



A CASE STUDY

# Lead-Acid Battery Recycling Success: Policy + Reverse Supply Chains

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# Acknowledgements

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## Executive Summary

Lead-acid batteries are a critical component of modern vehicles and stationary energy storage. Lead is different from other non-ferrous metals because when recovered and recycled from scrap material, it can meet even the highest quality standards equivalent to primary, or virgin, lead. In order to take advantage of lead's potential circularity, however, recovery and recycling of batteries must be done in a safe manner. The United States and Europe have created lead-acid battery recycling programs that have achieved 99% recycling rates while minimizing risks to humans and the environment.

The purpose of this report is to show how three different countries have created different regulatory policies and reverse supply chains that have enabled responsible recycling of lead-acid batteries: Brazil, the United States, and the European Union. These systems differ by the type of reverse supply chain they use, who collects used batteries, how centralized and standardized the program is across different states/countries, and whether a deposit is required on new batteries. Despite these differences, all have achieved very high recycling rates. As the case studies show, when the public and private sector work together, it reduces risks and makes for a fairer market amongst competitors. Any country's efforts require two components: a regulatory frame to ensure safe collection and reprocessing of lead-acid batteries, and a reverse supply chain structure that provides adequate financial incentives for all involved.

## Introduction

Lead-acid batteries are ubiquitous in society. The majority are used in vehicles, although a growing percentage also are used for stationary energy storage applications. The global market for lead-acid batteries is between 40 and 50 billion USD annually, with an almost five percent annual growth rate<sup>1</sup>. Lead-acid batteries are made of metallic lead, lead dioxide, lead sulfate and sulfuric acid<sup>2</sup>. The lead and acid can be hazardous to human health, and so manufacturing, recycling, and re-manufacturing of lead-acid batteries must be done in a managed manner in order to prevent accidental or negligent<sup>3</sup> exposure.

There are only two appropriate end-of-life options for a used lead-acid battery: to be recycled domestically in a licensed facility or to be exported to a licensed facility in another country to be recycled. Deviations from this may indicate leakage to the informal recycling sector, illegal disposal and potential for harm to human health and the environment. In the United States, it is estimated that between 97 to 99 percent of lead-acid batteries are recycled as part of a formal system, making it one of the most recycled products there are<sup>4</sup>. Coupled with a mature infrastructure and appropriate regulatory controls around recovery facilities, this has to be considered a success story. As this report will share, this has been replicated elsewhere around the globe. In locales where supply chain infrastructure or policy is lacking, however, risks exist. One study estimates that there are between ten to thirty thousand sites globally where lead acid batteries are being recycled in a potentially uncontrolled manner<sup>5</sup>.

Recycling and re-manufacturing are fundamental to the economics of lead-acid battery production. Lead is different from other non-ferrous metals, such as copper and zinc, because when recovered and recycled from scrap material, it can meet even the

highest quality standards equivalent to primary, or virgin, lead. According to the Basel Convention's technical guidance on lead-acid battery recycling, "Lead can be infinitely recycled, rendering a lead-acid battery an outstanding candidate for a sustainable product"<sup>6</sup>.

For every unit of material used or transported to produce secondary lead, nineteen units of material (e.g. ore) are required to produce the same amount of primary lead. This is confirmed by a U.S. Argonne National Labs study that concluded,

"The lead-acid battery example is a great success story. Battery plastics, acid and lead materials are all recovered and used in new products, such as plastic mouldings, detergents for the paper industry and lead products. For lead-acid batteries, recycling is mature and has resulted in substantial reductions in both cradle-to-gate battery production energy and SO<sub>2</sub> emissions."<sup>7</sup>

As part of their recommendation to the European Commission, the Öko-Institut and Fraunhofer Institute concluded, "Under the strict legal framework and long-term industry application, the environmental impact associated with [the] life cycle of lead-acid batteries can be considered very low. At least in the industrialized countries, a proper collection and recycling system enables a high collection and recycling rate of lead from these batteries is in place."<sup>8</sup>



**The purpose of this report is to show how three different countries have created different regulatory policies and reverse supply chains that have enabled responsible recycling of lead-acid batteries.**



Lead-acid battery recycling

In the next section, we'll outline some of the basics of how battery recycling works and the role of policy. We'll present a case study of Brazil, where we have observed a transition between an illegal and inefficient reverse supply chain and a regulated and efficient one. In the following section, we'll compare U.S. and E.U. programs, both effective but using differently configured reverse supply chains and different policy. Finally, we'll draw conclusions and make recommendations.

## **The Role of Public Policy and Regulation to Enable Responsible Recycling**

The responsible recycling of lead-acid batteries is a complex system. It involves multiple parties and, almost always, multiple governmental jurisdictions. While each country or region may have unique requirements, the common threads are policies that:

- 1. Support favorable economic conditions for legal recycling**
- 2. Establish stringent regulatory standards**
- 3. Enforce penalties for informal and unregulated practices**

“Recycling of lead-acid batteries is not a simple activity which can be done in small enterprises. Constructing, commissioning and operating a modern environmentally sound recycling plant is a very expensive undertaking. Not only does the initial capital investment run into many millions of dollars, but there is an ongoing and essential cost overhead to cover environmental and hygiene control systems. Any modern recycling plant must have a constant and high throughput of used lead-acid batteries. Local governments should focus on an environmentally safe collection of used lead-acid batteries and delivery to an environmentally sound smelter, even if this means that used batteries have to be exported to achieve this goal.”<sup>9</sup>

In a comprehensive training manual for policymakers, the Basel Convention noted that successful collection and recycling programs rely on the intrinsic economic value of lead. As a result, the Basel Convention concluded that the economic viability of recycling systems will depend on the following:

- 1. The market price of the recycled versus primary lead**
- 2. The availability of enough used lead-acid batteries to supply a recycling center**
- 3. The cost of collecting and storing used lead-acid batteries**
- 4. The cost of transporting used lead-acid batteries to the recycling center**

Further, the training manual identified additional elements that are key to successful national collection systems:

- 1. Stringent and clearly defined licensing and control requirements for collectors and transport agents**
- 2. A one-for-one (or old for new) exchange system at the point of sale and/or mandatory take-back requirements for manufacturers**
- 3. A deposit-refund system to encourage recycling and return of uncollected batteries**
- 4. Mechanisms, such as tax policy, that may help improve economic viability of the collection system<sup>10</sup>**

Building on the Basel convention guidance, The Commission on Environmental Cooperation in North America concluded that the additional elements are critical for a successful national collection and recycling program:

- 1. Consumers must be aware that lead-acid batteries can be recycled and need to understand they can return them to retailers or repair shops**
- 2. Used lead-acid batteries must be prohibited from being sent to landfills or environmentally unsound destinations such as informal smelters**
- 3. Retailers or repair shops that collect and temporarily store used lead-acid batteries must be licensed and have appropriate storage**
- 4. Lead smelters and recycling centers should be licensed and inspected while adopting the best available technologies and operating practices**
- 5. Public-private partnerships between government, industry and other organizations can help ensure the necessary conditions are maintained<sup>6</sup>**

## Case Study on Brazil Battery Recycling and Regulations

### Introduction

Although rich in natural resources, Brazil accounts only for 0.39 percent of the world's lead ore resources<sup>11</sup>, and therefore relies largely on imported lead, which imposes important cost and availability constraints to the battery industry. This, added to the country's inefficient monitoring and control of existing environmental legislation, led the industry to bypass regulations and environmental health and safety standards, which developed into a risky, illegal lead recycling process.

Starting in 1999, a series of legal restructurings – from environmental to fiscal requirements – were enacted to foster the development of a cleaner, reliable and efficient reverse logistics structure in the country, focused on reclaiming lead components from used lead-acid batteries. The changes undertaken reinvented an uncontrolled, low regulated and risky system towards a very

successful post-consumption reverse logistics system, both from economic and environmental perspectives.

Brazil's used lead-acid battery program was developed primarily by the country's Environmental Ministry and environmental government agencies, Brazilian Institute of Environment and Renewable Natural Resources, Environmental Company of the State of São Paulo and Foundation of the Environment, but also received support from across the industry, including companies like Johnson Controls, on providing technical expertise, practical experience and critical data.

### *The Old Model*

Given the high demand for lead-acid batteries, the country has to rely heavily on lead ore imports from global producers, such as Australia, China and the United States. Before the development of Brazil's used lead-acid battery model, the majority of post consumption lead-acid batteries were improperly discarded and ended up being processed by illegal smelters, that possessed no license nor had any legal authorization to perform such activity.

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

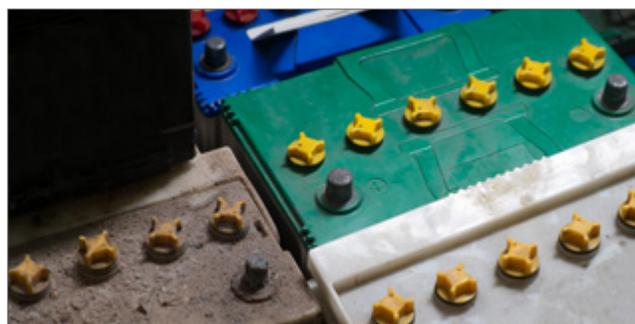
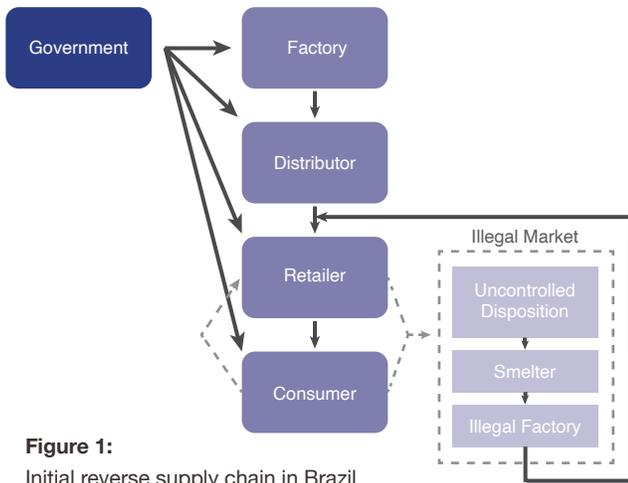


Figure 1 shows the configuration of the illegal reverse supply chain before reform. Government had regulatory control over the primary (forward) supply chain but lacked control and oversight of the informal reverse supply chain.



**Figure 1:**  
Initial reverse supply chain in Brazil

*The New Model*

To address this issue, Brazil adopted new environmental policies. The national CONAMA regulation number 257/1999, later replaced by CONAMA resolution number 401/2008<sup>12</sup>, instituted the limits for lead, cadmium and mercury in batteries produced or sold in the country and also defined the standards for lead-acid battery management and disposal.

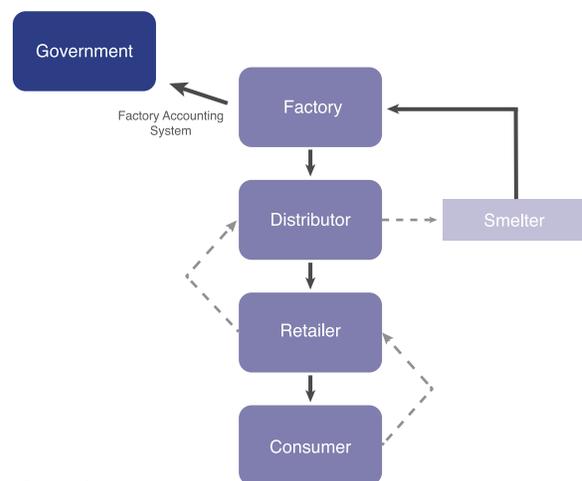
The implementation of the reverse logistics process made it mandatory for retailers to collect and send back all used lead-acid batteries to distributors, and for distributors to divert used lead-acid batteries to legal smelters, appointed by the manufacturers. The requirement for environmental licensing of used lead-acid batteries’ transportation activities was exempted, given that batteries kept their core and were handled only by trained drivers with the proper certification (MOPP), as required by Decree 96404/1988 (which created the regulation for transportation of hazardous materials). This made it viable to collect used lead-acid batteries and cores

all over the country and transport them through different states to the recycling facility without extra bureaucracies and costs.

Manufacturers of lead-acid batteries would only be allowed to process used lead-acid batteries and/or purchase lead from recycling processes from legal, environmentally licensed smelters. It also determined that manufacturers would be in charge of annually reporting the volume of lead-acid batteries produced, volume returned from final customers, volume of used lead-acid batteries processed, and lead recouped by the smelters. Applicable taxes over used lead-acid battery cores/ parts were exempted to promote a frictionless adoption of the intended recycling/reverse logistics program. As there were higher volumes of lead-acid batteries being produced/retailed due to the higher quantity and lower cost of reclaimed lead, the overall tax revenue increased.

Brazil’s standardization institute (INMETRO) defined industry requirements<sup>13</sup>, aligned with global standards, to assure that lead-acid batteries where being produced, tested and certified, favoring the usage of recycled lead in its process.

Figure 2 shows the reverse supply chain in the new model. In this model, the factory reports data about recycling flows back into operations, and all organizations in the value chain are covered by government regulatory controls.



**Figure 2:**  
New reverse supply chain in Brazil

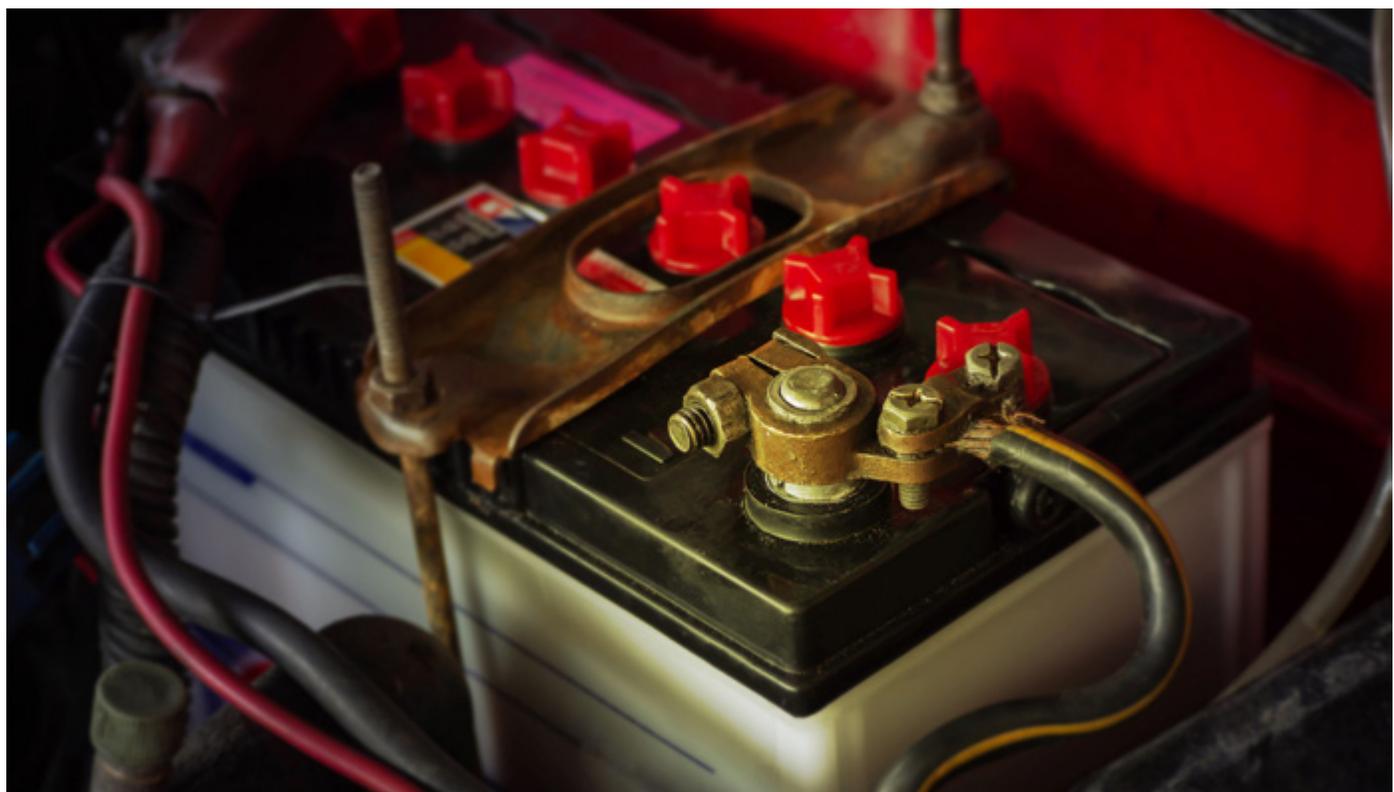
*Benefits of new model*

While the global secondary production of lead accounted for 54% of the refined lead production in 2007, in Brazil this numbers was close to 70% and aims to reach up to 90% by 2020<sup>14</sup>. This model stanchied tax revenue loss due to the previously high volume of illegal activities, and eased government control on activities for lead’s entire value chain as the obligation to report all steps of the process transferred over to the manufacturer. Table 1 below shows the comparison of the old and new models.

<b>Old Model</b>	<b>New Model</b>
<ul style="list-style-type: none"><li>• Illegal processing of used lead-acid batteries</li><li>• High environmental risks</li><li>• Low level of control by the government</li><li>• Unfair competition from small/medium companies, who benefited from illegal smelters</li><li>• Lack of industry standards</li></ul>	<ul style="list-style-type: none"><li>• Enhanced recycling levels</li><li>• Greater control of the process, reported by the manufacturer</li><li>• Leveled the field for all battery producers/ manufacturers, creating more competitive conditions for all companies</li><li>• Eliminated illegal players in the business</li><li>• Reduced environmental risks in the process</li></ul>

**Table 1:** Old and New Battery Recycling Models Compared

The more structured, industry-endorsed reverse logistics and recycling program helped to decrease the environmental impacts experienced by Brazil and imposed overall lower risks by decreasing the need for extraction of non-renewable natural resources.



# Case Study on US and EU Battery Recycling and Regulations

## Types of Lead-Acid Battery Reverse Supply Chains

While different countries have used various approaches to establish their national lead-acid battery recycling systems, there are three basic models that are prevalent across the globe. These systems are largely characterized by the degree of involvement and control exerted by the battery manufacturer, either voluntarily or as required by regulation.

Brazil's "old model" is an example of the first type, where recycled material becomes feedstock for a different application with a different vendor (Figure 3). This type of open-loop recycling is the most common type of circularity for most materials and products.

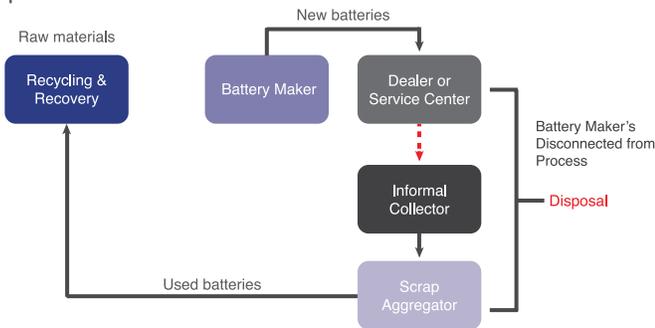


Figure 3: Open-loop recycling

Brazil's new model can be considered closed loop, in that recycled content becomes feedstock for the same product. This reverse supply chain form also exists in the United States, Canada, and Mexico. This approach depends on the battery manufacturer controlling the delivery of new batteries and collecting used ones using a reverse distribution or logistics system. Battery makers have requirements in place to collect used batteries at the point of sale for new ones, such as auto dealers, repair shops, parts stores and other retailers.

The "one for one exchange" is a critical element supported by incentives and regulations which encourage used batteries to be returned to these approved locations when new batteries are purchased. Battery makers maintain relationships and agreements

with recycling centers to handle the used lead-acid batteries, which in turn, supply their plants with raw materials for new batteries. Battery makers and their network partners are incentivized to lower costs and create economic value with tools like reverse logistics. The reduced number of players simplifies tracking and overall management, enabling greater economic and regulatory efficiencies. See Figure 4.

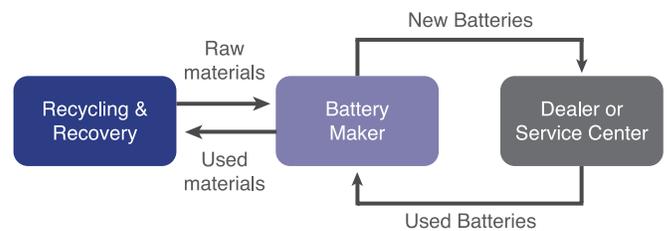


Figure 4: Closed-loop recycling (US)

Conversely, the European Union uses a semi-closed loop model. This approach largely emerged from historical context. In this model, new batteries are delivered from the manufacturer and the collection of used batteries are performed by different and unrelated parties. Licensed third-party scrap collectors are responsible for transporting used lead-acid batteries to approved and regulated recycling centers. While these recycling centers supply battery makers with raw materials, there is no direct connection within the collection process. This creates economic inefficiencies and regulatory complexities as additional rules and oversight is needed to address multiple, disconnected players in the market.

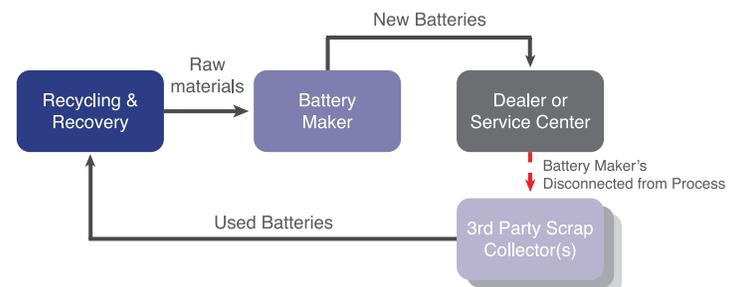


Figure 5: Closed-loop recycling (EU)

## *Enabling Regulation and Policies*

The European Directive 2006/66/EC of the European Parliament and of the Council of Sept. 6, 2006 on accumulators and waste batteries repealed Directive 91/157/EEC<sup>7</sup> and was adopted with the intention of harmonizing national measures concerning waste batteries and accumulators<sup>15</sup>. Lead-acid batteries can be placed on the market in one country and then collected at end-of-life in another country. Automotive batteries are often exported/imported as part of a second-hand vehicle. The Directive promotes the collection and recycling of waste batteries and accumulators and improves environmental performance of all operators involved in the life cycle of batteries and accumulators: producers, distributors, end-users and those directly involved in the treatment and recycling of batteries and accumulators. The Directive outlines the minimum rules for operating national collection and recycling schemes, and in particular, rules on how producers or third parties, must finance these schemes. Due to their economic value, waste industrial and automotive batteries are mainly collected by specialists. To avoid 'free-riders', each EU Member State is required to keep a register of producers who place batteries on the national market.

In the United States, a universal waste program was established to help encourage collection, separation and handling of specific wastes including used lead-acid batteries. This program also encourages but does not specifically require recycling. Universal wastes are subject to export notice and consent requirements, but not hazardous waste manifest requirements. A feature unique to the United States is an exemption to transportation rules that allows battery manufacturers to distribute new lead-acid batteries and collect used ones in the same truck. Used lead-acid batteries are not subject to specific Department of Transportation (DOT) requirements

if packaged in accordance with 49 CFR 173.159, shipped by road or rail and if all of the conditions below are met:

- There are no other hazardous materials in the same vehicle.
- The used batteries are loaded or braced in such a way as to prevent damage and short-circuits.
- Any other material loaded in the vehicle is secured so as to prevent contact with or damage to the batteries.
- The vehicle carries only material provided by the battery shipper.

A majority of states have enacted laws to incentivize the recycling of batteries by banning the disposal of lead-acid batteries in landfills, establishing a deposit system for new battery sales, requiring retailers, wholesalers and manufacturers to take back used lead-acid batteries and making it a violation of law to send used lead-acid batteries to unlicensed facilities<sup>16</sup>.

Thirty-four states have already enacted strict legislation to promote lead-acid battery recycling. Most laws include major provisions which:

- Prohibit disposal of lead-acid batteries in the municipal solid waste
- Require retailers to accept used lead-acid batteries from consumers when new ones are purchased
- Require retailers to post notices informing consumers of state requirements
- Compel battery manufacturers to accept used lead-acid batteries from retailers when new ones are purchased.

Several states include additional provisions such as:

- Require retailers to charge customers a deposit if an old one is not returned when a new one is purchased
- Require retailers to accept used batteries from consumers even if no battery is purchased.
- Place time limits on used lead-acid battery storage.

## *Program Performance*

Lead-acid batteries are currently the only automotive battery technology that operates in a closed loop in Europe, with more than 99% of lead-acid batteries sold being collected and recycled when they come to the end of their useful life, translating to over 100 million batteries recycled annually. According to European battery makers, the remaining 1% may represent a statistical error in approach or could be attributed to the movement of stored batteries and batteries with longer lifetimes than estimated, rather than batteries being landfilled or incinerated.

Compared with the recovery of only 68% of aluminum soft drink and beer cans, 72% of paper and 70% of glass, achieving a rate of 99% makes lead-acid batteries one of the most recycled consumer products in the European Union (EU). In the EU, recycling facilities for lead are not evenly distributed with some countries having multiple recycling facilities, and neighboring countries having none. As the countries with recycling facilities have recycling rates exceeding 100%, it suggests that there is a transfer of automotive lead-acid batteries across countries with and without recycling facilities.

For Europe, multiple factors contribute to this successful management of the battery life cycle. Both the market value of lead, which averages €20 per battery, and the high volume of used lead-acid batteries create strong economic incentives for responsible recycling. A challenge to the system is its sensitivity to lead prices, as fluctuation of these prices can significantly negate the economic incentives. To date, the industry has shown it can deal with this lead market fluctuation, but it remains an ongoing concern. An additional factor for the high recycling rates of lead-acid batteries is the established recycling technology, which is being continuously advanced and optimized. Furthermore, lead-acid batteries have an ideal design for recycling as they are composed of a limited number of materials that all share excellent recyclability. The comprehensive

regulatory framework regarding the lifecycle of batteries, as laid down in the European Battery Directive, gave another significant impulse to increase the recycling rate in Europe up to its current level<sup>17</sup>.

In the U.S., the National Recycling Rate Study, commissioned by Battery Council International, was completed for the years 2012–2016 and concluded that lead-acid batteries have a recycling rate of 99.3%, the highest recycling rate among other more well-known recycled products, such as newspapers (63%), aluminum cans (55.1%), tires (40.5%), glass containers (32.5%) and PET bottles (32.2%)<sup>18</sup>. Overall, Linda Gaines of Argonne National Labs, described the U.S. system as one that works because all the elements come together: “In summary, lead–acid battery recycling works well because: it is profitable, it is illegal to dispose the batteries without recycling, battery disassembly is simple because of the standard design used and the battery chemistry does not require segregation.”

The approach adopted in the United States is enabled by closed-loop model. New batteries are delivered while used batteries are collected at the point-of-sale (e.g., automobile repair shops) in what is referred to as the “One for One” or “Old for New” battery exchange model, which is incentivized through deposits or rebates to customers. With regard to this system in the United States, the Massachusetts Institute of Technology’s Supply Chain Management Review highlighted its unique aspects as well as the economic and environmental benefits:

“While conventional supply chains seek to efficiently move products in a linear fashion from raw materials to end consumers, a “circular” or “closed-loop” supply chain is one that is also dependent on feeding used products back as raw materials [to battery manufacturers]. As much as 80% of the materials used to make auto batteries can be derived from recycled batteries. The metals, plastics and acid used to make conventional auto batteries can all be recycled. This creates a significant business benefit by minimizing the impact of price volatility of these commodities and providing raw materials at a more competitive cost. Moreover, automotive batteries contain hazardous materials. The best and most responsible form of minimizing the health and environmental risks is to recycle them.”<sup>19</sup>

Table 2 compares programs in U.S. and Europe. Both programs have achieved 99% recycling rates using different reverse supply chains and different regulatory policy. These two systems differ by the type of reverse supply chain they have, who collects used batteries, how centralized and standardized the program is across different states/countries, and whether a deposit is required on new batteries. Thus, within any given country, different approaches can work, as long as they provide a regulatory frame to ensure safe collection and reprocessing, and a reverse supply chain structure that provides adequate financial incentives for all involved.

**Table 2:** Comparison of US and EU Battery Recycling

	<b>United States</b>	<b>Europe Union</b>
Type of reverse supply chain	Closed loop	Semi-closed loop
Collector of used batteries	Dealer/service provider	Third party collector
Centralization	Single program run across U.S. states	Programs run by different EU countries
Standardization	Mostly standard, but some state-to-state differences in regulations	Harmonized across EU countries
Deposit on new batteries	Yes	No
Recycling rate	99%	99%

## Conclusion

This report presented three different cases of national-level programs that have been very successful achieving recycling of lead-acid batteries. In Brazil, an open-loop reverse supply chain yielded many collection and recycling sites that were not adequately controlled by existing regulations. Over time, public and private actions created a closed loop system that created greater transparency of battery flows and much improved control of collectors and recyclers. In addition to enhanced recycling levels, it led to a more leveled playing field for all battery producers/manufacturers, creating more competitive conditions for all companies, eliminated illegal players in the business, and reduced environmental risks. In the

U.S. and Europe, we contrasted two different reverse supply chain structures and regulatory policies that nevertheless achieved the same 99% recycling rate.

In conclusion, lead-acid batteries must be recycled properly either domestically or exported for proper recycling. There is no excuse for informal recycling. As the case studies show, when the public and private sector work together, it reduces risks and makes for a fairer market amongst competitors. Any country's efforts require two components: a regulatory frame to ensure safe collection and reprocessing, and a reverse supply chain structure that provides adequate financial incentives for all involved.

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