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Collection and recycling of portable batteries: a worldwide overview compared to the Brazilian situation

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Abstract

Around the world there is no doubt about the increasing importance of recycling and the connected issue of sustainable development. In Brazil the new 2000 regulations have prompted society to discuss the future of spent batteries. Worldwide, different battery collection systems and recycling processes have been applied in the last 10 years. This paper presents the options applied in Europe and in the USA and compares the world situation to the current Brazilian reality.

Keywords: Battery recycling; Battery collection; Battery disposal

1. Introduction

The increasing importance of recycling and the related issue of sustainable development have prompted society to discuss the future of spent batteries.

In Brazil the result of these discussions is the CONAMA Regulation 257 (Brazilian Environmental Council Regulations) published in July 1999 [1]. This regulation, amended on December 1999 by Regulation 263 [2], has established limits to the potentially hazardous metal content used on products' composition. In January 2000, these Brazilian Battery Regulations came into effect. According to these regulations all kinds of household batteries containing lead, cadmium and mercury in a concentration higher than that established on the resolutions must be collected and sent to the manufacturers, to be recycled, treated or disposed of in an environmentally safe way. The zinc–carbon and alkaline batteries, as well as special batteries composed of different systems such as nickel–metal hydride (NiMH), lithium and zinc–air, with lead, mercury and cadmium content lower than the regulations' limits, can be landfilled together with municipal solid wastes (MSW).

At the Brazilian Federal State of Rio Grande do Sul, Law 11.187 from July 1998 [3] prohibits the disposal of any material containing heavy metals together with MSW. The concept of no generation of wastes, as well as the idea of a management system that aims at the minimization, reuse, recycling and treatment of wastes, is cited on State Regulation 38.356 (April 1998), where the Solid Waste Policy from the Federal State of Rio Grande do Sul is established [4]. The State Environmental Code emphasizes the importance of segregating domestic refuse before landfilling in order to improve the recycling rate of the products [5].

Considering the differences between Brazilian regulations and those of Rio Grande do Sul, it is important to analyze the possibilities for battery discharge, collection systems and available recycling processes.

1.1. Worldwide overview of battery disposal

Recycling rates for commonly used materials are growing in many industrial countries. Most of them, such as Japan, the United States and countries from the European Community, have created successful official recycling programs with collection centers located across the country.

In several European countries the battery industry has about 12 years' experience of collection, sorting and recycling of batteries. The 2000 collection rates vary between 32 and 54% as a percentage of battery sales in the same year [6].

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1.1.1. Battery disposal in Europe

In Europe, Resolution 91/157/EEC [7], amended in October 1993 [8] and in December 1998 [9], has established limits to the amount of dangerous substances present in the composition of batteries. According to these resolutions member states of the European Community shall prohibit, as from 1 January 2000 at latest, the marketing of batteries and accumulators containing more than 0.0005% of mercury by weight. Button cells and batteries composed of button cells with mercury content of no more than 2% by weight shall be exempted from this prohibition. Member states shall draw up programs in order to reduce the heavy metal content of batteries and accumulators. These materials shall also take appropriate steps to ensure that spent batteries and accumulators are collected separately with a view to their recovery or disposal.

The European Portable Battery Association (EPBA) represents the interests of portable battery manufacturers, those industries using portable batteries in their products, and portable batteries distributors active in the European Union. That association has a workgroup that focuses exclusively on issues related to the collection and recycling of portable batteries. The EPBA has contributed to the debate over proposed European Commission legislation that would require the collection and recycling of all portable batteries. The EPBA's "Two-Step Plan" calls for an immediate ban on all general purpose batteries containing more than 5 ppm of mercury and for the collection and recycling of all batteries beginning in 2003 [6].

The German Battery Decree (decree concerning the collection and disposal of used batteries and accumulators (BattV) of 27 March 1998) [10] came into force in two phases: the first phase concerned labeling provisions and a ban on marketing certain batteries containing harmful substances. This came into force on 1 April 1998 and is a direct implementation of the EU Directive. The second phase concerned the obligations of the manufacturers, importers, distributors, municipalities and end users, and had to be implemented by these parties after 1 October 1998.

Regardless of their electrochemical system and hazardous substance content, used batteries may no longer be disposed of in domestic waste. End users are the first element in the collection chain: they must return used batteries to the trade or the municipalities. Industrial users can hand over their used batteries directly to the collection system. Second in the collection chain are the distributors and municipalities, who have a duty to collect batteries free of charge and regardless of the brand or system. Manufacturers and importers are, for their part, obliged to provide distributors, industrial users and municipalities with suitable collection boxes and must take back the collected portable batteries free of charge. In order to guarantee this comprehensive returning of batteries the German Battery Decree provides manufacturers and importers with two alternatives: they can either join a common collection system or carry out collection individually [11].

Although the German Battery Decree has only been in force for a few years, it has already been reworked, primarily to prevent the marketing of batteries with a mercury content of more than 5 ppm Hg. This also includes batteries built into appliances. Button cells may still contain up to 2% mercury [12].

The German Battery Decree obliged manufacturers and importers to take charge of the sorting, recycling or disposal of used portable batteries. Under Section 4(2), the German Battery Decree provides for a common collection system among manufacturers [12]. As a result of this, Duracell, Panasonic, Philips, Energizer, Saft, Sanyo, Sony, Varta and the German Electrical and Electronic Manufacturers' Association established a foundation—the Common Battery Collection System, GRS Batterien, as a non-profit organization. The Senate of the Free and Hanseatic City of Hamburg, approved the foundation in May 1998 [11,13].

The service provided by GRS is equally available to all manufacturers and importers. Users of GRS pay a contribution towards waste disposal costs for the batteries marketed by them in Germany, according to weight and system. The foundation provides distributors and municipalities as well as commercial and industrial users with appropriate collection and transportation containers free of charge, and organizes sorting and disposal in accordance with the German Battery Decree. So far, more than 470 manufacturers and importers of portable batteries have joined GRS. These users put approximately 30,000 t of portable batteries into circulation in 2001. There are now approximately 150,000 points of collection/transportation Germanywide, 130,000 of which alone are trade outlets. Numerous commercial users and nearly all public waste disposal services likewise use the GRS. Since 1998 the quantity of batteries collected increased continuously. In 2001, 10,564 t of batteries were collected, an increase of approximately 13% compared to 2000 (9322 t of batteries). In 2001, an average of 129 g per inhabitant was collected [11].

Due to the increased circulation of UV-coded batteries, their sorting via UV detector and the general reduction of the mercury content in the battery waste stream thanks to the prohibition against bringing ZnC and AlMn batteries containing mercury into circulation, the proportion of recycled batteries will increase successively to over 70% in the year 2005. End users have been made aware of the free battery disposal through numerous public relations measures. According to Ricke and Knudsen [11] battery return has never before been so easy for end users. After the batteries have been collected, GRS Batterien organizes the sorting of the batteries into the various electrochemical fractions and their subsequent disposal.

Today there are different European Collection and Recycling Organizations (CROs), which can be divided into three major groups [6]:

1. *Systems where industry is responsible for collection, sorting, recycling, awareness programs and high mandatory*

collection targets. This type of system is characterized by high awareness program costs. In Belgium these are presently 5000 €/t still struggling to aim for an unachievable collection rate of 75% of sales.
2. *Systems with shared responsibility and high mandatory collection targets*. In this system, municipalities share the responsibility for collection. But industry is responsible for meeting the collection target resulting in high awareness program costs. In The Netherlands these are presently 3700 €/t aiming at a collection rate of 90% of batteries discarded, which is also unachievable.
3. *Systems with shared responsibility and no mandatory collection targets*. Here, the retailers and municipalities have the financial responsibility for collection from consumers. The awareness programs are part of the public responsibility. In Austria and Germany the costs are around 1300 €/t.

Different European countries have created alternatives to the problem of spent batteries.

In 1989, Austria started the first industry lead collection schemes called UFB, based on a battery directive and an agreement with the municipalities and retailers. Today approximately 160 g of batteries per inhabitant are collected which are about 54% of the batteries sold at the same time. The collection scheme is financed via an “environmental fee” charged per battery type to the consumer [6].

In 1995, Belgium started the collection of all batteries with the system called “Bebat”, established by the battery industry in Belgium. Today approximately 200 g batteries per inhabitant are collected, which is about 58% of the batteries sold in the same period. The costs are financed via an “environmental fee” per battery, defined by the Ministry of Finance and charged to the consumer [6,14].

In 1997, battery industry achieved an agreement with the Dutch government for the establishment of a collection scheme called “Stibat”. Today approximately 125 g batteries per inhabitant are collected which are about 33% of the batteries sold in the same time. The system is financed via an “environmental fee” charged per battery type to the consumer [6].

In 1998 the Swedish government started the collection of batteries containing lead, cadmium and mercury. Manufacturers and importers of batteries containing these metals must pay an “environmental levy” to the Danish Environmental Protection Agency, which finances the collection of batteries [6].

In 1999 the Danish government started the collection of batteries containing lead, cadmium and mercury. Manufacturers and importers of batteries containing these metals must pay an “environmental levy” to the Swedish Environmental Protection Agency, which finances the collection of batteries [6].

In 2001, the French government implemented a battery directive. Several systems are established in France. The battery industry has established the “Fibat/Screlec” organization. In 2001, approximately 600 t of batteries were collected [6].

Portugal, Czech Republic, Poland and Hungary have now established legislation to collect all batteries [6].

1.1.2. Battery disposal in the USA

In the USA, the Resource Conservation and Recovery Act (RCRA) lists different wastes as hazardous wastes, among these secondary nickel–cadmium and lead batteries. There are two types of handlers of wastes: small quantity handlers (that do not accumulate 5000 kg or more total of waste) and large quantity handlers (that accumulate 5000 kg or more total of waste). Both should send the batteries to other handlers, recyclers, or treatment/disposal facilities [15].

On May 1996 the Mercury-Containing and Rechargeable Battery Management Act (Battery Act) was signed into law. This act represents a major step forward in the effort to facilitate the recycling of NiCd and certain small sealed lead–acid rechargeable batteries and to phase out the use of mercury in batteries [16].

For NiCd batteries, the Rechargeable Battery Recycling Corporation (RBRC), a non-profit organization representing many rechargeable battery manufacturers, developed a recycling program. The program offers various recycling plans for communities, retailers, businesses, and public agencies. For each group, RBRC pays or shares the cost of consolidating the batteries, shipping them to the processing facility, and recycling them. The program sends all NiCd batteries to the INMETCO in Pennsylvania [16].

Other household batteries (without Cd, Pb or Hg) are still partially sent to sanitary landfills, since MSW are not regulated by RCRA. Sanitary landfills are projected to the treatment of small quantities of hazardous wastes [17]. But recycling processes have been encouraged and Environmental Protection Agency (EPA) has stimulated battery separation and collection systems [15].

In May 1995 EPA promulgated streamlined regulations that govern the collection and management of widely generated wastes known as universal wastes. EPA has identified hazardous waste batteries, certain hazardous waste pesticides, and hazardous waste thermostats as universal wastes. The universal waste regulations are designed to accomplish the following general goals:

- encourage resource conservation, while ensuring protection of human health and the environment;
- improve implementation of hazardous waste programs through a simplified set of requirements, that are easily understood by handlers of universal waste;
- separate universal waste from the municipal waste stream, by encouraging individuals and organizations to collect these wastes and to manage them in an appropriate hazardous waste management system [15].

By the Universal Waste Regulations the Federal States are encouraged to adopt collection and selection rules to batteries. NiCd and Pb batteries are considered dangerous in all American states. Other household batteries must be evaluated before final disposition. The generator of solid waste is required to make a determination as to whether the solid waste is hazardous, which may be accomplished by applying user knowledge or testing the waste. Typically, hazardous waste classification is based upon the Resource Conservation and Recovery Act (RCRA) characteristics of hazardous waste. Title 40 Code of Federal Regulations (CFR) Part 261, "Identification and Listing of Hazardous Waste," addresses the four hazardous waste characteristics: ignitability, corrosivity, reactivity, and toxicity. A waste is considered a hazardous waste if it exhibits any one or more of these characteristics [18].

All but four states (Alaska, Hawaii, Iowa, and Wyoming) are authorized by the EPA to administer their own hazardous waste programs. As a result, these states have promulgated hazardous waste regulations that may be more stringent than the Federal regulations. For example, California regulates zinc, a component of alkaline batteries, under the toxicity characteristic. Both Washington and California hazardous waste regulations include bioassay characterization criteria. Bioassay characterization is a method for determining the potential toxicity of a material by observing its effect on the growth of a suitable animal, plant, or microorganism under controlled conditions. Under this waste criteria, alkaline and carbon–zinc batteries may be considered a state-regulated hazardous waste. Therefore, the generator must ensure that most stringent regulations are applied when considering hazardous waste disposal [18].

Although in the USA batteries (except for lead–acid and NiCd batteries) are not specifically regulated under Federal RCRA regulations, many batteries may exhibit one or more of the characteristics of a hazardous waste and require management as such:

- *Mercury batteries*: Mercury is listed at the federal legislation of the USA as a hazardous element (code D009). Batteries containing mercury must be evaluated in terms of mercury concentration before final disposition.
- *Lithium batteries*: Lithium batteries are subdivided into the following categories:
  - Lithium–manganese dioxide batteries are non-hazardous solid wastes.
  - Lithium–sulfur dioxide batteries (single-cell) are non-hazardous solid wastes.
  - Lithium–sulfur dioxide batteries (multi-cell) may be non-hazardous solid wastes or characteristic hazardous wastes. If equipped with a Complete Discharge Device (CDD), the batteries are considered a non-hazardous solid waste after discharging. If not equipped with a CDD, multi-cell lithium–sulfur dioxide batteries are characteristic hazardous wastes due to ignitability (D001) and reactivity (D003).
  - Lithium–thionyl chloride batteries (multi-cell) are characteristic hazardous wastes. If these batteries have a CDD, after discharge, these batteries are a characteristic hazardous waste due to toxicity (chromium, D007). Batteries without a CDD are considered a characteristic hazardous waste due to toxicity (chromium D007), ignitability (D001), and reactivity (D003).
- *Silver batteries*: Silver is listed as a hazardous element (D011), what turns silver batteries into a hazardous waste.
- *Alkaline batteries*: Alkaline batteries are not considered an RCRA-regulated hazardous waste, when they are mercury-free. The electrolyte of an alkaline battery does not meet the definition of an aqueous solution or free liquid; therefore, they are not, by definition, a corrosive waste. However, aquatic bioassay analysis conducted to further characterize the toxicity of the battery leachates indicates alkaline batteries would be classified as hazardous waste in American states which use bioassay characterization criteria.
- *Zinc–carbon batteries*: Zinc–carbon batteries are not considered an RCRA-regulated hazardous waste. As with alkaline batteries, these batteries may be subject to state regulation as a result of bioassay characterization criteria [18].

2. Municipal solid waste management in Brazil

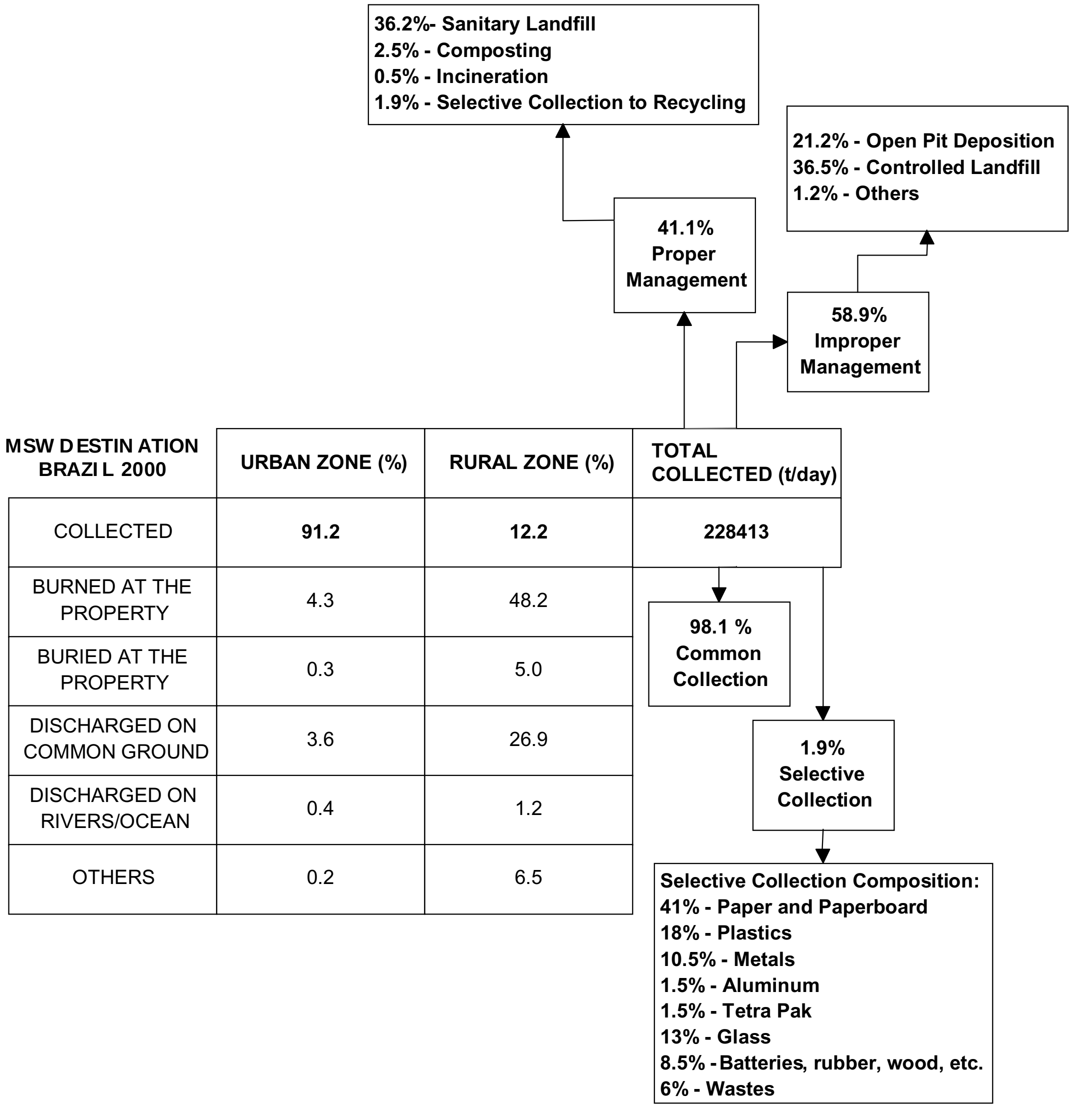
The solid waste generation in Brazil is about 0.5 kg per person per day. In São Paulo each person generates 1.0 kg per day. In urban zones almost all waste is collected, as can be seen on a survey conducted by Brazilian Institute of Geography and Statistics (IBGE) in 2000 and presented in Fig. 1 [33]. The final disposition systems are related to proper management (sanitary landfill, composting, incineration and recycling) and to improper sites (open pit deposition and controlled landfill). Open pit deposition is a final deposition method, where the wastes are discharged on the ground without any environmental or health control system. Unfortunately, this method is often used in Brazil. The so-called "controlled" landfill is also an improper way of disposing wastes and consists of an open pit deposition where the wastes are covered arbitrarily with earth, in order to decrease the visual impact.

Just 1.9% of the municipal solid waste is selectively collected and sent to recycling processes. From this fraction, there is no real knowledge about battery collection and recycling rates, as can be seen in Fig. 1.

2.1. Battery disposal in Brazil

In Brazil, almost one billion battery units (six units per capita) are consumed nowadays; of these, 25–30% are alkaline battery type and 2% are automotive batteries [19].

The CONAMA regulations have established limits to the amount of dangerous substances present in the composition of batteries. By these resolutions it is forbidden, as from 1 January 2001 at latest, the marketing of batteries and



MSW DESTINATION BRAZIL 2000	URBAN ZONE (%)	RURAL ZONE (%)	TOTAL COLLECTED (t/day)
COLLECTED	**91.2**	**12.2**	**228413**
BURNED AT THE PROPERTY	4.3	48.2	
BURIED AT THE PROPERTY	0.3	5.0	
DISCHARGED ON COMMON GROUND	3.6	26.9	
DISCHARGED ON RIVERS/OCEAN	0.4	1.2	
OTHERS	0.2	6.5	

Fig. 1. Municipal solid waste destination in 2000 in Brazil [33].

accumulators containing more than 0.01 wt.% of mercury, 0.015 wt.% of cadmium and 0.2 wt.% of lead. Button cells and batteries composed of button cells with mercury content of no more than 25 mg shall be exempted from this prohibition. By these CONAMA regulations all kinds of household batteries, containing lead, cadmium and mercury in a concentration higher than that established on the resolutions must be collected and sent to the manufacturers, to be recycled, treated or disposed of in an environmentally safe way [1,2]. NiCd batteries are above the limits imposed by the Brazilian regulations, since NiCd batteries contain around 17% of cadmium [20]. The NiCd batteries disposal is regulated by the resolution 257/99 [1,2]. The Federal Environmental Crime Law 9605 established fines and penalties from 1 to 4 years in prison, to those caught in the very act of disposing of NiCd batteries together with municipal solid waste. Brazil is the only country in South America with legislation about batteries [20], but control and penalties are not really applied.

Nowadays companies that commercialize NiCd batteries have implanted collection systems and the destination of batteries varies from company to company. Nokia implemented a recycling program, where the consumer must return the spent battery back to any shop. Nokia collects the batteries at the stores and sends to recycling programs abroad. Motorola's battery-recycling program collects all batteries also at shops and sends them to a SNAM industrial unity in France [21]. The largest problem of these recycling programs is that there is not enough advertisement about the collection system. According to Riedler [22] the largest problem is that the population and commerce employees in general do not know the legislation. The large majority of the population knows nothing about the collection systems.

Zinc–carbon and alkaline batteries, as well as special batteries composed by different systems as nickel–metal hydride, lithium and zinc–air, with a lead, mercury and cadmium content lower than the CONAMA regulations limits, can be landfilled together with municipal solid wastes [1,2]. According to the Brazilian regulations, final disposal for these spent household batteries includes sanitary and industrial landfill for hazardous waste respectively for domestic and industrial waste. The collection of used batteries could be made by separating them from household wastes. Unfortunately, there is no systematic collection scheme and no method for sorting if they are collected. Sometimes this task is not feasible due to educational problems and economical concerns [23].

The idea of recycling batteries is still incipient. Some research is current being done on the recycling of batteries, but there is no industrial process about it. A hydrometallurgical route based on the liquid–liquid extraction technique using Cyanex 272 (di-2,4,4-trimethylpentyl phosphinic acid) as extractant is proposed to separate zinc and manganese from spent alkaline batteries [19]. Another study proposes the use of hydrometallurgical process for the treatment of zinc–carbon and alkaline batteries. The soluble portion (dry powder), resulting from mechanical treatment and isolated from others coarse components was chosen to be treated as it contains the metals. The metal recovery proposition includes as its first stage an acid-leaching procedure followed by a purification step to remove impurities, such as iron, and followed by the metal recovery from aqueous solution through the electrolytic deposition step [10,24–27].

NiCd batteries recycling has also been studied in Brazil by hydrometallurgical [28] and pyrometallurgical techniques [29,30]. Although spent nickel–metal hydride batteries are not considered hazardous waste, there are valuable materials that could be recovered; therefore the recycling of these batteries should be considered. A research work discusses spent NiMH battery characterization and describes a process to recover valuable materials based on mineral processing techniques [31].

2.2. Final remarks

Considering that collection, separation and recycling processes are already available worldwide, the simple disposal of household batteries together with municipal solid waste should be avoided.

Batteries, even those that present cadmium, lead and mercury concentrations below the limits established by CONAMA [1,2], have important quantities of other heavy metals, what can bring environmental risks to disposal sites, specially when the waste is disposed of in an improper site as open pit deposit.

The emergence of new types of rechargeable (secondary) batteries has accelerated the replacement of portable nickel–cadmium (NiCd) batteries in many applications. Replacement has occurred because new battery technologies (nickel–metal hydride and lithium-based batteries (Li-ion and Li-polymer)) have better performance (e.g. higher energy density and no memory effect) in many applications. Another important reason for the replacement of NiCd batteries is due to the toxic properties of Cd. The new battery technologies are based on metals that are believed to have lower environmental impact. This replacement has been seen as an example of action in accordance with the precautionary principle. The new batteries contain metals (e.g. La, Nd, Co) for which only few toxicological or eco-toxicological data are available. Consequently, the introduction of new metals is associated with uncertainties regarding environmental impact, and a shift in the use of battery technology may induce a change from one problematic metal to another. The introduction of new battery technologies must be evaluated to determine whether the replacement of NiCd batteries will lead to other environmentally problematic metal flows [32].

When batteries are disposed of in sanitary landfills, these must have effluent treatment stations projected to treat heavy metals. If the station uses a physico-chemical treatment, the generated sludge will also be considered a hazardous waste. The open pit disposal of municipal solid wastes, very common in Brazil, is forbidden for batteries according to CONAMA resolutions.

The collection system is a big task to really implant recycling processes in Brazil, since its efficiency depends not only on education of and cooperation from people, but also on industries, distributors and government. Since batteries are usually disposed of together with municipal solid wastes, the responsibility for the collection is usually of the public sector. In this case, the associated costs turn the operation unfeasible. Some countries around the world have specific legislation about the problem based on the principle of payer polluter, i.e. the company that produces or imports the material is also responsible for its destination after the end use.

Although in Brazil there is no such legislation, it is interesting to analyze some isolated initiatives that occur in different sectors of the economy. Aluminum is the stronger example of the enterprise initiative of recycling. Nowadays the recycling rate of aluminum cans in Brazil is among the highest in the world. The collection of aluminum cans is so well established that it allows the recycling industry to profit from it. Lead–acid batteries are also largely recycled around the country. These examples occur without any incentive of the government. The materials segregation is done mainly because of economical factors. All advertisements to influence people is done by the recycling industries. Change stations are organized to receive materials and pay for it.

For batteries, the economical factor is not so evident and no recycling industry is established in the country. In this case the role of legislation and government is larger. Public power must create laws and regulations to make the producer responsible for waste management, even when the material is considered a municipal waste.

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