs range from $4-50 million to support capacities of more than 50,000 metric tons. These higher costs reflect the adoption of sophisticated technologies for breaking, separating, smelting, and refining, as well as ventilation, negative pressure enclosures, and pollution controls necessary to operate in these hazardous facilities. These significant investments are then averaged with higher volumes to reduce unit costs per ULAB recycled.

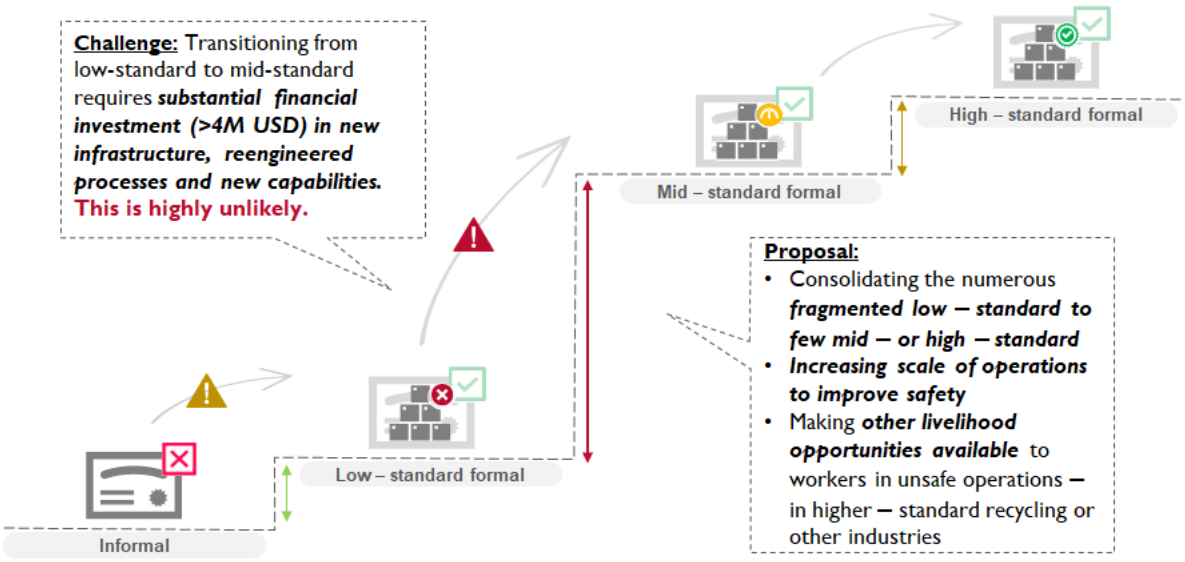
***Figure 5: Illustrative estimates of financial costs for ULAB recycling per recycling type***




**The financial viability of these safer, more advanced types hinges on their ability to leverage economies of scale.** By processing larger volumes of ULABs, mid-standard and high-standard operations can spread their fixed costs across more units, gradually reducing the unit cost of recycling. This scaling effect allows recyclers to dilute the substantial investments made in improved technologies, safety equipment, and more advanced processes.

**In addition to significant investment, the transition from low- to mid-standard recycling also requires a substantial overhaul of the recycling process to increase operational capabilities.** Recyclers must invest resources in enhancing their sourcing capacity, reengineer processes to incorporate industrial-scale operations, support workforce development to employ technically trained personnel capable of operating more complex machinery and equipment, and adopt new quality control measures, among other efforts, all requiring significant investments.

*Figure 6: Transitioning from low-standard to mid-standard recycling involves significant costs*




## A country's mix of ULAB recycling types depends on four market-shaping conditions

**Four market-shaping conditions influence the prevalence of different ULAB recycling types within a country: [i] Incomes for unskilled workers** largely determine the extent to which informal and low-standard recycling can be profitable; [ii] **regulations** governing takeback programs and recycling standards; [iii] **enforcement capacity** determines the consequences for recyclers operating in violation of such standards; and [iv] the **extent of battery manufacturers (OEM) participation in EPR programs** largely determines ULAB feedstock availability to formal recyclers to support investments in high standard recycling and pollution control technology.

- **Informal and unsafe recycling generally offers low incomes to workers, except in countries with stagnant and low average incomes.** In countries with very low incomes for other activities, workers are drawn to unsafe recycling practices, such as itinerant collection and manual breaking, these offer comparatively higher incomes than other informal jobs.

- **Countries with clear and effective regulations governing recycling tend to have a higher proportion of mid- and high- standard recycling operations**. Establishing clear, effective, and achievable regulations for all types of formal recycling helps increase compliance and the effectiveness of enforcement, with noncompliant recyclers facing the threat of penalties or business closure. Unclear provisions in regulations can lead to variations in compliance levels and increase differences between recycling practices. However, too

strict regulations can also promote informality if a country's recyclers are ill equipped to comply.

- **Effective enforcement is crucial for well-crafted regulations to operate as intended and is usually more likely to influence behavior change than are regulations themselves.** Regular inspections, fines for non-compliance, and potential closure of non-compliant facilities are among the credible consequences that encourage the transition to higher-standard types. Effective enforcement also creates a level playing field, ensuring that those operating outside of the regulatory framework do not undercut companies investing in safer practices.

- **When OEMs actively engage in EPR programs, taking responsibility for the entire battery lifecycle, they often partner with or operate mid- and high-standard recycling operations.** This involvement can include setting up collection through existing retail networks, providing financial incentives for sound recycling, or directly investing in recycling facilities. Moreover, by promoting higher quality batteries with longer lifespans, OEMs can potentially decrease the volume of ULABs requiring recycling. Strong OEM participation in EPR programs also supports a market shift towards mid- and high standard types by creating a reliable stream of ULABs for formal recycling channels, supporting formal recyclers in achieving economies of scale and operating less polluting facilities. (When OEMs are locally absent, importers can fill the EPR role in the domestic market.) Conversely, limited OEM participation in EPR programs can lead to a higher prevalence of informal or low-standard types—as can active OEM participation in informal markets, as when OEMs voluntarily buy lead inputs from unsafe sources. However, OEMs are not able to create an even-playing field among competitors without an underlying regulatory framework to force all producers to incur the same costs inherent in buying back used lead batteries through purchase discount programs or other means.



# 4. THE PATH FORWARD

## How can LMICs transition to sound ULAB recycling

*To reduce lead exposure and emissions from ULAB recycling, interventions should target both recycling facilities and the broader population. Such measures should be context-specific, tailored based on the ULAB market size and market-shaping conditions.*

**Improving ULAB recycling requires targeting both sector-specific practices across the recycling process and addressing broader population impacts.** While there are broad population-level environmentally sound efforts to pursue across contexts, a tailored approach that accounts for the unique context of each country is crucial for effectively reducing occupational exposures and environmental emissions in ULAB recycling facilities. Coordination between these two spheres is not a prerequisite for taking action but developing and following a robust and comprehensive strategy is the preferable approach.

*Figure 7: Two-pronged approach for environmentally sound ULAB recycling in LMICs*




**A national strategy for ULAB recycling interventions could combine shifting recycling activities to safer operations and improving existing operations at the margins.**

- **Shifting recycling operations from unsafe to safe operations** entails changing the composition of ULAB recycling operations by closing informal and low-standard operations and expanding the capacity of safer ones. This approach aims for transformational change.
- **Improving existing operations** entails building the capacity and awareness among existing private sectors actors in the ULAB recycling process and LAB manufacture and distribution. This approach promotes gradual change by steadily enforcing occupational and environmental standards and supporting investments in improved practices.

## Countries' ULAB market size and mix of recycling types should inform their ULAB recycling strategies

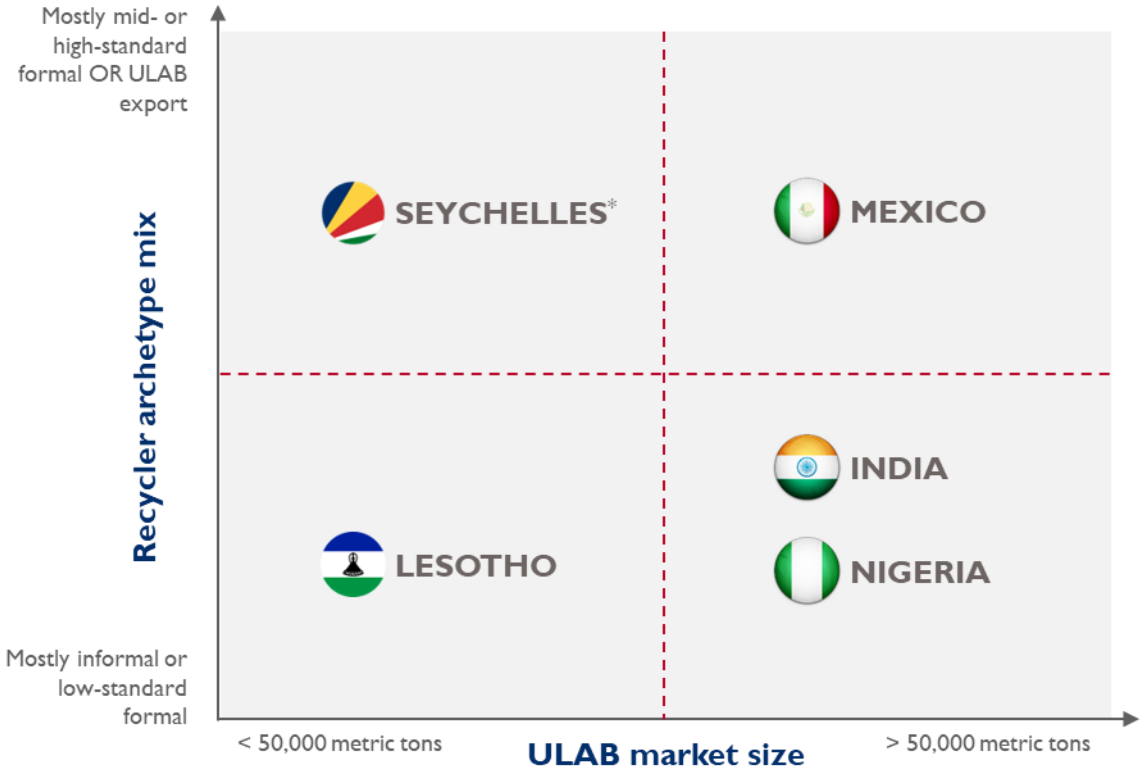
**The optimal national strategy for safe ULAB recycling depends on the country's ULAB market size and mix of recycling types, ranging from informal to high-standard formal.**

- **Domestic ULAB market size determines the scale of national recycling operations and the viability of investments in recycling.** Countries with a small market size and a limited ULAB stock can lack the economies of scale needed for environmentally sound recycling facilities or support domestic LAB manufacturing. These countries must often rely on ULAB exports for their environmentally sound recycling. If investment in environmentally sound recycling infrastructure occurs in such contexts, recycling operations will rely on ULAB imports given the limited domestic ULAB stock. In cases where the ULAB market size limits domestically recycled lead, LAB manufacturing will not be viable unless supported

by primary mining. Conversely, countries generating substantial ULAB quantities can achieve the economies of scale required for developing environmentally sound recycling infrastructure. Recycled lead from such operations can support domestic LAB manufacturing, which in turn would sustain the ULAB market. Self-sufficiency in both recycling and manufacturing fosters a circular economy approach to battery management.

- **The recycling types dominant in each country reflect the current domestic capacities in processing batteries and lead recovery.** The prevailing capacities in each country context present diverse challenges and opportunities for safe and sustainable ULAB recycling. Different interventions would be effective in countries where low-standard formal and informal recycling practices predominate compared to countries that exhibit a mix of high- and mid-standard formal recycling operations (alongside some informal activities).

***Figure 8: ULAB market size vs recycler type mix, with illustrative country examples***




** Note: Seychelles is placed as an illustrative LMIC where ULAB export volume is similar to LAB imports (UN Comtrade data 2023). Further studies are required to explore the implications of this trade balance on domestic recycling practices.*

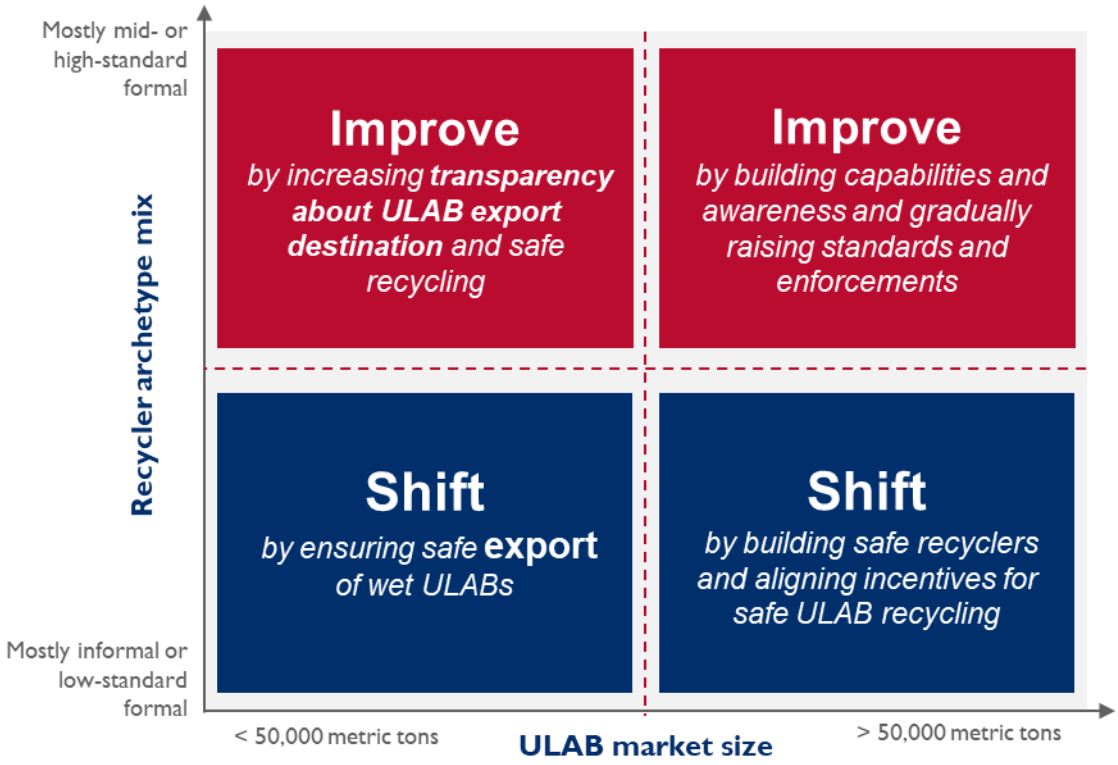
**For countries with predominantly informal and low-standard recycling, shifting recycling to improved operations is the most promising path, as "graduating" operators from low-standard to mid- or high-standard is impractical.** Expert advisors have emphasized that upgrading low-standard operations to mid-standard ones requires substantial investment—over $4 million per

operator—for new infrastructure, reengineered processes, and improved capabilities. Most low-standard recyclers cannot achieve this transition. In such contexts, low-standard actors must be phased out while either increasing the ULAB volumes processed by mid- or high-standard recycling units or facilitating exports to regional operators. This approach must also focus on creating alternative livelihood opportunities for workers previously engaged in low-standard recycling, either within higher-standard operations or in other industries.

**In such low-standard recycling contexts, a country's ULAB market size determines whether to shift operations by prioritizing improving domestic capabilities or expanding exports.** In large, low-standard ULAB markets processing above 50,000 metric tons of ULABs annually (like India and Nigeria in the figure above,) countries should focus on enhancing domestic capacity and increasing ULAB volumes processed in environmentally-sound facilities. This involves developing new or extending existing mid- and high-standard formal recyclers, while phasing out low-standard formal and informal recycling. In smaller ULAB markets processing less than 50,000 metric tons annually, such as Lesotho, consolidation of improved facilities might not be feasible due to scale. Here, efforts should concentrate on systematizing the export of ULABs to countries with established, environmentally-sound recycling infrastructure and partnering with regional operators.

**In countries where mid- to high-standard recycling infrastructure is already established, improving operations by optimizing existing capabilities and ensuring the responsible management of large ULAB volumes through strengthened regulations and enforcement is the best way forward.** For large ULAB markets with high-standard recycling operations, such as Mexico, the priority is to enhance operational performance and enable regulatory and enforcement improvements. Efforts to streamline and refine the recycling process can include investing in advanced recycling and pollution control technologies and in training and worker development. For smaller ULAB markets with high-standard recycling, such as Seychelles, the emphasis should be on improving the transparency and accountability of ULAB exports—ULABs that exceed the country's recycling capacity should be sent to other high-standard, environmentally responsible recycling facilities in other countries. Rigorous tracking and reporting mechanisms for ULAB exports and imports, as well as clear guidelines and quotas, must be implemented to monitor the flow of ULABs.

*Figure 9: Intervention approaches according to ULAB market size and recycler type mix*

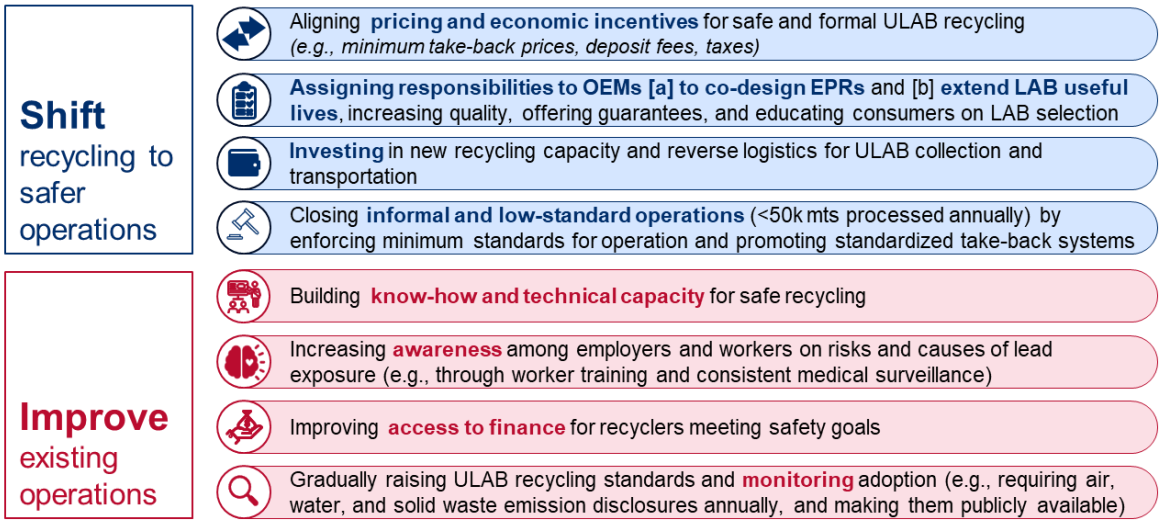


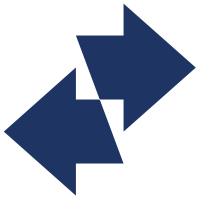

## A range of interventions exist for public and private stakeholders to support environmentally sound ULAB recycling, guided by ULAB market size and prevailing recycling types

**Interventions to support environmentally sound ULAB recycling should support both the private and public sectors to ensure effective outcomes.** Incentives and financing for formal recyclers to improve their practices should be paired with support for strong enforcement mechanisms to ensure compliance and promote environmentally sound recycling.

**To increase safe ULAB recycling, interventions could shift recycling to safer operations or improve existing operations.**

*Figure 10: Potential interventions for each broad intervention approach*



## ALIGN PRICING AND ECONOMIC INCENTIVES

**By aligning pricing and economic incentives, LAB users and ULAB collectors can be encouraged to return stock to retailers connected to formal and environmentally sound recycling.** This can involve setting minimum take-back prices with a purchase discount or refund fees higher than those paid in the informal sector and reducing taxes in the formal recycling sector to create a level playing field. With adequate enforcement, these systems can be effective to consolidate ULABs and gradually phase out informal operators.

### Setting a minimum take-back price

Legislation that mandates **a fee—higher than that offered in the informal sector—to be paid to consumers who return ULABs can incentivize them to use formal collection and recycling facilities**, reducing diversion of ULABs into the informal sector.

**For this approach to be effective, two conditions must be met:**

1. Encouraging consumers to switch to formal channels, the fee must be higher than the price paid by informal collectors
2. Uniformly applying the rule across formal retail outlets and collection sites to prevent ULABs from ending up in the informal sector



## ASSIGN RESPONSIBILITIES TO OEMs

**Assigning responsibilities to original equipment manufacturers (OEMs) to [a] co-design extended producer responsibility (EPR) programs and [b] extend LAB useful lives can minimize ULAB generation and create closed loops for LAB management.** Regulators should encourage OEMs in countries with LAB manufacturing and ULAB recycling capabilities to collaborate with producer responsibility organizations (PROs) in designing these programs. OEMs should be responsible for collecting and recycling a significant portion of the LABs they produce, possibly by paying fees to PROs for the collection and transport of ULABs to formal recycling facilities or back to the OEMs. Increasing OEM involvement ensures a more sustainable and efficient recycling process through formal channels. In addition, regulators should require OEMs to enhance the quality and lifespan of LABs coupled with education consumers on LAB selection and offering guarantees on LABs. This involvement ensures a more sustainable and efficient recycling process.



## INCREASE PRIVATE SECTOR FINANCING OF NEW RECYCLING FACILITIES

**Investing in new recycling facilities and aligned reverse logistics for ULAB collection and transportation will contribute to safe ULAB management.** This will involve the establishment of new recycling facilities equipped with modern technology and the implementation of efficient systems for collection and transport of ULABs from various sources. This will also involve ensuring geographic spread and accessibility of such facilities to minimize the logistical costs of transporting ULABs back to OEMs. National governments and other international stakeholders will need to facilitate private sector financing and development of these facilities. Success hinges on ensuring that new facilities adhere to stringent environmental and occupational safety standards, and that collection and transportation networks are comprehensive and well organized.



## PHASE OUT INFORMAL AND LOW-STANDARD OPERATIONS THROUGH STRICT ENFORCEMENT MEASURES

**Phasing out informal and low-standard operations through strict enforcement of minimum standards for operations can improve the quality of ULAB recycling in countries.** This will require a combination of revising of ULAB recycling standards (for example, adopting minimum size requirements for existing and new plants), strong enforcement strategies, and creating alternative livelihood opportunities for informal and low-standard workers, to avoid creating perverse incentives for additional informal operations.



## IMPROVE CAPACITY FOR ENVIRONMENTALLY SOUND RECYCLING

**Helping countries with mid- or high-standard recycling facilities to improve human resources and logistical capacity for environmentally sound recycling can increase the number of ULABs recycled in the formal sector.** This approach involves building additional recycling capacity in existing facilities, improving the technical training and knowledge of workers at recycling facilities, and expanding the network of formal ULAB collection points. To ensure the effectiveness of this intervention, countries should conduct thorough assessments to identify areas where workers either have inadequate capacity or consumers/retailers have limited access to recycling, and target investments accordingly. Collaboration between governments, international organizations, and private sector actors is essential for providing technical assistance, financial support, and knowledge sharing to facilitate capacity building.



## INCREASE AWARENESS AMONG EMPLOYERS AND WORKERS

**Raising awareness among employers and workers about the adverse risks and causes of lead exposure can improve existing recycling operations.** Many recycling facilities, including mid-standard units, employ workers who are often unaware of the dangers they face. As a result, workers either do not demand appropriate protection measures from their employers or do not utilize equipment provided to them. Employers

need to understand and consistently update the techniques and tools available to protect their workers and the community while efficiently recovering more lead. Educational campaigns should be conducted in major ULAB recycling hubs, utilizing various communication channels such as workshops, training sessions, and informational materials. Further, recurrent trainings and consistent medical surveillance should be required. Success depends on tailoring the content to the specific needs and knowledge levels of the target audience, emphasizing the importance of preventive and protective measures, and empowering workers to advocate for their occupational safety.



## IMPROVE RECYCLERS' ACCESS TO FINANCE

**Improving access to finance for recyclers meeting adequate standards for ULAB recycling can help enhance their operations.** Blended finance instruments, combining public and private funding, can provide affordable financing options for mid- and high-standard recyclers to improve their operations by investing in state-of-the-art equipment and environmental protection systems. Success requires establishing clear eligibility criteria based on environmental and occupational safety standards, as well as providing technical assistance to recyclers to develop viable business plans and loan applications.

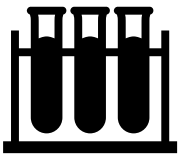


## RAISE ULAB STANDARDS AND IMPROVE MONITORING PRACTICES

**Raising ULAB recycling environmental and occupational standards and monitoring their disclosure can improve a country's recycling operations.** This approach involves progressively revising current standards to align with international best practices and providing recyclers with clear standard operating procedures (SOP) and training on how to implement these new standards and practices. Ensuring compliance requires equipping national, state, and/or local-level regulatory agents with the necessary financial resources, training, equipment, and laboratories to regularly monitor ULAB recycling facilities and take appropriate action when necessary.

## Beyond ULAB and facility-specific interventions, stakeholders can pursue population-level interventions to reduce lead exposure

**Interventions targeting the population at large can complement efforts to reduce lead exposure in the ULAB recycling supply chain.** These interventions can include:



### CONDUCT TARGETED POPULATION AND ENVIRONMENTAL LEAD SURVEILLANCE

**Systematically measuring blood lead levels in exposed populations, especially children, and testing for environmental emissions can help identify and mitigate sources of lead exposure.** Systematic measurement of blood lead levels, particularly in communities within 3 km of lead recycling facilities, will provide data for governments, health agencies, and decision makers to inform remediation strategies and draw attention to highly polluting facilities. Setting up ambient air testing operated by environmental authorities at factory property lines is a relevant complement for this surveillance. Public-private collaboration between local and national authorities, recyclers, and manufacturers, is necessary to raise awareness and highlight best practices and success stories.



### CONDUCT FORENSIC RESEARCH

**Conducting forensic research when testing the population and the environment for lead levels can help pinpoint specific sources of lead poisoning.** Investigation of the presence and levels of lead in environmental samples and their correlation with lead levels in biological samples is critical to determining the extent and source of lead exposure in specific locations. This will help establish a link between lead exposure and health effects and could also help pinpoint lead contamination sources, including informal ULAB recycling activities.



### PROVIDE NUTRITIONAL SUPPORT

**Providing nutritional support to exposed individuals, especially children, can mitigate the impact of lead exposure.** This intervention complements population testing by offering nutritional support to those with high blood lead levels. Key nutrients that reduce lead absorption, such as vitamin C,

calcium, and iron, can be measured for deficiencies. Nutritional advice on a healthy diet and supplementation can then be provided, helping to minimize the effects of lead exposure. It is important to note that while nutritional support is beneficial as a remedial intervention, it does not address the root issue of occupational lead exposure.



## RAISE AWARENESS AMONG THE POPULATION

**Conducting awareness campaigns about the risks of lead poisoning enables the population to understand how exposure to LAB components and unsafe lead recycling can pose life-threatening risks**. This information can empower people to advocate for better environmental protection from the government and local recycling facilities and responsible ULAB return practices. In response, recycling facilities may be motivated to elevate their ULAB recycling standards.



## REMEDIATE CONTAMINATED SITES

**Remediating contaminated sites, especially in urban and densely populated areas, is important for reducing the lead exposure for future generations.** Lead particulates released into the ground from lead smelting activities can remain in the top 2.5cm of soil indefinitely as lead is highly stable in soils; communities around such soil will continue to be contaminated unless site remediation is conducted (Global Battery Alliance, 2020). Remediation methods are contingent on the level of contamination, although they broadly involve the excavation and removal of contaminated soil, water, or other environmental features followed by capping the site with clean soil or other materials. In select cases, treating the soil in situ can also reduce lead contamination. Rather than conducting regular annual cleanups, which could imply high costs for operating recycling plants, provisions for remediation during plant closure could be established. This could include earmarked fees collected during a plant's operational phase to fund the eventual remediation at the end of a facility's lifecycle, ensuring that the site can be safely restored once recycling activities cease.



# 5.

# COUNTRY CASE STUDIES



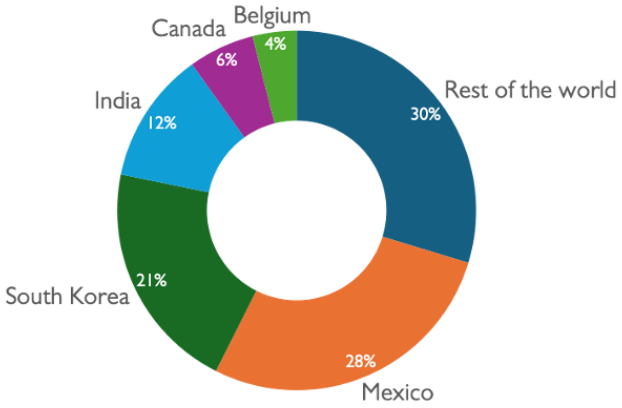
# 5.1. Mexico

*ULAB recycling in Mexico is predominantly a formal sector business, driven by three large players which together handle over 70 percent of the nation's recycling capacity. Mexico processes over 620,000 metric tons of ULABs annually, including significant imports from the U.S., due to its industrial capacity, geographic proximity, and relatively less strict environmental regulations. Despite the market being predominantly formal, significant challenges remain, such as insufficient regulation and enforcement, lack of regulatory oversight of self-reported emissions, and emissions resulting in elevated lead contamination in surrounding soils and communities. Tailored interventions and stricter enforcement are essential to ensure a future with environmentally sound recycling.*

## 5.1.1. MARKET OVERVIEW AND REGULATORY FRAMEWORK

**Mexico—world's leading ULAB importer—processes over 620,000 metric tons of ULABs annually.**[2] The ULAB market encompasses both domestic collection, which accounts for ~10 percent of total recycling, and ULAB imports from the United States, which make up ~90 percent (SEMARNAT, 2024) (Casa Cem, 2024). Although LAB manufacturing is the main driver of ULAB recycling in the country and globally —and accounts for most of the lead derived from the recycling process—recycled ULABs also generate lead derivatives that serve as inputs for other industries, such as lead oxides for pigments and glazes. (Detailed data are not currently available on the precise proportion of recycled lead destined for different end-uses.)

***Figure 11 Global ULAB imports***



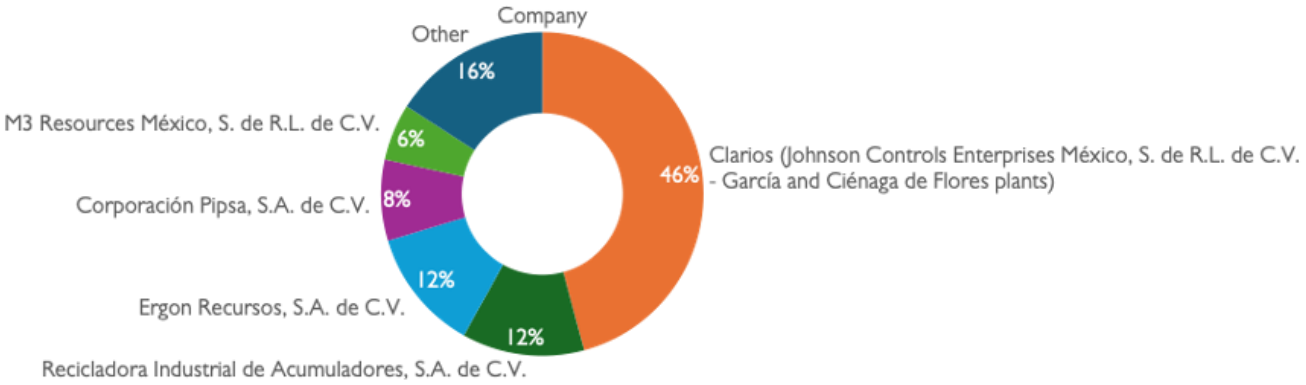

*Source: UN Comtrade data*

**The ULABs recycling market in Mexico is mainly formal, and dominated by three companies, which own ~70 percent of the country's total recycling capacity** (Casa Cem, 2024)**.** Mexico classifies ULABs as hazardous waste, which mandates that the management and recycling of ULABs must adhere to the country's strictest waste regulations (SEMARNAT, 2024). Small recycling companies have difficulty meeting these requirements; as a result, large and mid-size companies are the predominant ULAB recyclers. The market is highly concentrated: Clarios, Recicladora Industrial de Acumuladores (RIASA—part of Grupo Gohner), and Ergon Recursos S.A. control 70 percent of the country's recycling capacity, while just eight companies control 90 percent of the capacity (Casa Cem, 2024). Clarios—the largest player in the country—owns two recycling plants,

[2] Volume calculation was made from the 21 import authorizations emitted by the SEMARNAT in 2023, for 558,000 metric tons of ULABs. Additionally, the SEMARNAT has emitted ~11 import authorizations for a total of 225,000 metric tons of ULABs in 2024 to date (June 2024). The domestic market was calculated under the assumption that imports represent 90 percent of the total market in the country. However, the ~55 million registered motored vehicles in Mexico under the INEGI suggest that the domestic market could represent around 40 percent.

both located in the state of Nuevo León; these represent roughly 46 percent of the total recycling capacity nationwide. RIASA and Ergon each account for around 12 percent of the country's ULAB recycling capacity. The figure below illustrates the complete distribution of capacity among Mexico's ULAB recycling companies.

***Figure 12: Distribution of ULAB recycling capacity among companies in Mexico***




*Source: Data provided by Casa Cem*

**ULAB recycling facilities with a large capacity benefit from economies of scale, making it worth the investment to enhance the environmentally soundness of their operations.** By handling vast quantities of ULABs, large recycling companies can invest in advanced recycling technologies and infrastructure that smaller players cannot afford. These investments include automated systems for battery breaking and separation, which minimize direct human contact with hazardous materials, good extraction ventilation systems and improved pollution controls that reduce airborne lead particulates. While the scale of recycling operations in Mexico is appropriately large to make such investments viable, without rigorous enforcement of environmental and occupational safety standards, incentives to invest in environmentally sound recycling processes are minimal.

**In Mexico, vertical integration plays a crucial role in the ULAB recycling supply chain.** Clarios, Mexico's largest ULAB recycler, manages the entire lifecycle of their lead-acid batteries (LABs) from production to recycling, ensuring continuous reuse of lead. The Clarios facility located in *Ciénega de Flores*, Nuevo León, for example, both manufactures and recycles batteries. In their 2022 ESG report, they state that their supply chain both starts and ends when a consumer replaces a used vehicle battery with a new one, and given their expertise in closed-loop systems and logistics, they have worked alongside the U.S. Department of Energy (DOE) and industry partners in creating and implementing advanced technologies for recycling both low-voltage and high-voltage lithium-ion batteries (Clarios, 2022). Similarly, Grupo Gonher integrates the operations of its subsidiaries—Enerya manufactures new batteries and RIASA recycles used ones. This vertical integration allows

companies to control multiple stages of the supply chain, streamline operations, and ensure that lead remains within the formal sector. Although these are characteristics of the main players in the country, they do not necessarily apply to the country's mid-size manufacturers and recycling companies.

**Mexico's industrial capacity, proximity to the United States, and relatively less strict environmental regulations and enforcement make it a prime destination for ULAB imports; the country receives 75–95 percent of total U.S. ULAB exports globally** (Gottesfeld, Chavez Arce, & Macias Raya, 2023)**.** Mexico has sufficient installed ULAB recycling capacity (1.41 million metric tons (Casa Cem, 2024)) to support the vast majority of annual ULAB exports from the United States. Apart from its capacity, Mexico's proximity to the U.S. also makes it an attractive destination for ULAB exports. Additionally, Mexico's more lenient environmental controls and weaker enforcement relative to the U.S. result in lower processing costs, which further encourages the high volume ULAB outflow from the U.S. (see paragraphs under Table 1 below for a more detailed discussion of this point).

**Processing facilities for ULAB imports from the United States are strategically concentrated in the border state of Nuevo León.** Nuevo León's proximity to the U.S. border facilitates the easy import of ULABs, streamlining the logistics of recycling operations. For instance, Nuevo León is the only state in the country with registered international commercial purchases under the HS code 8548100540[3] (Casa Cem, 2024). Given the large volume of ULAB imports coming from the United States to be recycled, it is unsurprising that roughly 72 percent of Mexico's recycling capacity is located in Nuevo León. Four of the five largest plants in the country are located in this state, with an installed capacity of more than 100,000 metric tons. Additional mid-sized recyclers are geographically dispersed across the states of Tamaulipas, Baja California, Guanajuato, Tlaxcala, Chihuahua, San Luis Potosí, Jalisco, State of Mexico, Michoacán, Puebla, and Aguascalientes (see Table 1 below).

[3] The Harmonized System (HS) is a standardized numerical method of classifying traded products. HS code 8548100540 corresponds to lead-acid storage batteries of a kind used for starting engines, for the recovery of lead.

*Table 1: Recycling capacity distribution by states in Mexico*

| State | State recycling capacity | Percent of total country's capacity (%) |
|---|---|---|
| Nuevo León | 1,016,487 | 72.1 |
| Estado de México | 185,904 | 13.2 |
| Tamaulipas | 80,000 | 5.7 |
| Tlaxcala | 59,602 | 4.2 |
| San Luis Potosí | 26,273 | 1.9 |
| Baja California | 20,750 | 1.5 |
| Jalisco | 11,300 | 0.8 |
| Guanajuato | 7,425 | 0.5 |
| Michoacan | 3,000 | 0.2 |

**In response to regulatory deficiencies highlighted by the Commission on Environmental Cooperation (CEC) in 2013, Mexico updated its lead battery recycling standards.** The CEC's "Toxic Trade?" report highlighted deficiencies in Mexico's regulatory framework for lead battery recycling compared to the United States, pointing out discrepancies in ambient air standards and permissible air concentrations from stack emissions. Consequently, Mexico implemented the NOM-166-SEMARNAT-2014 standard for lead stack emissions. The creation of this norm involved extensive negotiations, with participation from major industry players like Johnson Controls and Gonher and allowed an eight-year phase-in period ending in January 2023 to prevent economic impacts on smaller operators. Despite these updates, Mexico's Ambient Air Standard for airborne lead remains more than three times greater than in the United States. Specifically, Mexico allows an annual average of 0.5 $\mu g/m^3$ for lead particulates less than 10 microns in diameter (PM10) (Mexico NOM-026-SSA1-2021), while the U.S. maintains a stricter limit of 0.15 $\mu g/m^3$ over a three-month rolling average—not only for PM10 particulates, but rather for total suspended particulate matter. Additionally, Mexico's occupational health controls are more lenient than U.S. Occupational Safety and Health Administration (OSHA) regulations. However, the enforcement and compliance of Mexican regulations on lead emissions and workplace safety (summarized in table 2 below) remains a challenge due to insufficient regulatory oversight and environmental monitoring capabilities.

*Table 2: Mexican regulations on lead emissions and workplace safety*

| Norm | Description |
|---|---|
| NOM-166-SEMARNAT-2014 | Sets the maximum permissible emission limits for lead, total hydrocarbons, nitrogen oxides, dioxins, and furans from secondary lead smelting processes. |
| NOM-010-STPS-2014 | Addresses the identification, evaluation, and control of chemical contaminants in workplaces to ensure occupational health and safety. |
| NOM-147-SEMARNAT/SSA1-2004 | Establishes the criteria for soil quality and the permissible concentrations of heavy metals, including lead, for the remediation of contaminated sites. |
| NOM-026-SSA1-2021 | Evaluates the quality of ambient air with regard to lead, specifically focusing on PM10 particulates, and sets permissible exposure limits to protect public health. |

**The disparity in regulatory standards between the U.S. and Mexico results in differences in permissible limits and enforcement mechanisms.** For instance, both countries set end-of-stack emission limits at 0.2 mg/m³ facility-wide and 1.0 mg/m³ for each stack. Additionally, both countries set the permissible exposure limit (PEL) for lead at 50 µg/m³ averaged over 8 hours (Gottesfeld, Chavez Arce, & Macias Raya, 2023). However, the U.S. has an additional safety regulation that requires workers to be removed from the site if their blood lead level is 50 µg/dl or greater; Mexico does not have an equivalent standard. While the establishment of blood lead level (BLL) limits is a step in the right direction, their impact is significantly diminished in the absence of comprehensive provisions. Despite regulations that mandate the remediation of contaminated soils and allow for the closure of noncompliant facilities, according to government records few plants have actually been closed, and the Mexican federal environmental agency has rarely exercised its authority to close facilities that violate standards (Fisher, 2023). Without strict enforcement, companies lack the incentive to invest in technologies to reduce emissions.

**Mexican regulations offer less protection to workers than U.S. regulations due to three main limitations:**

- **Less strict ambient air standards:** Mexico allows airborne lead levels that are over three times greater than those permitted in the U.S.
- **Lack of occupational health protections:** Unlike the U.S., Mexico does not have a standard for occupational blood lead levels necessitating medical removal.

- **Insufficient enforcement and monitoring:** Mexico struggles with enforcement and lacks an adequate environmental monitoring program, leading to inconsistent compliance.

**Civil society organizations have played a crucial role in addressing the challenges associated with ULAB recycling in Mexico and raising awareness about its health implications.** *Casa Cem*, a Mexican non-profit based in Guadalajara, has been at the forefront of these efforts, conducting critical research that exposes the high levels of lead in soil surrounding ULAB recycling facilities and advocating for stricter regulations to protect public health. *Mundo Químico*, comprised of environmental public health experts, focuses on improving chemical management in Mexico to protect public health. Its initiatives include implementing an epidemiological surveillance system for chemicals, creating a registry of chemicals used in Mexico, and addressing the backlog in chemical management. It also collaborated with the government to develop the action program for lead exposure in Mexico and proposed a BLL surveillance system to monitor lead levels in the population, ensuring that the health system is better equipped to address lead poisoning. Pure Earth, a global non-profit organization, has implemented numerous projects in Mexico to mitigate pollution from battery recycling. It works closely with local communities to clean up contaminated sites and promote safer industrial practices. Additionally, OK International, a non-profit organization dedicated to public health and reducing industrial pollution, has partnered with *Fronteras Comunes* and *Casa Cem* to address ULAB recycling issues in Mexico. They have conducted investigations revealing high lead levels in soil near recycling plants, advocated for stronger environmental regulations, and influenced policy discussions to improve lead pollution control. Their efforts have also prompted an investigation by the CEC to address regulatory gaps between the United States and Mexico (Occupational Knowledge International, n.d.).

## 5.1.2. SUPPLY CHAIN ANALYSIS

*Figure 13: Lead acid battery supply chain stages in Mexico*




### Stage 1: LAB sourcing

**The sourcing of lead-acid batteries (LAB) involves a combination of local manufacturing, imports, and recycling.** Some ULAB recycling plants in the country are co-located with lead battery manufacturing plants or other lead chemical production plants, in order to facilitate vertical integration and closed-loop systems. For instance, as previously mentioned, Clarios and Grupo Gonher both recycle ULAB and manufacture LABs which are not only sold locally but exported as well; it is important to note that this is not the case for all ULAB recyclers and LAB manufacturers in the country. Additionally, Mexico imports LABs from international companies, such as the AC Delco batteries brand from General Motors.

### Stage 2: Distribution and consumption

**A network of retailers, wholesalers, and specialized distributors facilitates the distribution and consumption of LABs.** This stage is the most fragmented in the supply chain—a few major retailers play prominent roles in LAB distribution while various mid-size retailers dispersed throughout the country are also active. Major retailers like AutoZone and O'Reilly ensure that LABs are widely accessible for both individual and commercial needs. Similarly, Costco and Walmart

offer LABs in their product portfolios. Clarios, meanwhile, offers its "LTH" brand of LABs through dedicated stores and automotive service centers. The automotive sector is the largest LAB consumer, driven by the high demand for vehicles. However, industrial applications also rely on LABs for backup power and energy storage; with companies like Grupo Gonher providing storage and motive solutions tailored for the industrial, solar, and telecom markets.

## Stage 3: ULAB collection and transport

**Take-back programs play a key role in the ULAB collection.** Major recyclers have implemented successful widespread battery take-back programs that offer up to 30 percent discount on new batteries in exchange for used ones, which is about 4 times the purchase discount price mandated in most U.S. states and considerably higher than in other countries such as India and Nigeria. The table below explains in more detail how this works for some of the main battery brands in the country. This economic incentive has contributed to keeping the recycling process predominantly within the formal sector.

***Table 3: Battery take-back in Mexico***

| Battery brand | Manufacturer | New battery price | Take-back discount (MXN) | Battery received for take-back |
|---|---|---|---|---|
| LTH | Clarios (formerly Johnson Controls) | $2,200–5,900 | $534 | Only the same brand |
| AC Delco | General Motors | $2,600–4,500 | $150 | ULAB from any brand |
| Duralast | AutoZone | $2,200–5,800 | $350–550 depending on battery condition | ULAB from any brand |

## Stages 4 and 5: Breaking and separation of ULAB components, and lead smelting and refining

**Just a few companies handle the majority of ULAB recycling nationwide.** They undertake the entire sequence, from breaking and separating the battery components to smelting and refining the lead—the final stages of the process during which the majority of lead exposure occurs. Occasionally, these companies subcontract certain processes, but these operations remain within the formal sector. Other international manufacturers, such as East Penn Manufacturing, have arrangements with local recycling companies—in this case, RIASA, the subsidiary of Grupo Gonher

that imports and processes ULABs, and then exports refined lead back to the United States. Similarly, M3 Resources located in Birmingham, Alabama, operates a smelter in Reynosa, Mexico.

**Informal ULAB recycling—although marginal, under-mapped and understudied— still exists in Mexico.** Although there has not been extensive research on the ULAB recycling informal sector in Mexico, regulatory agents and civil society organizations estimate that approximately 5 percent of the ULAB recycling is done informally. Experts shared that informal recycling "corridors" exist in urban peripheries (e.g., between Chalco and Valle de Chalco, in the outskirts of Mexico City). Small recyclers receive inputs for recycling from informal scrap metal collectors and employ low-income populations, including Central and South American migrants during their journeys to the US. Processes in the informal sector are manual and highly unsafe—exposing both workers and nearby communities to lead contamination.

> *"If informal battery recycling activities exist and generate emissions, they are minimal compared to the pollution generated in the formal sector. Nonetheless, the formal recycling of lead-acid batteries does not ensure protection from lead exposure, neither for workers nor for nearby communities"*
>
> *- Civil society organization-*

## 5.1.3. BARRIERS TO ENVIRONMENTALLY SOUND RECYCLING

**Mexico lacks a system of regulatory oversight for self-reported emissions to the *Registro de Emisiones y Transferencias de Contaminantes* (RETC); in fact, many companies do not report their emissions at all.** The RETC is a public database where companies report emissions of 104 chemicals, including lead. It is intended to be equivalent to the U.S. Toxics Release Inventory (TRI) and the EU's Pollutant Release and Transfer Register (E-PRTR), which also track and publicly disclose industrial pollutant releases and waste management activities. Although companies are required to report their emissions, only 7 out of the 18 facilities permitted to recycle hazardous waste by the *Secretaría de Medio Ambiente y Recursos Naturales* (Ministry of Environment and Natural Resources in Mexico - SEMARNAT) reported their emissions in 2022 (Casa Cem, 2024). It has been found that some companies appear to have submitted reports that closely resemble those of other companies, with identical geographic coordinates that do not correspond to their own plant locations. Diffuse regulatory responsibilities make it unclear who should oversee the self-reporting process and act on such discrepancies. Consequently, it has been claimed that companies that fail to report or show deficiencies have not faced penalties. Without a verification process in place, companies have an incentive to under-report emissions. Furthermore, regulations require reporting on soluble lead, instead of total lead emissions, leaving the definition open to interpretation and potential manipulation.

**There are instances where permissible lead levels in air, water, and soil are exceeded, indicating opportunities for improvement in industry practices.** While internal processes and environmental and occupational safety measures of recycling facilities are not publicly visible, observations of soil and water contamination in nearby areas suggest potential gaps in pollution controls. For instance, Casa Cem found that six out of seven recycling facilities evaluated, had at least one sample that exceeded the soil lead limit of 800 ppm. The arithmetic mean soil concentration for the 28 samples was 4,897 ppm, with levels ranging from 89 to 43,000 ppm, and a median of 1,035 ppm (Gottesfeld, Chavez Arce, & Macias Raya, 2023). Additionally, an academic study conducted in Torreón, an arid city affected by emissions from the Met-Mex Peñoles lead smelting and refining facility, revealed the presence of Pb-bearing particles in settled urban dust. These particles vary in size, morphology, and elemental composition, with lead contents ranging from 0.3 to 87.2% (Soto-Jiménez, et al. 2023). The study highlighted that weathering processes increase the bioavailability and toxicity of these particles, posing significant risks to the environment and human health.

**Regular measurement of blood lead levels (BLL) for workers is lacking.** The intent of Mexico's NOM-010-STPS-2014 regulation is to identify, evaluate, and control chemical contaminants, including lead, in workplaces. It mandates periodic BLL testing for workers exposed to lead and requires comprehensive record keeping and medical evaluations for those with elevated levels. However, the degree to which this regulation has been implemented remains unknown, same as the enforcement of regular testing and follow-up interventions. As a result, many workers may not be adequately monitored for lead exposure, and may be unknowingly exposed—continuously or repeatedly—to harmful levels of lead.

**Gaps in Mexico's occupational health regulations include the lack of mandatory medical removal for workers overexposed to lead and insufficient mandatory testing and reporting protocols.** Mexico updated its occupational exposure limit to match the United States' 50 µg/m³ limit. However, while the United States mandates medical removal[4] for workers with blood lead levels exceeding 50 µg/dL over an extended period, Mexico lacks such standards. Additionally, ineffective enforcement and the absence of regular blood lead level monitoring contribute to ongoing health risks.

## 5.1.4. COUNTRY-SPECIFIC INTERVENTIONS

Interventions to make ULAB recycling safer can focus either on "**shifting to safer operations**" or on "**improving existing operations**". Given the Mexican context, interventions are more focused on the latter.

[4] In the United States, workers with blood lead levels over 50 µg/dL must be medically removed from exposure. During this period, they receive full pay and benefits. A physician monitors their blood lead levels and determines when they can safely return to working with lead.



## REQUIRE THIRD-PARTY LEAD EMISSIONS TESTING

**Advocate for stricter reporting of lead stack emissions and ambient air emissions on the part of used battery recycling plants and support increased third-party auditing and testing.** This would ensure that emissions data reported to the RETC are more accurate and transparent, helping to identify non-compliant facilities and reducing the overall lead pollution in surrounding areas. It could also provide greater public visibility into inconsistencies in the reports that companies submit, putting pressure to regulatory agencies to act.



## MANDATORY BLOOD-LEAD-LEVEL (BLL) TESTING

**Conduct third-party or government BLL testing—mandatory for all workers—every 6–12 months; make reporting on these test results mandatory, subject to fines and penalties for noncompliance.** Regular testing would provide critical data for public health interventions and ensure that facilities are held accountable for maintaining permissible lead levels. Studies have shown that routine BLL testing can significantly reduce lead exposure risks by facilitating early detection and intervention, ultimately protecting vulnerable populations from long-term health effects. This would also support compliance with NOM-010-STPS-2014.



## STRENGTHEN ENFORCEMENT OF ENVIRONMENTAL REGULATIONS

**Enhance enforcement of regulations by increasing funding for monitoring equipment, inspector training, and regulatory agencies.** Specifically, ensure strict adherence to NOM-166-SEMARNAT-2014 and NOM-026-SSA1-2021, which govern lead emissions and air quality standards. Providing resources to regulatory bodies will enable more frequent and thorough inspections, ensuring compliance and reducing lead pollution from recycling facilities.



## STUDY THE EVOLUTION OF, IMPACT OF, AND ADHERENCE TO NOM-166

**Assessing the impact of and adherence to the updated lead stack emissions standard (NOM-166-SEMARNAT-2014) can greatly inform the effectiveness of regulatory updates.** Despite an eight-year phase-in period ending in January 2023, limited information on compliance is available. This study will identify gaps in adherence and inform future regulatory adjustments and enforcement strategies. Understanding the effectiveness of current regulations and identifying areas for improvement can help tailor more effective policies, ultimately leading to better environmental and health outcomes.



# 5.2. India

*India's ULAB recycling sector is characterized by over 600 low-standard formal and many informal recycling facilities, which are highly polluting and pose significant lead exposure risks to workers and communities. While regulations exist, enforcement is inconsistent, and the fragmented nature of the industry, coupled with loopholes in the Goods and Services Tax (GST) framework, hinders a shift towards safer practices.*

*To promote ULAB recycling in India that is environmentally sound and improved compared to low-standard practices, a multi-pronged approach is required. Firstly, establishing robust traceability systems that promotes the responsible sourcing of lead can curb informal recycling. Secondly, limiting the number of recycling licenses and granting them only to facilities with adequate pollution controls and capacity over 50,000 MT per year can consolidate the industry and eliminate the most polluting smelters. This needs to be accompanied by the enforcement of a national take back regulation that ensures a sufficient price is paid to traders and bulk purchasers that results in all batteries being returned to manufacturers. Thirdly, aligning the GST framework for ULABs with other waste products can incentivize formal collection and recycling.*

*Some potential interventions towards improved ULAB recycling practices in India involve exploring minimum take-back prices and expanding recycling capacity of manufacturers or high standard recyclers and in states with low capacity, to minimize challenges related to reverse logistics. This can promote formal collection and recycling. OEMs need to have increased capacity to collect and recycle a larger proportion of LABs produced.*

## 5.2.1. MARKET OVERVIEW AND REGULATORY FRAMEWORK

**The Indian LAB market was valued at $4.5 billion in 2023 and is expected to grow at a CAGR of 6.8 percent by 2029.** (TechSci Research 2023) LABs are a key source of power in India, used in automobiles, power storage (uninterruptible power supply or UPS installations and inverters) systems, and renewable energy installations. The starting, lighting, and ignition (SLI) segment and stationery and motive applications (SMA) segment split the LAB market share nearly equally.[5] Automobiles make up over 90 percent of the SLI segment and power backup installations such as UPS and inverters represent around 60 percent of the SMA segment. (India Energy Storage Alliance n.d.) Increased sales of solar installations and hybrid and electric vehicles have contributed to the recent growth of the lead-acid battery market.

**Indian producers export LABs to over 50 countries, in addition to supplying the domestic market.** (Amara Raja Energy & Mobility Limited n.d.) Exide Industries and Amara Raja Energy & Mobility together own over 75 percent of the organized lead acid battery market share. (Equitymaster 2024) India has been among the top 10 exporters of lead acid batteries in the world for over 5 years. LABs are also imported into India, primarily from China, Germany, and Vietnam. India is generates around two million metric tons of ULABs annually, of which around 98 percent are recycled. (Gattu et al. 2022)

**Expert inputs indicate that roughly 80 percent of recycling operations in India are formal; the remaining 20 percent are informal.** The extent of informality in the ULAB supply chain makes tracking the amount of lead recovered from ULABs challenging. Formal recycling in India is not always conducted with high-standard infrastructure and processes—fewer than 15 of the more than 650 formal units in India have adequate fugitive emissions installations. According to experts, around 70 percent Indian ULAB stock is recycled in formal recycling units, with over 90 percent of these being low-standard, and the rest high-standard. The remaining ULAB stock is recycled in the informal sector. ULAB stock processed by high-standard formal recyclers includes both local and imported stock. High-standard recyclers have indicated that over 60 percent of the ULAB stock they process is imported. Recycling operations are concentrated in Rajasthan, Maharashtra, West Bengal, Haryana, and Punjab. Although hubs exist that specifically cater to ULAB stock from northern, eastern, and western parts of India, more than 35 percent ULAB recycling units are confined to western India. (Central Pollution Control Board n.d.)

**The Ministry of Environment, Forest, and Climate Change (MoEFCC) is the central regulator of lead-acid batteries.** The *Battery Waste Management Rules, 2022*, govern ULAB collection,

[5] SMA (Stationary and Motive Applications) applications power a wide range of stationary and mobile applications requiring deep-cycle capabilities and durability. SLI applications include those where a battery is used for a high burst of current to start an engine and then sustain the electrical loads of lighting and ignition systems.

transportation, storage, and recycling in India. (The Gazette of India 2022) The new rules aim to reinforce the extended producer responsibility (EPR) principle, which holds producers (including importers) responsible for the collection and recycling of used batteries, the refurbishment of used batteries, and the utilization of recovered materials from waste in the manufacturing of new batteries. The Battery Waste Management Rules mandate that manufacturers and importers transfer the used batteries that they collect only to—and buy recycled lead only from—registered (formal) recyclers. The rules promote the establishment of new companies and promote entrepreneurship in collection and recycling/refurbishment of waste batteries. They indicate standards for the minimum percentage of recovery of materials from used batteries and set standards for compensation in the case of non-fulfillment of EPR targets. The Ministry has also set up a centralized online portal for the exchange of EPR certificates between producers and recyclers or refurbishers. (MoEFCC 2022) The impact of these new regulations on curbing the flow of ULABs to the informal sector and on improving recycling standards in the formal sector is to be ascertained.

**In 2024, the Central Pollution Control Board (CPCB) under MoEFCC published "Standard Operating Procedures for Recycling of Lead Scrap / Used Lead-acid Batteries."** (CPCB 2024) These regulations provide details on the procedures for safely transporting and handling used lead acid batteries and requirements for the grant of authorization for recycling facilities. It requires such facilities to have pollution control equipment (for the furnace), and mandates that workers be regularly monitored for blood lead levels. It is not clear which of these requirements apply to the renewal of existing facility authorizations. Like the Batteries (Management and Handling) Rules of 2001, these regulations do not establish a minimum size for new facilities and the smallest facilities with annual capacities less than 5,000 MT are exempt from having a mechanical battery breaking unit. No criteria have been outlined around where recycling facilities should be located. The fines and penalties for failure to comply with regulations have not been stated. Since these regulations have only recently been introduced (in 2022 and 2024) and their implementation is occurring in phases, it is too soon to evaluate their enforcement and impact.

**The most critical challenges in the Indian lead-acid battery supply chain involve poor engineering controls, unsafe locations, lack of administrative controls and faulty processes, and lack of worker protection.** Faulty processes and inadequate infrastructure are key issues in India both in formal and informal recycling. In the formal sector, the issue is one of low levels of compliance with waste management regulations. More than 75 percent of formal recyclers, especially smelters, in India operate with low-standard infrastructure. These units effectively operate like informal and unregulated recycling units, that employ hazardous recycling methods that expose workers and communities to lead. (Ericson et al. 2016)

**Both low-standard formal and informal units in India similarly lack adequate infrastructure and safety measures, leading to a cascade of negative consequences.** (Pure Earth 2020) Crude smelting processes in both low-standard formal and informal settings release dangerous levels of lead fumes and dust. Workers in these units lack appropriate protective equipment and face chronic exposure to lead through inhalation, ingestion, and direct skin contact. Poor engineering controls and unsafe locations present a large and ongoing challenge for the safe handling of ULABs. Both low-standard formal and informal units typically employ migrant laborers, who often move for employment with their children. Children of such laborers are then exposed to the crude infrastructure and resultant fume of low-standard formal and informal ULAB recycling units, further exacerbating the human cost of this system.

## 5.2.2. SUPPLY CHAIN ANALYSIS

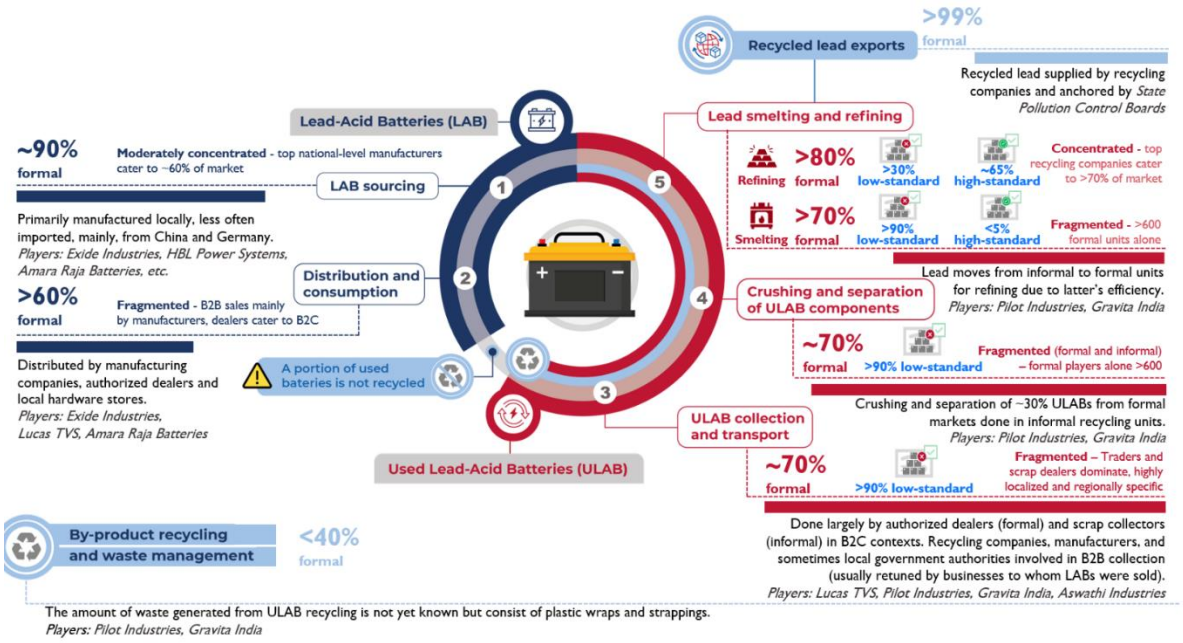
**India's ULAB recycling market aligns with the supply chain stages outlined in section 2.1 but faces distinct challenges that set it apart from countries like Mexico and Nigeria.** This section explores the unique operational landscape of ULAB recycling in India. The three distinctive aspects that set ULAB recycling in India apart are:

(1) **The lack of structured mechanisms and accountability among manufacturers for ULAB collection.** A range of diverse stakeholders attribute this to the expense and risks involved in collection. The lack of structure and accountability effectively prevents ULABs from being processed with high-standard infrastructure or diverts them to informal units.

(2) **The absence of robust traceability systems which encourage responsible sourcing of lead by manufacturers.** This not only facilitates the leakage of ULABs into the informal recycling sector but allows for the use of materials recycled with low-standard infrastructure in the manufacture of new batteries.

(3) **The fragmentation of the formal ULAB recycling sector in India.** This exacerbates the traceability issue and results in over 85 percent of the local ULAB stock being recycled using low-standard infrastructure. Although there is no systematic study on how recycling infrastructure quality influences the cost of lead, input from the field indicates that lead recycled in low-standard units is cheaper to LAB manufacturers. This can be one of the factors for low investment in collection by manufacturers.

*Figure 14: Lead-acid battery supply chain stages in India with formality, concentration of players, and standard of recycling as per expert inputs*




## Stage 1: LAB sourcing (~90 percent LABs manufactured formally, moderately concentrated)

**Over 90 percent of new LABs that enter the Indian market are manufactured domestically, including both formal and informal operations.** (Chechi 2017) Formally produced LABs are more compliant with industry protocols and safety standards. Nearly 80 percent of the LABs produced in India are made in the formal sector. Less than 10 large companies dominate formal LAB production, led by Exide Industries and Amara Raja Batteries' cumulative market share of over 75 percent. Other LAB manufacturers include HBL Power Systems, Luminous Power Technologies, Okaya Power, and Jayachandran Industries. The relatively small proportion of LABs that are imported primarily come from China, Germany, and Vietnam.

## Stage 2: Distribution and consumption (~60 percent distribution formal, fragmented)

**Formal manufacturers distribute LABs directly to bulk purchasers (such as automobiles and construction industries) and through dealer networks (both authorized dealers and local hardware retailers) to consumers.** Informally manufactured LABs are consumed in adjacent areas and not distributed widely. Around 50 percent of the LAB distribution in India is done directly by manufacturers, catering usually to the starting, lighting and ignition (SLI) segment (typically for

automobiles), whereas the SMA segment (such as in UPS and inverters, material handling equipment, and solar or wind energy installations) where distribution is through dealerships accounts for the remaining 50%. (India Energy Storage Alliance n.d.) A large, manufacturer-authorized LAB distributor reported that, "Around 30 percent of LAB stock are sold to individuals by distributors / wholesalers—the remainder is sold to consumers through one or multiple sub-dealers (all of whom may or may not be formal)."

## Stage 3: ULAB collection and transport (~70 percent collection formal, fragmented)

**The collection of ULABs for recycling in India is contingent on the consumer (both individual or industrial) returning ULAB stock.** This typically happens when the consumer purchases a replacement for an exhausted LAB – at local hardware stores or from a licensed distributor**.** Authorized dealers and scrap dealers receive ULAB stock from consumers, while recycling companies, manufacturers, scrap dealers and sometimes local government authorities receive ULABs from dealers and sub-dealers/retailers. Formal recycling enterprises such as Gravita India and Pilot Industries are also involved in collection and transport of ULABs. Although about 70 percent of ULAB stock is returned by consumers at the time of replacement, ULAB stock reaches recycling units from here through multiple channels, typically through scrap dealers. ULAB auctions also occur often, where bulk consumers, such as battery manufacturers and recyclers, bid for large quantities of used batteries.

> *"Manufacturers, distributors, and retailers do not have dedicated operations for ULAB collection. A hundred percent collection from sub-dealers and local retailers is an unrealistic goal, given their spread and the number of channels through which ULAB stock is sold"*
>
> *- Large manufacturer-authorized LAB distributor -*

**Market fragmentation is high at this stage due to the involvement of a range of small-scale and context-specific collectors and transporters.** Scrap dealers are often informal; when formal, they typically operate at the fringe of formality—i.e., only some of their operations take place within the formal ambit. Retailers in most contexts sell at least some of their ULAB stock to scrap dealers, or to informal or formal low-standard recyclers. Licensed LAB distributors are more likely to transfer collected ULAB stock to manufacturers. Manufacturers and recyclers (both formal and informal) rely primarily on scrap dealers for the supply of ULAB stock.

**Experts and stakeholders suggest that the diversion of formal stock to informal recyclers typically happens after collection by and through formal players, such as retailers.** The break in the formal flow of ULABs happens between dealers and manufacturers, and not between consumers and dealers. Sub-dealers / retailers acquire around 80 percent of LABs sold from consumers. Licensed distributors indicate that manufacturers collect ULAB stock unsystematically and infrequently. Stakeholders indicate that manufacturers are slow to pay the mandated fee to retailers for the return of used stock. They also indicate that manufacturers collect or receive less than 20 percent of total LABs produced by them from sub-dealers or retailers. Regulatory mandate states that manufacturers must collect 100 percent of batteries sold. (Occupational Knowledge International 2010) However, little information is available publicly on the actual percentage of ULAB stock received by major battery manufacturers in lieu of fresh LAB stock.

**The challenges at this stage—for all stakeholders—stem from the economic burden of ULAB logistics.** Unlike the logistics of LAB sales, which deal with new and high-value goods, the reverse logistics of ULAB collection concern used items of lesser value. Additionally, the hazardous nature of ULABs necessitates specialized handling and transportation, further increasing costs. This combination of lower value and higher risk makes ULAB collection simply more financially intensive than new LAB distribution and sales. Stakeholders involved in this stage often attempt to offset the costs associated with collection and transportation to other such stakeholders, when the revenue generated from selling ULABs does not compensate for logistics costs.

### Stage 4: Breaking and separation of ULAB components (~70 percent formal, >90 percent manual, fragmented)

**More than 90 percent of the ULABs recycled in India are dismantled manually.** Stakeholder inputs indicate formal low-standard recycling units account for roughly two-thirds of the manually dismantled ULABs; informal units account for the remaining third. These facilities, both low-standard formal and informal, have insufficient extraction ventilation resulting in ineffective dust control to capture and remove airborne lead particulates, which increases the risk involved with manually dismantling the ULAB. Many breaking sites—particularly those run by informal actors, but also those of low-standard formal recyclers—operate within residential areas, exposing communities to lead contamination.

**ULABs are sometimes dismantled and separated at the collection stage, as well, by scrap dealers or small-scale retailers.** The lead from such ULABs is also smelted in informal or low-standard formal recycling units, increasing the already high environmental and safety cost associated with such units due to manual breaking. Lead and acid leakages into water and soil around the operations of such collectors, and inside and around manual breaking sites, pollute the environment and expose neighboring communities to lead. In contrast, mechanized breaking using

a hammer mill—which occurs in less than 10 percent of recycling units in India—typically also involves acid neutralization and responsible plastic disposal / recycling, resulting in less waste and pollution.

### Stage 5: Lead smelting and refining (~70 percent formal smelting and >80 percent formal refining, fragmented smelting and concentrated refining)

**Refining and smelting take place in separate facilities when lead is processed with low-standard infrastructure and jointly when high-standard infrastructure is used.** Given that over 60 percent of the ULAB stock processed in high-standard operations in India is imported *and* since high-standard units account for less than 5 percent of all units in India, the majority of the lead recovered from ULABs in India is smelted and refined in separate locations.

**Over 90 percent of formal, registered smelting units are small in scale and have low-standard infrastructure.** There are more than 600 such formal recycling units operating with inadequate safety installations, in addition to informal recycling units that are unaccounted for. Smelting in low-standard formal and informal units is typically done in blast furnaces, compared to rotary furnaces deployed in high-standard units. Lead smelted in rotary furnaces is of higher quality since rotary furnaces operate at over 1000°C, almost double the temperature at which blast furnaces function. Stakeholders indicate that rotary furnaces recover more than 40 percent more lead and generate less waste compared to blast furnaces. The minimal waste generated in high-standard units is also managed responsibly, with minimal runoff into nearby water and soil. More waste and slag are generated in low-standard units, which are then disposed in nearby drains or bodies of water without treatment. Waste acid often has high lead content and is hazardous.

**The prevalence of poor waste disposal systems, in addition to the improper use or neglect of PPE, is a consistent feature of both (smaller) formal and informal sector facilities.** This can be attributed to poor enforcement of occupational safety regulations, lack of equipment availability and/or affordability, and insufficient worker awareness. The risk associated with low-standard recycling in India does not pertain only to informal recycling, because more than 600 facilities operate at these standards *with licenses* from pollution control boards – indicating regulatory gaps.

**Large recyclers with high-standard operations conduct more than 70 percent of all refining operations in India, according to expert inputs**. Experts also stated that these recyclers serve over 70 percent of the national demand for secondary or recycled lead. Lead smelted both formally and informally finds its way to formal refining units.

### By-product recycling

**In high-standard recycling units, a large portion of the byproducts generated by the lead recycling process are themselves recycled.** Waste generated during ULAB recycling includes plastic casings, sulfuric acid, and other metals.

### Sale of refined lead (locally and exported)

**Refined lead is sold to many industries including LAB manufacturing companies.** Both formal (high-standard and low-standard) and informal ULAB refiners supply refined lead, which is also exported through government agencies.

## 5.2.3. BARRIERS TO IMPROVED RECYCLING

**India's journey to an environmentally sounds ULAB recycling future faces challenges, stemming from a fragmented and largely low-standard recycling sector and limited investment by manufacturers in ULAB collection.** Loopholes in the Goods and Services Tax (GST) framework exacerbate these challenges, causing ULAB price disparities and the diversion of ULABs into the informal sector. The lack of traceability across the lead supply chain, and regulatory gaps around the provision and retention of recycling licenses, minimum performance parameters, and penalties for noncompliance hinder effective oversight and enforcement. These interconnected barriers create a complex landscape in which unsafe practices around lead batteries persist. This section details these barriers.

(A) ***Fragmentation of formal ULAB recyclers:*** The formal recycling sector in India is highly fragmented and characterized by a sharp disparity: there are over 600 small recyclers (operating with low-standard infrastructure) and fewer than 15 large recyclers (operating with high-standard infrastructure). Operations without adequate infrastructure in addition to being hazardous also disincentivize high-standard recyclers from making necessary improvements to reduce environmental emissions and employee exposure to lead. Appropriate safety installations involving adequate ventilation, negative pressure enclosures, and pollution control devices require large investments. For instance, setting up a safe smelting unit requires at least $4 million in investment and at least 24,000 metric tons of annual ULAB recycling just to break even, according to stakeholders. The smelter would need to invest not only in machinery but also in land. Adequate pollution control infrastructure requires at least three times the land occupied by smelting furnaces. In India, low-standard recyclers apply around 15 percent of their set- costs (which, in total, typically run to around $500,000) to safety installations; high-standard recyclers, in contrast, typically expend 50 percent of their

setup costs (usually at least $4 million) on safety and environmental health infrastructure. The fragmented landscape poses a challenge, as most formal recyclers in India lack the resources, technology, and knowledge necessary to implement lead-handling practices that are environmentally sound and least harmful to personnel.

**(B)** ***Challenges in formal collection due to reverse logistics costs:*** "Reverse logistics" refers to the retrieval of ULABs from consumers and traders. A ULAB is worth about 15 percent of a LAB but has slightly higher collection and transportation costs (because of higher handling risk). Due to the costs and risk involved in the collection of ULABs, manufacturers devote little investment or focused effort to procuring end-of-life products for recycling. The lack of efficient and affordable collection mechanisms results in ULABs being recycled in unsafe and environmentally damaging ways.

> *"When manufacturers are not keen on receiving the (ULAB) stock, why should we make the effort? They also do not always offer a good price for the stock. Thankfully, I have the space to hold my stock and wait for a good price. What will smaller traders do? It is good for us from an economic standpoint to receive less stock from consumers. We can at least save the handling cost and increase our margin a little bit"*
>
> *- Large and manufacturer-authorized LAB distributor -*

**(C)** ***Loopholes in the GST Framework causing leakage to the informal sector:*** The Goods and Services Tax (GST) framework offers differential treatment to different forms of end-of-life — ULABs are taxed at 18 percent (of cost of good) while other forms of waste are subject to a more relaxed rate (for example, e-waste is taxed at 3 percent). India's ULAB tax rate is also high in comparison to that of other countries, and all private sector actors who were consulted for this research indicated that the ULAB GST rate is a significant driver of informality and tax evasion. Interviews with private sector stakeholders revealed that evading GST allows scrap dealers or smelters to offer 15-20 percent higher prices than manufacturers offer for the purchase of ULABs from retailers (distributors and sub-dealers). This gap creates a strong economic incentive for retailers to divert ULAB stock to operations without GST application and provides recyclers with low-standard infrastructure and limited resources with channels to acquire ULAB stock that allow their operations to remain viable. The minimal effort on the part of manufacturers to improve collection logistics exacerbates the situation, while the ease of tax evasion presents stakeholders with an enticing opportunity to increase their profit margins. Without the application of GST, the formal flow of ULABs to

manufacturers or directly to recyclers operating within the GST paradigm (including high-standard recyclers) is not possible. Operations outside GST therefore retain the flow of ULABs into low-standard recycling operations.

**(D)** ***Lack of lead traceability:*** The lack of robust traceability systems that mandate the maintenance of lead purchase records and encourage responsible sourcing of lead from high-standard recycling facilities presents formal LAB manufacturers with the opportunity to obtain lead recycled with low-standard infrastructure. This results in lead recycled in low-standard facilities (including informal units) moving to formal LAB manufacture. It also results in the diversion of ULAB stock into low-standard recycling units, consequently sustaining operations in such units.

**(E)** ***Gaps in regulatory penalties and enforcement:*** Although existing regulations are oriented towards producer responsibility, minimum size requirements for recycling operations and sufficient performance standards (and penalties for noncompliance) are unclear. In addition, there are gaps in enforcement due to inadequate technical capacity and soft oversight, which contribute to the persistence of hazardous lead-handling practices. For instance, licenses are granted irrespective of the quality of pollution controls and safety systems. Audits are performed inconsistently and infrequently, while the parameters for passing them appear to vary—high-standard formal recyclers (which account for 3 percent of all formal actors and process over 10 MT of material per day) report regulatory inspections every six months, whereas low-standard recyclers (which account for about 70 percent of formal actors and process about 1 MT of material per day) report inspections once every two years, or annually at best. Inspection parameters vary widely, as well. A high-standard formal ULAB recycler said, "The pressure on large recyclers to meet standards is high whereas small formal recyclers get away with the same standards as informal recyclers. Officers from pollution control boards have even checked the quality of carbon dioxide in our fire hydrants."

## 5.2.4. COUNTRY-SPECIFIC INTERVENTIONS

**Interventions to make ULAB recycling environmentally sound can focus on "shifting to safer operations" and on "improving existing operations."** Given the fragmentation of existing recycling operations in the Indian context, interventions will likely focus more on the former; the scale of investment required to transition low-standard operations to mid-standard, as well as the sheer number of low-standard units, discourage focusing on the latter. Potential interventions involving shifting to safer operations include aligning the GST framework for ULAB with that currently applied to other waste products; improving EPR practices by increasing manufacturer

accountability in ULAB collection; incentivizing formal recycling; and establishing systems for the traceability of lead purchases. Efforts to improve environmentally sound management of ULABs in India will require a multi-faceted approach involving collaboration between government agencies, industry stakeholders, and civil society organizations. Below are a few specific interventions that focus on regulations and monitoring, incentives and financing, and capacity and awareness building.



## IMPROVE TRACEABILITY SYSTEMS

**Incorporating traceability systems that mandate maintaining records of the purchase of lead can encourage LAB manufacturers to source lead responsibly.** EPR certification (and subsequently, LAB manufacturing licenses) should be tied to responsible sourcing of recycled lead (in addition to 100% take-back, as mandated by law). This can prevent the movement of ULABs between recycling operations with low-standard infrastructure and those with appropriate and up-to-date infrastructure. If recycled lead is only purchased from high-standard recyclers (with high-standard smelting *and* refining), low-standard recycling operations are likely to lose their economic viability. Traceability will require a collaborative effort involving government agencies and industry stakeholders. The government can establish regulations that make public declaration of the source of lead mandatory. Crucial to success is a unified platform that seamlessly integrates data from all stakeholders, ensuring real-time visibility and accountability.



## LIMIT SMELTER LICENCES

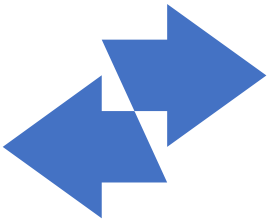
**Imposing a minimum size and specific siting criteria for recycling units, mandating higher standards for license attainment and renewal, assigning selected recyclers to manufacturers, and limiting the number of recycling licenses granted could ensure that ULAB recycling is handled exclusively with the most appropriate infrastructure.** Higher standards must include mechanical breaking, negative pressure enclosures, advanced pollution control systems, specific performance parameters, and regular monitoring and reporting. This must be accompanied by stricter EPR regulations including focused efforts to improve collection and to encourage responsible sourcing of lead to create

closed loops across the supply chain. Environmentally sound ULAB recycling is only viable at capacities over 50,000 MT, which is significantly larger than low-standard recycling operations. Scaling every low-standard unit to this level would require millions of dollars of investment per unit. Collaboration with industry associations can help identify and empower responsible recyclers who can meet the capacity and safety requirements. The success of this intervention hinges on strong enforcement mechanisms and a commitment to phasing out low-standard recycling operations.



## EXPLORE LOWER GST FOR ULABS IN LINE WITH OTHER WASTE

**Lowering the Goods and Services Tax (GST) for ULABs to align with rates for other waste materials could incentivize ULAB collection and formal recycling.** By reducing the tax burden on ULABs, the government can make them more attractive to collectors and recyclers, thereby diverting them away from the informal sector. This would improve the domestic supply of used batteries for formal recycling. Implementing this requires a policy change by the Ministry of Finance, in consultation with the Ministry of Environment, Forest, and Climate Change. Parallel efforts and investment towards improving collection is imperative for this to be effective. The success of this intervention depends on ensuring that the reduced tax benefits are passed on to collectors and recyclers, translating into higher and standard prices for ULABs, which will promote their formal collection.



## EXPLORE MINIMUM TAKE-BACK PRICE

**Setting minimum or standard and context-specific take-back prices or refund fees could incentivize the return of ULABs to LAB manufacturers by dealers and consumers.** EPR certification should be tied to offering the minimum or standard take-back price in addition to 100% take-back. Such financial incentives could incentivize formal collection and divert ULABs from informal recycling. Implementing this change would require a collaborative effort by government, manufacturers, industries purchasing LABs in bulk, retailers, and industry associations. The government can

mandate minimum take-back prices or facilitate the development of a framework to set context-specific prices. Manufacturers can establish collection centers or partner with existing networks to collect used batteries. Success depends on effective communication and awareness campaigns to educate retailers and consumers about the benefits and financial incentives of returning used batteries.



## INCREASE RECYCLING CAPACITY IN STATES WITH LOW RECYCLING CAPACITY

**Expanding high-standard recycling capacity in states without it can address high reverse logistics costs.** This intervention is focused on capacity of units as opposed to number of units, and therefore, limitations on smelter licenses (as proposed above) will have to be implemented in tandem. This would increase the overall recycling capacity in the country and reduce the costs and logistical challenges associated with transporting ULABs over long distances. Implementing this intervention requires a coordinated effort between the central and state governments, involving investments in infrastructure, technology transfer, skill development, and strict regulatory enforcement of licensing parameters. Partnerships with existing high-standard operations can enable expertise transfer. Success depends on identifying suitable locations, ensuring adequate supply of ULABs, and creating a conducive regulatory environment for recyclers.



## EXPAND MANUFACTURER AND HIGH-STANDARD RECYCLING CAPACITY

**Increasing the capacity of manufacturers to collect and recycle responsibly as many ULABs as LABs produced, in high-standard infrastructure, can reduce low-standard recycling.** By expanding their recycling facilities and investing in collection infrastructure (through drop-off points and take-back programs), manufacturers can increase the volume of ULABs channeled into high-standard recycling. Increasing the size and number of high-standard, large-scale formal operations can decrease the ULAB stock availability for and the scale of low-standard recycling. For this, manufacturers

need to develop comprehensive collection plans, expand their own or collaborate with other recycling plants, invest in infrastructure and technology, and collaborate with retailers, government agencies, and other relevant players. For instance, manufacturers can establish partnerships with third-party organizations specializing in reverse logistics to streamline the collection process and optimize recycling operations consequently.



## INCREASE STAKEHOLDER AWARENESS

**Increasing awareness among stakeholders regarding the health hazards of exposure to LAB components and unsafe recycling practices can increase efforts to achieve environmentally sound management of ULABs.** Educating consumers, traders, and recyclers about the life-threatening consequences of lead exposure can foster a sense of responsibility and encourage participation in formal collection and environmentally sound recycling systems. Government agencies, industry associations, NGOs, and media outlets will have to be involved for public awareness campaigns to be effective. Through channels such as print, television, radio, and social media, these campaigns can disseminate information about the risks of lead exposure and the importance of environmentally sound recycling. Training programs can educate informal and low-standard formal sector workers about safe handling practices and the benefits of formal recycling. Additionally, engaging with schools and community organizations can help instill responsible battery disposal habits more broadly.



# 5.3. Nigeria

*The Nigerian ULAB recycling industry comprises informal and low-standard recycling operations, which pose significant lead exposure risks to workers at each stage of the ULAB supply chain. Although regulations exist and are currently being updated to enhance the standards of ULAB recycling facilities, enforcement is limited. Efforts are needed to increase the number of ULABs recycled through the formal sector by involving battery manufacturers (OEMs) and setting minimum take-back prices. Additionally, recycling facilities require financial support to enhance their operations, while regulatory agencies need greater resources and capacity to improve coordination and standards enforcement.*

## 5.3.1. MARKET OVERVIEW AND REGULATORY FRAMEWORK

**Nigeria does not produce lead-acid batteries domestically; it imports LABs primarily from India, Germany, and France and exports lead ingots.** The country also imports used batteries in more than 130,000 used vehicles each year with many classified as salvaged. The country's only battery manufacturing plant, Union Autoparts Mfg. Co. Ltd, recently closed; it could not acquire enough ULABs—needed for recycling to produce LABs locally—because it could not match the prices paid for them by the informal sector. The most common imported types are HSN code 85072000 (electric accumulators, including separators, whether or not rectangular (including square) other lead-acid accumulators), HSN code 85072080 (non-liquid electrolyte lead batteries), and HSN code 85072020 (liquid electrolyte lead-acid accumulators) (Volza, n.d.). Most of the lead is exported in the form of smelted, non-refined lead ingots, sourced both through formal and informal channels.

**Each year, Nigeria generates ~ 190,000 metric tons of ULABs yearly** (Ugbor, 2020)[6]**—the equivalent of ~110,000 metric tons of lead—mostly from vehicles, backup power generation, telecommunication, and renewable energy industries.** The automotive sector generates over 45 percent of Nigeria's ULABs, followed by the backup power generators (over 30 percent), the telecommunication sector (over 10 percent), and solar mini grids (under 5 percent). (Ugbor, 2020) Motive industrial applications, such as forklifts, generate an additional portion of ULABs. Nigeria also brings a significant number of ULABs into the country within imported used vehicles. The ULAB industry is projected to keep growing over the coming years, driven by increasing vehicle numbers, the growth of the renewable energy sector, and continued demand for backup power generators given the unreliability of the national electric grid.

**Most of Nigeria ULAB recycling occurs in informal and low-standard settings.** While LAB sourcing is fully formal and ULAB smelting and refining activities happen in formal facilities, 80 percent of ULABs are collected and broken informally, causing significant contamination and lead exposure. Most formal smelting and refining occur in low-standard facilities without adequate ventilation and pollution controls, mainly in Ogun and Anambra states. ULABs are also reconditioned in the informal sector and are put back into the market, without reaching formal or informal recyclers. Lagos State was a major ULAB recycling hub, but a crackdown by the Lagos State Environmental Protection Agency against polluting facilities led many to relocate to nearby Ogun State, where enforcement is less strict.

**Although Nigeria has waste management regulations covering ULABs, enforcement is weak due to scarce resources, according to regulatory agencies and civil society actors.** The Federal Ministry of Environment's National Waste Battery Management Policy (2022) forms the core of

[6] Different sources and stakeholders report varying estimates of ULABs generated in Nigeria, with one source estimating it at 500,000 metric tons of ULABs annually

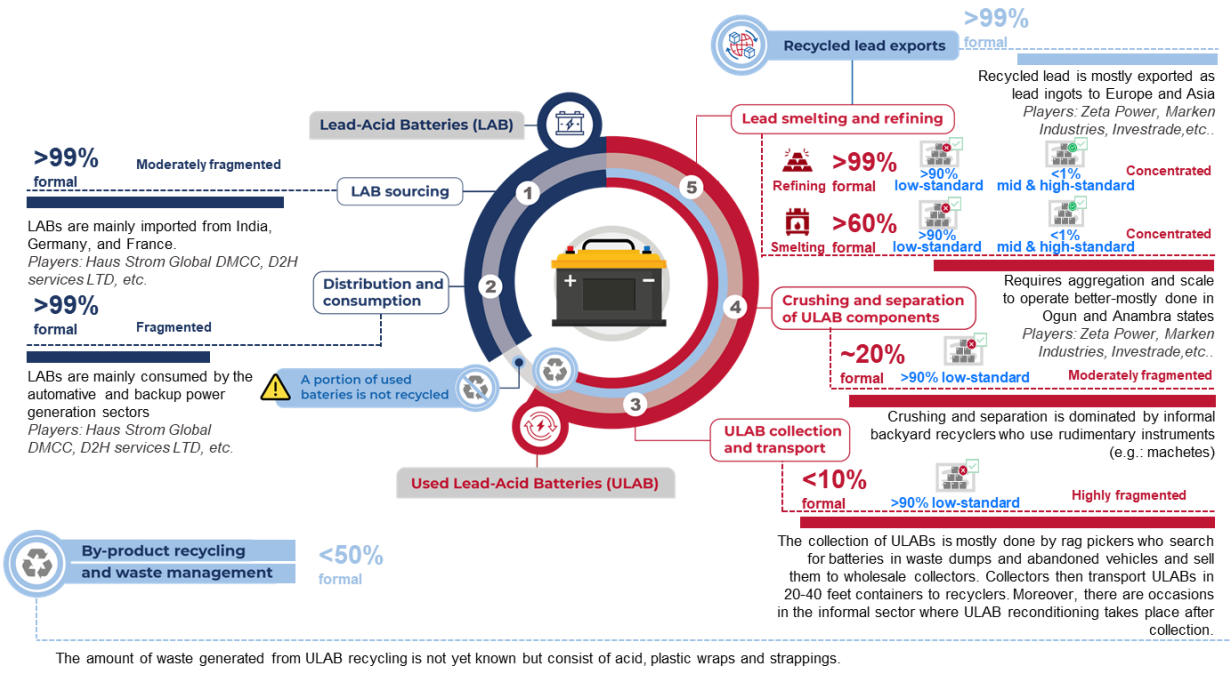
Nigeria's ULAB regulatory framework. This policy provides mechanisms for implementing the extended producer responsibility (EPR) program, involving all stakeholders in the supply chain, including battery manufacturers, users, retailers, and wholesalers. It requires collection centers to have registered collectors and valid environmental permits, offering guidelines and standards for each stage of the supply chain. The policy also outlines an institutional framework for overseeing waste battery management, including the roles of various organizations, and sets targets for battery collection, recycling, and disposal. The Nigeria Standards and Regulations Agency (NESREA) is responsible for monitoring and enforcing these provisions. However, although the policy offers detailed guidance on managing waste batteries, it lacks baseline data to highlight the urgency of action. Additionally, the agency lacks adequate incentives for collection and sufficient resources for effective enforcement. Poor coordination between federal and state agencies further weakens enforcement efforts. For instance, the Ogun state enforcement agency was unaware of the federal policy and created its own regulations, which companies in that state follow.

**The new draft National Environmental (Battery Control) Regulations, 2024, aim to enhance ULAB recycling standards by mandating best environmental practices and pollution abatement technologies; the regulations have not yet been implemented.** These regulations require facilities to ensure proper registration, handling, storage, and transportation of used batteries, while adhering to effluent and emission standards. The regulations also outline enforcement procedures, including inspection, sampling, and the issuing of enforcement notices. Non-compliance can lead to penalties, such as fines and imprisonment, and may result in the closure of facilities. The regulations hold facilities accountable for environmental damage, requiring them to cover costs of damage assessment, remediation, and reclamation through the Polluter-Pays Principle. These regulations are not yet implemented and enforced, as NESREA is still updating them.

**Various organizations are working to minimize lead exposure in the ULAB recycling supply chain, but further efforts are needed to address existing barriers.** For example, the Clean Technology Hub, the Renewable Energy Association of Nigeria (REAN), the Heinrich Boell Foundation, and the Recycling and Economic Development Initiative of Nigeria (REDIN) have attempted to craft a ULAB management framework suitable for Nigeria, such as an EPR program - The Alliance for Responsible Battery Recycling (ARBR) is the Producer Responsibility Organization (PRO) for the battery sector that oversees the EPR program for the battery sector in Nigeria. Moreover, in February 2024, the Government of Nigeria (through NESREA and Sustainable Research and Action for Environmental Development (SRADev) Nigeria), Germany’s development agency (GIZ), and Oeko-Institut entered into a partnership to develop, monitor, and enforce adequate standards for ULAB recycling. This effort includes training recycling plant managers on best practices and creating business opportunities for recycling that meets high standards for safety and quality. (Alliance for Rural Electrification, 2024) These endeavors—and many others, such as awareness building—are needed to mitigate ULAB-related lead exposure in Nigeria.

## 5.3.2. SUPPLY CHAIN ANALYSIS

*Figure 15: Simplified ULAB supply chain in Nigeria*




**Sources: Expert and stakeholder interviews inputs**

### Stage 1: LAB *sourcing (>99 percent formal, moderately fragmented)*

**Given the lack of domestic production of LABs, Nigeria relies on the imports of new LABs.** LABs are mainly imported from India, Germany and France. Players such as Haus Strom Global DMCC and D2H Services LTD are involved in the import of LABs.

### Stage 2: Distribution and consumption (>99 percent formal, fragmented)

**Formal importers of LABs use different distribution channels, each based on the sector they serve.** LABs are primarily used in the vehicles (~45 percent), backup power generation (>30 percent), telecommunication (>10 percent), and renewable energy (<5 percent) industries. In the automotive sector, local dealers distribute LABs and pay consumers a fee to return ULABs at the end of the battery's useful life. The backup power generation sector distributes generators through brand offices, approved dealerships, online e-commerce shops, and local retail stores. Major players in West Africa, including Nigeria, are Cummins, Caterpillar, and Generac Power

Systems. In the renewable energy sector, off-grid companies distribute their products mainly through their local sales branches in Nigeria.

### Stage 3: ULAB collection and transport (~90 percent informal, highly fragmented)

**ULAB collection and transport is the most fragmented and informal stage. Over 100,000 informal scrap dealers (about 20 percent of whom are women) collect different types of waste, including electronic waste** (Hinckley Recycling, n.d.)**—and 90 percent of used batteries.** Individual consumers typically sell used batteries to dealers for discounts on new batteries or for cash. This process takes place within a well-established, mostly informal system of collectors advertising their services through Facebook groups and posters on the streets, providing price and contact information. Companies like telecoms and banks often sell their batteries to the highest bidders, unaware of, or ignoring their final destination and fate. These batteries, too, frequently end up with informal scrap dealers—depending on the type of ULAB, the price offered by informal collectors can be ~35 percent higher than the price offered by formal collectors, according to interviews.

**In addition to searching for ways to collect used batteries themselves, recyclers also rely on informal scrap dealers for their supply of ULAB feedstock.** Recyclers purchase used batteries only in bulk, so the smallest collectors typically gather a few batteries to sell to intermediate collectors, who then sell them to large-scale collectors/aggregators—who deal with recyclers.

**Large—scale collectors/ aggregators transport ULABs to recyclers in 20-to-40-foot-long containers.** Trucks are not used exclusively to transport ULAB transport, resulting in cross-contamination of other goods, such as food items.

### Stage 4: Breaking and separation of ULAB components (~80 percent informal with manual breaking, fragmented)

**Around 80 percent of collected ULABs are manually broken and dismantled in the informal sector without use of PPE, according to interviews.** Backyard recyclers commonly use rudimentary tools, like machetes, to break down ULABs into components and discard the acid into municipal drainage systems. Large-scale collectors often break used batteries in the informal sector because most recyclers require that batteries be broken before delivery. ULABs that reach recycling facilities intact are also manually crushed in low-standard facilities before smelting, apart from one recycling facility with a mechanical hammer mill breaker.

## Stage 5: Lead smelting and refining (~60 percent formal smelting and >99% formal refining, concentrated)

**Lead smelting is mostly conducted in low-standard recycling facilities that achieve moderate levels of lead recovery.** Sources vary on the number of existing facilities, ranging from 10 to 20; these operations mostly follow the low-standard recycling type. Since most ULABs are diverted to the informal sector during collection, these facilities source some of their ULAB feedstock from there. This feedstock is typically already drained of acid and sometimes pre-smelted, requiring only refining. Aside from one facility (Green Recycling in Ogun State) with modern breaking, separation, and smelting equipment, all other facilities use basic tools, resulting in lead recovery rates of ~80 percent. These tools include rotary furnaces without ventilation or adequate pollution control of lead dust and fume. Additionally, workers in these facilities often lack PPE, increasing their risk of lead exposure.

> *"In the five formal recycling facilities that we visited, ULABs were being manually crushed and smelted in rotary furnaces that produce a lot of lead fume"*
>
> *- Regulatory agency -*

**These low-standard recycling facilities also engage in lead refining to increase the purity of lead to boost its export value.** Refining lead can increase lead purity to 99+ percent, therefore increasing its export value. However, this is not as common in Nigeria, as only 30 percent of exported lead is refined lead.

**The informal sector—with the lowest lead recovery rates—smelts around 40 percent of collected ULABs.** Informal smelting operations are highly polluting; they typically take place in the open air and are conducted by workers not using PPE. Lead recovery rates in the informal sector is estimated to range from roughly 50 to 60 percent with the rest escaping to the local environment. Lead smelted in the informal sector is either directly exported or sold to formal recyclers for additional refining before export.

**All recycled lead is exported.** Most of the lead is exported in the form of smelted, non-refined lead ingots (~70 percent pure), sourced both through formal and informal channels, destined most commonly for India and China. Recycled lead is also used to make other products such as fishing weights where lead content is not an issue.

### By-product waste management

**Byproduct waste management is a major source of concern, as most byproducts are discarded without adequate safety measures.** Acid from broken batteries is typically dumped into public drainage systems in the informal sector or neutralized in man-made lagoons in low-standard recycling facilities. Plastic cases from ULABs are sold to the plastic manufacturing sector, but some end up in landfills. Additionally, according to a low-standard formal ULAB recycler, lead-contaminated slag from ULAB smelting in low-standard facilities is often discarded in open fields around the facilities. The potentially cascading health and environmental effects of this pollution are not yet well documented in Nigeria.

## 5.3.3. BARRIERS TO ENVIRONMENTALLY SOUND RECYCLING

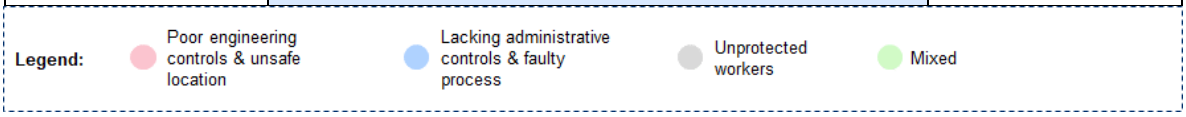
**Nigeria's journey to an environmentally sound ULAB recycling future faces challenges, stemming from a largely informal and low-standard recycling sector.** 90% of the generated ULABs go through the informal sector, where all work is done manually, frequently in sites co-located within residential areas and without the use of any precautions. The 10-20 low-standard recycling facilities in the country operate with basic engineering and pollution controls. The limited regulations enforcement in the sector further worsens the situation as actors are not often held accountable for their polluting activities which could be mitigated.

The table below summarizes the five main barriers to an environmentally sound ULAB recycling supply chain in Nigeria; the paragraphs that follow provide greater detail.

***Table 4: Summary of lead exposure sources across the Nigeria ULAB recycling supply chain***

| Stage | Source of lead exposure | Prevalence |
|---|---|---|
| **ULAB collection and transport** | • Diversion of 90 percent of generated ULABs from the formal to the informal sector due to better prices offered in the informal sector and a lack of commitment to and implementation of an effective extended producer responsibility (EPR) program. | ~90 percent |
| **Breaking and separation of ULAB components** | • Manual breaking and dismantling of ULABs in both the formal and informal sectors | >90 percent |
| **Smelting and refining** | • Inadequate and outdated smelting equipment used in the informal sector | >90 percent |

| | | |
|---|---|---|
| | • Sub-par environmental pollution controls and occupational safety standards in recycling facilities | >90 percent |
| | • Minimal enforcement of regulations in ULAB recycling facilities. | ~80 percent |




a) **Manual breaking and dismantling of ULABs in both the formal and informal sectors.** Informal collectors, without the use of PPE, manually break 80 percent of all ULABs in residential backyards and discard the acid into municipal drains, as recyclers pay more for broken batteries. Additionally, except for one recycling facility with a mechanical hammer mill breaker, workers (without PPE) at all facilities in the formal sector manually crush batteries directly collected from companies that use LABs.

b) **Inadequate and outdated smelting equipment used in the informal sector.** In the informal sector—which recycles ~40 percent of ULABs—ULABs are smelted using inadequate techniques such as open-air furnaces powered by charcoal without any pollution controls.

> *"Informal recyclers typically dig holes in the ground to discard the acid obtained from manually breaking the batteries. They then use metal containers for open-air smelting, producing lead ingots using ingot-shaped molds"*
>
> *- NGO -*

c) **Diversion of 90 percent of generated ULABs from formal to informal sector due to better prices offered in the informal sector and a lack of commitment to and implementation of an effective extended producer responsibility (EPR) program.** Depending on the type of ULAB, the price offered by informal collectors can be ~35 percent higher than the price offered by formal collectors, according to interviews. Moreover, the existing EPR program managed by the Alliance for Responsible Battery Recycling (ARBR) is not adequately structured and implemented. For instance, to avoid paying a 10 percent fee and an annual membership of 500,000 naira (around $325) to participate in the EPR program, companies generating ULABs, such as telecommunications companies and banks, often hold auctions to sell their batteries to the highest bidders—including informal collectors.

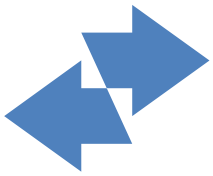
d) **Limited awareness of regulation and lack of enforcement in ULAB recycling facilities.** This is mainly due to a lack of political will and insufficient coordination between federal and state regulatory agencies in the enforcement of existing regulations. For instance, the Ogun state enforcement agency was unaware of the federal policy and created its own regulations, which companies in that state follow.

> *""There is a general lack of synergy among federal and state regulatory agencies— some states are not aware of the National Waste Battery Management Policy and often draft their own regulations"*
>
> *- Regulatory agency -*

e) **Sub-par environmental pollution controls and occupational safety standards in recycling facilities.** Most facilities use inadequate and outdated smelting equipment such as old rotary furnaces and do not have adequate extraction ventilation and dust control systems to prevent the release of lead dust and fume during the smelting process. In addition, facilities do not adequately dispose slag generated by the smelting process; it often ends up dumped in open fields around facilities, according to lead recyclers.

## 5.3.4. COUNTRY-SPECIFIC INTERVENTIONS

Given Nigeria's extensive informal and low-standard recycling practices, interventions to promote safer ULAB recycling focus primarily on **shifting operations to safer practices**, and only to a lesser extent on **improving existing operations** in formal facilities. To improve the current situation, efforts aim to increase the number of ULABs recycled through the formal sector. Additionally, interventions seek to provide financial support to recycling facilities to enhance their operations and improve coordination and standards enforcement among regulatory agencies.



### EXPLORE MINIMUM TAKE-BACK PRICE

**Setting minimum or standard and context-specific take-back prices or refund fees that are higher than the informal sector could incentivize consumers to return ULABs to formal dealers and retailers connected to formal recycling facilities.** Such financial incentives could incentivize formal collection and divert ULABs from informal recycling. Implementing this change would require a collaborative effort by government, industries purchasing LABs in bulk, retailers, ULAB recyclers, and industry associations. The government can mandate minimum take-back prices or facilitate the development of a framework to set context-specific prices. Recyclers can establish collection centers or partner with existing networks to collect used batteries. Success depends on effective communication and

awareness campaigns to educate retailers and consumers about the benefits and financial incentives of returning used batteries.



## INCREASE INVOLVEMENT OF OEM IN ENVIRONMENTALLY SOUND RECYCLING

**Promoting the involvement of battery manufacturers (OEMs) in ULAB take-back programs can reduce the diversion of ULABs into informal channels.** OEMs can get involved through (i) setting up local ULAB collection points for their batteries at the established minimum take-back prices—these collection centers can also be used for packing and exporting wet batteries to OEMs' recycling factories abroad—(ii) supporting the establishment of safe, large-scale formal recycling facilities in Nigeria, or (iii) initiate a cost-effective reverse logistics scheme. Large-scale formal operations can better compete on price for ULABs and thereby reduce the proportion of ULABs that end up in the informal sector.



## FACILITATE INVESTMENT IN TOP-TIER RECYCLING FACILITIES

**Exploring blended finance mechanisms for recycling facilities can enable new or existing high performing recyclers to buy better breaking and recycling equipment and expand their size.** By accessing affordable loans that combine public and private funds to reduce financial risks, existing few high standard recycling facilities or new high-standard recycling facilities can purchase better equipment, leading to more environmentally sound and more efficient operations. For this to be successful, it would have to be combined with improved formal collection of ULABs through battery take-back schemes to allow these facilities to have enough ULAB feedstock to operate at scale. in Tax breaks can also be considered to incentivize investments.



## IMPROVE COORDINATION AND STANDARDS ENFORCEMENT AMONG REGULATORY AGENCIES

**Enhance coordination between regulatory agencies and build capacity for effective monitoring and enforcement** to support the new regulations for environmentally sound recycling operations. Strengthening

collaboration among agencies ensures consistent enforcement and helps maintain high standards across all recycling facilities. Building capacity for effective monitoring and enforcement can include regular training programs for inspectors and investment in tools and equipment needed for adequate monitoring.

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