Final Report

Critical Review of the Literature Regarding Disposal of Household Batteries

December 2007

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Executive Summary

The main objective of this work was to conduct a comprehensive and critical review of the literature dealing with the management of spent household primary batteries. In particular, the focus of this study was on the literature concerned with the management of spent AlMn batteries and the impact of those batteries on landfills. An effort was made to identify literature dealing with the co-disposal of batteries with other household waste. Additionally, data on the potential environmental impacts for all stages of management of spent batteries also was considered.

The literature search was sub-divided into regions and within the regions into languages spoken in those regions. The languages were selected based on the knowledge and experience of the research team. As such, in this literature search, articles, reports, and books written in English, German (including German, Austrian, and Swiss sources), Dutch (including The Netherlands and Belgium), Polish, Italian, Japanese, and Korean were reviewed. A very limited amount of information was obtained from the literature in Spanish and in Portuguese. It became apparent that researchers and scientists from Spanish and Portuguese speaking countries generally publish in English journals. Emphasis was placed on the open literature and that which could be accessed through libraries and databases. Some pertinent publications which otherwise would have been difficult to collect were obtained through industry associations

The review of the literature published in English resulted in the identification of several publications dealing with the general subject of household batteries. The majority of the publications dealt with various issues associated with recycling, segregation, and treatment. A few other publications covered different subjects related to improvements in the manufacture of batteries, while others addressed environmental impacts as well as health and environmental risks and controls. A few publications dealt with emissions from landfills due to the disposal of household batteries, in particular emissions associated with heavy metals and mercury. The remainder of the articles covered the relative composition of dry cells in domestic waste, storage of spent batteries, and the characteristics of AA alkaline batteries.

No specific publications were found specifically covering impacts of the disposal of spent alkaline batteries in municipal landfills in the literature published in English.

With regard to the German, Dutch, and Polish language literature reviewed, the majority of the publications identified originate from Germany and The Netherlands. Some Austrian and Belgian reports also were reviewed. In the Polish literature, the environmental impacts of the management of spent batteries were dealt with very superficially.

In general, very few publications were concerned with environmental impacts of the management of spent batteries. The majority of the publications identified provide data on the performance of battery collection systems or describe technical aspects of recycling processes. The environmental impacts are only marginally covered and mostly at a qualitative level.

In the recent publications, co-disposal of batteries with household waste is not discussed at all. This is due to the legislation passed by the EU and its members, which prescribes separate collection and recovery/recycling of batteries. Thus, in the modern LCA studies on management of spent batteries, only alternative recycling scenarios are considered.

In the older literature (mostly from the 1980s), some results on research conducted on the behavior of batteries in landfill conditions, and in waste incineration plants, have been described. However, the results are mostly cited from other, even older, sources. These results refer to old batteries with significantly higher contents of heavy metals (especially Hg) than the modern AlMn batteries. Thus, these results cannot be directly applied to the modern batteries.

In general, it can be concluded that sound, scientific evidence on the environmental performance of modern AlMn batteries in the German, Dutch, and Polish language literature is lacking.

On the other hand, the search in the literature in Italian was unable to identify specific articles dealing with the disposal of alkaline batteries. It seems that the problem related to the disposal of household alkaline batteries has not as yet been analyzed or investigated in Italy. It is also possible that some of the investigations conducted in Italy have been reported in English in international scientific journals. At the present time, the only available information, about the management of batteries in general, from the production to the disposal, comes from the national laws, which are related to the implementation of the European Directives.

Some publications dealing with the impacts of treating and disposing primary batteries in landfills have been found in Korea and in Japan. Most of the publications deal with the release of heavy metals contained in the batteries (mostly older types of household batteries) into the surrounding waste and eventually into the leachate and into the environment.

Some of the research reported in the literature was conducted over a relatively short time, while other work (such as that performed at Fukuoka University) has been carried out over several years (7 years or longer).

The long-term experimental work on the behavior of metals such as Hg in the landfill indicated that most of the Hg remained in the landfill body and that very low concentrations were released through the leachate and through the landfill gas.

Critical Review of the Literature Regarding Disposal of Household Batteries

1. Introduction

This report presents the results of a comprehensive and critical review of the literature dealing with the management of spent household primary batteries. The work was conducted under contract to the National Electrical Manufacturers Association by CalRecovery, Inc. (USA), Den Boer Waste Consulting (Germany), Fukuoka University (Japan), IMAGE, University of Padova (Italy), and University of Central Florida (USA).

The focus of this study was on the literature concerned with the management of spent alkaline (AlMn) batteries. The following topics were considered in the search: segregation, collection, transport, storage, treatment, recycling, and final disposal of spent batteries. An effort was made to identify literature dealing with co-disposal of batteries with other household waste, in particular literature dealing with the co-disposal in landfills, in order to determine the impact of batteries on the landfill processes. Data on environmental impacts included in the literature search for all of the management processes of spent batteries previously mentioned. In particular, efforts were made to identify all available lifecycle assessment studies dealing with environmental impacts due to battery disposal processes, as well as other studies assessing the environmental impact of single processes/lifecycle phases of batteries.

The following topics were considered during the literature review: disposal of household batteries, leachate quality (particularly associated with batteries), the impact of household batteries on the leachate, and studies on LCA of battery management (segregation, storage, transport, treatment, and disposal). To the extent possible, the literature search concentrated on information on alkaline batteries, but considered other types of batteries that may be relevant for comparison purposes.

Scientific manuscripts and reports available in databases, libraries, and other sources were reviewed. The work included:

- National and international databases were searched, including databases of the following institutions:
    - ministries of the environment and other governmental organizations responsible for the environment protection;
    - national libraries and registers of environmental literature;
    - national research institutions;
    - Non-Governmental Organizations (NGOs) involved in the environment protection issues;
    - battery recovery and recycling organizations;
    - universities and institutes, especially those having an environmental engineering/waste management department;
- The content of scientific and thematic journals, especially those dealing with waste management, recycling, and general environmental engineering issues was reviewed;

- Internet search engines were used to identify and review thematic sites dealing with the management of spent batteries;
- A number of persons potentially involved in the management of spent batteries were contacted either by email, telephone or in person.

To broadly capture relevant information on batteries worldwide, the literature search was performed in a number of languages. A team of researchers was employed to identify and review literature published in English, German, Dutch, Polish, Italian, Japanese, and Korean. Based on this method of identifying, retrieving, and interpreting international literature, the results of the literature survey are organized in the following sections by language:

Section 2. English
Section 3. German, Dutch, and Polish
Section 4. Italian
Section 5. Japanese and Korean

The information presented in material that has been published in languages other than in English has been abstracted and summarized in English.

2. English Literature

2.1 Results of the literature review

This section includes research that has been conducted world-wide, and published in English. The literature abstracts are presented chronologically, with the most recent references first.

Shin, Kang, Yang, Sohn, 2007

Original title:	Development of Metal Recovery Process from Alkaline Manganese Batteries in Sulfuric Acid Solutions
Translation:	N/A
Author:	Shun-Myung Shin, Jin-Gu Kang, Dong-Hyo Yang, Jeong-Soo Sohn
Institution:	Korea Institute of Geoscience and Mineral Resources, Daejoen, South Korea
Editors:	
Publisher:	
Place, Year:	*Materials Transactions*, v. 48, no. 2, p. 244, 2007
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

A process for the recovery of Mn from a waste of spent alkaline batteries using sulfuric acid and hydrogen peroxide has been investigated. The proposed procedure consisted of mechanical separation of metal-containing particles and a leaching process. The effects of leaching agent, reaction temperature, time, and pulp density for the leaching were also examined. Crushing and sieving of the spent batteries resulted in satisfactory separation of particle size from the waste; 99% Zn and 97% Mn were successfully extracted from the spent battery powder by the leaching at 60°C for 60 min with the addition of hydrogen peroxide as a reducing agent. The hydrogen peroxide addition led to almost doubling Mn extraction compared to without it.

Slack, Bonin, Gronow, Van Santen, Voulvoulis, 2007

Original title:	Household hazardous waste data for the UK by direct sampling
Translation:	N/A
Author:	Rebecca J. Slack[a], Michael Bonin[a], Jan R. Gronow[b,d], Anton Van Santen[c], Nikolaos Voulvoulis[a]
Institution:	[a] Imperial College, London, UK; [b] Environment Agency, Bristol, UK; [c] Waste Strategy Review, London, UK; [d] Centre for Environmental Policy, London, UK
Editors:	
Publisher:	
Place, Year:	*Environmental Science and Technology*, v. 41, no. 7, p. 2566, 2007
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The amount of household hazardous waste (HHW) disposed of in the United Kingdom (UK) requires assessment. This paper describes a direct analysis study carried out in three areas in southeast England involving over 500 households. Each participating householder was provided with a special bin in which to place items corresponding to a list of HHW. The amount of waste collected was split into nine broad categories: batteries, home maintenance (DIY), vehicle upkeep, pesticides, pet care, pharmaceuticals, photographic chemicals, household cleaners, and printer cartridges. Over 1 ton of waste was collected from the sample households over a 32-week period, which would correspond to an estimated 51,000 tons if extrapolated to the UK population for the same period or over 7,000 tons per month. Details of likely disposal routes adopted by householders were also sought, demonstrating the different pathways selected for different waste categories. Co-disposal with residual household waste dominated for waste batteries and veterinary medicines, hence avoiding classification as hazardous waste under new UK waste regulations. The information can be used to set a baseline for the management of HHW and provides information for an environmental risk assessment of the disposal of such wastes to landfill.

Agourakis, Carneiro de Camargo, Cotrim, Flues, 2006

Original title:	Behavior of zinc and manganese from alkaline batteries in a soil column
Translation:	Translated from Portuguese by the McElroy Translation Company
Author:	D.C. Agourakis, I.M. Carneiro de Camargo, M.B. Cotrim, M. Flues
Institution:	Centro de Quimica e Meio Ambiente, Instituto de Pesquisas Energeticas e Nucleares, São Paulo, Brazil
Editors:	N/A
Publisher:	Quimica Nova, vol. 29, No. 5,
Place, Year:	Brazil, Sept./Oct. 2006
ISBN/ISSN:	0100-4042
Kind of publication:	Electronic Journal
Additional information:	

The main objective of this study was to assess the behavior of Zn and Mn from alkaline batteries in a soil column. Two soil columns were used in the study. On one column four discharged AA alkaline batteries were placed on the top. The batteries were previously cut lengthwise and the "wrappers" removed from the batteries to accelerate the rupture process. Filter paper was put between the batteries and the soil. An acid-rainwater solution made up from HNO_3 and H_2SO_4 at a pH of 4 was percolated through the column which contained the batteries. The results showed that the leaching of the alkaline batteries using the acid solution lead to an increase in the concentration of Zn (70 times) and of Mn (11 times) of the top soil. Furthermore, the results of the study showed that leaching of the electrolyte (KOH) from the batteries increased the solid pH in the column which had the batteries placed on the top.

Almeida, Xará, Delgado, Costa, 2006

Original title:	Characterization of spent AA household alkaline batteries
Translation:	N/A
Author:	Manuel F. Almeida, Susana M. Xará, Julanda Delgado, Carlos A. Costa
Institution:	Porto University, Porto, Portugal
Editors:	
Publisher:	
Place, Year:	*Waste Management*, v 26, no. 5, 2006, p. 466, 2006
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The aim of this work is identification of the structural components of actual domestic spent alkaline AA batteries, as well as the quantification of some of their characteristics. Weight, moisture content, ash content, zinc and zinc oxide on the anode, manganese on the cathode and other metals, potassium hydroxide on the internal components and heating values for papers, anode and cathode were determined for several batteries. As expected, the cathode, the anode, and the steel can container are the main contributors to the 23.5 g average weight of the batteries. The cathode also is the major contributor to the positive heating value of the batteries as well as to the heavy metals content. Mercury was detected in very low levels in these mercury-free batteries. Zinc and zinc oxide amounts in the anodes are highly variable. Results obtained were compared to information on alkaline batteries in the literature from 1993 to 1995; and a positive evolution in their manufacture is readily apparent. Data from the producer of batteries shows some small discrepancies relative to the results of this experimental work.

Arnold, 2006

Original title:	Efficiency of the Battery Channel
Translation:	From French
Author:	O. Arnold
Institution:	Ministry of Ecology and of Sustainable Development
Editors:	
Publisher:	
Place, Year:	France, 2006
ISBN/ISSN:	
Kind of publication:	Report
Additional information:	

The chemical composition of batteries (primary and rechargeable) varies substantially. This variation in composition shows up in their environmental impact at their end-of-life. The most notable environmental impact is the heavy metal emissions from waste incinerators. Since batteries were included in the European regulation in 1991, this category was amongst the first to experience product stewardship principles in France. A combination of instruments has been used including restrictions in the consent of the product to the implementation of collection programs downstream.

More than 820 million primary and rechargeable batteries were sold in France in 2003. These quantities do not include lead-acid batteries. This is equivalent to about 30,000 tonnes of batteries. The vast majority of this mass was made up of alkaline and zinc-carbon batteries. Since limits have been set on the concentration of mercury in these batteries, the environmental impact at their end-of-life is not considered dangerous. In the same year, approximately 7,200 tonnes of used batteries were recycled.

The results of an economic analysis related to the recycling of used primary and rechargeable batteries demonstrated that the costs vary from 1500 € per tonne for nickel metal hydride batteries to 4100 € per tonne for button cell batteries. The external costs and benefits primarily reflect the impact of heavy metals on emissions from incineration and the avoidance of those emissions through recycling. These have been considered in the cost analysis to determine the optimal end-of-life method of management.

Based on the results, it seems as though that the separate collection and recycling of most batteries is not desirable. The limited environmental impact of the batteries in mixed waste does not justify the high costs associated with recycling. In addition, the end-of-life treatment of button cells containing mercury and rechargeable batteries containing Ni-Cd is very difficult. A relevant method may be to limit their sale or to impose bans. The regulatory limit of 5 ppm concentration of mercury is strict and does not seem to add substantial environmental benefits.

The study concluded that the variety of management methods applied for dealing with used household batteries can be optimized by reinforcing upstream measures which would allow downstream solutions and the source of high costs to be discontinued. The policy for this should be aimed at placing stringent limits on the use of batteries that contain mercury or cadmium, using substitute chemicals as they become available, and discontinuing separate collection. This change in orientation should not, however, discourage the public from practicing recycling in general.

Avraamides, Senanayake, Clegg, 2006

Original title:	Sulfur dioxide leaching of spent zinc-carbon-battery scrap
Translation:	N/A
Author:	J. Avraamides, G. Senanayake, R. Clegg
Institution:	Murdoch University, Perth, Australia
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v 159, no. 2, p. 1488, 2006
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Zinc-carbon batteries, which contain around 20% zinc, 35% manganese oxides, and 10% steel, are currently disposed after use in landfills or reprocessed to recover metals or oxides. Crushed material is subjected to magnetic separation followed by hydrometallurgical treatment of the non-magnetic material to recover zinc metal and manganese oxides. The leaching with 2 M sulfuric acid in the presence of hydrogen peroxide recovers 93% Zn and 82% Mn at 25°C. Alkaline leaching with 6 M NaOH recovers 80% zinc. The present study shows that over 90% zinc and manganese can be leached in 20-30 min at 30°C using 0.1-1.0 M sulfuric acid in the presence of sulfur dioxide. The iron extraction is sensitive to both acid concentration and sulfur dioxide flow rate. The effect of reagent concentration and particle size on the extraction of zinc, manganese, and iron are reported. It is shown that the iron and manganese leaching follow a shrinking core kinetic model due to the formation of insoluble metal salts/oxides on the solid surface. This is supported by: (i) the decrease in iron and manganese extraction from synthetic Fe(III)-Mn(IV)-Zn(II) oxide mixtures with increase in acid concentration from 1 M to 2 M, and (ii) the low iron dissolution and re-precipitation of dissolved manganese and zinc during prolonged leaching of battery scrap with low sulfur dioxide.

Cheng, Tan, 2006

Original title:	Reduction of CO_2 concentration in a zinc/air battery by absorption in a rotating packed bed
Translation:	N/A
Author:	Hsu-Hsiang Cheng, Chung-Sung Tan
Institution:	National Tsing Hua University, Hsinchu, Taiwan
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources,* v. 162, no. 2, p. 1431, 2006
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The reduction of CO_2 concentration in a gas stream containing 500 ppm of CO_2 by a technique combining chemical absorption with Higee (high gravity) was investigated in this study. Using a 2.0 L aqueous amine-based solution to treat the feed gas with a flow rate, which varied from 12.9 to 20.6 L min-1, piperazine (PZ) was found to be more effective than 2-(2-aminoethylamino) ethanol (AEEA) and monoethanolamine (MEA) for reducing the CO_2 concentration to a level below 20 ppm. The effects of temperature, rotating speed, amine solution flow rate, and gas flow rate on the removal efficiency of CO_2 were systematically examined. The results indicated that the proposed compact device could effectively reduce CO_2 to a level below 20 ppm, as required by a zinc/air battery, for a long period of time using PZ and its mixture with AEEA and MEA as the absorbents.

Fisher, Wallén, Laenen, Collins, 2006

Original title:	Battery Waste Management Life Cycle Assessment
Translation:	N/A
Author:	K. Fisher, E. Wallén, P.P. Laenen, M. Collins
Institution:	
Editors:	
Publisher:	UK Department for Environment, Food and Rural Affairs (Defra)
Place, Year:	UK, 2006
ISBN/ISSN:	
Kind of publication:	Report
Additional information:	

In 2004, the EU produced a draft, *Directive on Batteries and Accumulators.* The draft directive includes a number of requirements:

- a partial ban on portable nickel-cadmium batteries (with some exclusions);
- a collection target of 25% of all spent portable batteries 4 years after transposition of the Directive;
- a collection target of 45% of all spent portable batteries 8 years after transposition of the Directive; and
- recycling targets for collected portable batteries of between 50% and 75%.

The present study was conducted to inform readers of the costs and benefits of various alternatives for implementing the collection and recycling requirements set forth by the Directive in the UK. The approach used in the study was a lifecycle assessment (LCA) followed by an economic valuation of the options. The LCA methods utilized comply with those laid down in international standards (ISO14040).

The study was commissioned by the UK Department for Environment Food and Rural Affairs (Defra). The purpose of the study was to assist in the formulation of policy by estimating the financial cost of using different methods of collection and recycling and by estimating the environmental return for that expenditure. Findings are to be used to inform the development of a regulatory impact assessment (RIA) for the implementation of the proposed Directive in the UK.

Based on ISO 14040 (standard for LCA), the study was critically reviewed by a third party.

To compare options for implementing the proposed Directive on Batteries and Accumulators, the study considered the environmental impacts associated with the management of forecast consumer portable battery waste generation in the UK from 2006 to 2030. This included the collection and recycling of every type of portable battery, excepting industrial and automotive batteries.

The assessment included the collection, sorting, recycling, and the management of the residual waste of the used batteries. Any impact associated with the production and use of batteries was excluded from the study. Consequently, the options compared differ only in method of collection and subsequent treatment or recycling. Three collection scenarios were evaluated. These collection scenarios were matched with three scenarios describing the main alternative options for recycling alkaline and saline batteries. These batteries account for more than 80% of battery sales in the UK.

A total of nine scenarios were developed. The scenarios were compared with a tenth scenario, a baseline. The baseline assumed that all batteries were managed as residual waste (89% landfill, 11% incineration).

For each of the scenarios evaluated, all of the materials, chemicals, and energy consumed during the manufacture of collection containers, sorting of batteries into separate types and processing for recycling or disposal were identified, along with the emissions to the environment at each stage. All flows were quantified and followed back to the point of extraction of raw materials necessary to produce them. Any avoided flows that resulted from the recovery of metals in recycling processes (and reducing the need for virgin metals production) also were quantified.

The total flows of each substance were compiled for each stage of the lifecycle and used to assess the environmental impacts of each system.

Information on the materials and energy requirements for collection, sorting, and recycling operations (including material recovery) was provided by members of the battery waste management industry. Published lifecycle inventory data were used to describe the production (and avoided production) of these material and energy inputs. A key limitation of the study was the use of secondary data in this manner.

Results

The study showed that increasing recycling of batteries is beneficial to the environment, due to the recovery of metals and avoidance of the consumption of virgin metal. However, this benefit is achieved at significant financial cost when compared with land disposal.

Estimates show that implementation of the proposed Directive on Batteries and Accumulators will result in a significant increase in the costs associated with the management of used batteries, with some savings in the financial costs quantified for environmental and social aspects. At the same time, the CO2 savings that can be achieved amount to between 198 kg and 248 kg of CO2-equivalents avoided per ton of battery waste, when compared with current management processes.

The present study found that the relative performance of different scenarios is mainly dictated by the choice of the recycling scenario. Scenarios sharing the same recycling scenario show more similarity in profile than those with the same collection scenario. Different recycling scenarios are favored in each impact category, with no clear overall high performer.

Summary of the critical review

The critical review concluded that:

- The methods used for the study were consistent with international standards (ISO 14040ff).
- The methods used for the study were scientifically valid and reflected the state of the art for LCA.
- Considering the goals of the study, the data used were adequate, appropriate, and consistent.
- The consistency of the interpretations with regard to the goals and the limitations of the study was regarded to be fully fulfilled.
- The report was certified to have a good transparency and consistency.
- Overall, the critical review concluded that the study was carried out in accordance with the requirements of the international standards ISO 14040ff.

Mantuano, Dorella, Elias, Mansur, 2006

Original title:	Analysis of a hydrometallurgical route to recover base metals from spent rechargeable batteries by liquid-liquid extraction with Cyanex 272
Translation:	N/A
Author:	Danuza Pereira Mantuano, Germano Dorella, Renata Cristina Alves Elias, Marcelo Borges Mansur
Institution:	Universidade Federal de Minas Gerais, Belo Horizonte, Brazil
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v. 159, no. 2, p. 1510, 2006
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

A hydrometallurgical route is proposed to recover zinc and manganese from spent alkaline batteries in order to separate base metals such as nickel, copper, aluminum, cadmium, lithium, and cobalt, which constitute the main metallic species of spent Ni-Cd, Ni-MH, and Li-ion rechargeable batteries. The route comprises the following main steps: (1) sorting batteries by type; (2) battery dismantling to separate the spent battery dust from plastic, iron scrap and paper; (3) leaching of the dust with sulfuric acid; and (4) metal separation by a liquid-liquid extraction using Cyanex 272 (bis-2,4,4-trimethylpentyl phosfinic acid) as extractant. The metal content of Ni-Cd, Ni-MH, and Li-ion batteries from three distinct manufacturers has been evaluated. A factorial design of experiments was used to investigate the leaching step using operational variables such as temperature, H_2SO4 concentration, S/L ratio, and H_2O_2 concentration. Analysis of metal separation by the liquid-liquid extraction with Cyanex 272 identified a pH1/2 2.5-3.0 for zinc and aluminum, pH1/2 4.0-4.5 for manganese, cadmium, copper and cobalt, pH1/2 6.5 for nickel, and pH1/2 8.0 for lithium. These results indicate that batteries must be previously sorted by type and treated separately. In addition, data fitting to an equilibrium model proposed for the reactive test system by the European Federation of Chemical Engineering (EFChE) have indicated that MR2(RH)2 and MR2 complexes (where M=Zn, Mn, Co, Cd and Cu) co-exist in the organic phase with Cyanex 272 depending on the loading conditions. The route has been found technically viable to separate the main metallic species of all batteries considered in this study.

Sathaiyan, Nandakumar, Ramachandran, 2006

Original title:	Hydrometallurgical recovery of silver from waste silver oxide button cells
Translation:	N/A
Author:	N. Sathaiyan, V. Nandakumar, P. Ramachandran
Institution:	Central Electrochemical Research Institute, Karaikudi, India
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v. 161, no. 2, p. 1463, 2006
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In recent years, recycling of household batteries has attracted much attention, mainly with respect to environmental aspects in addition to the savings. Small silver oxide primary cells used in electric watches become a waste after their life is over. Recycling procedures are needed to prevent any environmental impact from these wastes and to recover the value inherent in the scrap. Smelting and electrolytic methods are discussed for silver recovery from this battery waste. Acid leaching of waste batteries and precipitation of silver as silver chloride followed by smelting at 1000°C yields a silver recovery of about 83%. An electrolytic route is studied as an alternative to the smelting operation and involves the electrodeposition of silver with higher purity from a silver thiosulfate complex prepared from silver chloride. The electrolysis is potentiostatically controlled at a potential of -0.400 to -0.600 V (SCE) for avoiding side-reactions such as the sulfiding of silver. Although recovery methods have been identified in principle, their suitability for mixed small battery waste and economic factors have yet to be demonstrated.

Yasuda, Tanaka, 2006

Original title:	Report on hazardous household waste generation in Japan
Translation:	N/A
Author:	Kenji Yasuda, Masaru Tanaka
Institution:	Okayama University, Okayama, Japan
Editors:	
Publisher:	
Place, Year:	*Waste Management and Research,* v. 24, no. 4, p. 397, 2006
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Surveys of over 2000 households in Japan were conducted to investigate the characteristics of hazardous household waste (HHW) generation. In Japan, about 2.5 to 4.3 kg of HHW are produced per tonne of the residential waste stream. The percentage of used batteries in HHW was over 50%. Every household using spray (aerosol) cans had more than seven cans on average. The generation of HHW, in terms of both quantities and type of waste produced, appeared to vary with dwelling type. Detached dwelling residents tended to store HHW such as used batteries, whereas apartment residents tended not to store waste. The amounts of discarded HHW were larger at the end of the year in comparison with other months. The data accumulated were used to estimate the quantities of HHW disposed of annually, and the quantities and type of waste that might be received by a typical depot collection program in Japan.

Lau, Cheung, Kwong, Wan, Choy, Leung, Porter, Hui, McKay, 2005

Original title:	Removal of batteries from solid waste using trommel separation
Translation:	N/A
Author:	S.T. Lau[a], W.H. Cheung[a], C.K. Kwong[a], C.P. Wan[a], K.K.H. Choy[a], C.C. Leung[b], J.F. Porter[a], C.W. Hui[a], G. McKay[a]
Institution:	[a] Hong Kong University of Science and Technology, Kowloon, Hong Kong; [b] Green Island Cement Co. Ltd., New Territories, Hong Kong
Editors:	
Publisher:	
Place, Year:	*Waste Management*, v. 25, no. 10, p. 1004, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

This paper describes the design and testing of a trommel for separation of batteries from solid waste. A trommel is a cylindrical separation device that rotates and performs size separation. It has also been used in areas such as municipal solid waste (MSW) processing, classifying construction and demolition debris, screening mass-burn incinerator ash, and compost processing. A trommel has been designed based on size separation to separate household batteries from solid waste, which can then be used as feedstock for alternative applications of solid waste combustion, particularly where the metal content of the product is also a critical parameter, such as the Co-Co process for integrated cement and power production. This trommel has been tested with batches of university office and restaurant wastes against various factors. The recovery efficiency of batteries increases with decreasing inclination angle of the trommel and decreasing rotational speed. A physical characterization of the university solid waste has been performed with a 20-kg sample of the tested waste. It was found that there is a trend of decreasing recovery of batteries with increasing paper composition, and a trend of increasing recovery of batteries with increasing organic materials composition.

Lindberg, Southworth, Bogle, Blasing, Owens, Roy, Zhang, Kuiken, Price, Reinhart, Sfeir, 2005

Original title:	Airborne Emissions of Mercury from Municipal Solid Waste. I: New Measurements from Six Operating Landfills in Florida
Translation:	N/A
Author:	S.E. Lindberg, G.R. Southworth, M.A. Bogle, T.J. Blasing, J. Owens, K. Roy, Hong Zhang, T. Kuiken, J. Price, D. Reinhart, H. Sfeir
Institution:	Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
Editors:	
Publisher:	
Place, Year:	*Journal of the Air & Waste Management Association*, v. 55, no. 7, p. 859, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Mercury-bearing material enters municipal landfills from a wide array of sources, including fluorescent lights, batteries, electrical switches, thermometers, and general waste; however, the fate of mercury (Hg) in landfills has not been widely studied. Using automated flux chambers and downwind atmospheric sampling, the primary pathways of Hg vapor releases to the atmosphere at six municipal landfill operations in Florida were quantified. These pathways included landfill gas (LFG) releases from active vent systems, passive emissions from landfill surface covers, and emissions from daily activities at each working face (WF). The WFs at two sites with known Hg sources were spiked; these were readily detected downwind, and were used to test emission modeling approaches. Gaseous elemental mercury (Hg0) was released to the atmosphere at readily detectable rates from all sources measured; rates ranged from similar to 1-10 ng m-2 hr-1 over aged landfill cover, from similar to 8-20 mg/hr from LFG flares (LFG included Hg0 at ug/m^3 concentrations), and from similar to 200-400 mg/hr at the WF. These fluxes exceed earlier published estimates. Attempts to identify specific Hg sources in excavated and sorted waste indicated few readily identifiable sources; because of effective mixing and diffusion of Hg0, the entire waste mass acts as a source. It was estimated that atmospheric Hg releases from municipal landfill operations in the state of Florida are on the order of 10-50 kg/yr, substantially larger than original estimates, but still a small fraction of current overall anthropogenic losses.

Slack, Gronow, Voulvoulis, 2005

Original title:	Household hazardous waste in municipal landfills: Contaminants in leachate
Translation:	N/A
Author:	R.J. Slack[a], J.R. Gronow[b], N. Voulvoulis[a]
Institution:	[a] Imperial College, London, UK; [b] Environment Agency, London, UK
Editors:	
Publisher:	
Place, Year:	*Science of the Total Environment*, v. 337, no. 1, p. 119, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Household hazardous waste (HHW) includes waste from a number of household products such as paint, garden pesticides, pharmaceuticals, photographic chemicals, certain detergents, personal care products, fluorescent tubes, waste oil, heavy metal-containing batteries, wood treated with dangerous substances, waste electronic and electrical equipment, and discarded CFC-containing equipment. Data on the amounts of HHW discarded are very limited and are hampered by insufficient definitions of what constitutes HHW. Consequently, the risks associated with the disposal of HHW to landfill have not been fully elucidated. This work has focused on the assessment of data concerning the presence of hazardous chemicals in leachates as evidence of the disposal of HHW in municipal landfills. Evidence is sought from a number of sources on the occurrence in landfill leachates of hazardous components (heavy metals and xenobiotic organic compounds [XOC]) from household products and the possible disposal-to-emissions pathways occurring within landfills. This review demonstrates that a broad range of xenobiotic compounds occurring in leachate can be linked to HHW, but further work is required to assess whether such compounds pose a risk to the environment and human health as a result of leakage/seepage or through treatment and discharge.

Veloso, Rodrigues, Ferreira, Magalhães, Mansur, 2005

Original title:	Development of a hydrometallurgical route for the recovery of zinc and manganese from spent alkaline batteries
Translation:	N/A
Author:	Leonardo Roger Silva Veloso, Luiz Eduardo Oliveira Carmo Rodrigues, Daniel Alvarenga Ferreira, Fernando Silva Magalhães, Marcelo Borges Mansur
Institution:	Universidade Federal de Minas Gerais, Belo Horizonte, Brazil
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v. 152, no. 1-2, p. 295, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

A hydrometallurgical route is proposed in this paper for the selective separation of zinc and manganese from spent alkaline batteries. The recycling route comprises the following steps: (1) batteries dismantling to separate the spent batteries dust from other components (iron scrap, plastic and paper), (2) grinding of the batteries dust to produce a black homogeneous powder, (3) leaching of the powder in two sequential steps, 'neutral leaching with water' to separate potassium and produce a KOH solution, followed by an 'acidic leaching with sulfuric acid' to remove zinc and manganese from the powder, and (4) selective precipitation of zinc and manganese using the KOH solution (pH around 11) produced in the neutral leaching step. For the acidic leaching step, two alternative routes have been investigated (selective leaching of zinc and total leaching) with regard to the following operational variables: temperature, time, sulfuric acid concentration, hydrogen peroxide concentration, and solid/liquid ratio. The results obtained in this study have shown that the proposed route is technically simple, versatile, and provides efficient separation of zinc and manganese.

Boomfield, Davies, Bellamy, Carpenter, Hazell, Sellwood, Frith, Morrey, Harrison, Thomas, Gladding, Postle, Thurgood, 2004

Original title:	Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes
Translation:	N/A
Author:	M. Boomfield, J. Davies, N. Bellamy, R. Carpenter, C. Hazell, D. Sellwood, P. Frith, M. Morrey, R. Harrison, S. Thomas, T. Gladding, M. Postle, M. Thurgood
Institution:	Enviros, University of Birmingham
Editors:	
Publisher:	UK Department for Environment, Food and Rural Affairs (Defra)
Place, Year:	UK 2004
ISBN/ISSN:	
Kind of publication:	Report
Additional information:	

The authors of the report point out that about 430 million tonnes of waste are produced in the UK each year. Of this, approximately 29 million tonnes or about 7% is municipal solid waste (MSW). Municipal solid waste includes waste materials generated in the home, in schools, in shops, and in small businesses. A substantial amount of information in this report applies to the management of commercial and industrial waste streams. The report indicates that approximately 75% of the UK's MSW is disposed directly in landfills. Reuse and recycling (including composting) account for an additional 13% of the treatment method for municipal solid waste. The rest of the MSW is treated, mostly by incineration (approximately 9% of municipal solid waste). The remaining 1 % is treated using a variety of new or methods which include gasification/pyrolysis, mechanical biological treatment (MBT), and anaerobic digestion. The report, considered the potential effects of these management options, as well as the potential effects of transporting over 80,000 tonnes of municipal solid waste per day.

In the study, the effects of the particular facilities were investigated. Indirect effects, such as the benefits of avoiding use of raw materials by recycling were not part of the scope of work.

The review concluded that the effects on health from emissions from incineration, largely to air, are likely to be small in relation to other known risks to health.

In the study, an extensive search and review of the available literature relating to waste management activities was conducted. The literature review covered the following areas:

- studies, reports and information from MSW facility operators containing emissions data;
- studies and reports investigating the occurrence of health effects near municipal solid waste management facilities; and
- studies and reports investigating environmental impacts close to municipal solid waste management facilities.

The quality of the information was rated on a scale from poor, through moderate and good, to very good.

The review also addressed the effects on the wider environment. The most important in this context is the contribution that emissions from landfill make to emissions of methane. The review also indicated that odors from landfill can be important, and that measures to capture and use landfill gas could alleviate both of these potential problems. The review also reported that there was insufficient evidence of other environmental effects due to waste management.

The contributions of municipal solid waste to air emissions of methane (27% of total in the UK) and cadmium (about 10% of the total in the UK) are well known to primarily originate from landfills. This is one of the reasons why government policy is moving away from the option to dispose of wastes in landfills. With these exceptions, the management of MSW accounts for less than 2.5% of all other emissions for which data are available (including carbon dioxide and toxic gases). These conclusions mean that the overall scale of direct effects of releases to air from waste management practices is relatively small compared to emissions from other sectors such as transport. The review consisted of an assessment of the existing literature, coverage was limited by the availability of evidence; consequently, some areas of the science were analyzed in more depth than others. As such, there were some gaps and uncertainties in the evidence base.

Some of the areas where there is less work and the science is less certain include: releases to soil and water and releases from composting, or other forms of waste management like mechanical biological treatment or anaerobic digestion. One important study that is mentioned in this repot indicated an association between birth defects and proximity to landfill sites. The authors of that study were clear, however, that the association reported in this study does not demonstrate a causal relationship, and the current review reflects this. It would be desirable if additional studies were carried out to identify the non-waste related factors which may influence this association.

The authors of the present study indicate that it is necessary to undertake further research to reduce or remove these uncertainties, and to fill gaps highlighted by the review as missing from the current literature.

The Royal Society highlighted advantages offered by Life Cycle Analysis in extending the range and scope of comparative analyses available. Life Cycle Analysis is of particular relevance in recycling, and should be incorporated in future research design on this issue.

The main findings of the study were as follows:

- Methane and carbon dioxide are the two emitted substances which may significantly influence global warming.

- Approximately 150 million tonnes (MT) of CO2 are released in the UK every year. Management of municipal solid waste accounted for 3.6 MT (or 2.4% of the national total). Other major contributors include: electricity generation (42 MT; 28.5% of the national total); and transport (21% of the national total). These figures are of moderate or good quality.

- In the UK about 2.4 MT of methane are released every year. Emissions from MSW in landfill sites account for 0.7 MT (27% of the national total). These figures are considered of moderate or poor quality. Another important contributor is agriculture, which accounts for an estimated 1.0 MT (about 40% of the UK total).

- Benzene is a substance of concern because it can cause cancer. The work determined that less than 0.02% of UK emissions are due to municipal solid waste operations (this figure is of moderate quality). Transport is the main source of benzene, accounting for 47% of all emissions in the UK.

- A number of people are concerned about emissions of dioxins and furans. The development of the reproductive system of male offspring seems to be particularly sensitive to exposure to dioxins before birth. Dioxins are associated with other developmental and reproductive effects, and the immune system is also potentially sensitive. UK expert committees regard dioxins as a probable human carcinogens. This study determined that dealing with municipal solid waste accounts for about 1% of UK emissions of dioxins, shared approximately equally between incineration and emissions from the combustion of landfill gas. This figure is judged of poor quality because of uncertainty over dioxin emissions from other sources. Domestic sources such as cooking and burning coal for heating are the UK's single largest source of dioxins, accounting for about 18% of emissions. Transport accounts for about 3% and electricity generation about 4% of the total. Several other sources contribute to emissions of dioxins to a similar or greater extent: accidental vehicle fires; fireworks and bonfires; small-scale waste burning (for example on building sites); incineration of other wastes; as well as the iron and steel industry.

- Nitrogen dioxide is a substance of concern, particularly related to air quality in urban areas. Emissions of NOx contribute to acid rain, and excessive levels of nitrogen which can be harmful to some sensitive habitats. The management of MSW results in emissions of about 10,000 tonnes of oxides of nitrogen per year. Oxides of nitrogen form nitrogen dioxide in the atmosphere. This amount is less than 1% of the UK total – the main contributors to these emissions are electricity generation (24%) and road traffic

(42%) (these values are considered to be of moderate quality). Emissions of oxides of nitrogen and other substances from incineration of municipal solid waste are the most tightly controlled of all waste management processes.

- Metals emitted to the air have a range of possible health effects. Dealing with MSW accounts for about one tenth of UK emissions of cadmium (a substance associated with cancer of the lungs, throat and prostate, reproductive effects and kidney disease). The major portion of the cadmium emitted from facilities dealing with MSW comes from landfill sites. Municipal solid waste accounts for lower proportions of UK emissions of other substances. The iron and steel industry is the main source of emissions of most heavy metals (for example mercury, arsenic, lead, cadmium). The numerical values are of moderate or poor quality. Other important sources include:

    – lead emissions from the processing of non-ferrous metals;

    – burning coal in industrial facilities for electrical energy generation as well as for heating, which is an important source of arsenic emissions; and

    – road traffic, which is an important source of mercury. The manufacture of chlorine from mercury cells, non-ferrous metal production and coal combustion also are important sources.

- Although there was less information available, the study also evaluated emissions to groundwater and surface water. The substances investigated included nitrogen (which can promote the growth of unwanted algae); organo-tin compounds (which can affect fish and shellfish), phosphates, pentachlorophenol, copper, tin and lead. Information on these emissions is less widely available, and the study's estimates in this area were only of poor quality.

Some facilities (anaerobic digestion, pyrolysis/gasification, incineration, and landfill) include the generation of electrical energy. This means that the generation of electricity from other sources would be avoided.

The study reviewed available information on the health and environmental effects of waste management. While the information is not complete and not ideal, the evidence from studies conducted thus far is that present-day practice for managing MSW has, at most, a minor effect on human health and on the environment. This should be viewed in the light of the benefits of collection and disposal of the waste that we all generate. If waste were not collected, treated and disposed, it would become a source of disease, odors, litter and pests.

The authors of the study suggest that efforts continue to be made to reduce the amount of MSW generated. The government, regulators and the waste management industry should continue to be vigilant and improve their understanding of the effects of MSW management, so that this industry can be better regulated and controlled.

Specifically, the authors recommended that a number of additional studies would be helpful in improving the present level of understanding of the health and environmental effects of waste management. The most important areas to investigate are:

- a field study of population exposure to substances emitted from landfill sites;
- a study to improve current understanding of releases of microorganisms from all types of waste management facilities;
- a study to improve present understanding of releases of particulates, microorganisms, VOCs and methane from composting of MSW; and
- a study to improve our understanding of releases from MBT and anaerobic digestion of MSW.

De Souza, Tenorio, 2004

Original title:	Simultaneous recovery of zinc and manganese dioxide from household alkaline batteries through hydrometallurgical processing
Translation:	N/A
Author:	Cleusa Cristina Bueno Martha De Souza, Jorge Alberto Soares Tenorio
Institution:	University of São Paulo, São Paulo, Brazil
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v. 136, no. 1, p. 191, 2004
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

This paper describes the leaching experiments and the electrowinning tests conducted to recover Zn and Mn from spent household alkaline batteries. After the dismantling of the batteries, the black powder was analyzed and found to contain 21% wt. Zn and 45% wt. Mn. Therefore, it was considered that recovery of these metals would be interesting due to their relatively large amounts in this kind of waste. Batch laboratory experiments were carried out to develop an acid leaching procedure and to determine appropriate leaching conditions to maximize zinc extraction and to study the leaching behavior of Mn. An experimental study was undertaken to evaluate the feasibility of simultaneous recovery of zinc and particulate manganese dioxide using a laboratory cell. The results from these electrowinning experiments are also presented in this paper.

Dondelinger, 2004

Original title:	Batteries: From Alkaline to Zinc-Air
Translation:	N/A
Author:	Robert M. Dondelinger
Institution:	U.S. Mil. Entrance Proc. Command, Chicago, Illinois, USA
Editors:	
Publisher:	
Place, Year:	*Biomedical Instrumentation and Technology*, v. 38, no. 2, p. 100, 2004
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

There is no perfect disposable battery - one that will sit on the shelf for 20 years, then continually provide unlimited current, at a completely constant voltage until exhausted, without producing heat. There is no perfect rechargeable battery - one with all of the above characteristics and one that will also withstand an infinite overcharge while providing an equally infinite cycle life. There are only compromises. Every battery selection is a compromise between the ideally required characteristics, the advantages, and the limitations of each battery type. General selection of a battery type to power a medical device is largely outside the purview of the biomed. Initially, these are engineering decisions made at the time of medical equipment design and are intended to be followed in perpetuity. However, since newer cell types evolve and the manufacturers' literature is fixed at the time of printing, some intelligent substitutions may be made as long as the biomed understands the characteristics of both the recommended cell and the replacement cell. For example, when the manufacturer recommends alkaline, it is usually because of the almost constant voltage it produces under the devices' design loads. Over time, other battery types may be developed that will meet the intent of the manufacturer, at a lower cost, providing longer operational life, at a lower environmental cost, or with a combination of these advantages. In the Obstetrical Doppler, the user had put in alkaline cells, and the biomed had unknowingly replaced them with carbon-zinc cells. If the alkaline cells recommended by the manufacturer had been used, there would have been the proper output voltage at the battery terminals when the cells were at their half-life. Instead, the device refused to operate since the battery voltage was below presumed design voltage. While battery-type substitutions may be easily and relatively successfully made in disposable applications (for example, zinc-air for alkaline if it is cost effective), this is absolutely forbidden for secondary cells. Because of the differing cell voltages, charge characteristics and overcharge tolerance between different types of secondary cells, substituting a nickel-cadmium battery pack for the more expensive lithium-ion pack (if it is physically able to fit into the battery compartment) might appear to save money (e.g. US$50 vs. US$100), but it would be very ill advised. Since the cell characteristics are very different, it would be fatal to anyone within the 'kill radius' when the pack explodes. Those outside the kill radius would receive chemical burns from the electrolyte. Substitutions of secondary cell battery packs are generally not a good idea for biomeds to engage in. These are engineering decisions best left to either aftermarket battery pack manufacturers or the medical device manufacturer as a design engineering change.

O’Brien, 2004

Original title:	The Effectiveness of Municipal Solid Waste Landfills in Controlling Releases of Heavy Metals to the Environment
Translation:	N/A
Author:	Jeremy O’Brien
Institution:	Solid Waste Association of North America (SWANA)
Editors:	
Publisher:	SWANA
Place, Year:	United States, March 2004
ISBN/ISSN:	
Kind of publication:	Report
Additional information:	

This report presents the results of a research project that evaluated the effectiveness of landfills in controlling releases of heavy metals from municipal solid waste into the environment.

Recently, there has been a growing movement to ban certain products from disposal in MSW landfills due to the potential release of heavy metals contained in these products into the environment. In response to this concern, the Applied Research Foundation's Disposal Group of SWANA decided that there was a need to summarize and document what is known concerning environmental releases of heavy metals related to the disposal of these products in landfills.

The purpose of the report was to provide the most current scientific and technical information on the effectiveness of MSW landfills in controlling releases of heavy metals to the environment due to the disposal of products containing heavy metals in MSW landfills. This report presents data, findings, and conclusions based on a review of the published literature and ongoing research related to this topic.

Heavy metals in municipal solid waste

The "Resource Recovery and Conservation Act" (RCRA) was enacted in the United States in 1976 to address the management and disposal of municipal and industrial solid wastes. The act sets specific groundwater limits for some metals and metalloids. RCRA heavy metals include arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. These metals are the focus of this report.

The report indicates that approximately 130,200 tons of RCRA heavy metals were disposed in MSW landfills in the United States in the year 2000. This quantity represents 0.08% of the 162 million tons of MSW that were disposed in the same year. Lead, at 127,108 tons represents the major fraction (97.6%) of the RCRA heavy metals being disposed of in MSW landfills on an annual basis, followed by cadmium (2,680 tons or 2.1%) and mercury (383 tons or 0.3%).

Available information indicates that the relative fractions of products containing heavy metals in the waste stream are changing. For instance, the contribution of lead-acid batteries to the levels of lead in MSW seems to be declining, while lead contributions from discarded consumer electronic products appear to be increasing. Available data also indicate that, despite the dramatic increase in the disposal of discarded consumer electronics in recent years, the quantities of heavy metals disposed in MSW landfills have decreased over the last 15 years primarily due to the recycling of lead-acid batteries.

Heavy metals in leachate from MSW landfills

The concentrations of heavy metals in leachate vary over a wide range, depending on a number of factors, including waste composition, landfill age, and the availability of moisture.

On average, the concentrations of heavy metals in leachate have been reported in numerous recent studies to be relatively low.

For example, a draft database was developed for the U.S. Environmental Protection Agency (EPA) entitled "LEACH 2000" that includes data for leachate from over 200 MSW landfills. The data show that the mean concentrations of the RCRA heavy metals were relatively low, averaging less than 1 milligram per liter in all cases.

The "Toxicity Characteristic Leaching Procedure" (TCLP) is a test prescribed by the federal government used to determine whether or not a solid waste should be classified as hazardous. The mean concentrations of RCRA heavy metals reported in the LEACH 2000 database for non-hazardous waste landfills were at least 10 times less than the regulatory levels determined by the TCLP. In addition, the "90th Percentile" leachate values for RCRA heavy metals (values for which 90% of the data points are equal to or below) are all lower than the TCLP regulatory levels.

A study conducted at the University of Central Florida in 1997 to characterize leachate from MSW landfills in Florida found the average concentrations of the RCRA heavy metals to be low, and "generally on the order of micrograms per liter."

This research effort reviewed five studies representing all published investigations regarding leachate characteristics. The reviews are summarized in the report. All of these studies concluded that heavy metal concentrations in leachate are, on average, relatively low.

The EPA confirmed the findings of recent studies regarding the low levels of heavy metals in leachate in December 1999 when it published final effluent limitation guidelines, pretreatment standards, and new source performance standards for the landfill's point source category. Effluent limitation guidelines are U.S. government regulations that establish restrictions on the discharge of pollutants to surface waters or to publicly owned treatment works (POTWs) by specific categories of industries.

In the establishment of final effluent guidelines, the EPA concluded that national pretreatment standards were not necessary for landfills. The EPA found that POTWs adequately treated pollutants in landfill wastewater and only a very small quantity of pollutant loads discharged by landfills to POTWs are further discharged to rivers, streams, or estuaries. The EPA concluded that wastewater discharges from landfills do not cause operational problems at POTWs. Based on these findings, national pretreatment standards were not established for RCRA heavy metals or any other pollutants in MSW landfill leachate. Furthermore, the EPA did not establish direct discharge limits for any of the RCRA heavy metals for MSW landfill leachate that is directly discharged to receiving waters following on-site treatment at the landfill.

The mean concentrations reported in the LEACH 2000 database for MSW landfills were also compared with two national standards: Maximum Contaminant Levels in Groundwater and Drinking Water Standards.

EPA Groundwater Maximum Contaminant Levels (MCLs) -- The EPA established MCLs for allowable concentrations of RCRA heavy metals in groundwater for MSW landfills that are designed with alternative liner systems. In comparison to these MCLs, the LEACH 2000 mean concentrations for RCRA heavy metals are all less than 10 times higher than their respective MCL limits. In the case of barium, the mean concentration is less than the MCL established for barium. The Mn is measured at the "relevant point of compliance" (i.e., a location that is required to be not more than 150 meters from the boundary of the waste management unit. The EPA established the MCL limits by assuming that the TCLP maximum concentrations would be "diluted and attenuated" (and therefore reduced) by a factor of 100 before reaching the relevant point of compliance. Applying the same dilution and attenuation factor (DAF) to the LEACH 2000 mean concentrations, it is apparent that the RCRA heavy metals in leachate would most likely be diluted and/or attenuated to comply with their respective MCLs before any uncontained or uncollected landfill leachate reached the relevant point of compliance.

U.S. Drinking Water Standards - The primary drinking water standards for the United States are among the highest standards for potable water in the world. In the report, the mean RCRA heavy metal concentrations in leachate (collected at the bottom of MSW landfills) are compared to the primary drinking water standards which are required to be met "at the tap" by public water supply systems in the United States. It is noteworthy that all of the average concentrations of the LEACH 2000 for RCRA heavy metals are less than 10 times higher than the drinking water standards established for these metals. Furthermore, the mean concentration for barium (0.866 mg/l) is less than the drinking water standard for barium (2 mg/l), while the mean concentration for selenium (0.0585 mg/l) is only slightly higher than the drinking water standard for selenium (0.05 mg/l).

The present regulatory framework for water pollution control, allows a local government to establish pretreatment standards, based on local conditions, for industrial wastewaters such as landfill leachate that are discharged for treatment to a local POTW. The objectives of local pretreatment standards are to prevent pass-through of pollutants to receiving water bodies, interference with treatment plant operations, and to improve opportunities to recycle and reclaim wastewater and sludges.

Based on data from research and from the database representing many samples from hundreds of MSW landfills, the average concentrations of RCRA heavy metals in MSW landfill leachate were found to be significantly lower than the TCLP regulatory levels. The average RCRA heavy metal concentrations in MSW leachate were in compliance with the final effluent limitation guidelines and the national pretreatment standards set by the EPA in 1999 for the landfill's point source category. When compared with drinking water standards, average concentrations for RCRA heavy metals in leachate (from the bottom of an MSW landfill) were found to be less than 10 times higher than the drinking water standards and, for one metal, were found to meet drinking water standards. Finally, average RCRA heavy metal leachate concentrations were found to meet local pretreatment standards without leachate treatment except in cases where stringent pretreatment standards had been established for specific metals.

Attenuating mechanisms in MSW landfills that limit the leaching of RCRA heavy metals include: (1) the formation of relatively insoluble heavy metal precipitates due to the presence of sulfide, carbonate, and hydroxide ions; and (2) the adsorption and/or absorption of the heavy metals within the waste mass.

Theoretically, the concentrations RCRA heavy metals in leachate could increase over very long periods of time following the closure of a landfill if the landfill liner systems are breached and air re-enters the landfill, enabling aerobic decomposition processes to be reinitiated. This scenario would require the restoration and sustainment of a viable aerobic microbial consortium, with continuing availability of oxygen and nutrients. Computer modeling, and limited laboratory investigations, regarding this long-tem risk have indicated that mobilization of heavy metals from closed landfills, if it does occur, is not likely to occur within a very long timeframe.

Heavy metals in MSW landfill gas

Data from several studies of landfill gas indicate that the quantities of heavy metals in landfill gas also are relatively low. For example, in a study conducted at the Central Solid Waste Management Center Landfill of the Delaware Solid Waste Authority, mercury concentrations were found in the range of nanograms per cubic meter.

The same attenuating mechanisms that limit the leaching of heavy metals in landfills including: reducing conditions, neutral pH, and presence of sulfides also limit the release of significant gas phase metals (including metallic or methylated mercury). Additionally, the low vapor pressures for all metals except mercury also are limiting factors.

The low quantities of heavy metals contained in landfill gas are evidenced by the fact that, in its issuance of "National Emission Standards for Toxic Air Pollutants" for MSW landfills in 2003, the US EPA did not establish standards for any of the RCRA heavy metals.

There is evidence of the presence of gaseous mercury in LFG in the range of micrograms per cubic meter. In addition, recent studies have identified both monomethyl mercury and dimethyl mercury as being constituents of the total gaseous mercury in LFG.

The report indicates that the relative amount of mercury emitted into the air by MSW landfills also is low when compared to the amounts of mercury emitted from other sources. In 1997, as required by the Clean Air Act Amendments of 1990, the EPA issued a report to Congress referred to as the "Mercury Study." This eight-volume study provides an inventory of mercury emissions to the air from a number of sources related to human activity.

The EPA estimated that, in 1994 - 1995, landfills emitted to the atmosphere a total of 70 kilograms of mercury. This quantity represented less than 0.1% of the total amount emitted from all source categories.

Effectiveness of landfill pollution control systems

Landfill liner systems substantially prevent the leaking of leachate from the landfill to the land upon which the landfill is constructed. Recent investigations have shown that these liners appear to have a "half life" of 970 years. Therefore, the integrity of the liner system can be expected to last through the timeframe when significant quantities of leachate are being generated.

Due to the effectiveness of the landfill liner systems that have been constructed with good quality assurance programs, it appears that 99% or more of the leachate generated in MSW landfills is collected and treated.

Landfills equipped with LFG collection and control systems, the combustion of gas in landfill flares or energy recovery technologies enables the conversion of methylated mercury (and other methylated metal compounds) to elemental metal forms, which, at least in the case of mercury, are much less hazardous.

Overall conclusions of the study

Based on a review of published literature and of recent studies, this report concludes that MSW landfills can provide for the safe, efficient, and long-term management of disposed products containing RCRA heavy metals without exceeding limits that have been established to protect public health and the environment. MSW landfills should contain the releases of RCRA heavy metal pollutants at levels that protect public health and the environment for extremely long periods of time if not forever.

Campanella, Dragone, Grossi, Meo, Visco, 2003

Original title:	Environmentally friendly batteries by addition of chitin
Translation:	N/A
Author:	L. Campanella, R. Dragone, R. Grossi, A.E. Meo, G. Visco
Institution:	University “La Sapienza” Roma, Rome, Italy
Editors:	
Publisher:	EDP Sciences
Place, Year:	Conference date: May 26-30, 2003
ISBN/ISSN:	
Kind of publication:	Proceedings: *XII International Conference on Heavy Metals in the Environment*, v. 107, no. 1, p. 255
Additional information:	

This paper describes the results of research performed on pen alkaline-manganese batteries with the aim of checking the possibility of minimizing the release of metals from them when, exhausted, are disposed. This goal was to tentatively look for inserting in the batteries a certain amount of chitin, which would be able to bind the metal ions formed by the natural oxidation of the metals contained in the batteries and by the acid rain dissolving action. The results obtained show that 1.2 g of chitin for each middle size pen model alkaline-manganese battery practically prevented any release of metals, without relevant change of the discharge curve of the battery. The effect of the addition is particularly marked if realized by the additive contained in a PVC membrane.

Toto, 2003

Original title:	Some batteries excluded
Translation:	N/A
Author:	Deanne Toto
Institution:	Recycling Today
Editors:	
Publisher:	
Place, Year:	*Recycling Today*, v. 41, no. 3, p. 102, 2003
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The recycling of rechargeable batteries is discussed. Many battery recycling programs make use of retail collection centers, as they are convenient for consumers and relatively economical. Ever since the Congress enacted the Mercury-Containing and Rechargeable Battery Management Act in 1996, the recycling of rechargeable batteries has increased. However, recycling of alkaline batteries lags behind other household batteries.

De Oliveira, Tenorio, 2002

Original title:	Estudo da pre-reducao do MnO_2 presente em pilhas secas e alcalinas
Translation:	Study of the pre-reduction of MnO_2 present in household batteries
Author:	Denise Correa De Oliveira, Jorge Alberto Soares Tenorio
Institution:	Universidade de São Paulo, São Paulo, Brazil
Editors:	
Publisher:	Associacao Brasileira de Metalurgia e Materiais, São Paulo, 04605-030, Brazil
Place, Year:	Date: March 19-21, 2002
ISBN/ISSN:	
Kind of publication:	Proceedings: *Anais - 10th Seminario de Metals Nao Ferrosos, p.* 339
Additional information:	

Household batteries contain elements as zinc, manganese dioxide, graphite, and possibly mercury and lead. When mixed to the municipal solid waste, this kind of residue may cause serious health problems and environmental impacts. These damages can be reduced by recovery (which means saving natural sources and energy), recycling, and adoption of cleaner technologies. The work described in this paper is part of a project on batteries recycling, and presents the efforts to study the pre-reduction of the manganese dioxide from spent household batteries. Manganese is an important micronutrient for plants, but can only be absorbed if as Mn^{2+}. In batteries, however, it is present as Mn^{+4}. Succeeding the reduction process, the MnO obtained could be possibly used in agriculture. Samples of ground batteries were treated at 900°C and 1000°C. After treatment, they were submitted to X-ray diffraction and the MnO_2 reduction was observed.

Rydh, Karlstrom, 2002

Original title:	Life cycle inventory of recycling portable nickel-cadmium batteries
Translation:	N/A
Author:	C.J. Rydh[a], J. Karlstrom[b]
Institution:	[a] University of Kalmar, Kalmar, Sweden; [b] Chalmers University of Technology, Gothenburg, Sweden
Editors:	
Publisher:	
Place, Year:	*Resources, Conservation and Recycling*, v. 34, no. 4, p. 289, 2002
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In this study, the environmental impact of recycling portable nickel-cadmium (NiCd) batteries in Sweden is evaluated. A lifecycle assessment approach was used to identify lifecycle activities with significant impact, the influence of different recycling rates and different time boundaries for emissions of landfilled metals. Excluding the user phase of the battery, 65% of the primary energy is used in the manufacture of batteries while 32% is used in the production of raw materials. Metal emissions from batteries to water originate (96%-98%) from landfilling and incineration. The transportation distance for the collection of batteries has no significant influence on energy use and emissions. Batteries manufactured with recycled nickel and cadmium instead of virgin metals have 16% lower primary energy use. Recycled cadmium and nickel metal require 46% and 75% less primary energy, respectively, compared with extraction and refining of virgin metal. Considering an infinite time perspective, the potential metal emissions are 300 to 400 times greater than during the initial 100 years. From an environmental perspective, the optimum recycling rate for NiCd batteries tends to be close to 100%. It may be difficult to introduce effective incitements to increase the battery collection rate. Cadmium should be used in products that are likely to be collected at the end of their life, otherwise collection and subsequent safe storage in concentrated form seems to offer the best solution to avoid dissipative losses.

Cuevas, Joubert, Latroche, Percheron-Guegan, 2001

Original title:	Intermetallic compounds as negative electrodes of Ni/MH batteries
Translation:	N/A
Author:	F. Cuevas, J.-M. Joubert, M. Latroche, A. Percheron-Guegan
Institution:	ISCSA-CNRS, Thiais, France
Editors:	
Publisher:	
Place, Year:	*Applied Physics B: Lasers and Optics*, v 72, no. 2, p. 225, 2001
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

This review is devoted to the main families of thermodynamically stable intermetallic compounds (AB5-, AB2-, and AB-type alloys) that have been researched in the last thirty years as materials for negative electrodes in nickel-metal hydride batteries. The crystal structure of these compounds and their hydrides is widely described. Their solid-gas hydrogenation properties and, particularly, the related desorption isotherm curves are examined as a useful criterion for the selection of suitable battery materials. The electrochemical performances obtained with these alloys are reported and the given solutions to common problems such as corrosion, passivation, decrepitation, and short cycle life are discussed. Only AB5-based compounds have achieved, up to now, enough development for being widely present on the market, and exhibit improved battery performances in comparison with the polluting Ni/Cd batteries. The high capacity of AB2-based compounds and the remarkable electrochemical activity of some AB-based alloys make; however, further research on all the reviewed families still valuable.

De Oliveira, Espinosa, Tenorio, 2001

Original title:	Study of Hg removal and Zn recovery from spent dry batteries
Translation:	N/A
Author:	Denise Correa De Oliveira, Denise Crocce Romano Espinosa, Jorge Alberto Soares Tenorio
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society, Warrendale, Pennsylvania, USA
Place, Year:	February 11-15, 2001
ISBN/ISSN:	
Kind of publication:	Proceedings*: EPD Congress 2001*, p. 167
Additional information:	

Common dry batteries use zinc as the negative electrode. Producers commonly use additives such as mercury to prevent corrosion and to increase the mechanical resistance of the zinc anode. Alkaline batteries also contain Hg, as an anti-corrosive agent. When mixed with the common municipal solid waste, heavy metals such as zinc and mercury pollute soil and groundwater supplies, moving to the food chain and affecting human health. Due to these possible damages, this kind of waste must be properly disposed, or recycled. Thus, even in low amounts (ppm) in batteries, mercury has to be eliminated or, at least, its content should be reduced. This work presents the use of pyro-metalurgical processes, to reduce mercury content and recover zinc. The tests involved batteries treatment at temperatures from 300°C to 1000°C. Mercury is eliminated up to 650°C, and zinc is evaporated at higher temperature treatment.

De Oliveira, Tenorio, 2001

Original title:	Recycling dry and alkaline batteries using mining operations
Translation:	N/A
Author:	Denise Correa De Oliveira, Jorge Alberto Soares Tenorio
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society, Warrendale, Pennsylvania, USA
Place, Year:	Conference date: February 11-15, 2001
ISBN/ISSN:	
Kind of publication:	Proceedings*: EPD Congress 2001*
Additional information:	

Household zinc based batteries, dry and alkaline, have become the most popular sources of electrical energy, and are widely used. Because of their heavy metal content such as mercury, zinc, and manganese, spent batteries cannot be directly placed in common landfills without a pretreatment. As a municipal solid waste, these batteries may cause serious health problems and environmental impacts. These damages can be reduced by recovery (which means saving natural sources and energy), recycling, and adoption of cleaner technologies. Although this worry has been increasing recently, and producers are making efforts to reduce the mercury content, batteries still need proper safe disposal conditions or recycling processes. This work presents the efforts in progress to characterize and recycle mixed - dry and alkaline - spent batteries, by using low cost unit operations. Some possible recycling stages and recovery parameters of metals as zinc and manganese are also discussed.

Antenen, Villette, 2000

Original title:	The oxyreducer technology - A new technology to recycle metal containing waste
Translation:	N/A
Author:	Adrien Antenen, Didier Villette
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society, Warrendale, Pennsylvania, USA
Place, Year:	Conference Date: October 22-25, 2000
ISBN/ISSN:	
Kind of publication:	Proceedings: *4th International Symposium on Recycling of Metals and Engineered Materials*
Additional information:	

CITRON has developed a new process for the recycling of hydroxide sludge, household batteries, catalysts, automobile shredding residues, grinding sludge, and other metal containing organic and inorganic waste. A pilot plant with a capacity of 1,000 tons per year started operations in April 1998. In August 1999, an industrial plant became operational with an initial treatment capacity of 23,000 tons.

Coya, Maranon, Sastre, 2000

Original title:	Ecotoxicity assessment of slag generated in the process of recycling lead from waste batteries
Translation:	N/A
Author:	B. Coya, E. Maranon, H. Sastre
Institution:	
Editors:	
Publisher:	
Place, Year:	*Resources, Conservation and Recycling,* v. 29, no. 4, p 291, 2000
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The aim of this study was to evaluate the possible toxicity of the leachate produced by the residues generated in the process of recycling lead from waste batteries. These residues are slag, which once formed, is characterized by its content in ferrous sulfide, sodium carbonate, as well as residual coke from the process. It also contains, as minor components, lead, and other heavy metals. The slag was stored and watered periodically over a period of 6 months, its composition changing until finally becoming inert, with no exothermal activity. The slag was leached, and its ecotoxicity was determined by means of the bioluminescence test, along with its content in heavy metals. The results obtained indicate a greater degree of toxicity in the residues with a shorter storage period than the established one, and which were therefore still in the phase of decomposition. However, in the samples taken on completing 6 months of storage, the EC sub(50) value of the leachate was found to be higher than 3000 mg/l. Hence, a storage period under suitable environmental conditions, which leads to inactivity of the residue as well as a decrease in its ecotoxicity, is considered absolutely essential. At the same time, a direct relationship was observed between the lead content and the ecotoxicity value.

Antenen, 1999

Original title:	CITRON - A new generation of recycling plant
Translation:	N/A
Author:	Adrien Antenen
Institution:	
Editors:	
Publisher:	
Place, Year:	Conference date: September 5-9, 1999
ISBN/ISSN:	
Kind of publication:	Proceedings, *Global Symposium on Recycling, Waste Treatment and Clean Technology (REWAS 1999), p. 37*
Additional information:	

CITRON, "Centre International de Traitement et de Recyclage des Ordures Nocives," has developed a new process for the recycling of heavy metal containing wastes such as hydroxide sludges, catalysts, grinding sludges, automobile shredder residues, and household batteries. A pilot plant with a capacity of 1,000 tons per year started operations in April 1998 and an industrial plant with an initial treatment capacity of 23,000 tons was under construction. It was to be commissioned in the first half of 1999.

Earle, Rhue, Earle, 1999

Original title:	Mercury in a municipal solid waste landfill
Translation:	N/A
Author:	Celia D.A. Earle, R. Dean Rhue, Jonathan F.K. Earle
Institution:	
Editors:	
Publisher:	
Place, Year:	*Waste Management and Research*, v. 17, no. 4, p. 305, 1999
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Mercury (Hg) is deposited in landfills via household batteries and a variety of other Hg-containing devices and lamps. Although Hg ranks as number three on the US Environmental Protection Agency's toxic substances list, behind lead and arsenic, it has not been the focus of significant research in landfills. This study investigated the levels of Hg present in a municipal solid waste landfill and a municipal compost material. Mercury concentrations in 106 composite samples obtained from the Alachua County, Florida landfill (USA) ranged from 32.8 to 16,800 µg kg-^{1}, with a geometric mean of 178 µg kg-^{1} and a 95% confidence interval for the mean of 144 to 221 µg kg-^{1}. The distribution was highly skewed, with over half the samples having concentrations less than 150 µg kg-^{1}; only seven had concentrations exceeding 1,000 µg kg-^{1}. Mercury concentrations in compost samples from Palm Beach County, Florida, consisting of a 1:1 mixture of biosolids and yard waste, ranged from 368 to 5,320 µg kg-^{1} with a geometric mean of 924 µg kg-^{1} and a 95% confidence interval for the mean of 686 to 1,244 µg kg-^{1}. Mercury concentrations in the landfill and compost samples were generally above the background levels reported for surface soils in Florida, but were two to three orders of magnitude lower than the clean-up goals currently recommended by the Florida Department of Environmental Protection and US federal regulations governing the land application of sewage sludge. Some municipalities have begun excavating old landfills and using the compostable material as landfill cover. If the Alachua County landfill were reclaimed, the compostable solid waste residue should meet Hg guidelines that are stricter than those currently employed for sewage sludge.

Krebs, 1999

Original title:	Recycling of household batteries and heavy metal containing wastes
Translation:	N/A
Author:	Andreas Krebs
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society
Place, Year:	Conference date: September 5-9, 1999
ISBN/ISSN:	
Kind of publication:	Proceedings*: Global Symposium on Recycling, Waste Treatment and Clean Technology (REWAS 1999), v. 2, p. 1109*
Additional information:	

Batrec AG operates an industrial plant for recycling of used dry batteries with a production capacity of 3200 tons per year. The process consists essentially of the following three process stages: (1) Pyrolysis of the organic part of the waste in the shaft furnace at temperature up to 700°C where the mercury is also evaporated. (2) Reduction of the metallic parts in the melting furnace at temperature of 1500°C. The metals are either molten (Fe, Mn, Ni) or evaporated (Zn, Pb, Cd). (3) Recovery of the gaseous metals (Zn, Pb, Cd) in the splash condenser. This technology permits treatment of hazardous waste without the formation of new waste. As a demand, it has been seen that other heavy metal containing wastes could be treated in this plant. Today Batrec AG is able to treat the most mercury contaminated wastes from dental waste to track field coverings and from sludge to contaminated scrub.

Lindberg, Price, 1999

Original title:	Airborne Emissions of Mercury from Municipal Landfill Operations: A Short-Term Measurement Study in Florida
Translation:	N/A
Author:	S.E. Lindberg, J.L. Price
Institution:	
Editors:	
Publisher:	
Place, Year:	*Journal of the Air & Waste Management Association*, v. 49, n. 5, p. 532, 1999
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Large quantities of mercury (Hg) have been placed in municipal landfills from a wide array of sources, including fluorescent lights, batteries, electrical switches, thermometers, and general waste. Despite its known volatility, persistence, and toxicity in the environment, the fate of this Hg has not been widely studied. Using automated flux chambers and atmospheric sampling, the primary pathways of Hg vapor releases to the atmosphere at two municipal landfill operations in south Florida for eight days in April 1997 was quantified. These pathways included landfill gas (LFG) releases from passive and active vent systems, passive emissions from landfill surface covers of different ages (including CH sub(4) "hot spots"), and emissions from daily activities at a working face (WF). Hg vapor was released to the atmosphere at readily detectable rates from all sources measured. Emission rates ranged from similar to 1 to 20 ng m super(-2) hr super(-1) over aged surface covers (generally comparable to background soils), from similar to 6 to 2400 ng/hr from LFG vents and flares, and from similar to 5 to 60 mg/hr at the WF. In general, the fluxes increased from older to newer landfills, from fresh to aged cover, and from passive to active venting systems. Limited data suggest that methyl- and other organo-mercury compounds may also be emitted from these sites, suggesting an important area for future research. It is estimated that atmospheric Hg releases from municipal landfill operations in the state of Florida are on the order of 10 kg/yr, or < 1% of the estimated total anthropogenic Hg releases to air in this region.

Pietrelli, 1999

Original title:	Metal recycling from exhausted batteries
Translation:	N/A
Author:	Loris Pietrelli
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society
Place, Year:	San Sebastian, Spain, September 5-9, 1999
ISBN/ISSN:	
Kind of publication:	Proceedings: *Global Symposium on Recycling, Waste Treatment and Clean Technology (REWAS 1999), v. 1, p. 675*
Additional information:	

The world production of household batteries amounts to several billions of units per year and the environmental risk associated with uncontrolled disposal of exhausted batteries was increased; therefore, from 1991 the Commission of the European Community has developed directives to introduce condition for an efficient recycling of raw materials. From this point of view, recycling technology could be a growing priority for a modern society. Recycling some materials like water, metals, paper, and plastics occurs now and to reach this objective we need new techniques for waste treatment before landfill disposal. In fact, the final conclusion is that batteries cannot be dumped directly in common landfills, but their separate collection from municipal solid waste and, therefore, recycling materials must be done. Recycling plants operating with economical benefits cannot be effectively realized but it strongly depends on the quality (purity grade) of the recovered products and on the flexibility of the process (how many materials can be treated). From this point of view, the treatment of metal solutions using hydrometallurgical techniques (combination of solvent extraction, selective ion exchange membrane technology) is a well known and efficient method to recover metals from the original sources and from wastes; moreover it can reduce specific energy demand while improving energy efficiency. The main benefits are: complete recovery of metals at high purity; minimization of wastewater and avoid air emissions.

Tenorio, de Oliveira, Chaves, 1999

Original title:	Dry cell treatment by mineral processing methods
Translation:	N/A
Author:	Jorge Alberto Soares Tenorio, Denise Correa de Oliveira, Arthur Pinto Chaves
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society, Warrendale, Pennsylvania, USA
Place, Year:	San Diego, California, USA, February 28-March 4, 1999
ISBN/ISSN:	
Kind of publication:	Proceedings: *EPD Congress 1999 (TMS Annual Meeting)*, p. 673
Additional information:	

Household zinc-based batteries contain some heavy metals such as zinc, manganese, and mercury. There is a large effort from manufacturers in order to eliminate the last one. As a municipal waste, the disposal of batteries has become an increasing worry. The aim of the present work was to characterize dry batteries scraps, and establish a flow sheet for their processing. This was done using unit operations of mineral processing and parameters and yields of each stage have been defined. Such procedures have been chosen due to their low cost. The operations were hammer mill grinding, size separation, magnetic separation, and specific weight separation in water. The characterization step was done through chemical analysis and x-ray difractometry. After size classification, it was verified that 76.6% of the total amount of zinc was over 1.70 mm. This fraction was constituted basically of zinc and some coarse pieces from the steel body, paper, and plastics. This fraction was submitted to magnetic separation followed by specific weight separation in water. A visual examination showed that during the grinding process, graphite was concentrated in the finer fractions. Manganese concentration in the fractions over 6.35 mm was less than 2%. This means that there was low contamination by the paste in this fraction. It was due to the entrapment of the paste by steel scraps (from the body) and zinc (from the cup) during grinding.

Tenorio, de Oliveira, Chaves, 1999

Original title:	Carbon-zinc batteries treatment by ore processing methods
Translation:	N/A
Author:	Jorge Alberto Soares Tenorio, Denise Correa De Oliveira, Arthur Pinto Chaves
Institution:	
Editors:	
Publisher:	Minerals, Metals and Materials Society
Place, Year:	San Sebastian, Spain, September 5-9, 1999
ISBN/ISSN:	
Kind of publication:	Proceedings*: Global Symposium on Recycling, Waste Treatment and Clean Technology (REWAS 1999)*, v. 2, p. 1153
Additional information:	

Household zinc based batteries contain some potentially hazardous heavy metals such as zinc, manganese, and mercury. As a municipal waste, their disposal has become an increasing worry. The aim of the present work was to characterize dry batteries scraps and define some possible recycling parameters and stages using low cost unit operations. The employed methods were hammer mill grinding, magnetic separation, size separation, and specific weight separation. Characterization was done through chemical analysis and x-ray diffractometry. Size classification showed that 76.6% of the total amount of zinc concentrated over 1.70 mm. This fraction was constituted basically of zinc, paper, plastics, and some coarse pieces of the steel jacket. These last ones were taken off by magnetic separation. Some graphite electrodes and zinc were sorted out of the remained fraction by specific weight separation. Manganese got concentrated in the finer fractions, what means low contamination by the paste in the coarsest ones, specially over 6.35 mm.

Anderson, Pecharsky, Ting, Witham, Bowman, 1998

Original title:	Benefits of rapid solidification processing of modified LaNi5 alloys by high pressure gas atomization for battery applications
Translation:	N/A
Author:	I.E., Anderson, V.K. Pecharsky, J. Ting, C. Witham, R.C. Bowman
Institution:	
Editors:	
Publisher:	
Place, Year:	
ISBN/ISSN:	
Kind of publication:	*Proceedings of the 1998 MRS Fall Symposium*, v. 496, p. 37, 1998
Additional information:	

A high pressure gas atomization approach to rapid solidification has been employed to investigate simplified processing of Sn modified LaNi5 powders that can be used for advanced Ni/metal hydride (Ni/MH) batteries. The current industrial practice involves casting large ingots followed by annealing and grinding and utilizes a complex and costly alloy design. This investigation is an attempt to produce powders for battery cathode fabrication that can be used in an as-atomized condition without annealing or grinding. Both Ar and He atomization gas were tried to investigate rapid solidification effects. Sn alloy additions were tested to promote subambient pressure absorption/desorption of hydrogen at ambient temperature. The resulting fine, spherical powders were subject to microstructural analysis, hydrogen gas cycling, and annealing experiments to evaluate suitability for Ni/MH battery applications. The results demonstrate that a brief anneal is required to homogenize the as-solidified microstructure of both Ar and He atomized powders and to achieve a suitable hydrogen absorption behavior. The Sn addition also appears to suppress cracking during hydrogen gas phase cycling in particles smaller than about 25 µm. These results suggest that direct powder processing of a $LaNi_{5-x}Sn_x$ alloy has potential application in rechargeable Ni/MH batteries.

Geng, Han, Feng, Northwood, 1998

Original title:	Hydrogen-absorbing alloys for the nickel-metal hydride battery
Translation:	N/A
Author:	M. Geng, J. Han, F. Feng, D.O. Northwood
Institution:	
Editors:	
Publisher:	
Place, Year:	*International Journal of Hydrogen Energy*, v. 23, no. 11, p. 1055, 1998
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In recent years, owing to the rapid development of portable electronic and electrical appliances, the market for rechargeable batteries has increased at a high rate. The nickel-metal hydride battery (Ni/MH) is one of the more promising types, because of its high capacity, high-rate charge/discharge capability, and non-polluting nature. This type of battery uses a hydrogen storage alloy as its negative electrode. The characteristics of the Ni/MH battery, including discharge voltage, high-rate discharge capability, and charge/discharge cycle lifetime are mainly determined by the construction of the negative electrode and the composition of the hydrogen-absorbing alloy. The negative electrode of the Ni/MH battery described in this paper was made from a mixture of hydrogen-absorbing alloy, nickel powder, and polytetrafluoroethylene (PTFE). A multi-component $MmNi_5$-based alloy ($Mm_{0.95}Ti_{0.05}Ni_{3.85}Co_{0.45}Mn_{0.35}Al_{0.35}$) was used as the hydrogen-absorbing alloy. The discharge characteristics of the negative electrode, including discharge capacity, cycle lifetime, and polarization over-potential, were studied by means of electrochemical experiments and analysis. The decay of the discharge capacity for the Ni/MH battery (AA size, 1 Ah) was about 1% after 100 charge/discharge cycles and 10% after 500 charge/discharge cycles.

Jang, Jung, Kim, Yu, Lee, 1998

Original title:	Self-discharge mechanism of vanadium-titanium metal hydride electrodes for Ni-MH rechargeable battery
Translation:	N/A
Author:	Kuk-Jin Jang, Jae-Han Jung, Dong-Myung Kim, Ji-Sang Yu, Jai-Young Lee
Institution:	
Publisher:	
Editors:	
Place, Year:	*Journal of Alloys and Compounds*, v. 268, no. 1, p. 290, 1998
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In order to investigate the effect of the equilibrium hydrogen pressure (plateau pressure) of metal hydride (MH) alloys on self-discharge behavior, V0.9Ti0.1 alloys having multi-plateau pressures (low and high plateau pressures) have been used as working electrodes in a half cell. The thermal desorption experiment and open-circuit potential monitoring were conducted to observe the self-discharge behavior of the electrode. From the thermal desorption spectra of the fully charged and discharged V0.9Ti0.1 electrode (to -0.7 V versus Hg/HgO), it is found that only the higher one of the two plateau pressure regions of the V0.9Ti0.1 electrodes is electrochemically useful for battery application. But the open-circuit potential change and thermal desorption spectra of the V0.9Ti0.1 electrode after various open-circuit storage periods prove that the self-discharge behavior is attributed to the hydrogen desorption from the low plateau pressure (10-8 atm) as well as the high plateau pressure (0.1 atm). Therefore, it is suggested that the self-discharge behavior of V0.9Ti0.1 electrodes cannot be effectively suppressed by reducing the plateau pressure of alloys through alloy modification. In addition, the pressure-composition-isotherms (P-C-T) of the low pressure region can be estimated by using the open-circuit potential corresponding to this region in Nernst's equation.

Lindberg, Price, 1998

Original title:	Summary of measured mercury emissions from two municipal landfills in Florida
Translation:	N/A
Author:	Steven E. Lindberg, John L. Price
Institution:	
Editors:	
Publisher:	
Place, Year:	1998
ISBN/ISSN:	
Kind of publication:	*Proceedings of a Waste Manage Association Annual Meeting and Exhibition*
Additional information:	

Large quantities of mercury have been placed in municipal landfills from a wide array of sources, including fluorescent lights, batteries, electrical switches, thermometers, and general waste. Despite its known volatility, longevity, and toxicity in the environment, the fate of this mercury has not been widely studied. Using automated flux chambers and atmospheric sampling, the primary sources of Hg vapor releases to the atmosphere at two municipal landfill operations in south Florida for 8 days in April 1997 was quantified. These pathways included landfill gas (LFG) releases from passive and active vent systems, passive emissions from landfill surface covers of different ages (including CH_4 “hot spots”), and emissions from daily activities on a working face. Mercury vapor was released to the atmosphere at readily detectable rates from all sources measured. Emission rates ranged from approx. 1-20 ng m super(-2) h super(-1) over aged surface covers, from approx. 6-2400 ng/h from LFG vents and flares, and from approx. 5-60 mg/h at the working face. In general the fluxes increased from older to newer landfills, from fresh to aged cover, and from passive to active vented systems. It is estimated that atmospheric Hg releases from municipal landfill operations in the state of Florida are on the order of 10 kg/y, or < 1% of the estimated total anthropogenic Hg releases to air in this region.

Anderson, Ting, Pecharsky, Witham, Bowman, 1997

Original title:	Atomization and rapid solidification processing effects on AB5 alloys for battery applications
Translation:	N/A
Author:	I.E., Anderson, J. Ting, V.K. Pecharsky, C. Witham, R.C. Bowman
Institution:	
Editors:	
Publisher:	Metal Powder Industries Federation, Princeton, New Jersey, USA
Place, Year:	
ISBN/ISSN:	1042-8860
Kind of publication:	*Proceedings of the 1997 International Conference on Powder Metallurgy and Particulate Materials*, Part 1 (of 3), p. 5
Additional information:	

A high pressure gas atomization approach to rapid solidification has been employed to investigate simplified processing of Sn modified LaNi5 powders that can be used for advanced Ni/metal hydride (Ni/MH) batteries. The current industrial practice involves casting, annealing, and grinding and utilizes a complex and costly alloy design. This investigation is an attempt to produce powder for battery cathode fabrication that can be used in an as-atomized condition without annealing or grinding. In this initial study, Ar atomization gas was used and a high level of Sn was added to ensure sub-ambient pressure hydrogen absorption/desorption behavior at ambient temperature. The resulting fine, spherical powders were subject to microstructural analysis, hydrogen charging/discharging cycles, and electrochemical cell testing to evaluate suitability for Ni/MH battery applications. The results demonstrate that careful solidification microstructure control is required if the benefits of simplified AB5 alloy design are to be realized with maximum processing efficiency.

Hanewald, Schweers, Liotta, 1996

Original title:	Recycling nickel-cadmium batteries through the high temperature metal recovery process and New cadmium recovery facility
Translation:	N/A
Author:	R.H. Hanewald, M.E. Schweers, J.J. Liotta
Institution:	
Editors:	
Publisher:	IEEE, Piscataway, New Jersey, USA
Place, Year:	January 9-12, 1996
ISBN/ISSN:	
Kind of publication:	Proceedings: *Proceedings of the 1996 11th Annual Battery Conference on Applications and Advances*
Additional information:	

In the 1970s, it became apparent that landfill was an unacceptable solution for the disposal of wastes bearing hazardous metals. There was also widespread concern about the efficient use of natural resources. It was soon realized by Inco that reclamation and recycling was the best universally acceptable solution to these problems. Inco then developed its high temperature metal recovery process.

Kopczyk, Wojcik, Mlynarek, Sierczynska, Beltowska-Brzezinska, 1996

Original title:	Electrochemical absorption-desorption of hydrogen on multicomponent Zr-Ti-V-Ni-Cr-Fe alloys in alkaline solution
Translation:	N/A
Author:	M. Kopczyk, G. Wojcik, G. Mlynarek, A. Sierczynska, M. Beltowska-Brzezinska
Institution:	
Editors:	
Publisher:	
Place, Year:	*Journal of Applied Electrochemistry*, v. 26, no. 6, p. 639, 1996
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Multicomponent Zr-Ti-V-Ni-Cr-Fe and Zr-Ti-V-Ni-Cr alloy electrodes, with various Ti and Zr ratios, have been studied in alkaline solution by means of potentiodynamic current-overvoltage and galvanostatic overpotential-time responses during long-term continuous and intermittent charge-discharge cycles. The pressure-composition isotherms for absorption/ desorption of hydrogen, evaluated from the equilibrium potential, have been compared with the gas phase isotherms. The kinetic data demonstrate the reversibility of hydrogen electrosorption in the investigated systems. An increased discharge efficiency has been established for electrodes with lower values of both the activation and diffusion resistance. The alloy with Fe and Ti:Zr at the atomic ratio 2:1 prepared by using vanadium-ferro-alloy is shown to meet the requirements for the negative electrode in secondary nickel-metal hydride batteries.

Shapek, 1996

Original title:	Dry-cell battery health and environmental hazards and disposal options
Translation:	N/A
Author:	Raymond A. Shapek
Institution:	
Editors:	
Publisher:	
Place, Year:	*Journal of Solid Waste Technology and Management*, v. 23, no. 1, p. 53, 1996
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Nearly every state, including the District of Columbia, has passed some type of solid waste management law. Thirteen states have included laws to reduce landfill contamination by restricting the amount of mercury and cadmium entering the waste stream through dry-cell (household) battery separation or collection programs. Household (HH) batteries contribute 52% of the cadmium and 88% of all mercury found in the municipal solid waste, yet comprise less than 1% (by weight) of municipal solid waste. The public is generally unaware of the potential health and environmental risks of unrestricted disposal of dry-cell batteries and local officials are reluctant to initiate collection programs because of the high costs and subsequent disposal costs of collected cells. This article assesses the potential health and environmental risks of the unrestricted disposal of household batteries, the collection and available disposal options, and concludes with several recommendations for communities considering initiating HH battery collection/recycling programs.

Lindqvist, 1995

Original title:	Environmental impact of mercury and other heavy metals
Translation:	N/A
Author:	Oliver Lindqvist
Institution:	
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v. 57, no. 1, p. 3, 1995
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The environmental impact of heavy metals is reviewed. One significant source of emissions of heavy metals to air is waste incineration. Consumer batteries contribute significantly to this problem, as well as to heavy metal leakage to groundwater from landfill deposits. The situation in Sweden is used as an example to describe how the deposition from the atmosphere still is increasing the load of heavy metals, like mercury, cadmium, and lead, in top soils and aquatic sediments. Critical factors and effect levels for Hg, Cd, Pb, Cu, Zn, and As are discussed. Specific questions like mercury contents in present battery waste and heavy metal contents in new and future secondary batteries are addressed.

Panero, Romoli, Achilli, Cardarelli, Scrosati, 1995

Original title:	Impact of household batteries in landfills
Translation:	N/A
Author:	S. Panero, C. Romoli, M. Achilli, E. Cardarelli, B. Scrosati
Institution:	
Editors:	
Publisher:	
Place, Year:	*Journal of Power Sources*, v. 57, no. 1, p. 9, 1995
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

Heavy metals are present at different levels and concentrations in all the household dry batteries. The related environmental hazard is well known. The heavy metals are toxic and thus liable to produce serious problems for the health of the population and for the maintenance of the biosphere. Therefore, there has been recently an increasing concern on the risk associated with uncontrolled disposal of exhausted dry batteries. In this paper, a report is done on the efforts in progress in Italy for collecting spent batteries, as well as the most suitable strategies which can be followed to assure their safe disposal.

Rondia and De Graeve, 1994

Original title:	Environmental Risk Assessment of Zinc Arising from Disposal of Used Batteries with Municipal Solid Wastes
Translation:	N/A
Author:	D. Rondia and J. De Graeve
Institution:	
Editors:	
Publisher:	Environmental Toxicology Unit, University of Liege
Place, Year:	Liege, Belgium, 1994
ISBN/ISSN:	
Kind of publication:	Report
Additional information:	

The main objective of this study was to assess the environmental impact in Western Europe of zinc originating from household batteries.

At the time that the study was conducted, municipal solid waste was disposed in landfills or incinerated. The results of the assessment indicated that, in the absence of suitable recycling technology, the disposal of household batteries in municipal solid wastes did not pose nor increase any significant risk to human health or to the environment. The quantity of zinc added to the environment through landfilling of batteries, or through landfilling of bottom ash or of fly ash from MSW incinerators or from the zinc compounds escaping the air pollution control processes of these incinerators is acceptable due to:

1. the present sources of zinc in the environment;
2. the low solubility at neutral pH of zinc compounds adsorbed on soil material (especially clay, iron-manganese oxides and hydroxides and humic acids); and
3. the near absence of toxicity of zinc at the level of concentration presently observed in soils and rivers of West European countries (100 to 200 mg/kg in most non-sandy soils with a bio-disponibiiity of around 30%, and 50 to 100 pg/l in most surface or river waters with a proportion of 50% soluble zinc.

The estimation of household battery use in Europe per year is 4.6 manganese-alkaline batteries and 4.3 zinc-carbon/zinc-chloride batteries per person-year. This results in the disposal of about 29 g of zinc compounds per person-year in Western European countries. A study conducted in The Netherlands estimated the amount of zinc contributed by household batteries to be 30 g per kg of dry MSW. In this report, these figures are compared to other inputs of zinc into the environment and after a review of the toxicity of zinc, the conclusion is that the designation of household batteries as hazardous materials or materials requiring special legislative requirements over their use or their disposal is arbitrary and without scientific justification.

Haight, Asanti-Duah, Craig, 1992

Original title:	Assessing the Environmental Effects of Disposal Alternatives for Household Batteries
Translation:	N/A
Author:	M. Haight, D. Kofi Asanti-Duah, L. Craig
Institution:	Institute for Risk Research, University of Waterloo, Canada
Editors:	
Publisher:	
Place, Year:	*Canada, 1992*
ISBN/ISSN:	
Kind of publication:	Report
Additional information:	

The Canadian Battery Manufacturer's Association (CBMA) funded the Institute for Risk Research (IRR) to conduct an independent assessment of the impacts associated with management practices and disposal of used household battery on the environment, including an evaluation of the potential risks related with the options identified. This report discusses the issues related to disposal practices of used dry-cell batteries, their potential impacts on the environment, the potential risks to humans, and offers recommendations for what is considered as acceptable disposal practices for used household batteries. The investigation followed the following phases: a literature search, data collection and compilation, and private interviews; data review and analyses and chemical analyses of batteries. The information collected in this process lead to the evaluation of disposal options. This was followed by risk assessment of disposal alternatives for batteries. The final step dealt with making recommendations for the management of used household batteries.

The batteries of concern in the study included dry-cells classified by the AAA, AA, C, D, and 9 volt sizes and formats. These batteries belong to the alkaline, zinc-carbon/zinc-chloride and nickel-cadmium family of batteries. Current estimates for the Canadian household battery market for the selected dry cells are given in Table 2.1. Alkaline batteries represent the largest share of household battery market. Alkaline batteries are used for a variety of applications, including radios, toys, and portable appliances. Zinc-carbon batteries generally are less powerful, although there are some "high performance" cells in this group. Nickel-cadmium (Ni-Cad) rechargeable batteries which are a small portion of the total market can be recharged up to 1000 times and are also becoming popular. Ni-Cads are found in such appliances as power tools and portable vacuum cleaners. The majority of the Ni-Cad batteries are imbedded in the appliances and cannot be replaced by the user. Alkaline batteries have, in the past, contributed to the amount of mercury in household waste streams; however, with the current practice adopted by the manufacturers of batteries to reduce the amount of mercury, this situation has been significantly improved. On the other hand, nickel-cadmium batteries presently are major contributors of cadmium to the waste stream.

Table 2.1 Canadian household battery market estimates (1990/1991)

Battery Type	Total in Millions	Battery Size						% of Totals
		AAA	AA	C	D	9 Volt	Other	
Alkaline	100	9	60	9	8	9	5	65.4
Zinc Carbon	25							16.3
}		1	21	7	9	6	1	
Zinc Chloride	20							13.1
Nickel - Cadmium	8	0.5	5	1	1	0.5	--	5.2
Totals	153	10.5	86	17	18	15.5	6	
% of Totals		6.9	56.2	11.1	11.8	10.1	3.9	

Potential health and environmental impacts from disposal practices

The metals of potential concern present in the household batteries studied are: cadmium, manganese, mercury, nickel and zinc. In whatever disposal or management practice that is adopted for used household batteries, there is the potential for the release of metals which might affect human health directly or indirectly, or which might have an impact on the environment. Currently, used household batteries are almost exclusively disposed of with the domestic waste which eventually is incinerated or landfilled. Recently, a considerable amount of attention is being given to the idea of providing collection for used batteries, separation and possible recycling. The information in Table 2.2 shows the results of risk characterization conducted for the various disposal alternatives; no quantitative evaluation was performed for the recycling options.

Table 2.2 Risk comparison for disposal alternatives

Disposal Option	Quantitative Risk Measure*	
	Hazard Index	**Carcinogenic Risk**
Landfilling	0.4 (1.6)**	0.0 (0.0)
Incineration	3.5 (0.0)	5.3×10^{-3} (1.4×10^{-6})
Combined landfilling and incineration	*1.9*	*2.7×10^{-3}*
Recycling	Not Quantified	Not Quantified

* Shows value for the most sensitive potential receptor, i.e., population indicating highest risk measure.
** Numbers in parentheses show values for typical/actual case studies for selected disposal options; these are represented by Waterloo Landfill Site (Waterloo) and Tricil SWARU incinerator facility (Hamilton), both in Ontario.
Notes: Acceptable Hazard Index $\leq$
Acceptable Carcinogenic Risk Range is 10^{-4} to 10^{-7}

According to the authors, in theory, incineration of the batteries of concern in this study will present the greatest risks. However, in practice, these batteries may be safely incinerated mixed with MSW without any significant risks. Landfilling of the dry-cell batteries with MSW will generally present no significant risks of concern. Although recycling of household batteries has not been quantified, the qualitative indicators are that it is not the best disposal option for the alkaline (manganese) and the zinc-carbon/zinc-chloride cells. The authors point out that Ni-Cad recycling programs may be a worthwhile effort.

Used household batteries will undergo degradation under landfill conditions, with the rate and degree of decay depending on-the battery types, state of charge in battery and the physical conditions at the landfill site. Beyond the degradation process, it is important to determine if the metals from the batteries will leach from a landfill into an underlying aquifer. Several variables, including landfill management practices will have an impact on the leaching. Under ideal landfill conditions, metals will not leach rapidly through landfills and soils into groundwater. On the other hand, metals do not decompose or degrade, and thus have the potential of leaching into aquifers over long periods of time.

Metals are of critical concern in an incineration process since they are not combustible. Thus, the protection of the environment in an incineration management option depends on the ability of the air pollution control unit in the incinerator to capture and remove metals from the combustion gases. Although there are technologies available for the removal of most metals, which makes such a process available, albeit expensive, it is not completely effective in abating mercury emissions due to the low vapor pressure of mercury. The presence of other metals, including cadmium in the incinerator fly ash arising, in part, from the incineration of household batteries, renders such ash potentially highly toxic and as a result, the ash may not be disposed at municipal landfills.

Conclusions of the investigation

Several conclusions were made based on this investigation:

- The dry-cell batteries investigated (i.e., the alkaline, zinc-carbon/zinc chloride and Ni-Cads) do not generally present a concentrated source of heavy metals in MSW.
- There is no clear evidence to suggest that the co-disposal of dry-cell batteries with MSW via incineration or landfilling presents environmental or health problems.
- Risks to the environment from battery disposal by landfilling and incineration are not likely to be significant. Thus, most household batteries may be safely disposed in municipal landfills or municipal incinerators; Ni-Cads are better landfilled than incinerated unless recycled.

At present, "recycling" is more likely to present significant risks. There appear to be significant health-related problems associated with the separate collection, storage, and disposal of most household batteries. However, recycling for Ni-Cads may be a more viable and desirable measure to adopt. With the currently reduced levels of mercury in most primary cells (especially the alkaline and zinc-carbon-chloride batteries), recycling of alkaline and zinc-carbon-chloride cells is not necessary or needed.

Recommended disposal alternatives and management programs

The amount of mercury in household batteries has been drastically reduced during the past few years and should be reduced even further because of current research and development activities by the Canadian battery industry. Concern about alkaline household batteries being a major source of mercury in municipal solid waste is no longer true; in the past, these batteries had up to 1.5% mercury by weight, but today they have 0.025% by weight and this is expected to go down further in the future. Most of the information filtering to the public as to the amount of mercury in alkaline batteries manufactured in Canada today is out of date, leading to over-reaction by environmentalists and the general public to a non-existent problem.

On the other hand, Ni-Cad batteries may be of concern and it may be desirable to recycle them. The collection and recycling of Ni-Cads is desirable, although effective technologies may not be readily available at the present time. According to the authors, there is the need to develop adequate programs and technologies, or better yet develop substitutes for Ni-Cads which do not contain cadmium. Indiscriminate policy decision aimed at all batteries, on the other hand, could be detrimental and would only result in ineffective and uneconomical programs at best and be potentially hazardous and environmentally unsound at worst.

Based on the investigations carried out for the alkaline, zinc-carbon/zinc-chloride and Ni-Cad batteries, it is concluded that current disposal practices appear to be safe and adequate. Improvements may however be achieved by adopting the following recommendations:

- There is the need to educate the general public with respect to distinction between lead-acid automotive batteries and the various types of dry cell household batteries.

- Further research needs to be conducted to determine: the effect of household battery disposal on the quality landfill leachate, and the potential impacts on groundwater resources.

- There should be a policy implemented, that requires all municipal incinerators to be equipped with wet scrubbers. In that case, mercury emitted during combustion of municipal waste can then be removed. Also, since cadmium is carcinogenic by the inhalation pathway, it is critical that adequate scrubbers are used on municipal solid waste incinerators, that will capture as much of the fly ash as possible and reduce the amounts that could eventually reach potential human receptors. In the absence of that, Ni-Cads which may be a significant contributor of cadmium to municipal solid waste may have to be removed from the wastes to be incinerated.

- There seems to be some potential health-related problems associated with the separate collection, storage and disposal of most household batteries. Thus, with the currently reduced levels of mercury in most primary cells (especially the alkaline and zinc-carbon/zinc-chloride batteries) recycling of alkaline and zinc-carbon/zinc-chloride cells is not presently necessary or needed. However, recycling of Ni-Cads may be a more viable and necessary measure to adopt.

Overall, none of the current disposal practices for the used dry-cell batteries investigated in this study present any real risks. However, according to the authors, it may be prudent and safety-effective to adopt the recommended management options described in Table 2.3.

Table 2.3 Recommended management methods for used dry-cell batteries

Battery Type	**Preferred Management Option**	**Alternative Management Option**	**Comments**
Alkaline (manganese)	Landfilling	Incineration	Neither landfilling or incineration of even concentrated forms appear to present any significant risks
Zinc-carbon/zinc chloride	Landfilling	Incineration	Neither landfilling or incineration of even concentrated forms appear to present any significant risks
Ni-Cads	Recycling	Landfilling	Separate collection and recycling of Ni-Cads preferred due to potential risks from Cadmium

2.2 Conclusions

The review of the literature published in English resulted in the identification of several publications dealing with the general subject of household batteries. The majority of the publications dealt with a number of aspects associated with recycling, segregation, and treatment. A few others covered different subjects related to improvements in the manufacture of batteries, while others addressed environmental impacts as well as health and environmental controls. A few publications dealt with emissions from landfills due to the disposal of household batteries particular emissions associated with heavy metals and mercury in particular. The remainder of the articles covered the relative composition of dry cells in domestic waste, storage of spent batteries, and the characteristics of AA alkaline batteries.

No specific publications were found specifically covering impacts of the disposal of spent alkaline batteries in municipal landfills.

The publications were found in international scientific journals, trade publications, and proceedings from specialized conferences. A limited number of pertinent publications were collected from professional and trade associations.

3. German, Dutch, and Polish Literature

3.1 Results of the literature review

Reports and books written in the German (including German, Austrian, and Swiss sources), Dutch (including The Netherlands and Belgium) and Polish languages were reviewed. The results are presented chronologically for each country, starting from the most recent ones.

3.1.1 Austria

Skutan, Brunner, 2006

Original title:	Stoffbilanzen mechanisch-biologischer Anlagen zur Behandlung von Restmüll (SEMBA)
Translation:	Material balances of mechanical-biological plants for treatment of residual waste
Author:	Stefan Skutan, P.H. Brunner
Institution:	Technische Universität Wien, Institut für Wassergüte, Ressourcenmanagement und Abfallwirtschaft
Editors:	
Publisher:	
Place, Year:	Vienna, 2006
ISBN/ISSN:	
Kind of publication:	Report, 352 pages, available at: http://umwelt.lebensministerium.at/article/articleview/54477/1/6955/
Additional information:	Commissioned by Bundesministerium für Land und Forstwirtschaft, Umwelt und Wasserwirtschaft und Umweltbundesamt GmbH (Austrian Federal Ministry of Agriculture, Forestry, Environment and Water and Environment Agency)

The main target of this project was to analyze material balances of mechanical-biological pretreatment (MBP) plants for residual waste. Using the method of Material Flow Analysis three MBP plants in Austria were investigated: MBP Oberpullendorf, mechanical pretreatment (MP) plant Kirchdorf an der Krems and MP plant Splittinganlage der MA 48 in Vienna. Those plants allow recovery a fraction of the waste with a high calorific value for energy recovery, a fraction with a low calorific value (for landfilling or use as a low quality “waste composts”) and metal scrap for recycling. The material balance was performed such that samples were taken from the output streams and the composition of waste input was calculated based on the principle of mass balance. Special emphasis was placed on identifying the material balances of metals in the treatment plants, i.e., transfer coefficients of metals contained in the input residual waste to different output streams. After an in-depth analysis of the existing literature concerning investigations of the concentration of metals in the waste, the authors concluded that the commonly applied sampling methodology is inadequate and that the methodology leads to an underestimation of the concentration of metals in the waste. The main problem is the high heterogeneity of residual waste and problems related to the presence of pieces of bulky metal in the waste, which often are not accounted for in the analyses. To resolve this problem, the authors proposed a comprehensive sampling method in which both the concentration of background metals (i.e., content of metals in paper, plastics, organic matter, etc.) as well as their presence in the "metallic" form is considered. Metals present in bulky pieces were been identified either based on their outer appearance or based on chemical analyses of representative samples. As a consequence, significantly higher metals contents than the commonly reported ones were measured in residual waste. In addition, the presence of batteries in the waste was investigated as one of the "metallic" sources of metals. The existing literature data on the concentration of batteries in residual waste is provided in the report. The concentration varies between 260 and 680 g of batteries/ton of residual waste. Based on the literature data the potential contribution of batteries to the contents of different metals in Austrian residual waste was estimated. These estimates are provided in Table 3.1.

Table 3.1 Estimation of the contribution of batteries to the total contents of heavy metals in residual waste

	Average concentration in batteries				**Calculated contribution to the concentration in residual waste**			
	% wet mass				**mg/kg wet mass**			
	Zn	**Cd**	**Hg**	**Ni**	**Zn**	**Cd**	**Hg**	**Ni**
NiCd	-	20	-	20	-	6,6	-	6,6
AlMn + ZnC	20	-	0,0015	-	110	-	0,008	-
Button cells	15	-	3,5	0,84	0,3	-	0,08	0,02

During the sampling program conducted in this project, different types of batteries were identified, including primary batteries (AlMn and ZnC) and secondary batteries (NiCd and NiMH). Based on an assumed average composition of these types of batteries, their contribution to the total metals balance was accounted for. The assumed composition of batteries is provided in Table 3.2. Mercury was not taken into consideration due to a high uncertainty as to its actual content in different batteries.

Table 3.2 Average contents of heavy metals in batteries

Battery type	**Composition**
AlMn primary battery	15% Zn, 20% Fe
ZnC primary battery	20% Zn, 20% Fe
NiCd secondary battery	16% Cd, 20% Ni, 40% Fe
NiMH secondary battery	35% Ni

The results of average metals contents (and their standard deviations) in the input to the treatment plants are shown in Table 3.3 and compared to the values obtained from estimation of metals content in residual waste based on literature data. The data in the table show that the actual values derived from the measurements generally are higher than their estimates based on the literature data. These differences are due to the inclusion of metals contained in a "metallic" form (including batteries) within these investigations.

Table 3.3 Heavy metals contents in the input to the treatment plants

Metal	Oberpullendorf I	Oberpullendorf II	Kirchdorf	Vienna	Estimated
Cd mg/kg d.m.	12,2 ± 2,6	17,6 ± 5,1	11,4 ± 6,8	13,8 ± 4,8	9,4
Fe g/kg d.m.	49,0 ± 4,8	50,0 ± 5,5	59,2 ± 4,1	49,0 ± 1,9	50
Ni mg/kg d.m.	180 ± 57	170 ± 60	160 ± 36	110 ± 23	57
Zn mg/kg d.m.	2600 ± 540	2400 ± 360	2700 ± 500	1500 ± 260	860

In the report no data are provided on the concentration of batteries in the examined samples. However, additional data on battery content in the output streams of the Oberpullendorf II plant was obtained from the author of this report (Skutan, personal communication). These data are presented in Table 3.4.

Table 3.4 Results of the analysis of battery content in the output streams of the Oberpullendorf II plant and the calculated content in the input to this plant

Battery type	Output streams (mass contribution)				Input
	Metal scrap (3.4% d.m.)	Fraction 25 - 65 mm (14% d.m.)	Fraction < 25 mm (43% d.m.)	Fraction > 65 mm (39% d.m.)	Calculated average (100% d.m.)
	g/t d.m.				
ZnC	1686 ± 294	336 ± 92	0 ± 0	0 ± 0	104
AlMn	4072 ± 537	725 ± 144	85 ± 11	184 ± 110	347
NiCd	1633 ± 272	0 ± 0	0 ± 0	26 ± 26	65
NiMH	14 ± 14	26 ± 18	0 ± 0	143 ± 143	60

The calculated battery content in the input waste is 575 g/t d.m., of which approximately 60% constitute the AlMn batteries. Based on the concentration of batteries in the waste, concentrations of heavy metals in the batteries provided in Table 3.2 and average heavy metals contents in the waste summarized in Table 3.3, the contributions of heavy metals to the residual waste due to batteries can be calculated. These are to approximately 3% of Zn due to AlMn and ZnC primary batteries, approximately 60% of Cd due to NiCd secondary batteries and approximately 20% of Ni due to NiCd and NiMH secondary batteries.

The results of this research project also show that the mechanical pretreatment processes are able to concentrate heavy metals in targeted output streams (i.e., in the metal scrap fraction). Results of comparisons of different technologies show that the efficiency of magnetic separation has a profound effect on the quality of output streams (see Table 3.4). For example Cd as a compound of NiCd secondary batteries can be removed at the magnetic separator. The remaining Cd in the high calorific fraction originates from plastic waste. Only a very small proportion of Zn in the residual waste originates from the primary Zn batteries (AlMn and ZnC). The Zn batteries can be partly separated by a magnetic separator. The major portion of this metal comes from different alloys. The efficiency of Zn separation by non-ferrous separators in the plants investigated was relatively low, implying high transfer of this metal to both output fractions the high and the low calorific output fractions.

Vanazetta, Skutan, 2003

Original title:	Cd im MVA-Schrott; Cdgehalt, verursacht durch NiCd-Akkus
Translation:	Cd in the incineration slag; Cd content due to NiCd secondary batteries
Author:	Gian Matteo Vanzetta, Stefan Skutan
Institution:	Technische Universität Wien, Institut für Wassergüte und Abfallwirtschaft, Abteilung Abfallwirtschaft und Stoffhaushalt
Editors:	
Publisher:	
Place, Year:	Vienna, 2003
ISBN/ISSN:	
Kind of publication:	Report, unpublished
Additional information:	Summary of a master thesis of Gian Matteo Vanzetta (2002): "Beitrag zur Bestimmung, mechanischen Abtrennung und Rückgewinnung von Metallen aus Restmüll am Beispiel von Aluminium und Cd." ("A contribution to the determination, mechanical separation and recovery of metals from the residual waste, example of aluminum and Cd")

The aim of this master thesis was to determine the concentration of Cd in the metal scrap separated from the slag of a residual waste incineration plant. In order to determine the relevance of NiCd secondary batteries and Zn batteries (Cd as a Zn-accompanying metal) for the Cd content in metal scrap both types batteries were investigated.

Metal scrap separated from the incineration slag of the incineration plant in Flötzersteig, Austria was investigated. As a first treatment step the slag is fed to a drum sieve, in which separation into a fine (<50 mm) and coarse fraction (>50 mm) takes place. Metal scrap is recovered from both fractions by means of a magnetic separator. The concentration of batteries contents in both scrap fractions and in the coarse mineral fraction were manually investigated (see Table 3.5). The samples for analyses were obtained from over 24 tons of incineration slag.

Table 3.5 Composition and quantity of the investigated slag fractions

Fraction	**Description**	**Sample 1 [kg]**	**Sample 2 [kg]**
Coarse fraction >50 mm	Mixture of stones, glass, textiles, books, metal pieces, etc.	1,900	2,460
Coarse metal scrap >50 mm Fe	Mixture of pots, pans, auto parts, scissors, silvery, cans, spray doses, transformers, electro engines, etc.	770	1,200
Fine metal scrap <50 mm Fe	Mixture of bottle caps, metal pieces, screws, pins, etc.	320	360

Paint and foils of the sorted out batteries were burned, their surface was rusty and contaminated with other components of the slag. Some batteries were in a disintegrated form (especially the ZnC batteries). The batteries were sawed through to identify different battery types.

The concentration of batteries in the fractions investigated are given (both as the amount of single batteries and in kg per ton) in Table 3.6.

Table 3.6 Content of batteries in the investigated fractions

	Sample	**All batteries**		**NiCd batteries**		**AlMn batteries**		**ZnC batteries**		**Other batteries**	
		[kg/t]	**[bat./t]**	**[kg/t]**	**[bat./t]**	**[kg/t]**	**[bat./t]**	**[kg/t]**	**[bat./t]**	**[kg/t]**	**[bat./t]**
Fine metal scrap	1	29	1.728	2,4	122	21	1.159	3,2	234	2,4	213
	2	25	1.517	2,8	119	18	989	2,3	178	2,2	231
Coarse met. scrap	1	0,29	13	0,12	3,9	0,12	5,2	0	0	0,042	4
	2	0,6	15	0,14	2,5	0,35	8,3	0,01	0,8	0,045	3,3
Coarse fraction	1	3,8	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
	2	2,8	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.

n.i. not investigated

Table 3.7 summarizes the concentration of Cd in the types of batteries investigated. The data show that there is a high variation of the results for both the AlMn and ZnC batteries. However, in any case the results for Zn batteries are significantly lower than those for NiCd batteries. Thus it was not necessary to analyze the concentration of Cd in the second sample of AlMn and ZnC batteries.

Table 3.7 Cd content in batteries

Sample	**NiCd [%]**	**AlMn [mg/kg]**	**ZnC [mg/kg]**
1	10,9	1,2	4,5
		<0,3	<0,4
2	13,5	n.i.	n.i.

The results of the concentration of Cd in the metal scrap from the incineration slag are presented in Table 3.8. The contribution of batteries other than NiCd to the total Cd content in the incineration slag is insignificant.

Table 3.8 Cd content in the metal scrap from incineration slag

Probe	**Content of NiCd batteries [%]**	**Cd concentration in NiCd batteries [%]**	**Cd concentration in metal scrap [g/t]**
1	0,78	10,9	85
2	0,77	13,5	104
average	**0,77**	**12,2**	**94**

Goldschmid, Mayr, Vogel, Müllebner, 1989

Original title:	Recyclingtechnologien für Altbatterien und Maßnahmen zur Etablierung eines Altbatterienverwertungsverfahrens in Österreich
Translation:	Recycling technologies for spent batteries and measures towards establishing of a spent batteries recovery system in Austria
Author:	Gerald Goldschmid, Johann Mayr, Gerhard Vogel, Michael Müllebner
Institution:	Institut für Technologie und Warenwirtschaftslehre

	Wirtschaftsuniversität Wien, Umweltbundesamt
Editors:	Johannes Mayer
Publisher:	Umweltbundesamt
Place, Year:	Vienna, 1989
ISBN/ISSN:	3-85457-041-4
Kind of publication:	Report Monographien, Band 16, 139 pages, available at: http://www.umweltbundesamt.at/publikationen/publikationssuche/publikationsdetail/?pub_id=8
Additional information:	

At the time this publication was written, separate collection and management of spent batteries were at their very early stage. This publication describes battery systems, separate collection schemes for batteries and their recovery options that were available at that time in various countries as well as legislation related to batteries. The majority of data provided in this report is dated and therefore it is not presented in this summary. The introduction to the report, written by the Austrian Federal Environment Agency, discusses environmental problems of co-disposal of batteries with household waste. Since this subject hardly is discussed in the more recent literature, some issues discussed there will be presented in this summary.

According to the Austrian legislation the following spent batteries are considered hazardous waste: NiCd secondary batteries (classified as toxic and hazardous for natural waters), Hg batteries and dry batteries containing Hg and Ag. The only accepted disposal option for these batteries are hazardous waste landfills and incineration for the dry batteries. The most serious problem related to co-disposal of spent batteries with household waste is their heavy metals content, especially the concentration of Hg and Cd.

Behavior of batteries in the household waste landfills

The Federal Environment Agency does not know of any study in which interactions between the landfilled spent batteries and the waste body are described.

It is not doubted that under landfill conditions, especially in the phase of acid fermentation, the steel outer cover of batteries will corrode and the contents of the battery would be released into the waste body. It is not known how far the released substances will influence and contaminate the leachate and gas in the landfill. A discharge of Hg in the landfill leachate is not realistic due to the chemical properties of this metal. Thus the Hg content is rarely considered in the leachate analyses. Considering the complexity of the biological, chemical and physical processes taking place in a landfill, the mobilization or remobilization of metals, which are temporarily bound in the landfill body, can not be excluded.

Regarding Hg, it is assumed that it partly reacts with the hydrogen sulfide generated under anaerobic decomposition processes to form insoluble sulfides. It is also assumed that metallic Hg partly volatilizes with the landfill gas. Until now, no studies are known regarding the transformation of Hg thorough microorganisms to organic forms and their emissions with the landfill gas.

Behavior of spent batteries in waste incineration

Transfer coefficients of Zn and Hg to different outputs of a waste incinerator are provided in Table 3.9.

Table 3.9 Transfer coefficients for Zn and Hg in the incineration process

Element	Emission path			
	Slag	Fly ash	Filter cake	Cleaned flue gas
	%			
Zn	55 - 75	13 - 31	8 - 23	0,2
Hg	5	0	90	5 (<10)

With respect to the household waste generated in Vienna, 95 g/ton of Zn and 1,5 g/ton of Hg are assumed to be contributed by the ZnC and AlMn batteries. In 1988, in the waste incinerator Flötzersteig 115.000 t of waste (representing approximately 18% of 650.000 t Vienna household waste) was incinerated. The estimated quantity of emitted Zn was approximately 460 kg and of Hg < 30 kg. The estimated contribution of the ZnC and AlMn batteries to these amounts was approximately 22 kg Zn and approximately 20 kg Hg. It means that through a separate collection and treatment of batteries, approximately 60% of Hg emissions can be saved and 5% of Zn emissions. Additionally, approximately 10 kg of Cd were emitted. It is also important to note that the remaining heavy metals which end up in the slag and fly ash can also be emitted and/or influence the co-disposed materials in a landfill. From Switzerland it is known that the mobilization of Zn was observed during the analyses of the incineration slag (in an eluation procedure with CO_2 saturated water).

Behavior of spent batteries in the composting process[1]

At the time this article was written, there were 19 composting plants in Austria, cumulatively processing approximately 526,000 tons of waste/year. Many of the composting plants encountered problems marketing their final compost product, due to quality problems. In this particular case, the concentration of heavy metals in compost is an important criterion. Metal separators can only recover a portion of the ferromagnetic materials. Due to conditions in the composting process the metals contained in the input are distributed throughout the entire composting mass and become further enriched due to the decomposition of the organic matter in the. Measures targeted at better separation of metals from waste prior to composting were undertaken at the Aich-Assach composting plant. By applying separate collection of metals and manual sorting at the composting plant, reduction in the concentration of Zn and Cd content by factor 2 and Pb by factor 3 was achieved.

The Federal Environment Agency does not have any information about the behavior of batteries in a hazardous waste landfill. Furthermore, a description of the available progresses of battery recovery technologies at the time writing is not considered relevant for this review. In the main body of this publication no data on the environmental impact of spent battery management is provided.

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[1] At the time this publication was written commingled household waste was used to produce composts in Austria. Composting of mixed municipal waste aimed at production of quality composts to be used as fertiliser is no longer practiced. For this purpose only separately collected organic waste is used. Aerobic mechanical-biological pre-treatment is based on the same principle as composting, but the main objective is to produce a material that is suitably stable such that it can disposed in a landfill.

3.1.2 Belgium

Bebat, 2007

Original title:	Bebat - Algemene informatie
Translation:	Bebat - General information
Author:	BEBAT
Institution:	BEBAT
Editors:	
Publisher:	BEBAT
Place, Year:	2007
ISBN/ISSN:	
Kind of publication:	website presentation, available at: www.bebat.be
Additional information:	

Since January 1996 BEBAT has been responsible for organizing the collection, management and recycling of used batteries in Belgium. Since 2005 BEBAT has been supervised by the federal and the 3 regional authorities. Participation in the BEBAT system is available for all companies subject to environmental taxes on batteries, also to companies subject to regional return-duties. Today, more then 800 companies are registered with BEBAT to comply with these environmental regulations. The BEBAT system is financed by a collection & recycling contribution (C.R.C.) which is chargeable to the consumer. The C.R.C. amounts to 0.1239 € + VAT per battery. Today, there are more than 20,000 BEBAT-stalls where used batteries and flashlights can be returned free of charge. The stalls can be found in hyper- and supermarkets and local shops, jewelers, photo shops, do-it-yourself stores, toy stores, electrical stores, pharmacies, etc., as well as in schools, public and private institutions, and the eco-yards. The collection of spent batteries is mainly carried out by Sita Belgium. There has been a constant growth of collected batteries since the beginning of BEBAT activities in January 1996 (see Figure 3.1).

Based on a household waste analysis that was carried out in Flanders in 2005, the efficiency of the BEBAT collection system is 86% and even 88.5% in the Flanders region. The collected batteries are mostly treated in recycling companies within the country. An overview of the treatment options for Belgium batteries is given in Table 3.10.

Table 3.10 Destination of collected batteries in Belgium 2007

Battery type	Company	Products
Pb containing	Campine (B)	Pb
NiCd	SNAM (F)	Ferro-Ni, Cd
NiMH	Revatech (B)	
ZnC / AlMn mix	Revatech (B)	Zn, Mn sulfate, ferrous materials
Button cells	Indaver (B)	Hg, ferrous materials
Lithium	Revatech (B)	
Non-sortable	Revatech (B)	Various metals

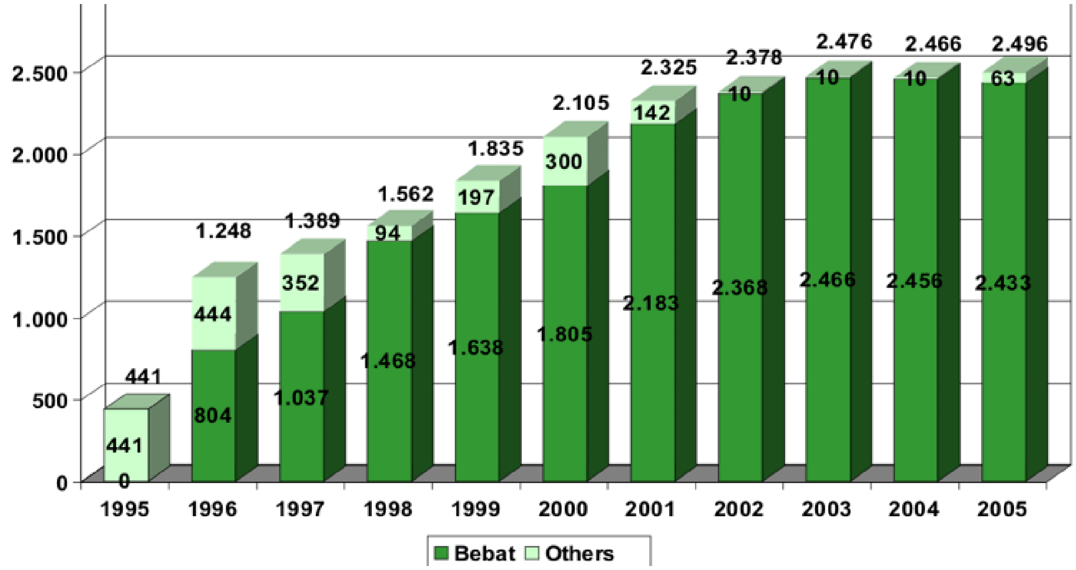

Figure 3.1 Separately collected spent batteries in Belgium

Briffaerts, Spirinckx, Van der Linden, Vrancken, 2006

Original title:	Integrale evaluatie van verwerkingstechnieken voor Belgische afvalbatterijen (zinkkool en alkaline batterijen)
Translation:	Integral evaluation of treatment technologies for Belgian spent batteries (Zn carbon and alkaline batteries)
Author:	K. Briffaerts, C. Spirinckx, A. Van der Linden, K. Vrancken
Institution:	VITO
Editors:	
Publisher:	OVAM
Place, Year:	2006
ISBN/ISSN:	
Kind of publication:	Report, 286 pages, available at: http://ovam.be/jahia/Jahia/pid/176?actionReq=actionPubDetail&fileItem=1162
Additional information:	Parts of the report, mainly the description of the processes, are in English

In this study, four different treatment scenarios for Belgian ZnC and AlMn spent batteries were evaluated. The method used was the integrated analysis of waste treatment techniques (IAW-method), developed by VITO. With this method different, waste treatment techniques are compared based on environmental performance, operational management and financial aspects (a cost-analysis turned out not to be feasible though).

In this research, to be able to compare these different treatment processes on an equal basis, they were combined with other processes into scenarios. The criterion for these combinations was that the fractions produced by these scenarios replace primary products. The scenarios compared were the following:

1. REVABAT scenario: technologies Revabat – Hydrometal - Harz-Metall
   a. Revabat, Liege (B) is a mechanical sorting technology in which batteries are sorted into a plastic, ferrous and non-ferrous fraction for recycling. A paper and a dust fraction are disposed at a landfill. The battery content in form of "black mass" is washed to sort out electrolytes and transported to Hydrometal.
   b. Hydrometal, Liege (B) is a hydrometallurgical process in which the black mass is treated by hydrochloric acid producing Zn sulfate. Filter cake produced is transported to Harz-Metall.
   c. Harz-Metall, Goslar (D) is a Waelz process in which a filter cake containing Zn, Mn, and carbon is treated (together with other wastes containing Zn) in a Waelz furnace, producing Waelz-oxide (ZnO) and a slag containing Mn, CaO and a minor share of the Zn. The slag is used as construction material at landfill sites.
2. REVATECH scenario: technologies Revabat – Revatech - Harz-Metall
   a. Revabat, as in 1.
   b. Revatech, Liege (B) is a new, alternative to Hydrometal, hydrometallurgical process in which the black mass undergoes acid extractions, producing Zn sulphate and Mn sulphate. The latter is oxidised to Mn dioxide.
   c. Harz-Metall, as in 1.
3. BATREC scenario: technologies Sumitomo/Batrec – Hydrometal - Harz-Metall
   a. Sumitomo/Batrec, Wimmis (CH) consists of pyrolysis and consequent melting in an electric furnace. Ferro-Mn, metallic Zn and Zn oxide are produced. The latter is further treated in the Hydrometal process. Slag produced in the furnace is landfilled. The flue gas of the furnace is cleaned, producing metallic Hg.
   b. Hydrometal: Zn oxide is treated by hydrochloric acid producing Zn sulphate. Filter cake produced is transported to Harz-Metall.
   c. Harz-Metall, as in 1.
4. VALDI scenario: technologies Valdi – Hydrometal - Harz-Metall
   a. Valdi, Feurs (F): the batteries are treated in an electric arc furnace, producing ferro-Mn and slag. The slag is used as construction material at landfill sites. Zn oxide is separated via air filter cake, which is further treated at Hydrometal. Activated carbon filter residues are treated at Claushuis, producing metallic Hg.
   b. Hydrometal, as in 3.
   c. Harz-Metall, as in 1.

Based on data from Revatech and Valdi the average battery composition shown in Table 3.11 is assumed for all processes (85% AlMn and 15% ZnC batteries).

Table 3.11 Assumed average battery composition

Component	Amount (kg/ton)	Component	Amount (kg/ton)
Zn	197	C	52
Mn	229	K(OH)	43
Fe	187	NH_4	3
Hg	0,13	Cl	5
Pb	1,9	H_2O	90
Cu	6,2	O_2	130
Cd	0,4	paper	27
Ni	3,3	plastic	25

The REVATECH, BATREC and VALDI scenarios recycle approximately equal amounts of metals. The REVABAT scenario recycles approximately equal amounts of Zn and iron, but no Mn. These amounts are shown in Table 3.12.

Table 3.12 Recycled materials for the scenarios considered (kg/ton batteries)

Component	REVABAT	REVATECH	BATREC	VALDI
Zn	188	189	196	194
Mn	0	181	151	125
Fe	177	177	183	181
Hg	0	0	0,13	0
Carbon:				
-within ferro-Mn	0	0	13	10
-as fuel/reduction agent	50	50	88	94
slag	221	42	19	113
Total	636	640	649	719

The emissions occurring at the processes modeled are described in a chaotic manner. Within the BATREC and VALDI scenarios, emissions are provided for the first battery treatment process. The emissions for the consequent treatment of outputs are not given because they are either not occurring according to the owners (Hydrometal) or because they are confidential (Harz-Metall). For all scenarios, the slag being used as construction materials at landfills is assumed to replace sand. No emission data to groundwater or soil of this slag is mentioned. Also, the landfilling of CdOH wastes from the Waelz process is not accounted for with environmental impacts. Refractory material of the Waelz process is landfilled and accounted for by the modeling of ‘construction waste (inert) to landfill’ from the Ecoinvent database. This database is also used for many up-stream and transport processes. In case of the use of activated carbon filters, the caught Hg is assumed to be regained in a specialized company. In the process, no emissions are assumed.

The secondary materials produced are assumed to replace virgin materials or intermediates. In this process, the quality of the produced materials also is accounted for (e.g., the concentration of Mn in the produced ferro-Mn is lower for the secondary material as for the input in the primary process).

For the Life Cycle Impact Assessment (LCIA), the characterization and normalization of the emission and resource consumption data is executed according to the Eco-Indicator 99 methodology. This results in the effect scores of Table 3.13. Negative results indicate net environmental benefits, positive – net environmental burdens.

Table 3.13 Environmental damage for all scenarios (Eco-Indicator 99 methodology)

Impact category		VALDI	REVABAT	BATREC	REVATECH	Unit
Damage to human health	caused by carcinogens	-9.87E-08	-4.13E-07	-1.66E-07	-4.14E-07	DALY[a]
	because of respiratory effects caused by organic pollutants	8.27E-10	6.86E-10	6.97E-10	8.50E-10	DALY
	because of respiratory effects caused by inorganic pollutants	-3.29E-06	-3.64E-07	-3.31E-06	1.70E-07	DALY
Climate change		1.89E-07	1.31E-07	3.01E-07	2.43E-07	DALY
Ecotoxicity		-2.50E+00	-2.17E+00	-3.03E+00	-2.20E+00	PAF[b]*m^{2}yr
Acidification/ Eutrophication		-2.37E-03	-1.04E-03	-7.92E-04	1.07E-02	PDF*m^{2}yr
Land use		-9.85E-03	-1.58E-03	-7.54E-03	-5.98E-03	PDF*m^{2}yr
Damage to mineral resources		-1.27E+00	-1.13E+00	-1.33E+00	-1.19E+00	MJ surplus
Damage to fossil fuels		9.71E-01	1.19E+00	1.93E+00	1.29E+00	MJ surplus

[a] DALY = Disability Adjusted Life Years
[b] PAF = percentage of all species present in the environment living under toxic stress
[c] PDF = Potentially Disappeared Fraction

The results of the environmental profile for the different treatment scenarios can only be compared for one environmental criterion at a time. The results for the different environmental criteria cannot be added up to one global score. Adding of the scores implies a weighting of the different criteria, which is not done in this study.

The results of the environmental analysis do not allow a ranking of scenarios. All four scenarios have net environmental benefits for the criteria carcinogens, respiratory effect by inorganic pollutants, ecotoxicity, damage to mineral resources and land use. Some scenarios also have net environmental benefits for other criteria. Although the REVABAT scenario does not recycle the metal Mn, the 4 scenarios have an equal environmental score for the impact category damage to mineral resources. This is because Zn is considered a scarce mineral. Compared to Zn, iron and especially Mn are not scarce, so their use does not influence the result.

Generally, it can be concluded that transport has an important influence on the results of the environmental profiles, therefore plants located in Belgium score better for the criterion damage to human health caused by carcinogens. It can be also concluded that higher recycling rates for metals do not necessarily result in a better environmental profile.

The Sumitomo/Batrec process is developed for the treatment of all used batteries (ZnC and AlMn), regardless of their Hg content. The efficiency of the process increases with the Hg content. In this study, the assumed Hg content is relatively low. This has a negative influence on the environmental profile of the BATREC scenario, compared to the other treatment scenarios. The results of this study can be used as a basis for the further development of the Belgian and European policy concerning the treatment of used batteries.

3.1.3 Switzerland

INOBAT, 2006

Original title:	INOBAT Bericht über die Tätigkeit 2005
Translation:	INOBAT Report about the activities in 2005
Author:	INOBAT “Interessenorganisation Batterieentsorgung”
Editors:	
Publisher:	INOBAT
Place, Year:	Bern 2006
ISBN/ISSN:	
Kind of publication:	a report, 8 pages, available at: http://www.inobat.ch/fiPbmin/user_upload/pdf /Inobat_Taetigkeitsbericht_2005.pdf
Additional information:	

INOBAT is the Swiss organization responsible for collection and recovery of batteries. INOBAT with its 130 members, representing manufacturers and importers of batteries, constitutes approximately 90% of the primary and secondary battery market in Switzerland. INOBAT operates under the control of the Swiss Federal Environment Agency (BAFU). The battery collection and recovery in Switzerland is financed through a product disposal fee (VEG), which at the moment amounts to 3.20 CHF (approximately 2.6 USD) per kilogram of batteries introduced to the market. The batteries are recovered in the Sumitomo/Batrec battery recycling plant in Wimmis. The costs of recovery are 4800 CHF/t of batteries. The product fee does not cover recycling costs of all batteries. Some batteries are sorted out in the recycling plant and delivered to other recovery plants with lower operational costs. Swiss data on battery sales in years 2005 and 2004 is provided in Table 3.14.

Table 3.14 Battery sales in Switzerland

Type of battery	Amount of batteries sold in 2005 [t]	Amount of batteries sold in 2004 [t]
ZnC	429	504
AlMn	2,337	2,593
Button cells	19	23
Lithium batteries	24	26
NiCd	69	228
Other secondary batteries	75	115
Block batteries	113	111
Batteries in-built in devices	618	219
TOTAL	3,684	3,820

In 2005 2,359 tons of batteries were collected for recycling and in 2004 2,530 tons. The recovery quota, calculated as the quantity of batteries collected and fed to the recovery in a report year in relation to the quantity of batteries introduced to the market in the previous year amounted to 62.9% in 2005 and 66.6% in 2004. The target of BAFU is to recover of 80% of batteries[2].

3.1.4 Germany

GRS Batterien, 2007

Original title:	Erfolgskontrolle
Translation:	Success control
Author:	Gemainsame Rücknahmesystem Batterien (GRS) - the Joint Collection System Batteries
Editors:	
Publisher:	Gemainsame Rücknahmesystem Batterien (GRS)
Place, Year:	Hamburg 2007
Kind of publication:	A report, 20 pages, available at: http://www.grs-batterien.de/ger/index.php?site=informationen/zahlen&siteID=4
Additional information:	

This report provides quantities of separately collected batteries within the GRS collection scheme in the year 2006. The year 2006 can be considered very successful: a 7% increase of the collected quantity as compared to the year 2005 was achieved. Also, the recovery quota has increased and amounts to 88% of the collected batteries. Due to higher prices for metals, sales the recovery costs were lower than in the previous years. The number of the GRS members has increased as well, amounting to 808 battery producers and importers by the end of 2006. In 2006, the members of GRS sold almost 1.5 billion batteries, which is 4% more than in 2005; however; the total weight of batteries only increased slightly. In 2005, the average weight of a battery was 24.3 g while in 2006 it decreased to 23.4 g. In 2006 the proportion of AlMn batteries sold increased by 3.2% as compared to the year 2005, while the sales of ZnC batteries decreased by 23%. Detailed data about the sales and segmentation of batteries in 2006 as compared to the year 2005 are presented in Table 3.15.

In 2006, about 34,736 tons of batteries were sold in Germany, primary batteries accounted for 78.4% (in 2005, 79.7%). Within primary batteries, AlMn batteries strongly dominate (84%).

In 2006, 13,138 tons of batteries were collected (approximately 38% of the sales in 2006). The average collection rate per inhabitant was 159 g in 2006, compared to 149 g in the year 2005. About 49% of batteries were collected through the retailers' collection points (shops). The batteries are collected as battery mixes which are subsequently sorted in sorting plants. The sorting takes place foremost in the sorting plants of the company Uni-Cyc GmbH and GMS GmbH & co. KG. In 2006, 12,426 tons of batteries were sorted (this includes some of the stored batteries from 2005). The major types of sorted batteries were AlMn and ZnC batteries (79%). The proportion of batteries sent to the recovery processes increases continuously: in 1999 these were 19%, in 2002 66% and in 2006 88% of the sorted batteries. Regarding the recovery of AlMn and ZnC batteries, apart from treatment in a blast furnace, other processes also are

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[2] In the press release of INOBAT from February 28, 2007, a recovery quota of 66.4% of batteries has been reported in 2006.

used, e.g., the technology of Redux GmbH and GMS mbH & Co. KG, where after shredding iron and Zn are separated. The iron is recovered in steel works, while the parts Zn containing are treated in a rotating kiln to Zn oxide. Another example is the Electric arc furnace of the company Valdi in Feurs (F), of which the final battery recovery products are ferro-Mn and Zn oxide; 12% of the sorted batteries (1,550 tons) were disposed of in hazardous waste landfills of the companies IAG, Selmsdoerf and HIM GmbH in Billigheim. AlMn batteries not UV-coded constitutes 12% of the disposed batteries (not Hg-free AlMn batteries). Qualitative results of the battery recovery processes are provided in Tables 3.16 and 3.17.

den Boer, 2007

Original title:	A Novel Approach for Integrating Heavy Metals Emissions from Landfills into Life Cycle Assessment Consideration of Waste Pretreatment, Landfill Processes and Long-Term Effects
Author:	Emilia den Boer
Institution:	Technische Universität Darmstadt, Germany
Editors:	Verein zur Förderung des Instituts WAR
Publisher:	
Place, Year:	Darmstadt, 2007
ISBN/ISSN:	3-932518-78-0
Kind of publication:	PhD thesis, a book, 203 pages
Additional information:	

This doctoral thesis is concerned with investigations of the time-dependent leachability of heavy metals from landfills and with defining the optimal way of its modeling within Life Cycle Assessment (LCA) studies. An important target of the European Waste Policy and legislation the CEE countries have to comply with is the reduction of waste going to landfill and the pretreatment of waste prior to landfilling. Precise modeling of the environmental impacts of landfilling of both raw and pretreated waste is needed to determine the consequences of waste pretreatment. Emissions of heavy metals from landfills are some of the main contributors to the potential human toxicity impact of a waste management system (WMS), which is a crucial impact category within an LCA. Currently, approaches used for the modeling of landfill emissions either neglect the long-term emissions from landfills or do not account for the leachability rates of pollutants, thus the environmental impact of waste pretreatment is not considered. The two approaches lead to a significantly different human toxicity indicator result. Based on the investigations undertaken in this thesis, an optimal method is provided to resolve this controversy. Results of a several years of investigations on the behavior of raw and pretreated waste in lysimeters simulating landfills are evaluated here, providing significant information towards understanding the mobility of pollutants from various types of wastes. Pretreatment options considered are aerobic MBP and incineration of residual waste. In the experiments, the behavior of metals from batteries in a biological stabilization process also was investigated.

Table 3.15 Battery sales and segmentation in 2006 as compared to 2005

			Weight				Amount of batteries			
			2005		2006		2005		2006	
			kg	%	kg	%	in 1.000 units	%	in 1.000 units	%
Primary batteries	Cylinder cells**	ZnC	4,717,446	13.6	3.616,472	10.4	194,505	13.6	151.551	10,2
		AlMn	22,162,384	64.0	22,874,233	65.9	889,728	62.4	941.372	63,5
		Zn-air	53,464	0.2	48,785	0.1	338	‹0.1	359	‹0,1
		Li	218,979	0.6	219,666	0.6	14,639	10	14.646	1,0
	Button cells	AgO*	40,068	0.1	36,119	0.1	24,920	1.7	24.946	1,6
		AlMn*	163,300	0.5	148,777	0.4	57,889	4.1	84.019	5,7
		Zn-air	59,553	0.2	58,496	0.2	66,980	4.7	64.021	4,3
		Li	169,080	0.5	244,112	0.7	52,661	3.7	60.456	4,1
	Sum		**27,584,274**	**79.7**	**27,246,660**	**78.4**	**1,301,660**	**91.2**	**1.341.370**	**90,4**
Secondary batteries	Cylinder cells**	AlMn	40,642	0.1	75,662	0.2	1,564	0.1	2.164	0,1
		Li-ion	2,212.384	6.3	2,480,805	7.1	29,516	2.1	34.824	2,4
		NiMH	1,921,010	5.6	1,952,781	5.6	69,057	4.8	79.235	5,3
		Pb	1,015,389	2.9	1,069,969	3.1	823	‹ 0.1	1.010	0,1
		NiCd	1,830,150	5.3	1,881,681	5.4	18,564	1.3	17.001	1,2
	Button cells	Li-ion	7,747	‹ 0.1	15,283	‹ 0.1	2,848	0.2	5.115	0,3
		NiMH	12,789	‹ 0.1	13,007	‹ 0.1	2,404	0.2	2.677	0,2
		NiCd	295	‹ 0.1	176	‹ 0.1	87	‹ 0.1	90	‹0,1
	Sum		**7,040,406**	**20.3**	**7,489,364**	**21.6**	**124,863**	**8.8**	**142.116**	**9,6**
	Total		**34.624.680**	**100.0**	**34,736,024**	**100.0**	**1,426,523**	**100.0**	**1.483.468**	**100,0**

* includes cylinder cells formed of button cells

** includes battery packets

Table 3.16. Quantities of collected, recovered and disposed batteries according to types and costs of the whole waste management system

	Group	System	Sold quantities (kg)	Collected quantity[1] (kg)	Quantity directed to recovery processes[2] (kg)	Quantity disposed of (kg)	Costs of the whole management system[3] (€/kg)
Primary batteries	Cylindrical	ZnC	3,442,388	2,812,900	2,457,030		1.20
		AlMn[4]	22,852,334	6.629,522	5,352,425	186,400 [6]	1.20
		Zn-air	3,706	0	0	1,363,790 Battery mixes	1.35
		Li	217,809	91,194	175,956		2.38
	Button cells[4]	AgO	36,119	71,021	45,501		3.03
		AlMn	148,776		0		
		Zn-air	58,496		0		
		Li	244,112		0		
	Block batteries (>500 g)	Zn-air	45,079	199,853	230,008		1.35
		ZnC	174,083	1,081,911	925,010		1.20
		AlMn	21,901	0	58,590		1.20
		Li	1,857	34,445	0		2.38
Secondary batteries	Cylindrical	Li-ion	2,480,805	55,131	33,919		0.87
		NiMH	1,952,781	91,010	72,794		–1.47
		NiCd	1,881,681	953,353	854,431		0.54
		AlMn[4]	75,662	0	0		1.20
	Button cells[5]	NiCd	176	0	0		3.03
		Li-ion	15,283	0	0		
		NiMH	13,007	0	0		
	Small Pb batteries		1,069,969	1,117,843	930,425		0.81
	Total		**34,736,024**	**13,138,183**	**11,136,089**	**1,550,190**	**1.12**

[1] Composition based on sorting results, [2] Quantity directed to recovery, referring to the sorted batteries; [3] The costs include system operation costs: collection, sorting, recovery and disposal, publicity and administration costs; [4] In case sorting was not possible, the results include both primary and secondary batteries, e.g. total quantity of button cells; [5] contained in the results for primary batteries, [6] not UV-coded

Table 3.17 Qualitative results of battery recovery processes in 2006 (in tons)

All recovered batteries	**AlMn, ZnC, Zn-air**	**Pb**	**NiCd**	**NiMH**	**Li**	**Button cells**	**Sum**
	9,146	**923**	**719**	**73**	**211**	**50**	**11,122**
Recovery Plants **Products**	Valdi, Redux, DK, Citron, GMA, Revatech	VARTA	ACCUREC, SNAM	REDUX	ACCUREC, Falcon bridge, Umicore	Remondis	
Zn und its compounds	2,373	0	0	0	0	5	2,378
Ferro-Mn	1,140	0	0	0	76	5	1,221
Steels (containing iron and/or Ni)	1,287	0	413	69	55	19	1,843
Hg and its compounds	0	0	0	0	0	3	3
Pb and its compounds	0	600	0	0	0	0	600
Cd and its compounds	0	0	102	0	0	0	102
Other Metals (Al, Co, Cu etc.)	10	0	4	0	9	1	24
Carbon	516	55	0	0	4	0	575
Plastics for recovery	184	0	0	0	0	0	184
Slag for recovery	1,245	28	0	0	0	0	1,273
Other materials for recovery	0	240	3	0	3	3	249
Waste							
Wastewater/Flue gas	1,087	0	127	4	37	4	1,259
Plastics for disposal	50	0	69	0	4	0	123
Slag for disposal	1,215	0	0	0	0	0	1,215
Other materials for disposal	39	0	1	0	23	10	73

To determine the impact of MBP on the mobility of heavy metals, the concentration of metals and speciation in the input to the biological stabilization plant and in the output after 3 weeks and 6 weeks of aerobic treatment were investigated. The input material was raw residual waste from Germany. The waste was biologically stabilized in an aerobic pilot plant at the Bauhaus-Universität Weimar. Four reactors were used for the investigations. Two of them were filled with original residual waste, while the other two contained samples enriched with shredded metals: aluminum, Cu and steel and shredded household batteries. The metals were derived from typical constituents of residual waste such as cans, foils, and cables. The metals were shredded to a size of approximately 1 cm^2. The mixture of batteries was obtained from the university collection point and it had an average composition of batteries available in the German market (i.e., approximately 80% constituted by AlMn and ZnC batteries). The batteries were sawed and ground and added to the reactors as a powder (including the outer covers).

The original content of metals fraction in Wetterau waste was approximately 3.7%. These metals were primarily present in the form of bulky pieces, thus being only partly available for reactions within the waste body. Moreover, they are a source of heterogeneity and cause sampling problems. Thus, the bulky metal pieces were removed and replaced by the respective quantities of shredded metals. The quantities of added metals were equivalent to the typical concentration of metals in residual waste (approximately 3% of the waste mass for steel plate and 0.2% for aluminum, Cu, and batteries). In fact, the samples were slightly enriched with respect to most of the metals as the bulky pieces removed from the samples consisted predominantly of steel. The aim of the replacement of the original metals by the shredded ones was to achieve a more homogeneous distribution of metals in the samples and thus the possibility of observing more profound effects on the stabilization process. The leachate from the reactors was investigated.

Generally, higher decomposition rates, especially during the first 3 weeks, were observed for the samples without shredded metals and batteries. This may imply inhibition of the microbial activity by heavy metals. However, during the next 3 weeks, the decomposition rate increased also in the reactors with metals and after 6 weeks, the summary loss of dry mass was only approximately 1% lower in the reactors with metals than in the reactors without metals. Naturally, the total metals content measured in the enriched samples was higher. The most profound increase was observed for Fe (approximately 5 times higher concentration than in the original samples), and for Mn, Ni and Zn (approximately 2 times higher concentrations than in the original samples). The increase in the concentrations of Mn, Ni, and Zn clearly results from the added batteries. The metals balance of the treatment process for the samples with shredded metals and batteries is presented in Figure 3.2.

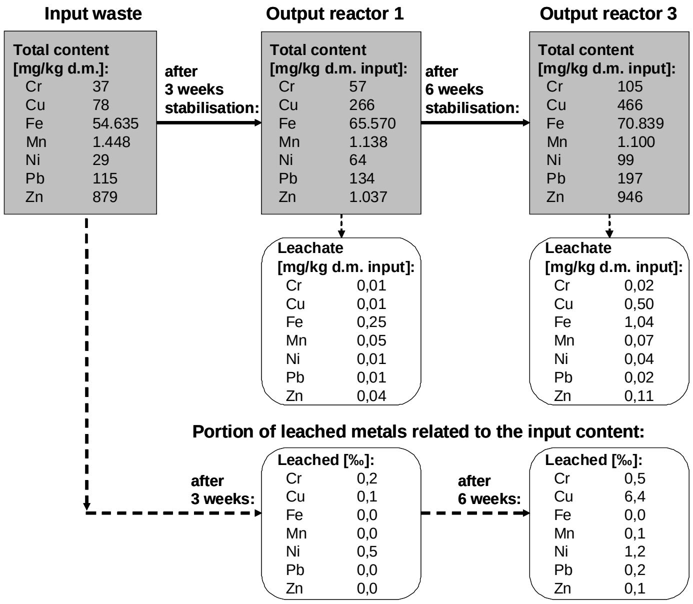

Figure 3.2 Mass balance of the metals within the biological stabilization process in the Weimar plant (related to 1 kg input d.m.) – samples with shredded metals and batteries

In general an increase of metals content is observed in the samples after 3 weeks and 6 weeks of treatment (the quantities of metals refer to the input dry matter to eliminate the influence of mass loss due to decomposition). This phenomenon was observed in all other experiments and probably is related to the increase of availability of metals due to higher disintegration of the material and mineralization of the organic fraction (also confirmed in the literature). It should be noted that the amount of metals leached from waste during the biological stabilization process is very limited (much below 1% of the total metals content in the waste). After 3 weeks of stabilization, the leaching rates in the samples with additional metals and batteries were lower than in the samples without shredded metals and varied from 0.00% (Mn, Pb, Zn) to 0.05% (Ni) of the initial concentration of metals in the input waste. The low leaching can be caused by the initial delay of the decomposition process due to the inhibiting effect of the metals on microorganisms. In contrast to the waste without shredded metals, after 6 weeks the leached amount for all metals increased. In general, it can be stated that all the metals are very well sorbed by the waste matrix and metals emissions to leachate during the MBP are very insignificant.

Moreover in this thesis the results of 8 years storage of raw, MBP and thermally pretreated (incineration slag) were evaluated. The lysimeter experiments allowed estimation of the short-term (up to 100 years) leaching rates of metals from different types of waste. These leaching factors are provided in Table 3.18.

Table 3.18 Short-term (100 years) leaching factors for different kinds of waste

Type of waste	Ca	Cd	Cr	Cu	Fe	Ni	Pb	Zn
	[%]							
Raw waste	28.2	38.7	0.6	0.7	3.4	5.8	0.5	20.9
MBP waste 1	0.49	0.12	0.01	0.10	0.29	0.04	0.18	0.49
MBP waste 2	0.63	0.14	0.15	0.05	0.16	0.00	0.06	0.63
Incineration slag	0.09	0.04	0.00	0.002	0.002	0.04	0.001	0.00

Furthermore, an innovative approach for the assessment of the long-term leachability of metals from landfills was proposed. Its crucial points are: (a) to analyze metals speciation and their changes in treatment and disposal processes; and (b) to include long-term processes, such as decomposition of organic matter and pH development combined with empirical investigations of metals behavior under different conditions into the modeling of metals leaching. The results of an estimation of the leaching curves for Zn from different types of waste are presented in Figure 3.3. Leaching of Zn from raw waste is estimated to progress much faster than from the pretreated waste. Generally, the results indicate that the release of metals from waste is a very slow process; requiring thousands of years to meet the adequate metals limit contents for soils in a waste body.

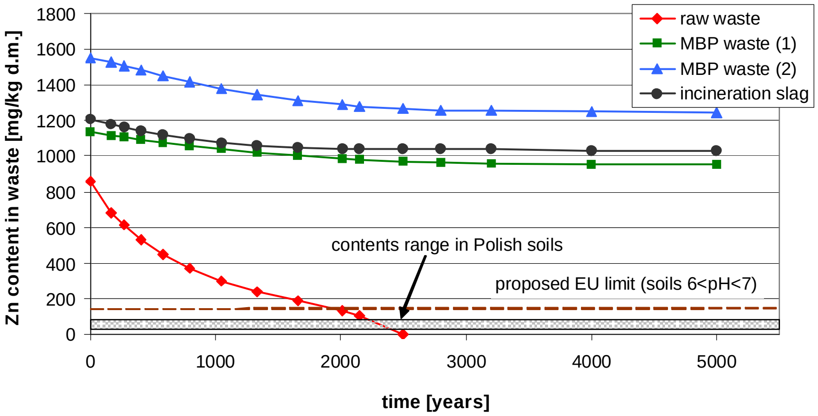

Figure 3.3 Time-dependent Zn leaching from landfills of different waste (cumulative)

UBA, 2006

Original title:	Batterien und Akkus; Das wollen Sie wissen!; Fragen und Antworten zu Batterien, Akkus und Umwelt
Translation:	Primary and secondary batteries; This is what you want to know! Questions and answers to primary and secondary batteries and the environment
Author:	Umweltbundesamt (UBA) – German Federal Environment Agency
Editors:	
Publisher:	Umweltbundesamt
Place, Year:	Dessau, 2006

ISBN/ISSN:	
Kind of publication:	Brochure, 27 pages, available at: http://www.umweltdaten.de/publikationen/fpdf-l/3057.pdf
Additional information:	

This brochure was released by the German Federal Environment Agency (UBA) and directed to the users of batteries. Its purpose is to provide a general overview on the battery systems, explain their functions and applications, and draw attention to their environmental problems. The brochure also provides guidelines on how to use batteries in an environmentally sound manner. It summarizes general types of batteries and the segmentation of portable batteries, based on the German sales data for the year 2004 (see Table 3.19).

According to UBA, the highest environmental risk is related to the batteries containing Hg, Cd, and Pb. Batteries containing these components have to be labeled. Heavy metals are very dangerous substances. Heavy metals can cause either direct health effects in humans or accumulate in the food chain and in the environment. Cd compounds can cause kidney damage and are considered carcinogenic if inhaled. Pb accumulates in bones and can distort bio-chemical processes in living organisms. Also, natural waters can be contaminated by heavy metals, which can be taken-up by fish and be transferred to humans through the food chain. Mn dioxide (out of AlMn batteries), lithium (out of Li-ion secondary batteries) and the electrolytes (e.g., potassium hydroxide and sulfuric acid) are partly corrosive or environment endangering substances. Also, the metals whose content does not require labeling are not entirely safe, e.g., Ni can cause allergic reactions.

Disposal of primary and secondary batteries combined with household waste is banned. Otherwise, contaminants contained in batteries could pollute the environment as emissions of waste incinerators or landfill (leachate). The separate collection prevents contamination of the household waste and of the environment. Moreover, separate collection allows the recovery of batteries in the form of secondary materials. In Germany, over a billion household batteries were sold in the year 2004. These contain approximately 4700 tons of Zn, 1500 tons of Ni, 700 tons of Cd, 7 tons of Ag and 3 tons of Hg. Although there is a legal obligation to collect all batteries, on a yearly basis only approximately one-third of sold batteries is being collected. This means that large amounts of contaminants still enter the environment through disposal with the household waste and other unclear disposal ways.

The concentration of heavy metals not only contributes to the negative environmental performance of batteries, but also the energy-balance of batteries is responsible for their high environmental burden. Approximately 40-500 times more energy is used in the production of primary batteries than they generate in their use phase. This energy consumption renders batteries as the most expensive source of energy. The recharging of batteries can improve their environmental and energy balances. A very good alternative to primary batteries is provided by secondary ones such as AlMn batteries.

Table 3.19 Sales of portable batteries[3] in Germany (year 2004)[4]

Battery type	Battery form	Chemical system	Portable batteries in millions (2004)	Portable batteries in tons (2004)
Primary batteries	Cylinder	Alkaline Mn (AlMn)	799	20,771
	Cylinder	Zinc carbon (ZnC)	210	5,633
	Cylinder	Zinc air (Zn-air)	0	57
	Cylinder	Lithium (Li)	16	251
	Button	Lithium (Li)	43	131
	Button	Alkaline (AlMn)	41	114
	Button	Zn-air	59	51
	Button	Silver oxide (AgO)	28	36
	Sum primary batteries		1,196 [a]	27,044 [a] (+3.421)[b]
Secondary batteries	Cylinder	Nickel Metal Hydride (NiMH)	55	1.483
	Cylinder	Lithium Ion (Li-ion)	23	1.737
	Cylinder	Nickel Cadmium (NiCd)	21	2.028
	Cylinder	Alkaline (AlMn)	3	66
	Cylinder	Small Pb Acid	1	972
	Button	Nickel Cadmium (NiCd)	0	1
	Button	Nickel Metal Hydride (NiMH)	2	7
	Button	Lithium Ion (Li-ion)	2	7
	Sum secondary batteries		107 [a]	6,301 [a] (+2.592)[b]
Sum			1,303 [a]	33,345 [a] (+6.013)[b]

[a] sales by the battery producers belonging to the GRS, accounting for 85% of the market

[b] additional sales of the remaining battery producers, belonging to the Vfw-Rebat and Bosch Recycling Werkzeuge (remaining 15% of the battery market)

Further on, the brochure discusses the applications for different batteries. It recommends using the secondary batteries instead of primary batteries, due to their better environmental performance. Especially the application of AlMn secondary battery is recommended, also due to its slowly progressing own discharge. It is also explicitly advised not to use the NiCd secondary batteries due to their high heavy metals content and fast progressing discharge.

The brochure also explains the functioning of the separate collection system for batteries and provides examples of recovery options for different battery types. The majority of battery producers and distributors operating in the German market belong to the GRS (85% market share). GRS organizes collection and recovery of spent batteries on behalf of its members. Some producers founded their own collection systems, e.g., the one owned by Bosch for the collection of special secondary batteries for tools. The collection of batteries is performed by retailers (shops), industry and public waste disposal authorities. The batteries that are collected are subsequently segregated in sorting plants into various chemical systems. The current battery recovery processes allow the recovery of primarily metals. Further on, examples of recovery options for different batteries are presented along with a short outline of their problems. Regarding the ZnC and AlMn batteries, recovery in the Zn smelter, including the use of slag is

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[3] Referred to as „equipment batteries" in the German literature

[4] based on the data of Gemainsame Rücknahmesystem Batterien (GRS) - the Joint Collection System Batteries and two other organisations responsible for the collection of batteries: Vfw-Rebat and Bosch Recycling Werkzeuge

given as an example. It is stated that Hg separation is not practiced any more with regard to these battery streams due to their low Hg content. In 2004, a small portion of the ZnC and AlMn batteries was disposed in a hazardous waste landfill.

The proportion of batteries undergoing recovery has gradually increased in the past years. In 2004, 77% of the batteries collected by GRS have undergone different recovery processes. The remaining 23% were disposed in a hazardous waste landfill. As a comparison, in the year 2000 only 33% of the separately collected batteries were sent to recovery processes and 67% were directly disposed. The recovery technologies for batteries have also undergone a significant improvement in the past years. Unfortunately, still only a low proportion of sold batteries enter the separate collection and recovery schemes. Since March 2006 the users of electric and electronic equipment are obliged to bring their waste equipment to a communal collection point. The separate collection of this equipment is expected to increase the quantity of recovered batteries (the in-built batteries will be also co-collected).

The problem of AlMn and ZnC batteries that were produced before 2001 was their high content of Hg, up to 100 ppm. Since 2001 the Hg limit in the produced batteries is 5 ppm; however, batteries with high Hg content can be still found in the mixes of collected batteries. The reduced Hg content will enable enlarging the recovery potential for the AlMn and ZnC batteries in the coming years. According to UBA, too high a proportion of these batteries is still disposed in a hazardous waste landfill.

Bräutigam, 2001

Original title:	Ökologische Bilanzierung von Verwertungsverfahren für Trockenbatterien
Translation:	Ecological balance of recovery technologies for dry batteries
Author:	Andreas Bräutigam
Editors:	B. Bilitewski, P. Werner
Publisher:	Forum für Abfallwirtschaft und Altlasten e.V.
Place, Year:	Dresden, 2001
ISBN/ISSN:	3-934253-13-X
Kind of publication:	Book, 188 pages, dissertation (PhD thesis), 1st edition
Additional information:	Band 24 of the series “Schrifenreihe des Instituts für Abfallwirtschaft und Altlasten Technische Universität Dresden”

This publication is concerned with a comparison of the environmental impacts of recovery technologies for dry batteries containing Zn (ZnC and AlMn batteries). The environmental assessment methodology is based on the method of Life Cycle Assessment (LCA), according to the international standards EN ISO 14040 to 14043.

Three recovery scenarios have been investigated and assessed:

- The Sumitomo/Batrec technology as a technology designed especially for the recycling of dry batteries and heterogeneous mixes of batteries, aimed at recovery of Zn, ferro-Mn (and Hg);

- The Imperial Smelting process (production of mainly primary Zn in a shaft furnace) for co-treatment of Hg-free dry batteries, accompanied by the recovery of Zn;
- The Waelz process (production of secondary Zn in rotary Waelz furnace) for co-treatment of Hg-free dry batteries, followed by Zn recovery from Waelz oxides in an electrolysis process.

All three technologies are used for the recovery of separately collected batteries. The environmental impacts of separate collection, transport and sorting are not subject to the investigations, as it is assumed that they are comparable for all three technologies. Also no basic scenario, i.e., disposal of batteries commingled with household waste has been considered.

The three technologies considered can be characterized by different recovery rates of the materials contained in spent batteries. Thus, in order to provide a level playing field for the comparison, the equivalent (conventional) processes for the production of substituted materials have been also modeled. The equivalent processes have been incorporated into the pair-wise comparison of technologies, as required by the LCA methodology. The technologies considered for the substituted due to batteries recycling production processes include:

- For the Sumitomo/Batrec technology: production of ferro-Mn from Mn ores in a electric arc furnace and production of Zn from sulfidic ores in the roasting/electrolysis and the roasting/sintering/Imperial Smelting technologies;
- For the Imperial Smelting technology: production of Zn from sulfidic ores in the roasting/sintering, followed by the pyrometallurgical treatment in the Imperial Smelting furnace
- For the Waelz process: production of Zn from sulfidic ores in the roasting/electrolysis process.

For all recycling processes for batteries and the respective equivalent processes, the Life Cycle Inventories (LCI) have been modeled using the software UMBERTO. The inventories include up-stream energy generation processes. The Life Cycle Impact Assessment (LCIA) has been performed according to the assessment method recommended by UBA (UBA method). The following impact categories are considered: resource use, global warming, toxic effects to humans, toxic effects to ecosystems, photochemical oxidant formation, acidification, eutrophication and land use. The impact category “toxic effect to humans” within the UBA method only includes emissions to air (the human toxic impact of water emissions is considered relatively low). The air emissions considered toxic to humans within this publication are restricted to the following: Pb, Cd, carbon monoxide, sulfur oxide, polyaromatic hydrocarbons (PAHs) and particulate matter. Inclusion of other emissions was not possible due to data gaps. Out of these, emissions of Cd and PAHs (in the form of benzo(A)pyrene) are aggregated to a so-called “carcinogenic risk potential” while the other emissions are considered on an individual basis. For the impact category “toxic effects to ecosystems” within the UBA assessment method, both emissions to air and emissions to water are considered without being further aggregated. Similarly, due to data gaps, the assessment of ecosystem-toxic emissions is limited to the air emissions of ammonia, hydrogen fluoride, sulfur oxides, dust, nitrogen oxides, Zn and Pb. Aggregated indicators are used for the assessment of other impact categories.

Further steps of the LCIA performed in the publication are normalization and ranking, i.e., the prioritization of different impact categories by their ecological priority, according to the UBA methodology. Finally, sensitivity analyses of the LCA results are performed. Within the sensitivity analysis, modifications of the equivalent processes originally proposed have been considered as well as different quantities of batteries to be recycled.

Results of the LCA indicate that the Sumitomo/Batrec scenario shows the lowest environmental impacts in the majority of the investigated impact categories. No clear ranking of their environmental impacts could be established for the two other recycling scenarios (the Imperial Smelting and Waelz processes). The normalization step allows assessment of a magnitude of environmental impacts of the scenarios investigated by relating them to a cumulative impact of all activities taking place in a country (e.g., emissions from energy generation, industry, transportation, etc.), expressed in kg of emitted substance per inhabitant (the so-called inhabitant equivalents (inh. eq.)). In this LCA, emissions related to 1 ton of treated batteries were normalized by relating them to the respective inhabitant equivalents. The results obtained from the LCA indicate that the highest relative impacts occurring at all investigated battery recycling processes are the human-toxic impacts due to air emissions of Pb and ecosystem-toxic impacts due to air emissions of Zn and Pb. In case of human-toxic impact due to Pb, emissions from treatment of 1 ton of batteries, the highest relative impact amounting to 2.0 inh. eq. was calculated for the Imperial Smelting scenario. Similarly, the battery recovery in the Imperial Smelting scenario showed the highest relative ecosystem-toxic impacts in form of air emissions of Zn and Pb, amounting to 7.2 and 2.0 inh. eq., respectively. However, it should be underscored that the equivalent processes of the battery treatment in the Imperial Smelting technology (i.e., production of Zn from sulfidic ores within the roasting/sintering, followed by the pyrometallurgical treatment in the Imperial Smelting furnace) showed even higher relative impacts in the mentioned categories. This indicates that these impacts cannot be contributed to the input of batteries, but rather to the technology itself.

The results of the overall LCA indicate that the selection of the equivalent processes have a significant impact on the results obtained from the LCA. The complexity of the selected equivalent processes depends on the quality and quantity of the materials recovered from batteries. Within the Sumitomo/Batrec technology, both Zn and ferro-Mn are recovered, while in the two other technologies only Zn. Therefore, the equivalent processes of the Sumitomo/Batrec technology show the highest complexity. The higher the environmental impacts of the equivalent processes to a given technology, the better the final LCA score of this technology. This partly explains the best environmental score of the Sumitomo/Betrec technology.

Rentz, Engels, Schultmann, 2001

Original title:	Untersuchung von Batterieverwertungsverfahren und -anlagen hinsichtlich ökologischer und ökonomischer Relevanz unter besonderer Berücksichtigung des Cdproblems
Translation:	Investigation of battery recovery technologies and plants with regard

	to ecological and economic relevance under special consideration of Cd problem
Author:	O. Rentz, Bernd Engels, Frank Schultmann
Institution	Deutsch-Französisches Institut für Umweltforschung Universität Karlsruhe (TH)
Editors:	
Publisher:	
Place, Year:	Berlin, 2001
ISBN/ISSN:	
Kind of publication:	Report, 276 pages, available at: http://www.umweltdaten.de/medien/battdfiu.pdf
Additional information:	Final report of a research project 299 35 330, commissioned by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety in frame of a series: UFOPLAN (Environmental Research Plan)

This report was written three years after Directive 98/101/EC entered into force, adapting to technical progress Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances (Battery Directive 98/101/EC). The Battery Directive 98/101/EC introduces, *inter alia*, stringent limits on the content of Hg in batteries (maintaining the previously established limits for Cd and Pb content) and prohibits marketing of batteries with the limit of Hg higher than that proposed on January 1, 2000. In this project, the Deutsch-Französisches Institut für Umweltforschung (the German-French Institute for Environmental Research) was commissioned by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) to investigate and assess the existing structures and technologies for separate collection and recovery of batteries. The study focuses on both primary and secondary household (portable) batteries. The report provides a detailed overview of battery sales in Germany in the period between 1994 and 2000 according to different types of batteries. The legal requirements for battery manufacturers in Germany are outlined. Further on, the German collection system for batteries and the collection rates achieved in the year 2000 are discussed. In Germany, the majority of battery manufacturers fulfill their requirement of setting up collection schemes for batteries by assigning this task to third parties acting on their behalf. The major market players are the GRS, Vfw-REBAT-Batterierücknahmesystem (Vfw-REBAT battery Collection System) and Robert Bosch GmbH, with respective market shares of 85%, 10% and 5% in 1999. These institutions organize collection and transport from the battery collection points to the sorting plants, battery sorting, recovery and disposal activities by assigning them to individual transport and treatment/disposal companies in a tender procedure.

In the following section of the report, sorting technologies and sox reference sorting plants located in Germany are described. Battery sorting is a necessary step for most recovery technologies: a) to prevent contamination of the final products with undesirable substances; and b) to prevent excessive environmental impacts (and violating of permitted emission limits) in case of co-treatment of batteries in, for example, metal industry plants. In the latter case, co-treatment of batteries containing Zn with a high content of Hg (>> 5 ppm weight) may pose an emissions problem. The sorting technologies described are partly manual, partly automatic systems (based on battery size, geometry, bar codes, and chemical fingerprint).

A significant portion of the report is concerned with description of individual battery recovery processes worldwide. *Inter alia*, ten recovery technologies for batteries containing Zn (especially AlMn and ZnC batteries) are presented (see Table 3.20). Descriptions of some technologies include mass balances; however, the data are highly incomplete and only in some cases data on emissions are provided. The authors perform an assessment of the environmental and economic aspects of the technologies presented. They underline the suitability of the LCA methodology for the assessment of environmental impact; however, due to a lack of data at a required level of detail, this approach is not followed. Instead, they propose an assessment matrix based on a qualitative assessment criteria. In the assessment matrix, the technologies and the individual treatment plants are assessed. The collection and transport systems are not subject to an assessment, because the authors do not expect any significant changes of these systems to occur in Germany in the near future. The assessment is based on six process-related and four plant-related criteria. In the following, the meaning of these criteria is shortly outlined.

Process-related criteria:
Criteria A1 and A2 assess if a given process is environmentally more advantageous than disposal of batteries with household waste:
A1. Environmental pressure: assesses: a) if emissions from a given process are lower than the permitted emission level for a given technology; and b) if due to battery input an enrichment of contaminants (especially heavy metals) in the final products and co-products of a given technology takes place.
A2. Resources use (energy and ancillary materials): assesses if the technology is resource intensive.
Criteria B1 and B2 assess the recovery rate of the materials contained in the batteries.
B1. Recovery rate: assesses recovery products both qualitatively and quantitatively.
B2. Market for the products: assesses if the recovered products can be marketed.
C. Cost effectiveness: assesses if a given technology can be operated in an economically viable way, i.e., to what extent the operation costs are covered from the secondary materials sales and what the fee for the acceptance of batteries for the treatment is.
D. Requirements concerning the inputs: assesses to what extent the technology can deal with the contamination of the input, e.g., if the Hg contained in batteries will cause excessive emissions to air or final product contamination.

Plant-related criteria:
E. Transport burden: assesses transport distances from sorting plants in Germany to each treatment plant considered.
F. Operational experience: assesses how long the plant has been successfully operating.
G. Capacity: assesses the maximum contribution of each plant to the recycling of all batteries in Germany.
H. Transparency: assesses how easy it is to obtain information from the plant regarding the activities associated with the recovery of batteries.

Table 3.20 Comparison of technologies for recovery of Zn batteries

		Process-related criteria					
Technology	Main products and co-products	A1 Environmental pressure	A2 Resources use (energy, materials)	B1 Recovery rate	B2 Market for the products	C Cost effectiveness	D Requirements on the batteries fractions
Imperial Smelting process	**Zn, Pb, sulfuric acid, slag**	↑	→	→	↑	→	↓
Waelz process	**Waelz oxide, slag**	↑	→	→	↑	→	↓
Sumitomo/Batrec process	**Ferro-Mn, Zn, Hg, slag**	↑	↘	↗	↑	↓	↑
Electric arc furnace – ferroalloy prod.	**Ferro-Mn, Zn ash, slag**	↑	↘	↗	↑	↘	→
Blast furnace process	**Foundry pig iron, Zn concentrate, slag**	↑	→	↗	↑	↗	↓
Electric arc furnace – steel production	**Steel, slag, ash**	↑	→	→	↑	↑	↓
Erachem process	**Metals scrap, plastics, Zn- and Mn-sulfate**	↑	↘	↗	↗	↓	↗
DMA Battery recycling	**Zn ash, metals scrap**	↑	→	→	↑	↘	↑
Short rotary furnace	**Metals scrap, Hg, Zn, Cd, slag**	↑	→	→	↑	↘	↑
Oxyreducer process	**Zn oxide, Mn oxide, iron scrap, Hg, saline water**	↑	→	↗	↗	↓	↑

		Plant-related criteria				
Technology	Operator	Location	E Transport burden	F Operational experience	G Potential contribution to recycling	H Level of transparency
Imperial Smelting process	**MIM Hütenwerke Duisburg GmbH**	**Duisburg (D)**	↑	↑	↗	↑
Waelz process	**B.U.S AG Duisburg**	**Freiberg (D)**	↑	↑	↗	↑
Sumitomo/Batrec process	**Batrec Industrie AG**	**Wimmis (CH)**	↗	↑	↗	↑
Electric arc furnace – ferroalloy prod.	**Valdi**	**Feurs, Le Palais, (F)**	↗	↑	↗	↘
Blast furnace process	**DK Recycling und Roheisen GmbH**	**Duisburg (D)**	↑	↑	↗	↑
Electric arc furnace – steel production	**different plants e.g. Nedstaal BV**	**Alblasserdam (NL)**	↗	↗	↑	↑
Erachem process	**Revatech S.A., Erachem Europe**	**Liege, Terte (B)**	↗	↑	↗	→
DMA Battery recycling	**Chemtec**	**Simmering (A)**	↗	↑	↗	↑
Short rotary furnace	**ABRG**	**Arnoldstein, A**	↗	↓	↗	↑
Oxyreducer process	**Citron S.A.**	**Rogerville (F)**	→	↑	↑	↑

Results of the assessment of ten technologies and their reference plants are provided in Table 3.20. The assessment is qualitative. An arrow directed upwards indicates that the technology/plant scores positively with regard to a given scenario, downwards – negatively. Intermediate scores are depicted by other positions.

The results for criterion A1 show that for all technologies examined, the emissions caused by the treatment of batteries containing Zn remain within the emission levels permitted for respective plants. Also no increase of contamination of final products is observed at the battery input quotas admitted. The resource use (criterion A2) is the highest for the Sumitomo/Batrec process and the Electric arc furnace with ferroalloy production. However, it should be emphasized that in this process a higher recovery rate is achieved (criterion B1), e.g., the final product of battery recovery in Sumitomo/Batrec process is Zn in metallic form, while other processes (e.g., Waelz or DMA) deliver a Zn concentrate, which needs further processing to obtain pure Zn. The additional treatment will naturally require an additional input of resources. Considering criteria B1 and B2, technologies in which apart from Zn also Mn in a form of ferro-alloy or Mn oxide score best. The fees for battery treatment (criterion C) differ significantly from one another. While the fees for the electric arc furnace process aimed at steel production lie at the level of those of the hazardous waste landfill or even below them, fees for treatment in some technologies are several times higher. Processes, which are sensitive to contamination in the input, are labeled with an arrow directed downwards in column D. The content of Hg in batteries is critical for most technologies. Most technologies accept only batteries with a content of Hg lower than 20 ppm.

Comparison of batteries recovery and landfilling

In Germany, for some batteries an alternative to the recovery option is disposal in a hazardous waste landfill. This option is used especially for the AlMn, ZnC and Zn-air batteries. The fees for landfilling of these batteries are, in most cases, significantly lower than the fees for recovery. Recovery technologies accepting batteries with high concentrations of Hg or battery mixes containing such batteries have high gate fees due to the complex and expensive flue gas purification system (needed to control Hg emissions). The less expensive recovery technologies of the iron/steel and non-ferrous metals smelters require low Hg content in the battery input stream. Moreover, disposal of batteries with high Hg contents in hazardous waste landfills is prohibited. For the NiCd and NiMH secondary batteries, recovery is a less expensive option than landfilling, due to the high value of the materials recovered.

Thus the comparison of battery recovery and landfilling is performed only for the Zn batteries: AlMn, ZnC and Zn-air batteries. For such an assessment, both the environmental burdens due to recovery and landfilling have to be considered, as well as the positive impact on the global resources balance due to the recovery of secondary materials. The main components of the Zn batteries are Zn, iron, Mn and carbon. The contribution of the battery industry to the total consumption of these elements by all anthropogenic activities is insignificant. Moreover, none of these elements is considered as being scarce at the moment. Thus the positive environmental impact of the recovery of Zn batteries is relatively low. It is also not expected that in the predictable time span the recycling costs can be covered by the income from selling the recovered materials. The comparison of further environmental impacts of battery recovery and disposal in hazardous waste landfills can only be done by means of an LCA methodology. Such a comparative study has been performed by ERM, commissioned by the British Department of Trade and Industry. This study comes to the conclusion that the negative environmental impacts occurring at separate collection of batteries and sorting processes can only be reduced by increased quotas of battery recovery. Thus, the study recommends that the levels of battery recovery should possibly be high. No further results of similar studies were available at the time this report was completed.

Another important aspect is consideration of the transport distances. Here authors of this report conclude that the differences in distances between the recovery and disposal options are insignificant. This is due to the fact that distances covered at battery collection and transport to sorting plants are significantly higher than those from the sorting plants to either a recovery plant or a hazardous landfill. Moreover, due to a more or less equal distribution of the recovery plants and the hazardous waste landfills in Germany, it is not significant to which one of the facilities the batteries are transported.

Bräutigam, Fellmuth, Weltin, 1999

Original title:	Verwertung von Zink-Kohle- und Alkali-Mangan-Batterien sowie von Batteriegemischen
Translation:	Recovery of Zn Carbon and Alkaline Batteries as well as Battery mixes
Author:	Andreas Bräutigam, Petra Fellmuth, Diethelm Weltin
Institution	
Editors:	
Publisher:	Erich Schmidt Verlag GmbH & Co.
Place, Year:	Berlin, 1999
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	MuA Lfg. 11/99; Verwertung von Altbatterien 8528.4

This article is concerned with the recovery of ZnC and AlMn batteries. The main components of these batteries are Zn, Mn oxide and iron. Other metals include Cu and Ni. The electrolyte in ZnC batteries is a Zn chloride solution and to a smaller extent ammonium chloride solution. In AlMn batteries the potassium hydroxide solution is used as an electrolyte. Recovery of ZnC and AlMn batteries takes place in hydrometallurgical and pyrometallurgical technologies. Based on the literature, the input of non-pretreated battery mixes as raw materials in the steel and Zn industry can be accompanied by a number of environmental impacts. For example, in the steel industry (electric arc furnace), high emissions of Zn, NOx, Hg, chlorides and dioxins can be expected, as well as increased slag formation, lower utilization potential of ashes from flue gas purification, because of higher salts, Hg and dioxins content and lower steel quality due to higher contents of Cu and other nonferrous metals. Further on, technical problems due to an increased corrosion of the oven inner surface can be expected.

In this article, four recovery technologies for Zn batteries are presented in more detail. Two of them: the Batenus and Debatox technologies are in the development phase (laboratory scale) and two other ones: the Recytec and Sumitomo-Batrec technologies are already implemented on a technical scale. The Batenus technology is designed for household battery mixes. The technology consists of two main processes: mechanical pretreatment and hydrometallurgical treatment, in which the following recovery products are obtained: Mn carbonate, Zn, Ni, Cd, Cu, Hg, iron scrap and graphite/soot. The by-products/residues of the process include: plastics/paper mixture, iron sludge, non-magnetic scrap, KOH/NaOH, HCl and NH_3. The process requires 2000 – 2500 kWh/ton of batteries. No data about emissions were available.

The Debatox (Demercurization of Batteries by Oxidative Treatment) is a pretreatment method for ZnC and AlMn batteries, developed by Sulzer Chemtech AG, which is supposed to provide an economically encouraging alternative to the existing battery recycling technologies. This pretreatment method allows the removal of Hg, organic components such as plastics and paper and chlorides in order to allow recovery of the remaining Zn and iron in the steel industry. The products of this technology are metallic oxidation products consisting of 19%-40% of Zn, 10-30% of Fe, 16%-30% of Mn and other metals, iron scrap, non-iron scrap, ZnO/MnO mixture and metallic Hg. The by-products/residues include filter cake (heavy metals sludge), spent active coal and ashes. Energy demand amounts to 110 – 125 kWh/ton and 105 – 120 m^3 natural gas/ton. The authors also provide data on major ancillary materials consumption. The wastewater of the process contains 0,005 mg Hg/l. No other emission data is given.

The Recytec technology was developed for the pretreatment of mixes of household batteries. It consists of a 2-step pyrolysis process in which organic components and Hg volatilize. The actual recovery of Zn takes place in a conventional Zn industry (Waelz process). Final recovery products of Recytec technology are iron scrap, non-iron scrap (Cu, Zn and Ni), ground battery powder (graphite, ZnO, MnO_2), metallic Hg and pyrolysis oil. The by-products and waste include heavy metals sludge, spent activated coal and ashes. Energy demand of the process is 1200 – 1250 kWh/ton and 69,5 kg natural gas/ton. Data on the consumption of ancillary materials by the process is also provided in the article. Regarding the process emissions, only the range of the total quantity of wastewater and total volume of flue gases is provided with no reference to individual contaminants.

The Sumitomo-Batrec technology has been developed for the treatment of household battery mixes. It is a pyrometallurgical process consisting of two main steps –pyrolysis in a shaft oven and a further thermal treatment in an induction casting furnace. In the pyrolysis process at temperatures of 300° to 850°C, the organic compounds are converted to pyrolysis gas and Hg volatilize. The residual solid material is transferred to the induction casting furnace where it is melted at temperatures between 1350° and 1500°C. Zn, Pb and Cd volatilize in the induction casting furnace and Zn is subsequently recovered in a condensation process. The slag from the induction casting furnace consists of ferro-Mn and mineral phases, which are separated from each other. Ferro-Mn contains 55% Fe and 35% Mn, as well as contamination in the form of Ni, Cr, Cu and other metals, depending on the plant input. The mineral slag has to be landfilled. Thus the main products of the Sumitomo-Batrec technology are Zn, Hg and ferro-Mn. The by-product/residue is a slag. The energy consumption of the process is 20 to 94 kg heating oil/ton and 0.9 m^3 propane/ton. Data on the consumption of ancillary materials is also given. In contrast to the technologies described above, emissions values of individual contaminants for the Sumitomo-Batrec technology are provided for both wastewater and flue gas effluents. In the process, 0.7 – 1.5 m^3 wastewater/ton is produced. The data on the following waterborne emissions is provided: Hg, Zn, Cd, Pb, Cu, NaCl and KCl. The volume of flue gas is 1250 – 2900 m^3/ton. The data on gaseous emissions include: CO, HC, CO_2, Hg, SO_2, HCl, particulate matter, Cd, Zn and dioxins/furans. In this article no further analysis of the environmental impacts resulting from the described technologies is provided. However, due to the availability of good data on the environmental impacts, the Sumitomo-Batrec technology was selected for further analysis by means of an LCA study by the primary author of this article (see the reviewed item: Bräutigam, 2001).

Bräutigam, Fellmuth, 1999

Original title:	Aufkommen, Umweltrelevanz, Sammlung und Sortierung zur Verwertung von Altbatterien
Translation:	Generation, environmental relevance, collection and sorting for the recovery of spent batteries
Author:	Andreas Bräutigam, Petra Fellmuth
Institution	
Editors:	
Publisher:	Erich Schmidt Verlag GmbH & Co.
Place, Year:	Berlin, 1999
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	MuA Lfg. 9/99; Verwertung von Altbatterien 8528.1

In this article, generation (sales) of batteries in Germany according to the various types of batteries is presented and the metals content of all batteries are summarized. The data are for the year 1996. For all main metal constituents of batteries, their yearly use for batteries production is compared to the total yearly consumption of relevant metals in Germany. This proportion is especially high for Cd (used mostly in the secondary batteries), Pb (used in automotive batteries) and Hg (used primarily in button cells) amounting to 75.4%, 63.8% and 10%, respectively. Contribution of batteries production to the use of other metals is significantly lower and amounts to 1.1% for Zn, 1.7% for Ni, 0.03% for Cu and 0.02% for iron. Regarding the environmental impacts at the disposal phase of spent batteries, it is stated that the main problem is related to the concentration of Pb, Cd and Hg. If the heavy metals contained in the batteries are disposed with the household waste – through landfilling or incineration – the metals can be released into the environment and become enriched in the food chain: in plants and animals and in this way endanger humans. In 1992 in New Jersey (USA) it was reported that 38% of the anthropogenic Hg emissions stem from waste incineration plants, of which 84% are caused by co-incineration of batteries. Investigations in a waste incineration plant Zürich/Hagenholz have shown that the contribution of heavy metals to municipal waste by batteries amounts to 10% of Zn, 85% of Cd and 67% of Ni. In Germany, the heavy metal content of batteries has been perceived as a problem since the end of the 1970s/beginning of the 1980s. This resulted in a voluntary agreement in 1988 between battery producers and BMU, concerning reduction of the concentration of Hg in AlMn batteries to less than 0.025%. In the meantime, Hg has been completely eliminated from both the AlMn and ZnC batteries. Due to the reduction of Hg content in AlMn batteries from 0.5% to 1% to less than 0.025%, the Hg content in household waste decreased significantly. In Germany, the input of Hg due to AlMn and ZnC batteries has been reduced from approximately 70 tons in 1985 to approximately 2.7

tons in 1996. As a result of the voluntary agreement mentioned, a marking system has been introduced for the batteries with high metal content (*inter alia* for NiCd secondary batteries, button cells and AlMn batteries with Hg content higher than 0.1%). This system should allow a user to identify the batteries which were to be separately collected. However, low content of the marked batteries in the collected battery mixes proved that the identification system failed to fulfill its function. In mixes of collected batteries the contribution of marked batteries was lower than 20% or even 1%. The majority of collected batteries consisted of Hg-free AlMn and ZnC batteries in accordance with their market share. Thus in the new German battery directive (Verordnung über die Rücknahme und Entsorgung von gebrauchten Batterien and Akkumulatoren) of February 4, 1998, the obligation for collection was extended to all batteries (not only the ones with higher heavy metals content).

Further on, the article describes existing sorting systems for battery mixes. The EURO BAT TRI-technology is described in more detail. Identification of different battery types is based on their physical parameters, such as geometry and behavior in a magnetic and ferromagnetic field. The sorting efficiency is 98.5% for AlMn and ZnC batteries and 96% for NiCd batteries. No data about environmental impacts of the sorting plant or consequent battery recovery is provided in this article.

Vest, Jantsch, 1999

Original title:	Umwelt-Handbuch; Arbeitsmaterialien zur Erfassung und Bewertung von Umweltwirkungen; Umweltkatalog; Umweltverträgliche Batterieentsorgung und –verwertung
Translation:	Environment-Handbook; Working materials for compilation and assessment of environmental impacts; environmental catalogue; environmentally compatible battery disposal and recovery
Author:	Heino Vest, Franziska Jantsch
Institution	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ)
Editors:	BMZ
Publisher:	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
Place, Year:	Eschborn, 1999
ISBN/ISSN:	
Kind of publication:	Report, 43 pages, available at: http://www2.gtz.de/uvp/publika/pdf/de-umweltkatalog-eschrott.pdf
Additional information:	

This report deals with the problems of disposal of spent batteries in the developing countries. In developing countries, the electricity supply network usually covers only part of the population. Thus, batteries become a common alternative to provide electric power for electric and electronic equipment. Investigations have shown that the cheapest batteries, imported from the Far East (especially ZnC batteries), most frequently find application in the developing countries. The content of Hg in these batteries still is relatively high as compared to the more expensive batteries from Europe and the USA. Additionally, due to their shorter lifetime and non-existing waste management infrastructure, disposal of spent batteries poses a serious environmental threat in developing countries. In the report, an average composition of different battery types is provided, as well as per capita consumption of primary batteries in different parts of the world. Out of 12 geographic regions, the highest consumption of primary batteries is reported in the USA (10.9 batteries/inh./yr) and the lowest in India (1.5 batteries/inh./yr). However, in the first case the contribution of the environmentally friendly AlMn batteries reaches 86.5%, while in the latter case only 0.3%. The report briefly presents existing battery collection schemes worldwide and focuses on their financing. Further on, environmental impacts related to the disposal of spent batteries are discussed in more detail. It is stated that, apart from batteries containing Hg, Cd and Pb, also other metals such as Ni, Zn and Li and their compounds are harmful to human health. Regarding the contribution of batteries to the pollutants in the household waste in Germany in the year 1996, approximately 10% of Zn, 67% of Ni and 85% of Cd and in 1994, 4-8% of Hg originated from the battery input. It is predicted that due to the strict limitations on Hg content in batteries its input to the household waste will decrease. Two options are possible in the case of co-disposal of batteries with household waste: landfilling or incineration. Regarding co-landfilling, the authors present two opinions: according to the representatives of battery industry, batteries remain inert in the landfill body and the release of metals does not take place. On the other hand, excavations of old landfills have shown that batteries corrode in the landfill body and the contaminants can be released. The duration of the corrosion process is expected to be 1-3 years. Whether the leachate or groundwater can be contaminated by the released content of batteries depends on various aspects:

- The organics content in the landfilled waste;
- pH value in the landfill body;
- density of the waste;
- quantity of rain water, etc.

Processes occurring in a landfill body have to be understood to understand the release mechanisms of metals from batteries. Regarding release of Cd from batteries, a Canadian study is cited in the report in which pollution of the leachate by different types of batteries has been reported. The results of this study were used to establish criteria for inert waste, non-inert waste and toxic waste. These results are shown in Table 3.21.

Table 3.21 Allocation of spent batteries based on the leachate contamination[1] attributed to them

Battery type	Parameter	Limit value for non-inert waste [mg/l][a]	Limit value for toxic waste [mg/l][b]	Result of the investigations [mg/l]
ZnC	Cd	0.05	0.5	0.067
NiCd	Cd	0.05	0.5	2900
Li	Cd	0.05	0.5	0.31
	Fluoride	24	240	43

[a] Hg in AlMn batteries was also investigated in Haight et al. 1992 (Haight, M., Kofi Asanti-Duah, D. and Craig, L.: Assessing the Environmental Effects of Disposal Alternatives for Household Batteries; Final Report; Institute for Waste Research, University of Waterloo, Canada 1992), but is considered as presenting no issue for the European market since 1994.

[b] According to the Ontario Regulation 309 Criteria

Considering the above results, it must be acknowledged that metals contained in batteries are released and after some time they will be present in landfill leachate. Thus in case of faults in the landfill bottom liner or in case of a direct discharge of leachate, they pose a danger to groundwater and surface water. This is especially a problem at non-engineered landfills. However, it also has to be underscored that in the case of modern landfills which are operated according to the current standards, including collection and treatment of leachate, batteries no longer pose any danger to the environment. This is especially valid for mono-landfills and landfills for hazardous waste, where batteries do not come in contact with the organic waste and where the biochemical processes, which are characteristic for the household waste landfills, do not take place.

In many countries waste incineration is common. Hence, batteries co-disposed with household waste also undergo incineration. The heavy metals contained in the batteries are transferred to both the flue gas and the incineration slag. Especially the volatile metals, like Hg, Cd, Zn and partly also Pb, are concentrated in the flue gas and fly ash. The main proportion of Hg is found in a gaseous form and thus presents a problem in the gas purification process. In the incineration plants which are not equipped with a wet scrubber, especially Hg(II)-chloride remains in the flue gas. In a modern incineration plant, removal of Hg no longer presents a problem. However, due to relatively high investment costs, this technology may be unavailable in developing countries. Cd emissions in flue gas play a minor role and are not considered to pose a health hazard. Cd and Zn can be found both in the fly ash and in the slag. Their content in the slag is significantly higher than in the earth crust; therefore, the slag needs to be pretreated prior to its recovery. Fly ash must be either pretreated or disposed in hazardous waste landfills.

Regardless of the transfer mechanism of metals to the environment, they impose some environmental risk. In the annex to this report, the general negative impacts of Hg, Cd, Zn, Mn and Ni are briefly presented. Hg is the most hazardous battery component. It can cause distortion of the neural system, kidneys and mucous membrane. It is accumulated in the brain and in the liver. However, waste management is only one of many other exposure routes to Hg. Cd is regarded as a carcinogenic metal. It also leads to chronic lung and kidney damage, as well as distortion of the neural system. Regarding the impacts of Zn, its human-toxic effects are mentioned: metal fume fever and food poisoning, as well as its potential accumulation in blood cells and in bones. As for Mn, it is stated that the toxicity of this metal is very low. Only one uptake of MnO_2 in a very high dose can lead to inflammation of lungs or neuro-psychiatric illnesses. The latter is attributed to chronic exposure to MnO_2.

Some risks can also be attributed to battery recycling, especially due to related emissions to air, water and waste disposal in the soil. Here, again, a higher risk exists in developing countries where recycling plants may not be equipped and operated according to the modern technology standards.

To conclude, the authors make recommendations regarding the use of batteries in developing countries. They recommend, *inter alia*, the use of secondary batteries, the application of batteries with lower content of hazardous substances, the development of separate collection schemes for batteries and the identification of safe battery disposal options for each region.

Bräutigam, Bilitewski, 1998

Original title:	Trocken bilanziert; Auf der Grundlage von Stoff- und Energiebilanzen lassen sich Umweltbeeinträchtigungen durch die metallurgische Verwertung von Zink-Kohle- und Alkali-Mangan-Batterien beurteilen
Translation:	Dry balance; On the basis of material and energy balances it is possible to assess environmental impacts of the metallurgic recovery processes of ZnC and AlMn batteries
Author:	Andreas Bräutigam, Bernd Bilitewski
Institution	
Editors:	
Publisher:	RHOMBOS-VERLAG
Place, Year:	*Müllmagazin* 3/2000, pp. 44 – 53, Berlin, 2000
ISBN/ISSN:	0934-3482
Kind of publication:	Journal
Additional information:	

This article describes preliminary results of LCIs of two recovery processes for Zn batteries: the Sumitomo/Batrec technology and the Imperial smelting process. Results of the LCA of these processes are part of the larger publication (PhD thesis) which has been summarized under reference: Bräutigam, 2001. Thus here only a very short review of this article will be provided, focusing on the aspects which have not been discussed in the mentioned publication.

At the time of writing of this article the majority of separately collected batteries were disposed in hazardous waste landfills. This especially concerned the AlMn and ZnC batteries, the reason being the high concentration of Hg, rendering recovery processes in the metal industry ecologically unacceptable (the condition for the recovery of Zn batteries is that the concentration of Hg should be less than 20 ppm). Specific plants for the recovery of battery mixes accept batteries with higher Hg content, but those were unavailable in Germany and also not planned due to their investment costs. To verify the proposed strategy to recover batteries in the existing metal industry plants, material and energy balances were needed. Therefore, the subject of this article and the PhD thesis mentioned was comparison of the environmental impacts of a recovery process designed especially for battery recycling and is less cost intensive alternative, recovery of batteries in the metal industry plants.

In this article only results of the LCI of both recovery processes are provided, without further stages of LCIA and the normalization of results. Also, only actual recovery processes are referred to, without including the substituted processes into the analysis. The problem arising at this point is “unfair“ comparison, due to different spectrum of final products in both technologies. In the Sumitomo/Batrec technology Zn, ferro-Mn and Hg are recovered, while in the Imperial smelting, predominantly Zn is recovered. Steel and Mn can be partly recovered from slag, but they are of significantly lower quality.

Regarding the results for energy demand, the Sumitomo/Batrec process shows 1.3 - 1.4 times higher values that the Imperial smelting. This can be partly explained by 30% higher temperatures in the first process (1500°C) as compared to the latter one.

Surprisingly, the CO_2 emissions which are directly related to the energy demand are higher for the Imperial smelting than for Sumitomo/Batrec technology. It is, however, explained by gaps in the inventory. A significant proportion of energy demand of the Sumitomo/Batrec technology is in the form of electric energy, while of the Imperial smelting technology in the form of primary energy carriers. The emissions from electricity generation elsewhere (i.e., not directly in the plant) were not accounted for in the inventory; hence, lower CO_2 emissions for the Sumitomo/Batrec technology despite higher total energy demand. Regarding other emissions, for most of the parameters the Imperial smelting technology scores worse. In particular, airborne emissions of Pb, particulate matter, Zn and SO_2, as well as waterborne emissions of Zn and Pb are higher for the Imperial smelting technology. The author explains, however, the difficulty of allocating emissions in this technology. Due to the treatment of other secondary materials in this process, it is difficult to say what the emissions are due to the input of batteries. Therefore, the allocation is based on the mass distribution of the metallic treatment inputs. Zn originating from the input of 3,000 tons of batteries/year constitutes 0.4% of the total metal input and thus the respective proportion of emissions is assigned to batteries. This allocation procedure may be responsible for the relatively high emissions of Cd and Pb, which are assigned to batteries, although the content of Cd and Pb in batteries is in fact very low.

Scholl, Baumann, Barlinn, 1998

Original title:	Nachvollziehbare Kriterien Die Europäische Union arbeitet an einem Umweltzeichen für Batterien
Translation:	Traceable criteria The European Union works on Ecolabel for Batteries
Author:	Gerd Scholl, Werner Baumann, Ann-Katrin Barlinn
Institution	Institut für ökologische Wirtschaftsforschung (IÖW), Heidelberg and Institut für Umweltforschung (INFU) Dortmund
Editors:	
Publisher:	RHOMBOS-VERLAG
Place, Year:	*Müllmagazin* 2/1998, pp 52 – 55, Berlin, 1998
ISBN/ISSN:	0934-3482
Kind of publication:	Journal
Additional information:	

This article presents a proposal for eco-labeling (EU flower) criteria for batteries that have been developed by the German institutes IÖW and INFU, commissioned by the EU Commission. These criteria have been developed based on a market analysis and a streamlined LCA for this group of products in order to identify “key ecological issues.” The product group that was investigated are portable batteries (here referred to as household batteries), both primary and secondary. In the article main battery types are briefly characterized. At the time of the writing 4.3 billion batteries were used in the EU per year, excluding batteries sold in different kinds of devices. The experts estimated that 80% of secondary batteries enter the market not as single cells, but as in-built in devices.

The proposed criteria for eco-labeling are partly based on a “streamlined LCA,” i.e., a compilation of the input and output data along a lifecycle of batteries and their qualitative assessment. The selected criteria are briefly characterized.

Within the streamlined LCA, the concentration of contaminants has been identified as a central ecological aspect of the assessment, followed by energy and material efficiencies. For all three categories, limit values have been proposed which are to be kept if the EU flower is to be awarded. Regarding the criterion “content of dangerous substances,” the batteries must not contain any substances that have been classified as “very toxic,” “toxic,” “carcinogenic,” “mutagenic,” or “toxic to reproduction” according to the EU-Directive 67/548/EEC. Moreover, the batteries must not contain any Hg, Cd and Pb. Exempted from this requirement are traces of these metals, which may be introduced as metals contamination (e.g., Zn contaminated with Cd).

“Energy efficiency” is the proportion of energy used for the production of batteries (including up-stream processes) to the energy quantity that can be generated by this battery in its use phase (energy input/energy output). For secondary batteries the recharging energy and the maximum recharging frequency also is taken into account. It has been proven that for many batteries the energy use for the up-stream processes, i.e., extraction of the raw materials, is very energy intensive. It is especially true for the AlMn and ZnC batteries. The maximum ratio of energy input to energy output is 20. Only secondary batteries with 100 and more recharging cycles are capable of fulfilling this criterion.

“Material efficiency” is a quantity of material used to achieve a specified goal. In order to allow comparison of different batteries, a functional unit based on a battery energy capacity was assigned. For cylindrical cells the functional unit is 1,000 mili Amper hour (mAh) and for the button cells, 100 mAh. The factor “material efficiency” must lie below 1. Here again the secondary batteries score better than the primary batteries (material efficiency is higher for batteries with more recharging cycles). Within primary batteries, only the Li-Mn oxide batteries have material efficiency within the proposed limit value (due to very low self-discharge rate).

“Consumer information” is a further market-oriented criterion. At the packaging of the battery, eco-label information about application areas and if applicable suitable charging device should be provided.

“Accessibility for recycling systems”: Producers and importers have to make sure that the spent eco-labeled batteries are directed to recycling.

“Type of packaging”: PVC and other plastics containing halogens are banned for the eco-labeled batteries; packaging made out of a single material are preferred over composite material packaging.

The criteria described above were proposed to the EU Commission. If they were accepted in their current form, the following batteries could be awarded the EU flower: NiMH secondary batteries, secondary AlMn batteries and probably Li-ion secondary batteries (not all of the necessary data was available yet).

It should be pointed out that LCA performed in this study contains significant limitations, e.g., due to data gaps, the energy demand for recycling processes was not considered.

Baumann, Muth, 1997

Original title:	Batterien Daten und Fakten zum Umweltschutz
Translation:	Batteries Data and Facts for the Protection of Environment
Author:	Werner Baumann, Anneliese Muth
Institution:	Institut für Umweltforschung (INFU), Universität Dortmund
Editors:	UBA
Publisher:	Springer-Verlag
Place, Year:	Berlin Heidelberg, 1997
ISBN/ISSN:	3-540-61594-6
Kind of publication:	Book, 637 pages
Additional information:	The book is based on the results of the project 103 10 610, which were published in a report: Abfallverhalten neuartiger Batterien (see above). Some data has been updated.

Baumann, Muth, 1993

Original title:	Abfallverhalten neuartiger Batterien
Translation:	Waste problems of modern battery systems
Author:	Werner Baumann, Anneliese Muth
Institution:	Institut für Umweltforschung (INFU), Universität Dortmund
Editors:	UBA
Publisher:	UBA
Place, Year:	Berlin, 1993
ISBN/ISSN:	
Kind of publication:	Report, 326 pages
Additional information:	Final report of a research project 103 10 610, commissioned by BMU in frame of a series: UFOPLAN (Environmental Research Plan)

Results of the two publications described above are presented together as they are based on the results of the same research project and their contents are overlapping. Even though this research project was completed in the early 1990s, references to these two publications can be often encountered in the modern literature, which is probably due to the lack of similar studies from more recent times. Therefore, it was decided to include these two publications in this literature review. In these publications all types of portable batteries with their chemical compounds, working mechanism, application, and market data are described. The characterization of all available batteries at the time of the writing is very detailed. Moreover in the appendix, datasheets of all chemicals contained in batteries are provided. These datasheets contain general information bout the substance, such as name, chemical formula and application areas, as well as a description of its environmental hazard. For example, with regard to Zn the following information under "toxicological/eco-toxicological" is provided:

Registry of Toxic Effects of Chemical Substances (RTECS): # ZG 8600000;
Water hazard class (WGK): 0 (in general no hazard for water);
Threshold Limit Value (TLV): 5 mg/m^3 or 6 mg/m^3
Danger (R-Phrases): 15-17
(R 15: Reacts with water and forms light inflammable gases; R17: Self-inflammable in the air)
Safety measures (S-Phrases): 7/8-43a
(S 7/8: Keep dry and enclosed; 43a: In case of fire extinguish with water)

When heated up Zn oxide is formed (ZnO), its inhalation can cause metal fume fever; after a few hours delay the following symptoms may occur: fever, pain, abnormal fatigue, coughing, ague, temperatures up to 40°C, sweating.
Cell poison; internally: 1-10 g fatal;
In soft waters 0.1 – 1.0 mg/l fatal for fish;

Chronic poisoning not known; small amounts are harmless; in high doses leads to irritation of mucous membrane and sickness. Inhalation can lead to fever, muscle pain, shivering and nausea. These are conditions which normally cease within 24 hours and lead to no after-effects.

These datasheets are provided for each individual substance, which can be found in batteries.

Collection systems for batteries along with the achieved collection rates in Germany are described in both publications. Further on, existing recycling technologies for batteries are briefly characterized and costs are provided for each of them. The authors do not discuss the environmental impacts of the recycling technologies. They only mention a problem of the content of polychlorinated biphenyls (PCB), which were recorded at the concentration of 11 ppb in the battery filling materials. PCB becomes enriched in the pyrolysis oil being a product of different recycling processes. For example, the recycling company Recytec reports PCB concentration in pyrolysis oil of 80 ppb, while the limit for spent oils is 20 ppb.

Further on, the problems related to co-disposal of batteries with household waste are outlined. These are discussed in more detail in the older publication and only very superficially in the newer one. Regarding the co-landfilling of batteries, it is stated that excavations of old landfills have confirmed that batteries corrode in the landfill body and the battery content can be released. Whether the leachate or groundwater can be contaminated by the released content of batteries depends on the contaminants themselves and the conditions in a landfill. An important help in assessing the environmental hazard can be transfer coefficients for pollutants from the waste body into leachate. These are provided in Table 3.22.

Table 3.22 Transfer coefficients for metals from landfilled waste to leachate

Metal	Transfer coefficient
Cd	$6 \cdot 10^{-5}$
Hg	$6 \cdot 10^{-5}$
Zn	$2 \cdot 10^{-4}$

In the publication, reference is also made to a Canadian study, in which the contamination of leachate due to landfilling of batteries is reported (see Table 3.21). Further on, the toxic effects of heavy metals contained in batteries are described. The toxicity of Hg is discussed in most detail. Regarding Zn, it is stated that it is classified as an essential element for humans. Toxic effects are observed due to inhalation of particles and gases containing Zn, without understanding its working mechanism. Regarding Zn chloride, it is stated that in water solutions it is corrosive. Mn is presented as an essential element for humans, which can be toxic in higher doses. The TLV for Mn is 5 mg/m^3 in total particulate matter. Significant over doses lead to lung inflammation and neural disorder. The biochemical processes occurring in household waste landfills also are presented, finalized with a conclusion that batteries should not be disposed in household waste landfills. As a much better alternative, disposal of batteries in mono-landfills and hazardous waste landfills is proposed. In the following section, the processes occurring in incineration of household waste are described. Regarding co-incineration of batteries with household waste, it is stated that batteries cause additional emissions of heavy metals. In the later publication the transfer coefficients of metals contained in batteries to different output streams of an incineration plant are provided (see Table 3.23). It can be seen that Hg, as a volatile metal, is transferred to gas and finally remains in the products of the gas purification system. Cd volatilizes as well and afterwards condensates on the fly ash particles. Zn as Zn oxide remains in slag and as Zn chloride is transferred to flue gas, where it also condenses on the fly ash particles. Ni and Mn remain as oxides (e.g., Mn_3O_4) in the slag. In the earlier publication a concern about excessive Hg and Cd emissions due to co-incineration of batteries is expressed. This was especially a problem in the incineration plants which were not equipped with modern flue gas purification systems (no activated charcoal filter, no aerosols separation). In the newer publication this concern is not confirmed any more, mostly due to more strict emission limits for the incineration plants in Germany which enforced additional flue gas measures.

Table 3.23 Transfer coefficients for metals in incineration process

Element	Emission paths				
	Slag	Fly ash	Flue gas	Sludge[a]	Wastewater
	%				
Cd	7	89	0	4	0
Ni	89	10	-	1	0
Zn	37	60	2	3	0
Mn	83	16	-	1	0
Hg	1	2	6	91	0

[a] Sludge from the treatment of wastewater from flue gas purification

3.1.5 The Netherlands

STIBAT, 2006

Original title:	Jaarverslag stichting batterijen 2005
Translation:	Year report of the foundation batteries 2005
Author:	STIBAT
Institution:	STIBAT
Editors:	
Publisher:	STIBAT
Place, Year:	2006
ISBN/ISSN:	
Kind of publication:	Yearly report, available at: www.batteryworld.nl
Additional information:	

The Foundation Batteries (STIBAT) responsible for organizing collection and recovery of spent batteries in The Netherlands operates according to a management plan, which has been approved by the Dutch Ministry of Environment. It is valid from 2003 to 2008. The management plan is a reaction to the Decision Management Batteries (a decree of the ministry) of 1995, amended in 2002. All producers and importers of batteries have to make either an individual management plan for spent batteries or join the collective STIBAT plan. Currently only one company has an individual plan, while 751 companies are united in STIBAT.

All companies pay a contribution for each battery put on the Dutch market to STIBAT, which finances the management plan.

In the past 6 years the amount of batteries sold in The Netherlands has steadily increased, as can be seen in Table 3.24.

Table 3.24 Sold batteries in The Netherlands (millions)

Year	Primary batteries	Secondary batteries	Total
2000	189	20	209
2001	204	19	223
2002	204	20	224
2003	244	28	272
2004	280	36	317
2005	309	39	348

Spent batteries are collected through the STIBAT collection service (from supermarkets, other shops, schools, recreation companies and scouting groups) or collection companies (from hazardous waste depots, offices and companies). Collected batteries are sorted at the national sorting centre in Ermelo.

The amount of collected batteries was 2,489 tons in 2004 and 2,704 tons in 2005.

Apart from the batteries collected by STIBAT, 12 tons were collected by the company Battrex (which is not in the STIBAT management plan) and 20 tons are in used mobile phones which were exported. Both flows are used to calculate the collection quota.

The calculation of the collection quota is based on the amount of batteries remaining in the residual waste (not on the amount of batteries put to the market), which was determined by extrapolation of the data of a mechanical sorting plant treating approximately 20% of the Dutch residual household waste. As can be seen in Table 3.25, the collection quota is steadily increasing.

Table 3.25 Collection quota in The Netherlands (% collected of total spent batteries)

Year	Collection quota
2001	70%
2002	71%
2003	74%
2004	80%
2005	83%

The table above shows that the collection goal of 80% for the year 2007 was already met in the year 2004. The destination of the collected batteries is given in Table 3.26.

Table 3.26 Destination of collected batteries in The Netherlands, 2005

Battery type	Amount (tons)	Company	Products
Pb containing	438	Campine (B)	Pb
NiCd	180	SNAM (F)	Ferro-Ni, Cd
NiMH	37	SNAM (F)	Ferro-Ni
ZnC/AlMn mix	820	Valdi (F)	Ferro-Mn, Zn oxide
ZnC/AlMn mix	821	Redux (D)	Zn concentrate, iron concentrate
Button cells	15	Batrec (CH)	Hg
Li	28	Batrec (CH)	Various metals
Non-sortable	57	Batrec (CH)	Various metals
Total	2,396		

Afval Overleg Orgaan, 2002

Original title:	Milieueffectrapport (MER) Landelijk afvalbeheerplan (LAP) 2002-2012
Translation:	Environmental Impact Assessment (EIA) for the National Waste Management Plan (NWMP)
Author:	Afval Overleg Orgaan
Institution:	Afval Overleg Orgaan
Editors:	
Publisher:	Afval Overleg Orgaan
Place, Year:	Utrecht, 2002
ISBN/ISSN:	

Kind of publication:	Research/policy supporting Report, 266 pages, available at: http://www.aoo.nl/images1/aoo_nl/bestanden/MER_LAP_Hoofdrapport.PDF
Additional information:	

An Environmental Impact Assessment (EIA) has been performed to validate decisions contained in the National Waste Management Plan (NWMP) regarding minimum standards and capacity planning for incineration. The validation was made by comparing the environmental effects of different techniques for processing a waste stream. The method of LCA was used for the comparisons. Various weightings were performed to gain an insight into the relevance of the results for policy development. For all waste streams considered, background documents were prepared, which contain detailed descriptions on technologies and accompanying resource consumptions and emissions of substances (LCIs). In the main report these data are compiled in a LCIA, whereby the various treatment technologies are compared. Both reports are included in this summary.

For the waste stream batteries, it was decided only to include AlMn and ZnC batteries. No baseline scenario of non-separately collected batteries disposed together with the residual waste stream (mainly incineration in The Netherlands) was included. All technologies considered have a common starting point: transport from the sorting centre of AVR in Rozenburg (near Rotterdam). The previous collection and transport of the batteries is considered equal for all scenarios and therefore not modeled. For all technologies considered, one reference plant is chosen, mostly unique for the selected technology. In that case, also actual distances are applied in the calculations.

The technologies considered are the following:

1. Electric arc furnace-Steel process. Reference plant: Nedstaal BV in Alblasserdam (NL). Approximately 0.8% of batteries are added to iron scrap in the steel production process. The batteries serve as additive, energy source and reduction agent. Emission measurements of steel production with and without batteries were carried out to determine the effect of the addition of batteries.
2. Pyrolysis/melting or Sumitomo/Batrec process. Reference plant: Batrec AG in Wimmis (CH). The input consists of approximately 90% of AlMn and ZnC batteries. By pre-sorting, pyrolysis, melting, condensation and cleaning the following products are produced: ferro-Mn, Zn, Zn-oxide, slag and Hg.
3. Electric arc furnace – Ferroalloy process. Reference plant: Valdi in Feurs (F). The process is comparable with process 1, but the input consists of 100% batteries and instead of steel ferro-Mn (and furnace dust (mainly ZnO) and slag) is produced. Process steps include: pre-sorting, melting, and gas cleaning.
4. Hydrometallurgical process. Reference plant: Zimaval Technologies in Falaise (F). The input consists of approximately 83% of AlMn and ZnC batteries, which are treated at different process conditions in the same installation. After pre-sorting, mechanical treatment, alkaline treatment, acidic treatment and wastewater treatment, the following products are

obtained: steel, non-ferrous metals, FeOH, Zn particles, Zn powder, Zn sulfite, Mn carbonate, carbon residue and Hg amalgam.

Detailed mass balances are given for all processes in which the transfer of the main heavy metal fractions to the various products and environmental compartments is described. Also gaps in knowledge are discussed, e.g.:

- Nedstaal process: non-battery input is varying; therefore it is hard to determine the effect of added batteries on leaching behavior of produced slag. No information available for one of the two furnace dust treatment plants; not exactly known how secondary resources substitute primary ones. Not clear whether or not input of batteries leads to changing process resources.
- Batrec process: no information for the Zn dross treatment plant available; not exactly known how secondary resources substitute primary ones.
- Valdi process: no information for the furnace dust treatment plant available; not exactly known how secondary resources substitute primary ones.
- Zimaval process: no information is available for the emissions of landfilled iron hydroxide

Detailed information on resource consumption and process emission is normalized, leading to a large number of indicator scores as shown in Table 3.27. The figures shown in the table are the total characterized results (according to the CML methodology), which are then related to the total yearly environmental impact in The Netherlands.

Table 3.27 Normalized effect scores (*10^{-13}) for the treatment alternatives of batteries

Impact Category	**Nedstaal**	**Batrec**	**Valdi**	**Zimaval**
Depletion of Abiotic Resources	233.939	278.788	113.939	1.557.576
Climate Change	252.036	354.299	162.443	1.425.339
Stratospheric Ozone Depletion	-19	10.338	1.607	11.566
Photo-oxidant Formation	1.087.912	-12.637	7.308	398.352
Eco-toxicity (freshwater aquatic)	311.671	92.042	60.610	200.265
Eco-toxicity (terrestrial)	42.231.491	432.742	796.663	723.670
Human toxicity	255.851	18.138	7.713	77.660
Acidification	18.236	327.354	281.016	3.198.804
Eutrophication(aquatic)	12.550	64.542	51.992	177.888
Eutrophication (terrestrial)	37.611	299.115	195.575	553.982
Biodiversity	-230.928	-111.340	-217.526	205.155
Life support	-183.556	-55.556	-136.000	272.889
Total	44.026.794	1.697.825	1.325.340	8.803.146

Higher scores mean higher environmental burden. Negative scores mean environmental release.

The LCA Impact Categories (themes) can be assigned to several environmental themes. To aggregate the environmental effect scores of Table 3.27, several weighting methods are applied that result in the weighted effect scores of Table 3.28. Thereby stands Distance to Target (DtT) for how close the political environmental goals regarding the considered themes are met. Dispersion is an environmental theme that includes the LCA-themes, photo-oxidant formation, freshwater aquatic and terrestrial Eco-toxicity and Human toxicity.

Table 3.28 Weighted effect scores ($*10^{-11}$) for the treatment alternatives of batteries

Weighing method	Nedstaal	Batrec	Valdi	Zimaval
All environmental themes equal	7.872	978	575	6.394
All LCA themes equal	44.027	1.698	1.325	8.803
Distance to Target for environmental themes	-93.836	-71.289	-107.159	-69.436
Distance to Target for environmental themes	-21.177	-69.520	-105.172	-65.088
Only Climate Change	252	354	162	1.425
Dispersion (weighted)	7.676	91	151	314
Dispersion (non-weighted)	43.887	530	872	1.400

The conclusions indicate that the Valdi process leads in most cases to the lowest environmental burden. In many cases, the Batrec process shows a low environmental burden, but also leads to relatively little final waste disposal prevention. The Zimaval process shows a mixed view. Because of its relatively high energy intensity, it shows higher environmental burdens in some weighing methods and average results in others. The Nedstaal process leads to the most environmentally unfavorable results. This is mainly due to the large effect score in 'terrestrial Eco-toxicity', which is approximately 96% of the total score. This is mainly caused by emissions of Hg. A concentration of Hg of 36 mg/kg was assumed in the input batteries; this is the upper limit of battery acceptance of the process. Currently (2002) produced batteries contain a maximum 5 mg of Hg /kg, so that the environmental performance of the Nedstaal process will gradually improve. Moreover, the Hg emissions were measured directly only at the Nedstaal process. In the other processes they were calculated from the mass balances and emission factors.

All four processes actually aim at a different typical input material (e.g., Nedstaal at Hg-free batteries as an additive only, Batrec at Hg-rich batteries), which leads to different gas/water cleaning technologies. Nevertheless the same average input was modeled for all processes.

In the study, secondary products are assumed to directly substitute primary resources. Whether or not effects from other factors such as extra process additives or energy should also be incorporated is uncertain.

Wetsteyn, 2000

Original title:	Cadmium, kwik en lood in uit Azie geimporteerde batterijen.
Translation:	Cd, Hg and Pb in batteries imported from Asia
Author:	F.J. Wetsteyn
Institution:	IMH Zuid-West
Editors:	Inspectie Milieuhygiëne (IMH)
Publisher:	VROM, Ministry of Housing, Spatial Planning and the Environment
Place, Year:	The Hague, 2000
ISBN/ISSN:	
Kind of publication:	Research Report
Additional information:	

Since March 1995, the Decision on the disposal of batteries has been in force. In it, limits for the amounts of Hg, Cd and Pb are prescribed. Concern had risen in The Netherlands, whether or not imported batteries from Asia meet these limits. Especially Hg was of concern, for which the limit is 0.025% by weight for AlMn batteries and 25 mg per battery for non-AlMn batteries. Future limits for all batteries will be 0.0005% Hg by weight. Button cells are exempted.

Samples of 118 shipments of Asian batteries were analyzed. Three shipments exceeded the current limits. Future limits would not be met by 17 of the shipments.

The annex of the report provides details on the batteries examined and on the results of the analyses.

Leijting, 1997

Original title:	Milieukundige beoordeling van primaire en secundaire batterijen
Translation:	Environmental assessment of primary and secondary batteries
Author:	Jorrit Leijting
Institution:	IVEM - Center for Energy and Environmental Studies, University of Groningen
Editors:	
Publisher:	IVEM
Place, Year:	Groningen, 1997
ISBN/ISSN:	
Kind of publication:	Doctoral dissertation, 91 pages
Additional information:	IVEM Dissertation no. 63

This doctoral thesis consists of an Energy Analysis and an LCA of the production, use and disposal of ZnC, AlMn and rechargeable NiCd batteries. The LCA is far from complete, since a LCIA, as well as several up-stream processes of used materials and energy, are lacking.

Battery history

Prior to 1985 (from 1960), an estimated amount of 125,000 tons of batteries were disposed together with mixed waste in The Netherlands. Since 1985, batteries were considered hazardous waste and more and more were collected separately through the household hazardous waste collection system. Rechargeable Pb and NiCd batteries were collected separately and treated in The Netherlands and in France. Cylinder cells were disposed in the Schönberg landfill in Eastern Germany and in Western German salt mines. A minor part was stored in The Netherlands. From 1990 onwards, the export of used batteries was prohibited. As a consequence, in the period between 1990 and 1995, batteries that were collected were stored in the C2 landfill of AVR at the Maasvlakte. In 1992, a fire broke out, probably caused by hydrogen emissions combined with a short circuit. With the coming into action of the ‘Besluit verwijdering batterijen,’ the landfill was emptied and all contained batteries (6,200 tons) were transformed into secondary raw materials in The Netherlands and abroad. From that moment on, all collected batteries were to be treated, preferably in The Netherlands.

Lifecycle Assessment (simplified)

The fate of the batteries disposed of in the years 1993 and 1994 is given in Table 3.29. Two methods are used for the calculation of the amount of batteries remaining in the residual waste:

- sorting method: the amount is determined by the results of sorting analyses of the residual waste which are undertaken yearly by RIVM
- sales method: all batteries sold within 1 year are assumed to be disposed of in the same year.

Table 3.29 Fate of spent batteries in The Netherlands

Year	Collected (tons)	Within residual waste (tons)		Total (tons)	
		Sorting method	Sales method	Sorting method	Sales method
1993	1,781	1,880	1,423	3,661	3,204
1994	2,910	1,320	477	4,230	3,387

In 1994, half of the residual waste (and with it the batteries contained) was landfilled; the rest was incinerated. For further calculations, a quantity of 3,880 tons of batteries sold is assumed for the year 1994. Three types of batteries are considered: NiCd, AlMn and ZnC. For the treatment of the first kind, the new hydrometallurgical TNO-IMET process is considered. The latter types are treated in the Nedstaal process, of which very little data are available. The treatment processes are mainly considered by the amounts of resources that are used and the secondary materials that are produced. Combined with production data, the net use of metals for batteries in 1 year is thus calculated. No information concerning emissions to water or air in the treatment processes is addressed in the study.

Spent batteries entering landfills are estimated at 485 tons in 1994. The consequent amount of battery-based metals in the landfill body was determined and compared to the intervention values for a standard soil in The Netherlands (see Table 3.30).

Table 3.30 Battery based metal concentration in landfilled waste (1994) and intervention values for soil

Metal	Concentration (mg/kg dry matter)	Intervention value (mg/kg dry matter)
Ni	3.8	210
Cu	1.6	190
Zn	36.0	720
Iron	44.1	*
Mn	36.7	*
Cd	2.9	12
Chrome	**	380

*: no intervention value available
**: negligible (< 1 mg/kg)

In the dissertation, it is concluded that all concentrations are well below the intervention values. It should be noted, that Hg is not considered in Table 2.30.

For the incineration of waste containing batteries is stated that:

- it is unclear to what extent metals are volatilized at incineration
- the amount of incineration air determines the concentration in the flue gas
- Dutch incinerators have flue gas cleaning devices

Therefore, it is concluded that it is not relevant to make an estimation of the metal emissions of Dutch incinerators caused by batteries.

Posthumus, 1997

Original title:	Recycling van batterijen na opslag
Translation:	Recycling of batteries after storage
Author:	Willem Posthumus
Institution:	Chemiewinkel, University of Groningen
Editors:	
Publisher:	Chemiewinkel, University of Groningen
Place, Year:	Groningen, 1997
ISBN/ISSN:	
Kind of publication:	Report, 26 pages
Additional information:	Report no. 79. Requested by the PvdA (a Dutch political party)

An overview of available and planned treatment plants and methods is given in the report. The methods are briefly described and the costs are estimated. Treatment in processes that are not especially designed for batteries (e.g., electric furnace steel production) tends to be less costly.

Furthermore the role of storage is discussed. Because no treatment methods were available, non-sorted batteries were stored in the C2-landfill of AVR, in the open air until 1992. In April of that year, a fire broke out at this landfill. In the same year, a battery-fire took also place in Switzerland. Heating (heat production from biological activity) probably was not the cause of the fire, but rather a short circuit (not all batteries were completed drained). Short circuits lead to a fast discharge of the batteries, combined with heat production and danger of explosion of the batteries. Moreover, there are many corrosive metals present, which can react with water to produce hydrogen. After the fire, the old stocks were transported to Recovery and Reclamation (R&R) in the USA. In 1997 an estimated amount of 7,600 tons was waiting to be treated, stored indoors in 200-L casks.

Since 1996 the batteries were sorted based on size and then stored. The machinery for further sorting was not yet installed in 1997.

After 6 to 18 months of storage, the possibilities for sorting are reduced because of leaking and corrosion, which decreases the possibilities to identify the batteries. For better results, sorting should be carried out prior to storage. It is estimated that in 1997 approximately 5,000 tons of stored batteries could no longer be sorted.

Proper storage should be conducted in a dry place. Economically not feasible, but safer would be storage in a nitrogen atmosphere. In the event of a fire, fire extinguishers, should not be water or CO_2. For safety reasons, the storage of batteries should be as short as possible. Sorting enables a cheaper treatment of the batteries.

van Gemert, 1987

Original title:	Verwerking van gebruikte batterijen
Translation:	Treatment of used batteries
Author:	W. van Gemert
Institution:	TNO-MT
Editors:	
Publisher:	
Place, Year:	*Energiebeheer & Afvalbeheer,* 2/87, pp. 34 – 37, 1987
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

The article is mainly based on the results of a project that are previously described in a report by VROM. The research project was performed by the Twente University of Technology and TNO-MT.

In The Netherlands, approximately 100 million batteries are consumed yearly (approximately 5,000 tons). Relative composition given in the article leads to the details on the amount and absolute composition of used batteries in Table 3.31.

Table 3.31 Amounts and composition of yearly used batteries in The Netherlands (1982)

Battery	Anode/cathode	No. (mill.)	Total amounts of material		
			Hg (kg)	Zn (t)	Cd (kg)
ZnC	Zn/MnO_2	60-73	282-343	705-858	282-343
AlMn	Zn/MnO_2	16-25	6,400-10,000	83-130	?
Hg-oxide	Zn/HgO	2,8	1,680	0.7	?
Ag-oxide	Zn/AgO_2	4,0	68	0.8	?
Zn-air	Zn/O_2	0,4	14.4	0.2	?
NiCd	NiO/CdO	5	-	-	35,000
Li	Li/X				
Total		88,2-105	8,444-12,100	789-989	35,300

Expectations for future amounts are that the AlMn batteries will slightly increase, thereby replacing the ZnC cells. Zn-air batteries will more and more take over the market share of Hg-oxide batteries. Ag-oxide and NiCd batteries will show a minor increase. Li batteries will increase in applications where performance is more important than price. In the near future, the Hg contained in AlMn batteries will be reduced significantly by the manufacturers.

Collection and treatment

Hg-oxide batteries are collected separately by Foundation Collection and Treatment of Hg-oxide batteries (IVK). Ag-oxide batteries are assumed to be collected because of their economic value. All other batteries are disposed of via household residual waste. The main disposal option is landfilling. Impacts of the batteries on the landfill processes are not known as yet. A minor disposal option is incineration, whereby Cd and Hg will be turned into a gaseous state. Depending on the gas cleaning devices, these metals may be emitted to the atmosphere.

Alternatives

A number of possible actions are summarized:

- prevention;
- substitution of battery-containing appliances by non battery using ones;
- substitution of non environmentally friendly batteries by more environmentally friendly ones;
- reduction of the amount of Hg in, e.g., AlMn batteries;
- separate collection and storage or treatment of Hg containing batteries; and
- collection of mixed batteries, followed by controlled storage. Eventually recycling technologies could be applied.

Societal steering mechanisms to influence the waste battery flows consist of administrative, economic and informative methods.

International developments

Denmark: HgO and NiCd are collected separately. If no treatment option is found, batteries will be disposed of in a Western German salt mine.

Western Germany: Collection of HgO batteries by traders, treatment by Elwenn & Frankenbach (Hg distillation process).

France: ANRED offers financial support for the construction of Hg recycling installations and starts a battery collection organization.

Sweden: The battery association started with collecting HgO batteries; currently communal collection of NiCd and AlMn batteries can be observed as well.

Switzerland: Battery traders voluntarily collect HgO and AgO batteries. Autophon ag collects and treats NiCd batteries. The government is planning collection of other Hg containing batteries (AlMn).

The Netherlands: Apart from the above, the company Battrex has started a collection test running at sale points.

Other treatments: Varta is doing research on the recycling of MnO_2 and Zn. In Japan, a demonstration plant for Hg extraction is operating. In Switzerland, the Institute for Technical Physics at the University of Technology Zürich is doing research together with Varta ag. The first steps, i.e., sorting and size reduction, are finished; further treatment research is ongoing.

Twente University of Technology and TNO-MT finished a research project on the recovery of Zn and Hg from ZnC and AlMn batteries. Principal steps in the treatment process are: sieving, X-Ray sorting, size reduction, hydrometallurgical treatment, electrolytic Hg-reduction and finally Zn precipitation. The process costs are estimated at 250-1000 Hfl per ton, at a yearly amount of 5,000 tons.

For further developments it is of vital importance to continue research on an international level. Preparatory discussions are on their way.

Gemert, Kolster, 1986

Original title:	Onderzoek naar verwerking van gebruikte batterijen
Translation:	Research on the treatment of spent batteries
Author:	W. van Gemert, B. Kolster
Institution:	University Twente, TNO-MT
Editors:	
Publisher:	VROM
Place, Year:	1986
ISBN/ISSN:	9034609375
Kind of publication:	Report series no. 27, Afvalstoffen' (Waste Materials) by VROM
Additional information:	

The Division of Technology for Society TNO and the University of Technology Twente, Department of Mechanical Engineering, has carried out a project on the separation and treatment of spent batteries. This has been done by order of VROM. Its purpose was to indicate whether and how the separation and treatment of spent batteries is in essence possible, thus aiming at a recycling of potentially hazardous components (Hg) and economically profitable components (Zn).

Spent batteries, as they are collected for example by Battrex B.V. in the Dutch province of South Holland, consist of a mixture of ZnC, AlMn, Hg-oxide and NiCd batteries. Besides, there are small quantities of other types of batteries available (e.g., Li and Zn-air batteries). NiCd batteries are available in several dimensions and differ from the former types in that they can be recharged after use.

Hg batteries contain about 30% of Hg, AlMn batteries about 0.8% and ZnC batteries approximately 1%. Estimations are that the annual consumption of batteries in The Netherlands is 100 million. Nearly 75% of the batteries are ZnC batteries, 20% AlMn and the rest are other types of batteries.

A study of the available literature shows that the interest in treating spent batteries is, in general, of recent times. In the first instance, the activities were in particular aimed at recycling Hg from Hg-oxide buttons, but nowadays there is a growing interest in the treatment of other types of batteries (ZnC, AlMn). This interest is especially directed at recycling Zn and Mn. Relatively few initiatives have been taken so far for recycling Hg from these batteries.

The most important results of the experimental research are summarized below:

- Sorting: It seems possible to sort batteries on their content on the basis of x-ray pattern recognition and a consequent selection. Sorting of 300 batteries per minute seems to be possible.

- Shredding/sieving: It is possible to shred batteries by means of a hammer mill. The energy consumption for shredding is estimated at about 75 kWh/ton of batteries. It has not been the subject of this research project to further select the most suitable method of shredding and to optimize it. It is possible to separate the battery content after shredding (carbon, Zn, Hg, Mn) (fine fraction) from the coarse fraction by sieving at a mesh of approximately 2.5 mm. The coarse fraction consists of metal covers, paper and plastics.
- Separation of Hg from the fine fraction by thermal methods: Hg can be separated from the fine fraction to a residual Hg content of approximately 200 mg/kg by heating it to a temperature of 375°C for 15 min in a nitrogen atmosphere. This is true for both AlMn batteries and a mixture of ZnC and AlMn batteries (ratio 80:20). A further reduction of the residual Hg content could not be achieved.
- Separation of Hg from the fine fraction by non-thermal methods: If the sieving step can be carried out so effectively that there are no pieces of the coarse fraction left in the fine fraction, then it is possible to separate Hg from the fine fraction by treating it with hydrochloric acid, followed by an oxidative treatment with sodium hypochlorite. After this, the pH in the solution is about 3. This treatment solves both Hg and Zn. Through filtration, a residue is separated containing carbon and Mn dioxide (30% to 40% of the original battery mass). The residual Hg content does not exceed 50 mg/kg, which is the limit stated in the Dutch Chemical Waste Act. All this is true for AlMn batteries, as well as for a mixture of ZnC and AlMn batteries.
- Electrolytic separation of Hg from a solution: By electrolytic reduction Hg can be separated selectively from the solution containing Hg and Zn. The efficiency of electrolysis is high and the residual Hg content is lower than 1 mg/l in solution. It is justified to carry out electrolysis in two steps. The second step is meant as a further purification.
- Precipitation of Zn from the solution: At pH = 10 Zn, can be separated from the solution as $Zn(OH)_2$ by precipitation. The residual Zn content is lower than 1 mg/l. By a further purification treatment, the metals content in the solution (Hg, Zn, Cu, Ni) can be reduced to a level of 10 -100 µg/l.

Especially on the basis of the efficiency of the Hg separation and of the investment costs to be expected, it has been decided to recommend a process route based on the principle of non-thermal Hg separation. It is furthermore estimated that it is advisable to precede the treatment process by a sorting process. With respect to the NiCd batteries, it is stated that in the near future these quantities will be relatively small and that they will be stored temporarily. The proposed process is as follows:

1. Sorting of the batteries after x-ray pattern recognition. Selection of NiCd, AlMn, ZnC and other types of batteries.
2. Shredding and sieving. The coarse fraction is scrap-like and still contains several hundreds of mg Hg per kg.

3. Solving Hg and Zn by treating it with hydrochloric acid and sodium hypochlorite, followed by filtration. The filtration residue contains carbon and Mn dioxide and is not a chemical waste as far as the Hg content is concerned.
4. Electrolytic reduction of Hg from the solution.
5. Separation of Zn from the solution by precipitation as $Zn(OH)_2$ at pH = 10 followed by filtration.
6. Discharging the neutralized chloride solution. Occasionally further treatment is necessary to reduce the metals content to a level of several µg/l.

Witte, 1984

Original title:	(Afval)stroom uit batterijen
Translation:	Waste flows from batteries
Author:	Frank Witte
Institution:	Chemiewinkel, University of Groningen
Editors:	
Publisher:	Chemiewinkel, University of Groningen
Place, Year:	Groningen, 1984
ISBN/ISSN:	90-71150-01-1
Kind of publication:	Report, 63 pages
Additional information:	Written on request of the Groenwinkel (Green shop) of the University of Groningen: an institution that provides the public with scientific information

Between 1977 and 1982 the number of sold batteries increased from 80 million to 100 million. Along with the increase, Hg (8 to 12 tons out of a total emission of 46 to 50 tons in 1982) and Cd (110 tons out of a total consumption of 210 tons in 1980) entered the environment by the disposal of the batteries with household waste. Details of the various types of batteries are given in Table 2.32.

Table 3.32 Amounts and composition of yearly used batteries in The Netherlands (1982)

Battery	**No. (mill.)**	**Weight (g)**	**Total amounts of material**			
			Cu (t)	**Hg (kg)**	**Zn (t)**	**Cd (kg)**
ZnC	60-73	47	8.5-10,3	282-343	705-858	282-343
AlMn	16-25	40	6.4-10,0	6.400-10.000	83-130	?
Hg-oxide	2.8	2	0	1.680	0,7	?
Ag-oxide	4.0	1.7	?	68	0,8	?
Zn-air	0.4	1.89	?	14,4	0,2	?
NiCd	5	35	-	-	-	35,000
Total	88.2-105		88.2-105	14.9-20.3	789-989	35,300

From the total amount of household waste produced in The Netherlands in 1983 and the total amounts of metals in batteries the loading of metals due to batteries in household waste is determined at:

- 2 - 3 mg Hg /kg

- 190 - 235 mg Zn /kg
- 3.5 – 4.8 mg Cu /kg
- 8.4 mg Cd /kg

Incineration
At incineration (37% of the waste) most of the Hg (3 to 4 tons) is emitted to the atmosphere as $HgCl_2$. About 50% of the Zn remains in the bottom ash and the rest ends up in the fly ash (as $ZnSO_4$). Cd is primarily collected in the fly ash.

Landfilling
The Stichting Verwijdering Afvalstoffen (SVA) investigated the behavior of heavy metals originating from batteries under landfill conditions in 1981[5]. Lysimeters were filled with 180 kg of household waste containing batteries and subsequently watered artificially (at the average Dutch precipitation). The leachate was collected and tested. Three columns were installed: one reference column, one Hg-poor column with 9 g of battery-based Hg (AlMn and ZnC batteries) and one Hg-rich column (additionally Hg-oxide batteries) with 2,883 g of battery-based Hg. Concerning Hg, the same leaching behavior was observed for the two latter columns. The first 30 L of leachate contained the highest amounts of Hg. After that, the concentrations of Hg did not exceed the detection limit any more. It was concluded that the clear difference in Hg content in the columns does not lead to a difference in leaching behavior. Both columns, on the other hand, had Hg loads that are higher than can be expected in average household waste. The experiment showed, however, that Hg can leach out of waste piles.

At the end of the experiment the columns were opened. The Hg-oxide batteries, but also the AlMn and ZnC batteries were clearly degraded. Both columns showed free Hg as well. This corresponds with the results of American research[6], which shows that Hg-oxide batteries corrode fast and consequently release Hg. Here, however, the Hg hardly leached out. The reason might be the lower Hg loads.

Another American study[7] concludes, based on data of the transport of iron and barium from a landfill body, that heavy metals from batteries, such as Zn, Hg and Pb will not leach out to the soil under landfills.

In the current study, the results of both American studies are not considered generally applicable. The conclusion that batteries in waste are not sources of heavy metals should be doubted.

Results for Cd are less well known. In the first American, study the NiCd batteries were perforated, which led to hardly any leaching after 100 days.

It is concluded, that since batteries tend to degrade quickly and release Hg, it is not to be avoided, that the Hg gets into the groundwater and soil. This is confirmed by the Dutch study.

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[5] Interactie tussen stedelijke afvalstoffen en batterijen, Amersfoort; not available any more

[6] Fochtman, E. W., Relationships of spent dry batteries to the heavy metal content of solid wastes, IIT Research institute, USA, 1975

[7] Jones, C. J., An investigation of the degradation of some dry cell batteries under domestic waste landfill conditions, J. of Hazardous Materials, 2, 1977/1978, pp. 259-289

Furthermore it is possible that the Hg is transformed to the very toxic methyl Hg, which can be easily up-taken by organisms.

Composting
Only a small portion of the Dutch household waste is composted. Swedish research show increased levels of Zn, Cu, Pb, Cd and Hg in compost from household waste. Thus application of compost will lead to soil contamination. Cd and Hg can be taken up by plants. Therefore batteries should be sorted out prior to composting.

The study ends with an overview of some initiatives for the separate collection of batteries. Alternatives for the current batteries are also presented.

3.1.6 Poland

Szczepaniak, Sobianowska, 2007

Original title:	Odzysk surowców z odpadów baterii, Baterie cynkowo-manganowe, Cz.I-IV
Translation:	Recovery of resources from battery waste, Zn-Mn batteries, Parts I – IV
Author:	Włodzimierz Szczepaniak and Agnieszka Sobianowska
Institution	Wrocław University of Technology
Editors:	
Publisher:	Abrys Sp.z o.o.
Place, Year:	Part I: *Recykling 1*, (73), pp. 26-27, Part II: *Recykling 2*, (74), pp. 36-37; Part III: *Recykling 3*, (75), pp. 28-29; Part IV: *Recykling 4*, (76), pp. 38-39, 2007
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In this series of articles, modern recycling technologies for the AlMn and ZnC batteries are presented. The EU Battery Directive (2006/66/EC) requires that all EU Member States are obliged to achieve 50% recycling efficiency of all other than Pb acid and NiCd batteries by September 26, 2010. This directive also sets collection targets for batteries at 25% by September 26, 2012 and 45% by September 26, 2016. Member States shall encourage the development of new recycling and treatment technologies, and promote research into environmentally friendly and cost-effective recycling methods for all types of batteries and accumulators.

Total sales of batteries in Poland amounted to 236 million batteries (approximately 6,500 tons) in 2002, 254 million batteries in 2003 and 275 million batteries in 2004. The data indicates that every year approximately 8% more batteries are introduced to the Polish market. About 93% of these batteries are ZnC and AlMn batteries, contributing 55% and 38%, respectively. The proportion of ZnC to AlMn batteries in Poland differs from the old EU Member States, where the contribution of more environmentally friendly and more durable AlMn batteries is at approximately 75%. This is due to the lower price of ZnC batteries, and also from a lower public awareness. ZnC batteries are less reliable, as they can corrode and release the aggressive electrolyte and thus damage the electronic equipment. Further on, part I describes the composition and functioning of both types of batteries. Regarding the recovery methods for batteries, three groups of methods are mentioned: (1) mechanical separation methods, being a pretreatment step for further processing; (2) hydrometallurgical processes (i.e., acid or base leaching of ground materials and physical-chemical separation of different material streams); and (3) pyrometallurgical methods using high temperature processes. In the end, the following existing recovery processes for batteries are briefly outlined: Sumitomo/Batrec (in Wimmis, Switzerland), Recytec (Aclens, Switzerland), Waelz (Germany), TNO (Belgium) and Batenus (Germany). In part II, the pyrometallurgical processes for battery recovery: Sumitomo/Batrec, Recytec and Waelz are closer characterized. The advantage of using the pyrometallurgical processes is recycling of various batteries, including their organic content. The authors concentrate on a description of technologies, including general mass balances. The environmental protection measures of the Sumitomo/Batrec process are shortly characterized; however, no further environmental impact data is provided. Similarly, part III of this series of articles characterizes hydrometallurgical methods for battery recovery. The hydrometallurgical methods are considered less energy-intensive than the pyrometallurgical methods, but the waste generated in these methods is more difficult to handle. Two methods implemented on an industrial scale are described in this article: Batenus and TNO. Again, the technological processes are characterized in detail; however, no data about their environmental impacts are provided.

In the part IV of this article, innovative processes for battery recovery are presented, which until now has been only investigated on a laboratory scale. Current research concentrates on advanced chemical processes, which allow higher efficiency of material recovery from batteries than the pyrometallurgical methods. In this article, four methods for treatment of AlMn and ZnC batteries are presented: (1) acid leaching (using diluted H_2SO_4 solutions), (2) dissolution of cathode active materials in HCl, (3) electrochemical recycling, and (4) liquid-liquid extraction. These methods can be characterized by high efficiency of metals recovery, which is their clear advantage in the light of the high recycling efficiency stipulated by the new EU Battery Directive. No data are provided about the environmental impacts of the technologies described. As these technologies still are in their early development stage, such data probably do not exist at the writing.

Korkozowicz, Szykasiuk, 2006

Original title:	Baterie Segragacja czy Degradacja
Translation:	Batteries Segregation or Degradation
Author:	Michał Korkozowicz, Mariusz Szykasiuk
Institution	Dolnośląska Fundacja Ekorozwoju (Lower Silesian Sustainable Development Foundation) and REBA Organizacja Odzysku S.A. (REBA Recovery Organisation)
Editors:	
Publisher:	Dolnośląska Fundacja Ekorozwoju
Place, Year:	Wrocław 2006
ISBN/ISSN:	83-916884-8-8

Kind of publication:	Brochure, 36 pages
Additional information:	

The brochure is supposed to provide informational material for the end users of batteries within the framework of a public information campaign. It has been prepared by the Lower Silesian Sustainable Development Foundation (Dolnośląska Fundacja Ekorozwoju) and the Polish main battery recovery organization (REBA Organizacja Odzysku S.A.). The brochure describes the history of battery development and provides an overview of the main types of batteries available in the market. It explains how secondary batteries should be used in order to extend their lifespan. Further on, one section is dedicated to the impact of batteries on the environment. The brochure state that 1 ton of currently collected spent batteries contains:

- MnO_2: 270 kg
- Zn: 190 kg
- Fe: 160 kg
- Graphite: 60 kg
- NH_4Cl: 35 kg
- Cu: 20 kg
- KOH: 10 kg
- A few kg of Cd, Ni and lithium
- Ag (Ag-oxide): 0.3 kg
- Hg (Hg-oxide): 0.1 kg
- Small amounts of: Nd, Pr, Gd, Y, Mo, V, Ti, Co
- Silicates, paper, foil and hydrogen

Some of these compounds can have a negative environmental impact and therefore batteries should undergo separate collection and treatment. Another reason for battery recovery is the market value of the secondary materials, which amounts to over US$800/ton.

Regarding the environmental impact, only toxicological data on the action of the main heavy metals on the human body is provided. The main potential impacts of Pb, Cd, Hg, Ni and Li on the human health are described. Also, a table summarizing the material composition (including the content of the above mentioned heavy metals) of the following battery types is provided: Pb/PbO_2, NiCd, Zn/MnO_2 (acid-based and AlMn), Zn/AgO_2, Zn/HgO, Zn/O_2 and Li/MnO_2. None of the toxic heavy metals characterized in the brochure are mentioned as being components of the Zn/MnO_2 batteries.

The brochure describes European legislation related to batteries and the existing battery collection systems in Germany, The Netherlands, Belgium, Denmark and Czech Republic. Regarding the Czech and the Polish battery markets, it is characteristic that the primary batteries most often used are ZnC batteries and not AlMn batteries as in the old EU Member States. In Czech Republic in 2004, the shares of ZnC and AlMn batteries constituted 67.5% and 19.7%, respectively. In Poland in 2004, ZnC batteries constituted 68.9% of the primary battery market and AlMn batteries approximately 31.1%. In the old EU Member State, the relation is the opposite. Regarding the treatment of spent batteries, mixed ZnC and AlMn batteries from the Czech Republic are sent to the Austrian treatment plant (Fernwarme Wien in Simmering), while the Hg-free ZnC and AlMn batteries are incinerated in a waste incineration plant.

In total 320 million batteries/yr are sold in Poland, which constitutes 8 batteries/person, as compared to an average of 12 batteries/person in the EU-15 Member States. The currently available recovery and recycling capacities for batteries are much higher than the achieved battery collection rates. Both primary and secondary batteries are recovered in a battery recycling plant of Dolnośląska Korporacja Ekologiczna Sp. z o.o. (DKE) in Polkowice. In 2004, this plant treated 127 tons (4.6 million batteries), constituting 18% of the collected batteries. In this process, batteries are sorted, shredded, and mechanically separated to material fractions. The metal fractions obtained from batteries are recycled in metal smelters. The light fraction (paper, plastics) is used for residual-derived fuel production. Other residuals are solidified and disposed of in a landfill. ZnC and AlMn are also recovered in “Boleslaw Recycling” in Bukowno, where batteries together with other Zn containing waste are treated in a rotary kiln to produce a Zn concentrate. The Zn concentrate is recovered in Zn smelters to metallurgic Zn. The slag is used in road construction. This plant has a capacity to treat 2,000 tons of AlMn batteries and 2,500 tons of ZnC batteries. Other plants exist that are specialized in the treatment of different types of batteries.

In 2001, obligatory recovery and recycling quota were introduced in Poland. The required recovery and recycling quota for primary batteries in the years 2006 and 2007 are presented in Table 3.33.

Table 3.33 Recovery and recycling quota for primary batteries, based on Dz.U. 2005 Nr 175 Poz. 1458

Battery type	**Year 2006 %**		**Year 2007 %**	
	Recovery	Recycling	Recovery	Recycling
Primary batteries, excl. batteries > 300 cm^3	15	15*	25	25^a

^{a} does not refer to ZnC and AlMn batteries

In Poland, the battery producers and importers are obliged to pay a product fee if they do not fulfill the obligatory recovery and recycling quota. For the AlMn and ZnC batteries those fees are 0.16 to 2.57 PZL (US$0.055 to US$0.89) for batteries of <50 g to 252-2,000 g, respectively. The battery collection in Poland is more segmented than in the EU-15 Member States. There are 15 or more battery recovery organizations which can be assigned by the battery producers or importers to fulfill the recovery tasks on their behalf. REBA is the biggest recovery organization, cooperating with the largest battery producers. The recovery and recycling rates required and achieved in years 2002 – 2004 are presented in Table 3.34. The data for the years 2005 – 2006 were not complete at the time of writing. Polish battery statistics are only available, according to the amounts of single batteries (not their weight). The Polish law does not prescribe recycling targets for the ZnC and AlMn batteries; for these, only the recovery targets exist. However, this will have to change because Poland like other EU Member States is obliged to adopt the new EU Battery Directive.

Table 3.34 Required and achieved recovery and recycling targets for selected batteries in Poland in 2002 – 2004

Year	Battery type	Amount of batteries introduced to the market			Recovery rate [%]		Recycling rate [%]	
		Total	**Recovered**	**Recycled**	**Required**	**Achieved**	**Required**	**Achieved**
2002	NiCd[a]	2,285,660	122,787	121,560	10	5.37	10	5.32
	Primary batteries	233,867,732	2,359,987	8,913	5	1.01	5	0.03
2003	NiCd*	2,124,450	292.859	305.049	15	11.87	15	12.37
	Primary batteries	251,974,874	12,565,953	542,523	7	4.99	7	4.13
2004	NiCd*	3,168,370	1,109,582	1,245,957	25	35.02	25	39.32
	Primary batteries	253,183,265	24,051,352	948,728	10	9.68	10	6.83

[a] NiCd secondary batteries ≤ 2000 g

Data on battery sales in 2003 are provided in Table 3.35. Data presentation is again determined by the Polish reporting obligations.

Table 3.35 Segmentation of battery market in 2003 (data from the Polish Ministry of Environment, available at: http://www.mos.gov.pl/odpady/index.html)

Battery Type	Amount [battery units]	Market Contribution [%]
NiCd[a]	2,593,041	1.0
Button cells (excluding ZnC and AlMn)	7,618,797	3.0
Button cells (ZnC and AlMn)	7,011,795	2.8
ZnC and AlMn batteries	231,827,130	91.1
Zn-air and NiMH batteries	732,933	0.3
Li and Li-ion batteries	4,614,471	1.8
Other batteries >250 g	7,331	0.0
Total	254,405,498	100

[a] both small (≤ 2000 g) and large (>2000 g) batteries included

Kopczyk, 2005

Original title:	Technologie recyklingu zużytych baterii i akumulatorów w Polsce
Translation:	Recycling technologies of spent primary and secondary batteries in Poland
Author:	Maciej Kopczyk
Institution	Central Laboratory of primary and secondary batteries, Poznań
Editors:	
Publisher:	Abrys Sp.z o.o.
Place, Year:	*Przegląd Komunalny* 4 (2005), pp. 78-79, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

It is difficult to distinguish a clearly dominating battery recycling process for portable batteries. Metals or their compounds are constituents of all portable batteries. There are installations capable of processing non-sorted battery mixes. Such an installation is Citron (France), in which Zn, Pb and Cd can be recovered after their volatilization in a rotary kiln at 1250°C. The other metals (Fe, Mn, Ni, Cr, Co, Cu, etc.) can be recovered through additional processing. Further on, the author describes pyrometallurgical technologies for the recovery of NiCd batteries (SAB, NIFE, SNAM and INMETCO), as well as hydrometallurgical technologies for NiCd, NiMH and Li batteries. It is also mentioned that in Spain, a hydrometallurgical method for recovery of ZnC and AlMn batteries exists, which is based on leaching of batteries in H_2SO_4, followed by the extraction of Zn. However, data on the environmental impact are not provided for any of the methods described.

In Poland up until now, recycling of batteries was performed only to a small extent. The first technologies for treatment of ZnC batteries were done in the 1970s and 1980s. The spent batteries were added to the input of rotary kilns in the Zn smelters “Boleslaw” and “Miasteczko Śląskie.” Later on, Polish technologies for the treatment of Pb-acid and NiCd batteries are described briefly.

The author argues that recovery of batteries in the installations which have not been specifically designed for the treatment of batteries may pose an environmental hazard. Moreover, these technologies are not able to comply with the minimum recycling targets which are imposed in the battery-related legislation.

As a conclusion the author underscores a need to develop or import environmentally sound technologies which will allow compliance with battery recovery and recycling targets.

No specific environmental impacts arising from the management of spent batteries are described in this article.

Korkozowicz, 2005

Original title:	Zbiórka i odzysk baterii – doświadczenia i prognozy
Translation:	Collection and recovery of batteries - experiences and prognoses
Author:	Michał Korkozowicz
Institution	REBA Recovery Organisation
Editors:	
Publisher:	Abrys Sp.z o.o.
Place, Year:	*Recycling* 3(51), pp. 22-23, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

This article discusses the current collection levels of batteries in Poland against the legal recovery and recycling quotas. In January 21, 2005 in the directive amended from May 11, 2001 about the producers responsibility regarding management of selected waste and about the product fee and deposit fee, new reduced recovery and recycling targets for batteries have been introduced[8]. Regarding the primary batteries (mainly Zn batteries), this target has been reduced from 50% to 35% in the year 2007 (current recovery target is 25% in the year 2007[9]). This measure of the Polish Parliament should be considered as very necessary in the light of currently achieved separate collection rates of batteries. Nevertheless, achieving a recovery level of 35% in less than 3 years still is very unrealistic. This can be proved by the results of separate collection rates achieved in the years 2002 – 2004, and the prognosis for the year 2005. In 2002, only a 1% recovery rate of primary batteries was achieved, as compared to the required 5%. In 2003, a 4.9% recovery rate was achieved although the requirement was 7%. According to the data already available, it can be concluded with a high degree of certainty that the required recovery levels will not be achieved in the year 2005. Based on the current developments, a question arises whether or not the required recovery quota is realistic.

A prognosis of the amount of batteries that could be collected between 2004 and 2009 is presented in Table 3.36, compared with the prognosis of the required amount to be collected to fulfill the obligatory recovery quota for the respective years.

Table 3.36 Prognosis of the achieved collection of primary batteries in the period 2004 – 2009 as compared to the required recovery levels of primary batteries (in tons).

	Year					
	2004	**2005**	**2006**	**2007**	**2008**	**2009**
Prognosis of collected amounts	470	630	945	1,417	2,126	2,650
Prognosis of required recovery amounts	790	1,200	2,400	2,800	2,940	3,090

Since the required recovery and recycling targets were not achieved in the period between 2002 and 2004, the producers and importers of batteries had to pay the “product fees” for the difference between the targeted and achieved quantities of batteries. For the primary batteries, the total sum of product fees amounted to 6.6 million PZL (approximately US$2.3 million). The product fees are collected by the National Environment Protection Fund and should be used to support development of, *inter alia*, a battery recovery system. However, due to the lack of high quality applications, the battery product fees have not been used for the development of a battery management system. Considering the prognosis of battery collection in 2006, the producers of batteries will have to pay approximately 22 million PZL of the products fees for non-compliance with the recovery targets, in addition to the 6 million PZL costs of organizing collection and recovery systems. Since the yearly value of the Polish battery market is estimated at 200 million PZL, contribution of the “environmental costs” would be at a level of 14%, which exceeds the tax normally applied in this environmental branch. Thus, it is strongly recommended to reduce the required recovery/recycling quota for the coming years (for primary batteries to 15% in 2006[10]) and to reduce the level of product fees.

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[8] These targets have been once more reduced in the year 2005, for the current targets see Korkozowicz & Szykasiuk, 2006.

[9] See above.

[10] The proposed 15% recovery level in 2006 for primary batteries has been accepted by the Polish Parliament (see Korkozowicz & Szykasiuk, 2006).

Korkozowicz, 2005a

Original title:	Systemy selektywnego zbierania akumulatorów i baterii
Translation:	Separate collection systems of secondary and primary batteries
Author:	Michał Korkozowicz
Institution	REBA Recovery Organisation
Editors:	
Publisher:	Abrys Sp.z o.o.
Place, Year:	*Przegląd Komunalny* 4 (2005), pp. 72-73, 2005
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In the EU Member States, separate collection systems for batteries are based on different national laws. This resulted in the establishment of different collection systems across Europe in terms of their organization and logistics. Separate collection systems for batteries already exist in 12 EU Member States (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, the Netherlands, Poland, Portugal, Sweden and Italy) and currently are being developed in Greece, Spain and Hungary. In countries where all battery producers and importers are required to enter the national register and where one battery recovery organization exists (e.g., Bebat in Belgium, Ekobat in Czech Republic, Stibat in The Netherlands and Ecopillas in Portugal), in a very short time the battery producers and importers joined those recovery organizations. However, the lack of competition in these countries results in relatively high fees for battery recovery. In Poland, battery producers and importers must comply with the recovery and recycling targets. However, they can assign one of many recovery organizations to fulfill these targets on their behalf. The free market of recovery organizations with limited control and weak law enforcement results in many battery producers and importers avoiding their responsibilities. Besides, the system for battery collection and recovery develops slowly and at the cost of those battery producers and importers who participate in it. Another problem is the lack of legal obligation for the battery retailers to participate in the collection system. Thus the containers for separate collection are available only in some shops and it is difficult to enforce higher participation in the system. The current battery collection in Poland is based on four collection channels: (1) schools, (2) battery distribution points (shops), (3) services and industry sector, and (4) municipal collection systems (to a very small extent). The majority of collected batteries (approximately two-thirds) stems from the schools channel. For the collection, containers made out of cardboard (up to 30 kg), HDPE, PVC or steel plate are used.

Regarding the transport, it should be noted that Li and Li-ion batteries will present more and more important logistical problems. This is because of the very strict requirements regarding the transport of dangerous goods, pursuant to the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), which apply to these batteries. In Germany and in The Netherlands, these batteries are wrapped with a PE foil in sorting plants and transported separately to the recycling plants. In Poland, 2 years ago the batteries were still transported in a loose form. At the moment, transport in the so-called “big bags,” pallet containers or steel and plastic barrels is very common. Requirements pertaining to the transport of dangerous good will result in higher transportation costs for batteries.

Czajka, 2003

Original title:	Zagospodarowanie odpadowych baterii i akumulatorów
Translation:	Management of waste primary and secondary batteries
Author:	Bogdan Czajka
Institution	Central Laboratory of primary and secondary batteries, Poznań
Editors:	
Publisher:	Abrys Sp.z o.o.
Place, Year:	*Przegląd Komunalny* 6 (2003), pp. 96-98, 2003
ISBN/ISSN:	
Kind of publication:	Journal
Additional information:	

In this article problems of the management of waste primary and secondary batteries in Poland are discussed.

To limit the waste of primary batteries, it is recommended to use secondary batteries, which can replace a few hundred primary batteries. However, in Poland, due to economic reasons, primary batteries are used most frequently.

Further on, the author briefly characterizes the types and functioning of batteries. For a long time already, Zn batteries have been the most popular batteries. Their primary advantage is low price, but they have a relatively short lifespan. Among existing Zn batteries, the Zn-air battery is the most environmentally friendly.

In some Polish cities, collection schemes for portable batteries have been introduced. The collected batteries are then stored in specially sealed HDPE containers and in this form are disposed in designated sectors of industrial waste landfills. Further development of separate collection schemes is expected due to the imposed batteries product fee and the growing concern about the environmental impact of batteries.

The data on the collected batteries was analyzed for the period 1998-2000. Additionally, random analyses of the content of those battery containers were performed in the year 2002. The amount of batteries in the HDPE container is approximately 35 kg. The content of a few containers was analyzed in order to determine the segmentation of collected batteries. The data indicate that primary ZnC batteries with chloride-based electrolytes (NH_4Cl and $ZnCl_2$) represent almost 80% of the total amount of batteries. Primary AlMn batteries contribute less than 20% to the mass. Other batteries represent less than 3% of the total mass. In all containers, Zn primary batteries strongly dominated. Other batteries identified include the secondary NiCd, NiMH and Li batteries and the primary Zn-air batteries. Secondary small Pb acid and Li-ion batteries, popular in other EU Member States, were not identified. Thus, the composition of Polish battery scrap is different than in other EU Member States where the contribution of other than Zn primary batteries is much higher.

The Hg content in 7 randomly selected batteries, produced in the year 2000, was also investigated. The results showed that, in all cases, the Hg content was lower than that prescribed by the EU battery Directive (91/157/EEC) of 5 ppm. In all of the batteries investigated, the Pb content was below 0.035%. No Cd was detected in the batteries analyzed.

As the European data show, the ZnC batteries with chloride-based electrolytes were commonly used in the 1980s. The problem related to these batteries was a small amount of Cd, which was added to Zn as well as Hg chloride, which was added to the electrolyte as the inhibitor of Zn corrosion. To comply with the requirements of the EU Battery Directive (91/157/EEC), the quantities of Cd were reduced and Hg eliminated from these batteries. Currently these are the most common primary batteries used in Poland.

The degree of the environmental contamination by the compounds of Zn, Fe and Mn from spent batteries depends on the efficiency of the battery collection systems. At the time this article was written the only large-scale management option for the separately collected portable batteries was their disposal in industrial waste landfills. Thus, it was crucial to elaborate technologies for the recovery/recycling of these batteries. Considering the quantities of primary batteries used in Poland, every year approximately 1,100 tons of Zn and 1800 tons of Mn can be recovered. It does not seem to be possible to systematically collect all of the portable batteries. For that, public education at a primary and secondary school levels is needed. Recovery of separately collected batteries can be realized by applying one or more of the methods mentioned.

3.2 Discussion on similarities and/or dissimilarities among the results of the literature reviewed

3.2.1 Existing battery collection/recovery schemes in the countries investigated

In all countries investigated, there is a legal obligation to collect all portable batteries. In the majority of those countries, one joint battery recovery organization operates. This organization is responsible for organizing the management of spent batteries on behalf of the battery producers and importers. In some countries, one or two other recovery organizations exist; an exception is Poland where there are over 15 battery recovery organizations. In Table 3.37, the main battery recovery organizations operating in the countries investigated are listed. For each country, the destination of AlMn and ZnC batteries is also provided.

Table 3.37 Main battery organizations and destinations of Zn batteries in the investigated countries

Country	Battery Recovery Organization	AlMn and ZnC recovery/recycling plants
Austria	Umweltforum Batterien (UFB)	Fernwarme Wien (Austria)
Belgium	Fonds Ophaling Batterijen (BEBAT)	Revatech (Belgium)
Switzerland	Interessenorganisation Batterieentsorgung (INOBAT)	Sumitomo/Batrec (Switzerland)
Germany	Gemainsame Rücknahmesystem Batterien (GRS)	Valdi (France), Redux (Germany), DK (Germany), Citron (France), GMA (Germany) , Revatech (Belgium)
The Netherlands	Stichting Batterijen (STIBAT)	Valdi (France), Redux (Germany)
Poland	Organizacja Odzysku S.A. (REBA)	Dolnośląska Korporacja Ekologiczna DKE (Poland), Boleslaw Recycling (Poland)

3.2.2 Segregation of primary household batteries

The segregation of the portable battery market in the EU-25, based on data provided by the European Portable Battery Association (EPBA), is shown in Table 3.38.

Table 3.38 Segregation of portable battery market in 2003 in the EU-25, based on sales data of the major battery producers

Battery system		Weight 2003 [tons]	%
Primary batteries	ZnC	50,196.6	30.5
	AlMn	99,137.9	60.3
	Button cells	610.8	0.4
	Li and other	981.7	0.6
Total primary		150,927.00	91.8
Secondary batteries	NiCd	7,882.1	4.8
	NiMH	4,133.4	2.5
	Li-ion	1,399.1	0.9
Total secondary		13,414.6	8.2
Total batteries		164,341.6	

Source: EPBA (Cegasa, Duracell, Energizer, Germanos, GP Batteries, Kodak, Leclanché, Mitsubishi, Moltech, Panasonic, Rayovac, Renata, Saft, Sanyo, Varta Consumer, Varta Microbattery), available at: http://www.epbaeurope.net/batterymarket.html

Data on battery segmentation can be obtained from the respective national battery collection and recovery organizations for most of the EU Member States. However, because of differences in data presentation by each country, it is difficult to compare the battery market segmentation between individual EU Member States. The different data formats result from differences in the national battery-related legislation and different reporting obligations. An attempt was made to present the data from different Member States in a comparable form: battery market segmentation according to the weight of sold batteries is provided in Table 3.39. The statistics of some countries, including The Netherlands and Poland are provided only in numbers of battery units sold. Data in this form are provided in Table 3.40. The data provided by GRS for the segmentation of battery market is the most detailed and complete. Thus for Germany the data is provided in both forms.

Table 3.39 Segregation of the battery market, according to the weight of sold batteries (tons)

Battery system		Germany 2006[a]		Switzerland 2005[b,c]	
		[tons]	%	[tons]	%
Primary batteries	ZnC	3,616	10.4	510	13.7
	AlMn	22,874	65.9	2,347	63.0
	Button cells	488	1.4	19[d]	0.5
	Li and other	268	0.8	46	1.2
Total primary		**27,247**	**78.4**	**2,922**	**78.5**
Secondary batteries	NiCd	1,882	5.4	69	1.9
	NiMH	1,966	5.7	115	3.1
	Li-ion	2,496	7.2		
	Other	1,146	3.3		
Total secondary		**7,489**	**21.6**	**184**	**4.9**
In-built in devices				**618**	**16.6**
Total batteries:		**34,736**		**3,724**	

[a] based on data of GRS, representing 85% of the German battery market (GRS Batterien, 2007)

[b] based on data of INOBAT (INOBAT, 2006)

[c] for block batteries based on the German data, the following composition was assumed: ZnC: 71,7%, Zn-air: 18.6%, AlMn: 9,0% and Li: 0.8%

[d] all button cells have been accounted as primary batteries, from German data it can be concluded that approximately 4.6% of button cells are secondary batteries

In general, the following trends can be observed. In the weight-based data provided by the EPBA the contribution of primary batteries is higher than in the German and Swiss data. The EPBA data are given for both Western and Eastern Europe (the EU-15 and the EU-10 Member States). In the EU-15, the contribution of primary batteries is lower than in the EU-10; thus the average for the EU-25 lies in between. Regarding the Swiss data, the distribution between primary and secondary batteries is almost identical to the German data, assuming that all of the built-in batteries in devices are secondary batteries. The distribution of primary and secondary batteries is not known, but it is expected that part of them are primary batteries (e.g., those in toys), thus in Switzerland the overall contribution of primary batteries to the total amount of batteries will be slightly higher than in Germany. Looking at the battery segmentation for Germany according to weight and according to numbers of batteries, it can be seen that in the weight-based statistics the contribution of primary batteries is significantly lower than in the number-based. This indicates that comparisons of statistics expressed in different units are misleading. The number-based statistics indicate that the proportion of primary batteries to the total battery stream is the lowest in The Netherlands, followed by Germany, and significantly higher in Poland. The Polish market for primary batteries differs from the others in terms of its very high contribution of ZnC batteries to the total amount of primary batteries. In countries such as Germany, Switzerland, The Netherlands and (probably) the majority of the EU-15 Member States, the AlMn batteries strongly dominate the primary batteries market. Due to a lower price, in countries like Poland and Czech Republic (Korkozowicz & Szykasiuk, 2006), ZnC batteries have a significantly higher contribution.

Table 3.40 Segregation of the battery market, according to the number of batteries sold (in thousand units)

Battery system		Germany 2006[a]		The Netherlands, 2005[b]		Poland, 2003[c]	
		[1000 units]	%	[1000 units]	%	[1000 units]	%
Primary batteries	ZnC	151,551	10.2			231,827[e]	62.8[d]
	AlMn	941,372	63.5				28.3[d]
	Button cells	233,442	15.7			14,631[f]	5.8
	Li and other	15,005	1.0			7	0.0
Total primary		**1,341,370**	**90.4**	**309,223**	**88,8**	**246,465**	**96.9**
Secondary batteries	NiCd	17,091	1.2			2,593	1.0
	NiMH	81,912	5.5			733[g]	0.3
	Li-ion	39,939	2.7			4,614[h]	1.8
	other	3,174	0.2				
Total secondary		**142,116**	**9.6**	**38,903**	**11,2**	**7,940**	**3.1**
In-build in devices							
Total batteries		**1,483,486**		**348,126**		**254,405**	

[a] based on data of GRS, representing 85% of the German battery market (GRS Batterien, 2007)

[b] based on data of STIBAT (STIBAT, 2006), detailed data on battery segmentation is not collected by STIBAT (Broers, personal communication)

[c] based on data of the Polish Ministry of Environment, available at: http://www.mos.gov.pl/odpady/index.html, the data includes batteries up to > 2000 g, so not only portable batteries which are considered those < 1,000 g

[d] contribution of ZnC and AlMn batteries based on (Korkozowicz & Szykasiuk, 2006)

[e] including secondary ZnC and AlMn batteries (only 0.1% of AlMn batteries are secondary)

[f] all button cells have been accounted as primary batteries, from German data it can be concluded that approximately 4.6% of button cells are secondary batteries

[g] Zn-air batteries included (based on the German data, their amount is less than 0.1% of all batteries)

[h] Li batteries included (in Germany contribution of Li batteries to the total batteries amount is 1%, and Li-ion batteries 2.4%)

3.2.3 Separate collection -- quantities and rates

In Table 3.41, an effort was made to present the collection quantities and rates in different countries in a comparable form. A number of assumptions have been made to calculate the quantities presented. The calculated or estimated numbers (i.e., not cited directly from the literature) are written in italics. Regarding the collection rates, a number of calculation approaches exist across the EU. Most countries provide their official collection rates based on the weight of batteries separately collected referred to the sales. In The Netherlands and Belgium, the collection rate is provided with reference to the additional quantity of batteries that are disposed of with the household waste. This calculation method requires waste analysis to be performed on a regular basis. For The Netherlands and Belgium, estimates of sales-based collection rates also are provided. The official collection rates are written in bold.

Table 3.41 Battery collection quantities and rates[11]

	Germany, 2006 [a]	**Switzerland, 2005** [b]	**The Netherlands, 2005** [c]	**Belgium 2005** [d]	**Poland, 2003** [e]
Total battery sales [tons]	34,736 *(40,866)*	3,820	*8,152* [f]	*4,992* [g]	*7,007* [h]
Sales per capita [g]	*421 (495)*	*515*	*500*	*478*	*184*
Collected batteries [tons]	13,138 *(15,456)*	2,359	2,704	2,496	*355* [h]
Collected per capita [g]	*159 (187)*	*318*	*180*	*239*	*9*
Collection rate (sales-based)	**38%**	**62%** [i]	*33%*	50%	**5%**
Collection rate (based on household waste analysis)			**83%**	**86%**	

[a] based on data of GRS, representing 85% of the German battery market (GRS Batterien, 2007), total estimated amounts are provided in parentheses, assuming the same collection rates as of the GRS

[b] based on data of INOBAT (INOBAT, 2006)

[c] based on data of STIBAT (STIBAT, 2006), detailed data on battery segmentation is not collected by STIBAT (Broers, personal communication)

[d] based on data of BEBAT (BEBAT, 2007)

[e] based on data of the Polish Ministry of Environment, available at: http://www.mos.gov.pl/odpady/index.html, the data includes batteries up to > 2000 g, so not only portable batteries which are considered those < 1000 g

[f] calculated assuming average battery weight of 23.4g (based on the German data from GRS Batterien, 2007)

[g] calculated assuming approximately 50% sales-based collection rate of batteries (BEBAT, 2007)

[h] calculated assuming average battery weight of 27.5 g, based on the data for 2002, provided in (Szczepaniak & Sobianowska, 2007)

[i] in Switzerland the sales-based collection rate is calculated referring to the sales data from the previous year (here 2004)

3.2.4 Co-disposal of batteries with household waste

Identification of literature dealing with environmental impacts occurring at the co-disposal of household primary (AlMn) batteries with the household waste was one of the main objectives of this study. In general it can be concluded that very few publications deal with the co-disposal of batteries with the household waste. If this topic is tackled at all, it is mostly done by the older literature sources (dating from the 1980s and the beginning of the 1990s). This is due to the introduction of battery-related national and European legislation from the beginning of the 1990s, which imposed an obligation of separate collection and treatment/separate disposal of batteries. The first European Battery Directive 91/157/EEC[12] (amended by 93/86/EEC[13] and 98/101/EC[14]) had a limited scope since it only applied to batteries with a certain Hg, Cd and lead content. Those batteries were classified as 'hazardous waste' on the basis of the European Waste List. The Directive only covered a small portion (approximately 7%) of all portable batteries placed on the EU market annually. In Germany initially also only batteries with a certain content of Hg (since 1980) and later also Cd and lead (since 1986) were to be collected separately, based on a voluntary agreement between the battery producers and the German ministry of environment. A marking system for the batteries with a metals content exceeding certain limits (*inter alia* for

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[11] In the table the official collection rates are written in **bold**; all calculated or estimated values are provided in *italics*

[12] Directive 91/157/EEC on batteries and accumulators containing dangerous substances

[13] Commission Directive 93/86/EEC adapting to technical progress Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances

[14] Directive 98/101/EC adapting to technical progress Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances

NiCd secondary batteries, button cells and AlMn batteries with a Hg content higher than 0.1%) was supposed to allow a user to identify the batteries which were to be separately collected. However, the low content of marked batteries in the collected battery mixes proved that the identification system failed to fulfill its function. In collected battery mixes, the contribution of marked batteries was lower than 20% or even 1%. The majority of collected batteries constituted Hg-free AlMn and ZnC batteries in accordance with their market share (Bräutigam & Fellmuth, 1999). Thus with the first German battery directive from 1998[15], the collection obligation was extended to all batteries. In Switzerland, an obligation for separate collection of all spent batteries has existed since 1986 (Goldschmid et al., 1989). Also in The Netherlands, since 1985 batteries already were considered hazardous waste and increasingly collected separately through the household hazardous waste collection (Leijting, 1997). In Poland the obligation for the separate collection of batteries has existed practically since 2001[16], in which recovery targets apply to all batteries; however, ZnC and AlMn batteries are exempted from the recycling obligation. Based on the experiences of the Member States, the new EU Battery Directive (2006/66/EC[17]) also applies to all batteries.

The introduction of the above mentioned legislation resulted in separate collection schemes being established for all batteries in the countries investigated and the subsequent recovery/recycling of separately collected batteries. Thus the environmental performance of battery co-disposal with household waste has not been further discussed or analyzed. Consequently, the publications presented here are often relatively old and the presented results refer to the batteries as they were produced and marketed in the past, i.e., with higher heavy metals contents.

3.2.5 Enrichment of the contaminants content in household waste due to batteries

Bräutigam and Fellmuth (Bräutigam & Fellmuth, 1999) provide the yearly consumption of metals for the production of batteries in comparison to the total yearly consumption in Germany (data from 1996). This proportion is especially high for Cd (used mostly in the secondary batteries), lead (used in the automotive batteries) and Hg (used primarily in button cells) amounting to 75.4%, 63.8% and 10%, respectively. The contribution of batteries production to the total use of other metals is significantly lower and amounts to 1.1% for Zn, 1.7% for Ni, 0.03% for Cu and 0.02% for iron.

In the majority of publications reviewed, the heavy metal content in batteries, especially the contents of Hg and Cd and their potential emissions, are perceived as the most serious problem related to co-disposal of spent batteries with household waste. In Table 3.42, reported data on the content of heavy metals in household waste, which is attributed to the battery input to waste, is provided for The Netherlands and Austria. The table also provides data on the relative contribution of batteries-derived metals to the total contents of respective metals in waste. Especially in the older data, the contribution of Cd and Ni from batteries to the total content of metals in waste is very high. In the most recent analysis of residual waste performed in Austria,

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[15] Verordnung über die Rücknahme und Entsorgung von gebrauchten Batterien and Akkumulatoren of 02.04.1998

[16] based on the directive from 11.05.2001 about the producers responsibility regarding management of selected waste and about the product fee and deposit fee

[17] Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC

the content of batteries in residual waste was estimated at 575 g/ton d.m., of which approximately 60% constituted AlMn batteries (Skutan & Brunner, 2006). Results of these analyses presented in Table 3.42 indicate a significantly lower contribution of batteries for the Ni content in waste than 10 years ago; however, the value for Cd is still relatively high. As far as Zn is concerned, batteries have never been considered as a main contributor of this metal to the household waste. This is despite the strong domination of AlMn and ZnC batteries in the whole battery stream. However, also in the case of Zn, recent data show over three times lower contribution than the German data from 1996. According to Skutan and Brunner (Skutan & Brunner, 2006), only very small proportion of Zn in residual waste originates from the primary Zn batteries. The major portion of this metal comes from different alloys.

Table 3.42 Battery contribution to the content of heavy metals in household waste

	Content of metals in household waste due to battery input		**Contribution of batteries to the total content of metals in household waste**	
Metal	**The Netherlands, 1983 [a]**	**Austria, 1989 [b]**	**Germany, 1996 [c]**	**Austria, 2006 [d]**
Cd	8.4 mg/kg	n.a.	85%	60%
Cu	3.5 – 4.8 mg/kg	n.a.	n.a.	n.a.
Hg	2 - 3 mg/kg	1.5 mg/kg	4-8%	n.a.
Ni	n.a.	n.a.	67%	20%
Zn	190 – 235 mg/kg	95 mg/kg	10%	3%

Sources:

[a] Witte, 1984: determined based on the total amount of household waste produced in The Netherlands in 1983 and the total amounts of metals in batteries

[b] Goldschmid et al., 1989

[c] Vest & Jantsch, 1999

[d] Skutan & Brunner, 2006

The significantly reduced input of heavy metals from batteries to waste has been achieved, both due to the separate collection of batteries, as well as the reduction of the content of certain metals in batteries. The latter has been especially important for the reduction of the Hg content in waste.

In Germany, the heavy metals content of batteries has been perceived as a problem since the end of the 1970s/beginning of 1980s (Bräutigam & Fellmuth, 1999). This resulted in a voluntary agreement of 9 September 1988 between battery producers and the German ministry of environment, concerning a reduction of the Hg content in AlMn batteries to less than 0.025%. Due to the reduction of Hg content in AlMn batteries from 0.5% - 1% to less than 0.025%, the Hg content in household waste decreased from approximately 70 tons in 1985 to approximately 2.7 tons in 1996. Further reduction has been achieved due to the regulatory Hg limit of 5 ppm since 2001. Despite all of the progress that has been achieved in the management of spent batteries, the German Federal Environment Agency (UBA) still perceives batteries in household waste as an environmental problem. According to UBA, in 2004 in Germany over a billion portable batteries were sold, which contained approximately 4,700 tons of Zn, 1,500 tons of Ni, 700 tons of Cd, 7 tons of Ag and 3 tons of Hg (UBA, 2006). Although there is a legal obligation to collect all batteries, on a yearly basis only approximately one-third of sold batteries is being collected. This means that large amounts of contaminants still enter the environment through disposal with household waste and other unclear disposal ways. Moreover, even though since 2001 the Hg limit in the majority of produced batteries has been 5 ppm, batteries with high Hg content can be still found in the collected battery mixes. According to GRS, in 2006 186 tons of separately collected non UV-marked, thus potentially Hg-rich, AlMn batteries (approximately 3.3% of all AlMn batteries sorted in 2006) were disposed of in a hazardous waste landfill (GRS Batterien, 2007), which, according to UBA, still constitutes too high a proportion of these batteries (UBA, 2006).

Concerns about Hg in AlMn batteries, despite the enforced strict limits on the Hg content in batteries, also existed in other countries.

In The Netherlands, since March 1995 the Decision on the disposal of batteries has been in force (Wetsteyn, 2000). In it, limits for the amounts of Hg, Cd and Pb are prescribed. However, a concern arose whether imported batteries from Asia meet these limits. Especially Hg was of concern, which limit at this time was 0.025% for AlMn and 25 mg per battery for non-AlMn batteries. In the reported investigations, samples of 118 shipments of Asian batteries were analyzed. Three shipments exceeded the current limits. Future limits of 5 ppm would not be met by 17 shipments.

The problem of inexpensive batteries from Asia, with a high level of contaminants was also discussed in the older publication of Vest and Jantsch (Vest & Jantsch, 1999) with regard to developing countries. In developing countries, the electricity supply network usually covers only a proportion of the population. Thus batteries become a common alternative to provide electric power for the electrical and electronic equipment. Investigations have shown that in these countries most often the cheap batteries imported from the Far East are used (especially ZnC batteries). The content of Hg in these batteries still is relatively high as compared to the more expensive batteries from Europe and the USA. Additionally, due to their shorter lifetime and the non-existing waste management infrastructure, the disposal of spent batteries poses a serious environmental threat in developing countries. Out of 12 geographic regions, the highest consumption of primary batteries is reported in the USA (10.9 batteries/inh./yr) and the lowest in India (1.5 batteries/inh./yr). However, in the first case the contribution of the environmentally friendly AlMn batteries reaches 86.5%, while in the latter case only 0.3%.

Also in Poland, the Hg content in batteries was investigated (Czajka, 2003). For this, 7 randomly selected batteries, produced in the year 2000, were analyzed. The results showed that in all cases the Hg content was lower than the limit of 0.0005% (weight) prescribed by the EU battery Directive (91/157/EEC). In all of the investigated batteries, the Pb content was below 0.035%. No Cd was detected in the batteries analyzed.

Thus it can be concluded that the voluntary initiatives of the battery industry and regulatory limits on the content of certain metals in batteries introduced within the past 15 years have had a very positive effect in terms of reduced heavy metals input into household waste. This is especially clear for Hg. However, there still is a concern about the smaller battery streams with a high Hg content which enter the market with imported cheap products, e.g., from Asia.

The contribution of batteries to the concentration of Cd in waste still is relatively high. Input of Zn originating from AlMn and ZnC batteries presents only a marginal stream as compared to other sources of this metal in waste.

3.2.6 Impacts of battery components on human health and the environment

Many of the literature sources describe the toxic impacts of the heavy metals contained in batteries. These descriptions mostly focus on discussing the potentially harmful effects of the substances after inhalation or other kind of uptake. However, the assumed transport routes of the pollutants from a spent battery to the receptor (here a human or animals) are not described. In the following are presented some of the toxic effects mentioned. Most of the data refer to the effects of Hg and Cd; however, some data on the impacts of Zn and Mn can be found as well.

Vest and Jantosch (Vest & Jantsch, 1999) argue that regardless of the transfer mechanism of metals into the environment, the metals pose some environmental risk. In the annex to the report, the general negative impacts of Hg, Cd, Zn, Mn and Ni are briefly presented. Hg is the most hazardous battery component. It can cause distortion of the neural system, kidneys and mucous membrane, and is accumulated in the brain and in the liver. However, waste management is only one of many other exposure routes to Hg. Cd is regarded as a carcinogenic metal. It also leads to chronic lung and kidney damage, as well as distortion of the neural system. Regarding the impacts due to Zn, some of the human-toxic effects mentioned are: metal fume fever and food poisoning, as well as its accumulation potential in blood cells and in bones. As for Mn, it is stated that the toxicity of this metal is very low. Only an uptake of MnO_2 in a very high dose can lead to lung inflammation or neuro-psychiatric illnesses. The latter is attributed to a chronic exposure to MnO_2.

The toxic data provided by Vest and Jantosch is partly based on the work by Baumann and Muth (Baumann & Muth, 1997); thus these two sources largely overlap. Baumann and Muth also discuss the toxicity of Hg in great detail. Regarding Zn, it is stated that it is classified as an essential element for humans. Toxic effects are observed due to inhalation of particles containing Zn and gases, without understanding their working mechanism. Regarding Zn chloride, it is stated that it is corrosive in water solutions. Mn is presented as an essential element for humans, which can be toxic in higher doses. The Threshold Limit Value (TLV) provided for Mn is 5 mg/m^3 in total particulate matter. Significant overdoses lead to lung inflammation and neural disorder.

Additionally Baumann and Muth provide detailed data sheets to all chemicals contained in batteries in the annex to their book, including their “toxicological/eco-toxicological” characterization. With regard to Zn, a water hazard class of 0 is provided (in general no hazard for water); however, later it is stated that in soft waters Zn concentrations of 0.1 – 1.0 mg/l are fatal to fish. A TLV of 5 - 6 mg Zn/m^3 is given. Regarding the dangers related to Zn, its reactivity with water to form light flammable gases and self-inflammability in the air are listed. As safety measures, the following recommendations are made: keep the material dry and enclosed and in case of a fire extinguish it with water. Also it is stated that Zn oxide is formed (ZnO) when heated up. Inhalation of ZnO can cause metal fume fever; after a few hours delay the following symptoms may occur: fever, pain, abnormal fatigue, coughing, ague, temperatures up to 40°C, and sweating. Chronic poisoning by Zn is not known; small amounts are harmless, but in high doses it leads to irritation of the mucous membrane and sickness. Inhalation can lead to fever, muscle pain, shivering, and nausea. These are conditions which normally cease within 24 hours and lead to no after-effects.

The publication of UBA (UBA, 2006) indicates that the highest environmental risk is related to batteries containing Hg, Cd and Pb. Heavy metals are very dangerous substances. They can cause either direct health effects in humans or accumulate in the food chain and in the environment. Cd compounds can cause kidney damage and are considered carcinogenic if inhaled. Pb accumulates in bones and can distort bio-chemical processes in living organisms. Also, natural waters can be contaminated by heavy metals, which can be taken-up by fish and be transferred to humans through the food chain. Mn dioxide (out of AlMn batteries), lithium (out of Li-ion secondary batteries), and the electrolytes (e.g., potassium hydroxide and sulfuric acid) are partly corrosive or substances that endanger the environment. Also metals whose concentration does not require labeling are not completely safe, e.g., Ni can cause allergic reactions.

In general in most of publications the toxic effect of Zn and Mn are either not discussed at all or are presented as marginal compared to those of Hg, Cd and Pb (Baumann & Muth, 1997; Vest & Jantsch, 1999; Bräutigam & Fellmuth, 1999; Korkozowicz & Szykasiuk, 2006; UBA, 2006).

Apart from the impact related to heavy metals, the energy efficiency of batteries is discussed in two German publications (Scholl et al., 1998; UBA, 2006). Scholl et al. proposed criteria for the European eco-label for batteries, one of them being “Energy efficiency.” It is defined as the proportion of energy used for the production of batteries (including up-stream processes) to the energy quantity that can be generated by this battery in its use phase (energy input/energy output). For secondary batteries, the recharging energy and the maximum recharging frequency also are taken into account. It has been proven that for many batteries the energy use for the up-stream processes, i.e., extraction of the raw materials is very energy intensive. It is especially true for the AlMn and ZnC batteries. The proposed maximum ratio of energy input to energy output for the eco-label is 20. Only secondary batteries with 100 and more recharging cycles are capable of fulfilling this criterion.

In its recent publication, UBA perceives the energy-balance of batteries as responsible for their high environmental burden (UBA, 2006). Approximately 40 to 500 times more energy is used for the production of primary batteries than they generate in their use phase. This renders the batteries the most expensive energy source. Recharging of batteries can improve their environmental and energy balances. Thus UBA recommends using secondary batteries instead of primary batteries, due to their better environmental performance. Especially the application of AlMn secondary batteries is recommended, also due to their relatively slow discharge.

3.2.7 Landfilling of solid waste containing batteries

Regarding the co-disposal of batteries in household waste landfills, only rather older publications deal with this topic at all. This is because landfilling of batteries has not been practiced for quiet a long time in most of the EU Member States.

In The Netherlands, the behavior of battery based heavy metals in landfill conditions was investigated in 1981 (Witte, 1984). Lysimeter experiments involving waste with a lower and a higher content of AlMn, ZnC and Hg-oxide battery-based Hg (0.05 g Hg/kg waste and 16 g/kg waste) were performed. Concerning Hg, the same leaching behavior was observed regardless of the concentration of Hg. The first 30 L of leachate contained the highest amounts of Hg. After that, the concentrations of Hg did not exceed the detection limit. The experiment showed, however, that Hg can leach out of waste piles. However, both Hg loads investigated were significantly higher than those to be expected in average household waste (compare Table 3.6).

Re-opening of the lysimeters at the end of the experiment showed that the Hg-oxide batteries, as well as the AlMn and ZnC batteries, were clearly degraded. Both columns showed free Hg as well. This corresponds with the results of American research[18], which showed that Hg oxide batteries corrode fast and consequently release Hg. There, however, the Hg hardly leached out, which might be explained by the lower Hg loads.

Another American study concluded, based on data of the transport of iron and barium from a landfill body, that heavy metals from batteries, such as Zn, Hg and Pb will leach out to the soil below the landfills[19].

In a Dutch study reviewed, the results of both American studies were not considered generally applicable. The claim that batteries in waste are no sources of heavy metals should be doubted. It is also concluded, that since batteries tend to degrade quickly and release Hg, it cannot be avoided that the Hg gets into the groundwater and soil. Furthermore, it is possible that the Hg is transformed to the very toxic methyl-Hg, which can be easily up taken by organisms.

According to the German literature (Baumann & Muth, 1993; Vest & Jantsch, 1999[20]), excavations of old landfills have confirmed that batteries corrode in a landfill body and the battery content can be released. The duration of this process is expected to be 1 to 3 years. Whether the leachate or the groundwater can be contaminated by the released content of batteries depends on the landfill conditions (waste organic content, pH, density, rain quantity). Processes occurring in the landfill body have to be understood in order to understand release mechanisms of metals from batteries. Regarding the release of Cd from batteries, in both publications a Canadian study[21] is cited in which pollution of the leachate by different types of batteries has been reported. The results of this study were used to establish criteria for inert waste, non-inert waste and toxic waste. These results are shown in Table 3.43.

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[18] cited from: Fochtman, E. W., Relationships of spent dry batteries to the heavy metal content of solid wastes, IIT Research Institute, USA, 1975

[19] cited from: Jones, C. J., An investigation of the degradation of some dry cell batteries under domestic waste landfill conditions, J. of Hazardous Materials, 2, 1977/1978, pp. 259-289

[20] Description of environmental impacts of battery disposal in Vest & Jantsch_1999 is mostly based on Baumann & Muth_1993, so the contents of these publications overlap to a large extent

[21] cited from: Haight, M., Kofi Asanti-Duah, D. and Craig, L.: Assessing the Environmental Effects of Disposal Alternatives for Household Batteries; Final Report; Institute for Waste research, University of Waterloo, Canada 1992

Table 3.43 Allocation of spent batteries based on the leachate contamination attributed to them[a]

Battery Type	Parameter	Limit Value for Non-Inert Waste [mg/l][b]	Limit Value for Toxic Waste [mg/l][b]	Result of the Investigations [mg/l]
ZnC	Cd	0.05	0.5	0.067
NiCd	Cd	0.05	0.5	2,900
Li	Cd	0.05	0.5	0.31
	Fluoride	24	240	43

[a] Hg in AlMn batteries was also investigated in Haight et al., 1992, but is considered as presenting no issue for the European market since 1994

[b] According to the Ontario Regulation 309 Criteria

In Baumann & Muth, 1993, transfer coefficients for metals from landfilled waste to the leachate also are provided; the coefficients are summarized in Table 3.44.

Table 3.44 Transfer coefficients for metals from landfilled waste to leachate

Metal	Transfer coefficient [mg leached/mg in waste]
Cd	$6 \cdot 10^{-5}$
Hg	$6 \cdot 10^{-5}$
Zn	$2 \cdot 10^{-4}$

It is concluded that considering the results presented in the previous paragraphs, it must be acknowledged that metals contained in batteries are released and after a time delay will be present in the landfill leachate. Thus, in case of faults in the landfill bottom liner or in case of a direct discharge of the leachate, they pose a danger of ground and surface water contamination. This is especially a problem at non-engineered landfills. However, according to Vest & Jantsch, 1999, it also has to be underscored that in the case of modern landfills which are operated according to the current standards, including collection and treatment of leachate, batteries do not pose any danger to the environment any more. This is especially valid for mono-landfills and landfills for hazardous waste, where batteries do not come into contact with the organic waste and where the biochemical processes, which are characteristic for household waste landfills, do not take place.

In the Austrian literature, in the introduction to Goldschmid *et al*., 1989, written by the Federal Environment Agency, it is stated that at that time the Agency did not know of any study in which the interactions between disposed spent batteries and the landfill body were described. On the other hand, however, it is not doubted that under landfill conditions, especially in the phase of acid fermentation the steel outer covers of batteries will corrode and the battery content will be released to the waste body. It is not known how far the released substances will influence and contaminate the landfill leachate and gas. But considering the complexity of the biological, chemical and physical processes taking place in the landfill, the mobilization or remobilization of metals temporarily bound in the landfill body can not be excluded.

According to this publication, a discharge of Hg in the landfill leachate is not realistic due to the chemical properties of this metal. Thus the Hg content is rarely considered in the leachate analyses. It is assumed that Hg partly reacts with the hydrogen sulfide gas generated within the anaerobic decomposition process to form insoluble sulfides. Metallic Hg is also assumed to partly volatilize with the landfill gas. Regarding the transformation of Hg through microorganisms to organic forms and their emissions with the landfill gas, no studies are known until now.

About the behavior of batteries in a hazardous waste landfill, the Federal Environment Agency did not have any information.

In the doctoral thesis of Leijting (Leijting, 1997), an Energy Analysis and a simplified LCA of the production, use and disposal of ZnC, AlMn and NiCd batteries is attempted. The LCA is far from complete, since an LCIA, as well as several up-stream processes of used materials and energy, are lacking. In 1994, the amount of spent batteries entering landfills in The Netherlands was estimated at 485 tons. The consequent amount of battery-based metals in the landfill body was determined and compared to the intervention values for a standard soil in The Netherlands (see Table 3.30).

Table 3.45 Battery based metal concentration in landfilled waste (1994) and intervention values for soil

Metal	Concentration (mg/kg dry matter)	Intervention value (mg/kg dry matter)
Ni	3.8	210
Cu	1.6	190
Zn	36.0	720
Fe	44.1	*
Mn	36.7	*
Cd	2.9	12
Cr	**	380

*: no intervention value available
**: negligible (< 1 mg/kg)

It is concluded, that all concentrations are well below the intervention values and the environmental impacts of battery landfilling are not discussed any further. It should be noted, that in Table 3.30, Hg is not considered.

The behavior of heavy metals in landfilled waste was investigated in the doctoral thesis of Den Boer (den Boer, 2007). In this publication, the results of 8 years storage of raw waste, MBP waste and incineration slag were used. This publication is not concerned with the landfilling of batteries, but provides some insight on the general behavior of heavy metals in landfilled waste. The lysimeter experiments allowed estimation of the short-term (up to 100 years) transfer coefficients of different metals from waste to leachate for different waste types. These coefficients are given in Table 3.18. The estimated coefficients are significantly higher than the ones in Baumann & Muth, 1993. In the case of the latter ones, the time-span is not provided.

Table 3.46 Short-term (100 years) transfer coefficients from waste to leachate

	Ca	Cd	Cr	Cu	Fe	Ni	Pb	Zn
	[%]							
Raw waste	28.2	38.7	0.6	0.7	3.4	5.8	0.5	20.9
MBP waste 1	0.49	0.12	0.01	0.10	0.29	0.04	0.18	0.49
MBP waste 2	0.63	0.14	0.15	0.05	0.16	0.00	0.06	0.63
Incineration slag	0.09	0.04	0.00	0.002	0.002	0.04	0.001	0.00

Furthermore, in this thesis the long-term leachability of metals from landfills was assessed. The assessment is based on: (a) the analysis of speciation of metals and their changes in treatment and disposal processes; and (b) the consideration of long-term processes, such as organics decomposition and pH development combined with empirical investigations of metals behavior under different conditions into the modeling of metals leaching. Generally, the results indicate that release of metals from waste is a very slow process, requiring thousands of years to meet the respective metals limit contents for soils in the waste body. This is because of the high sorption capacity of waste. During the first period, after waste deposition, the leachability progresses significantly faster than after the methanogenic phase in the landfill has been reached. Also, looking at the example of Zn, it can be concluded that leaching of metals from raw waste progresses faster than from the MBP waste and from incineration slag.

To summarize, it can be concluded that in most of the publications reviewed, a concern is expressed that batteries in a landfill body corrode and release their content (Witte, 1984; Baumann & Muth, 1993; Vest & Jantsch, 1999; Goldschmid et al., 1989). Thus, in case of deterioration of a landfill bottom liner, a risk of contamination of the underlying soil exists. These assumptions are made based on results of studies cited which have been performed in the 1970s and the beginning of the 1980s. The batteries investigated in these studies differed significantly from the modern ones, with Hg being a commonly used component. For modern batteries, no literature on similar investigations could be found.

Based on results provided in den Boer, 2007, it can be concluded that release of metals from landfilled waste to leachate progresses very slowly, especially in MBP waste, in incineration slag and in raw waste after the landfill has reached the methanogenic phase.

3.2.8 Incineration of waste containing batteries

In discussing the environmental impacts of the incineration of waste containing batteries, most of studies concentrate on the emission paths for individual metals in the incineration process. Most of the publications which deal with the fate of batteries in an incineration plant for household waste also are relatively old.

In the Netherlands, in 1984 approximately 37% of household waste was incinerated. In the Dutch publication from this time (Witte, 1984), it is concluded that most of the Hg originating from batteries (3-4 tons) is emitted to the atmosphere as $HgCl_2$. About 50% of Zn is assumed to stay in the slag and the rest in the fly ash (as $ZnSO_4$). Cd is assumed to end up in the fly ash.

Table 3.47 provides transfer coefficients of heavy metals to different outputs of the waste incineration process, based on German data (Baumann & Muth, 1993) and Austrian data for Zn and Hg (Goldschmid et al., 1989).

Table 3.47 Transfer coefficients for metals within incineration processes (based on Baumann & Muth, 1997 and Goldschmid et al., 1989)

Element	**Emission paths**				
	Slag	**Fly ash**	**Filter cake**	**Sludge**[a]	**Flue gas**
	%				
Cd	7	89		4	0
Ni	89	10		1	-
Zn	37 55-75 [b]	60 13-31 [b]	n.a. 8-23 [b]	3 n.a.[b]	2 0.2 [b]
Mn	83	16		1	-
Hg	1 5 [b]	2 0 [b]	n.a. 90 [b]	91 n.a. [b]	6 5 (<10) [b]

[a] sludge from the treatment of waste water from flue gas purification
[b] databased on Goldschmid et al., 1989

In the Austrian publication (Goldschmid et al., 1989) the environmental effects of the incineration of 115,000 tons (approximately 18% of the Viennese household waste) in the waste incinerator Flötzersteig are discussed. The estimated quantity of Zn emitted was approximately 460 kg and of Hg <30 kg. The estimated contribution of the ZnC and AlMn batteries to these amounts was approximately 22 kg Zn and approximately 20 kg Hg. It means that through a separate collection and treatment of batteries, approximately 60% of Hg emissions can be saved and 5% of Zn emissions. Additionally, approximately 10 kg of Cd were emitted. The authors also stress that the remaining heavy metals that are contained in the slag and ash can be also emitted and influence the co-disposed materials in a landfill.

From Switzerland it is known that in the analyses of the incineration slag (in the eluation procedure with CO_2 saturated water), mobilization of Zn was observed. This is partly due to the Zn contribution of co-incinerated batteries.

Bauman and Muth (Baumann & Muth, 1993, 1997) also point out that batteries cause additional emissions of heavy metals from incinerators. Hg as a volatile metal after incineration is transferred to the flue gas and finally remains in the products of the gas purification system. Cd volatilizes as well and afterwards condensates on the particles of fly ash. Zn as Zn oxide remains in the slag and as Zn chloride is transferred to the flue gas, where it also condenses on the fly ash particles. Ni and Mn remain as oxides (e.g., Mn_3O_4) in the slag. In the earlier publication (Baumann & Muth, 1993), a concern about excessive Hg and Cd emissions due to co-incineration of batteries was expressed. This was especially a problem in the incineration plants that were not equipped with modern flue gas purification systems (no activated charcoal filters, no aerosols separation). In the more recent publication (Baumann & Muth, 1997), this concern is not confirmed any longer, due to more strict emission limits for incineration plants in Germany[22] which enforced additional flue gas measures.

Vest and Jantsch (Vest & Jantsch, 1999) come to a similar conclusion regarding the sufficient efficiency of Hg and Cd removal from the flue gas in modern incineration plants. However, since this publication is concerned with the management of spent batteries in developing countries, they express a concern that such advanced technologies may be unavailable in those countries. Regarding the solid residues of the incineration process, it is concluded that Cd and Zn can be found both in the fly ash and in the slag. Their content in the slag is significantly higher than in the earth crust; therefore, the slag needs to be pretreated prior to its recovery. Fly ash must be either pretreated or disposed of in hazardous waste landfills.

Bräutigam and Fellmuth (Bräutigam & Fellmuth, 1999) report that in New Jersey (USA) in 1992, 38% of the anthropogenic Hg emissions stem from waste incineration plants, of which 84% were caused by co-incineration of batteries.

In The Netherlands in 1994, approximately 50% of the waste was incinerated. In the doctoral thesis of Leijting (Leijting, 1997) mentioned above, a simplified LCA of batteries is attempted, including incineration as one of the disposal processes. For the incineration of battery containing waste is stated that:

- it is unclear to what extents metals are volatilized at incineration,
- the amount of incineration air determines the concentration in the flue gas, and
- Dutch incinerators have flue gas cleaning devices.

Therefore, it is concluded that it is not relevant to make an estimation of the metal emissions of Dutch incinerators caused by batteries.

More recently Vanazetta and Skutan (Vanazetta & Skutan, 2003) investigated the composition from a residual waste incineration slag. The aim of this research was to determine the content of Cd in the metal scrap separated from the slag. In order to determine the relevance of NiCd secondary batteries and Zn batteries (Cd as Zn accompanying metal) for the Cd content in the metal scrap, both battery types were investigated. The authors report that the batteries separated from the slag were burned; their surface was rusty and contaminated with other components of the slag. Some batteries were in a disintegrated form (especially the ZnC batteries). The content of batteries was the highest in the fraction of fine metal scrap: 25 – 29 kg/ton (approximately 1,500 – 1,700 batteries/ton), of which AlMn batteries constituted 18 – 21 kg/ton (approximately 1,000 – 1,150 batteries/ton).

The results show that, on average, metal scrap contains 94 g of Cd/ton. The main contributors to the Cd content are NiCd batteries. The contribution of other than NiCd batteries to the total Cd content in the incineration slag is insignificant.

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[22] 17th Ordinance on the Implementation of the Federal Immission Control Act ("17th BImSchV") (Ordinance on waste incineration plants for waste and similar flammable materials) of 23. November 1990 –17. BImSchV)*), amended on 14. August 2003 (BGBl. I S. 1633)

According to the author of the publication above, the research currently performed confirms that the AlMn battery bodies found in the incineration slag still contain high amounts of Zn and its complete Mn content. This means that in the incineration process only a small proportion of Zn is being emitted through the other paths. ZnC batteries show a different behavior – they fall apart and are burned out in the incinerator, so that only graphite remains in the slag (Skutan, personal communication).

Similar observations have been confirmed by a Swiss researcher (Bunge, personal communication). It is assumed that batteries, due to their higher density, become separated from the waste mass and fall down directly on the grate. The incinerator grate is cooled down by the primary air, thus preventing the burning out of batteries. In this way batteries can be found in the incineration slag in an almost intact form. Within the slag treatment, batteries are separated in a magnetic separator and transferred to the fine metals scrap.

Thus, the results of recent investigations are contradictory to the older literature in which it was assumed that the behavior of battery-derived heavy metals in the incineration process is analogical to that of the heavy metals contained in the remaining waste mass.

To summarize in the older literature, the main environmental impact occurring at the incineration of battery containing waste is attributed to the emissions of heavy metals, especially Hg and Cd (Witte, 1984; Baumann & Muth, 1993; Goldschmid et al., 1989; Bräutigam & Fellmuth, 1999). For battery-derived metals, an analogous emission path as for the other metals in the waste mass is assumed (Goldschmid et al., 1989; Baumann & Muth, 1997). In later publications, it is acknowledged that, due to high efficiency of gas purification, the Hg and Cd emissions no longer present a problem at waste incineration (Baumann & Muth, 1997; Vest & Jantsch, 1999). This problem may, however, still be present in the developing countries where such expensive technology is not available (Vest & Jantsch, 1999). According to the most recent investigations on batteries, especially AlMn can to a large extent be found in an intact form in the incineration slag and be separated from there with a magnetic separator. It indicates a different behavior of battery-derived heavy metals in the incineration process than the behavior of heavy metals contained in the remaining waste mass.

3.2.9 Composting of waste containing batteries

Composting of mixed waste containing batteries was commonly practiced in the past. In countries with advanced waste management systems, composting of mixed household waste is no longer practiced. Instead, composts are produced out of separately collected biowaste (kitchen and garden waste), which do not contain batteries. However, since in some countries, including, e.g., the EU-10 Member States, low quality compost is still produced from mixed waste (e.g., after sorting), the literature on battery problems at composting is summarized here as well.

Here again the main concern is contamination of the compost by the heavy metals derived from the batteries. In the 1980s in The Netherlands, only a minor part of the household waste was composted (Witte, 1984). The Dutch publication refers to Swedish research showing increased levels of Zn, Cu, Pb, Cd and Hg in compost from household waste. Thus application of compost would lead to soil contamination, and Cd and Hg could be up-taken by plants. Therefore, batteries should be sorted out prior to composting.

At the time this article was written, 19 composting plants in Austria existed, processing together approximately 526,000 tons of waste/yr (Goldschmid et al., 1989). Many of the composting plants encountered problems with marketing of their final compost product, due to quality problems. Here, the heavy metals content in compost was an important criterion. In metal separators, only a proportion of ferromagnetic materials can be separated. Due to conditions within the composting process, the metals contained in the input are dispersed throughout the whole compost mass. Moreover, the final product becomes enriched due to partial decomposition. Experiences in one composting plant show that, through separate collection of metals and manual sorting in the composting plant, reduction of Zn and Cd content by a factor of 2 and Pb by a factor of 3 was achieved.

The publications cited above are concerned with the problem of heavy metals contamination in composts from household waste, of which one source are batteries. However, the fate of batteries within the composting process, e.g., the question whether they corrode and release heavy metals, is not discussed in any detail.

3.2.10 Mechanical-biological pretreatment

In the past decade, mechanical-biological pretreatment (MBP) became a more and more common method of pretreatment of residual waste prior to landfilling. It is a lower cost alternative to the incineration process for waste stabilization before landfilling.

Recently in Austria, research has been performed on the material balances of MBP plants for residual waste (Skutan & Brunner, 2006). Using the method of Material Flow Analysis, three MBP plants in Austria were investigated: MBP Oberpullendorf, mechanical pretreatment (MP) plant Kirchdorf an der Krems and MP plant Splittinganlage der MA 48 in Vienna. Those plants allow separation of the high caloric fraction of waste for energy recovery, low caloric fraction (for landfilling or use as a low quality “waste composts”) and metal scrap for recovery. Due to the applied advanced analysis methodology, significantly higher metals content in the input residual waste were determined than the commonly reported values. Also, the occurrence of batteries in the waste was investigated as one of the “metallic” sources of metals. The resulting contributions of batteries to the heavy metals content in waste are presented in Table 3.6. The results of this project also show that mechanical pretreatment processes are able to enrich heavy metals in targeted output streams (i.e., in the metal scrap fraction). Results of comparisons of different technologies show that the efficiency of magnetic separation has a profound effect on the quality of output streams. For example, Cd as a composite of NiCd secondary batteries can be removed at the magnetic separator, the remaining portion of Cd in the high caloric fraction originates from plastic waste. Only a very small proportion of Zn in residual waste originates from primary Zn batteries (which can be partly separated by the magnetic separator). The major portion of this metal comes from different alloys. The efficiency of Zn separation in non-ferrous separators in the investigated plants was relatively low, implying a high transfer of this metal to both high and low caloric output fractions.

Behavior of the battery-derived heavy metals in the biological stabilization of the low caloric fraction within a MBP process was part of the doctoral thesis of Den Boer (den Boer, 2007). The waste was biologically stabilized in an aerobic pilot plant, using original residual waste samples and samples enriched with shredded metals: Al, Cu and steel (from packaging waste) and shredded batteries (average composition of batteries available in the German market i.e., approximately 80% constitutes AlMn and ZnC batteries). The batteries were sawed and ground and added as a powder (including the outer covers) to the reactors. Generally, higher decomposition rates, especially in the first 3 weeks, were observed for the samples without shredded metals and batteries. It may imply the inhibition of the microorganisms activity by heavy metals. However, in the next 3 weeks the decomposition rate also increased in the reactors with metals and after 6 weeks the combined loss of dry mass was only approximately 1% lower in the reactors with metals than in the reactors without metals. The total content of metals measured in the enriched samples was approximately 5 times higher than in the original samples for Fe and approximately 2 times higher for Mn and Ni and Zn. The increase of the concentrations of Mn, Ni and Zn clearly results from the added batteries. The amount of metals leaching from waste during the biological stabilization process (waterborne emissions) is very limited (well below 1% of the total metals content in the waste). After 3 weeks of stabilization, the leaching rates (quantity of metals that leached out related to their total content in waste) were lower in the samples enriched with metals and batteries than in the original samples. The low leaching can be caused by the initial retardation of the decomposition process due to inhibiting effect of the metals on microorganisms. In contrast to the waste without shredded metals, after 6 weeks the leached amount for all metals slightly increased. In general, it can be stated that all of the metals are very well sorbed by the waste matrix and metals emissions to leachate during the MBP are very insignificant.

Further, the results of 8 years of investigations of metals emissions from lysimeters containing MBP waste indicate that the heavy metals release from this waste in landfill conditions is very low compared to those from raw waste. This may be explained by the lower bio-chemical activity in the landfill body of the MBP waste.

To summarize, only two literature sources dealing with the battery problem in MBP processes have been identified. In these publications the main focus was on the fate of heavy metals in the MBP in general and the problem of batteries is only marginally dealt with. The results of the research performed in Austria indicate that mechanical pretreatment processes are able to enrich heavy metals in metal scrap fraction, including sorting out of batteries to a certain extent. Results of comparisons of different technologies show that the efficiency of magnetic separation has a profound effect on the quality of output streams.

The investigations of the behavior of, *inter alia*, battery-derived heavy metals within the biological stabilization process indicate very low emissions of these metals within the process. This can be explained by a large sorption capacity for metals provided by the residual waste.

3.2.11 Separate collection and transport of batteries

None of the publications are concerned with the quantitative assessment of the environmental impacts of separate collection of batteries. This is because none of them compares quantitatively the environmental impacts of co-disposal of batteries with household waste and of separate collection and recycling of batteries. Rentz *et al.* (Rentz et al., 2001) conclude that the environmental impacts of battery collection and their transport to sorting plants is significantly higher of the transport from a sorting plant to a recycling plant or to a hazardous waste landfill. On the other hand, the differences in distances between the recovery and disposal options (at hazardous waste landfills) are insignificant. This is due to a more or less equal distribution of the recovery plants and the hazardous waste landfills in Germany, so it is not significant to which of them the batteries are transported.

In the publications concerned with assessing different recycling technologies according to the LCA method (Bräutigam, 2001; Afval Overleg Orgaan, 2002; Briffaerts, 2006), only transport of batteries from the sorting plants to recycling plants is considered. Environmental impacts due to collection are assumed to be equal for all recycling options. Thus, the LCA scenarios involving recycling of batteries in another Member States score worse in some impact categories due to excessive transport distances.

3.2.12 Storage and landfilling of separately collected batteries

The risks related to storage of batteries in a mono-landfill are described in Dutch literature (Posthumus, 1997). This publication describes a battery-fire which arose at an open-air mono-landfill for non-sorted batteries. In the same year, a battery-fire also took place in Switzerland. According to the authors, heating (heat production by biological activity) is probably not the cause of the fire, but rather a short circuit (not all batteries are completed empty). Short circuits lead to a fast discharge of the batteries, combined with heat production and danger of explosion. Moreover, there are many corrosive metals present, which can react with water to produce hydrogen. After the fire, the old battery-stocks were transported to recovery plants.

The authors also report that after 6 to 18 months of storage, the possibilities for sorting are diminishing because of leaking and corrosion, which decreases the recognizability of the batteries. For safety reasons, batteries should be stored for as short a time as possible, in a dry place and possibly in a nitrogen atmosphere.

3.2.13 Recycling of separately collected batteries

Due to the extension of the battery legislation to other than hazardous batteries, imposing an obligation to collect also Zn batteries (AlMn and ZnC), there was a need to identify the most advantageous technologies for the treatment/recycling of these batteries. Thus since the late 1990s, a number of research projects concerned with the comparison of different technologies were initiated. Some of these analyses involve an LCA of environmental impacts of these technologies. In the following, the results of these investigations are discussed.

In The Netherlands, some of the first publications regarding the recycling of Zn batteries date from the 1980s (Gemert & Kolster, 1986). In this publication, an overview of the existing methods for Zn recovery from batteries is provided. The publication summarizes the results of a research project on processes targeted at Hg recovery from these batteries. Especially on the basis of the efficiency of the Hg separation and of the investment costs to be expected, it was decided to present a process route based on the principle of non-thermal Hg separation. In this report, no data on the environmental impacts of the proposed treatment method are provided.

Baumann and Muth (Baumann & Muth, 1997) also generally do not discuss the environmental impact of the recycling technologies. However, they mention a problem of the content of Polychlorinated biphenyls (PCBs), which were recorded at a concentration of 11 ppb in battery filling materials. PCBs become enriched in the pyrolysis oil, being a product of different recycling processes. For example, the recycling company Recytec reports PCB concentration in the pyrolysis oil of 80 ppb, while the limit for spent oils is 20 ppb. This problem is not mentioned in any other publication.

In the publication dealing with the management of spent batteries in developing countries (Vest & Jantsch, 1999), the authors conclude that besides environmental impacts at landfilling and incineration, some risks can be also attributed to the recycling of battery. This is especially due to the related emissions to air, water and waste disposal to soil. Here again, a higher risk exists in the developing countries where the recycling plants may not be that well equipped and not be operated according to the modern technology standards.

Bräutigam *et al.* (Bräutigam et al, 1999) describes technologies for the recycling of ZnC and AlMn batteries. In the article, it is stated that, based on the literature, the input of non-pretreated battery mixes as raw materials in the steel and Zn industry can be accompanied by a number of environmental impacts. For example, in the area of the steel industry (electric arc furnace), high emissions of Zn, NOx, Hg, chlorides and dioxins can be expected, as well as an increased slag formation, a lower utilization potential of ashes from flue gas purification because of higher salts amounts, Hg and dioxins content and lower steel quality due to higher contents of Cu and other nonferrous metals. Further on, technical problems due to an increased corrosion of the oven's inner surface can be expected.

In this article, four recovery technologies for Zn batteries are presented in more detail: Batenus, Debatox, Recytec and Sumitomo-Batrec. The data on the environmental impacts provided in this article are concerned with the consumption of energy and ancillary materials for the treatment of batteries and very few emission data (except for the Sumitomo-Batrec technology for which more complete data is given). In this article, no further analysis of the environmental impacts resulting from the described technologies is provided. However, due to good data availability on the environmental impacts, the Sumitomo-Batrec technology has been selected for further analysis within an LCA study by the main author of this article, whose results are discussed below.

In Table 3.48, recycling technologies for the AlMn and ZnC batteries for which a comparative environmental assessment has been provided within the reviewed literature are listed. For each technology, a reference is made to the publication in which it was considered. Out of the referred publications, the first one (Rentz, 2001) provides only a qualitative assessment of the environmental effects of the assessed technologies. The three other publications (Bräutigam, 2001; Afval Overleg Orgaan, 2002; Briffaerts, 2006) provide a quantitative assessment, according to the LCA methodology. In the LCA studies, only the alternative recycling options are evaluated, without considering co-treatment/disposal of batteries with residual waste.

No single technology has been identified as the best one within the qualitative assessment by Rentz *et al.* (Rentz et al., 2001). The environmental data underlying this comparison is highly incomplete and data on emissions is provided only in some cases. The results for the criterion “environmental pressure” show that for all examined technologies, the emissions caused by the treatment of Zn containing batteries remain within the permitted emission levels for respective plants. Also no increase of contamination of final products is observed at the reported battery inputs. The use of resources is the highest for the Sumitomo/Batrec process and the Electric arc furnace with ferroalloy production. However, it should be underscored that in this process a higher recovery rate is achieved, e.g., the final product of battery recovery in Sumitomo/Batrec process Zn in a metallic form, while other processes (e.g., Waelz or DMA) deliver Zn concentrate, which needs further processing to obtain pure Zn. The further treatment will naturally require an additional input of resources. Considering the recovery rate and product sales, technologies in which, apart from Zn also Mn in a form of ferroalloy or Mn oxide are produced, score best. Processes accepting batteries with a higher contamination level of mainly Hg (Sumitomo-Batrec, DMA battery recycling, Short rotary furnace and Oxyreducer process) score better in environmental terms, but are more expensive than the recycling of batteries in the metal industry. In general, however, the authors do not consider the environmental gain due to the recycling of AlMn and ZnC batteries as being significant. This is because the contribution of the battery industry to the total consumption of Zn, Mn and iron is insignificant. Moreover, none of these elements is at the moment considered as being scarce.

According to Bräutigam (Bräutigam, 2001), the results of an LCA of the Sumitomo/Batrec, Imperial Smelting and Waelz technologies indicate that the Sumitomo/Batrec technology shows the lowest environmental impacts in the majority of the investigated impact categories. For the two other recycling technologies (the Imperial Smelting and Waelz process), no clear ranking of their environmental impacts could be established. The LCIA is performed according to the UBA method. The results obtained from the LCA indicate that the highest relative impacts occurring at all investigated battery recycling processes are the human-toxic impacts due to air emissions of Pb and ecosystem-toxic impacts due to air emissions of Zn and Pb. It should, however, be underscored that the processes substituted (with a battery-less input) with the battery treatment in the Imperial Smelting technology (i.e., production of Zn from sulfidic ores within the roasting/sintering, followed by the pyrometallurgical treatment in the Imperial Smelting furnace) showed even higher relative impacts in the mentioned categories. This indicates that these impacts cannot be contributed to the input of batteries, but rather to the technology itself or the co-treated input materials (exact allocation of emissions to the battery input is not possible).

Table 3.48 Recycling technologies subject to a comparative environmental assessment

Technology	Reference plant	Main products	Publication			
			Rentz et al., 2001	Bräutigam, 2001	Afval Overleg Orgaan, 2002	Briffaerts, 2006
Imperial Smelting process	MIM Hütenwerke Duisburg (Germany)	Zn, Pb, sulphuric acid, slag	+	+		
Waelz process	B.U.S AG Duisburg (Germany)	Waelz oxide, slag	+	+		
	Harz-Metall Goslar (Germany)	Waelz oxide, slag				+
Sumimito/Batrec process (pyrolysis/melting)	Batrec Industrie AG, Wimmis (Switzerland)	Ferro-Mn, Zn, Hg, slag	+	+	+	+
Electric arc furnace – ferroalloy prod.	VALDI, Feurs, Le Palais (France)	Ferro-Mn, Zn ash, slag	+		+	+
Blast furnace process	DK Recycling und Roheisen GmbH, Duisburg (Germany)	Foundry pig iron, Zn concentrate, slag	+			
Electric arc furnace – steel production	Nedstaal BV in Alblasserdam (The Netherlands)	Steel, slag, ash	+		+	
DMA Battery recycling	Chemtec (Austria)	Zn ash, metals scrap	+			
Short rotary furnace	ABRG, Arnoldstein (Austria)	Metals scrap, Hg, Zn, Cd, slag	+			
Oxyreducer process	Citron S.A., Rogerville (France)	Zn oxide, Mn oxide, iron scrap, Hg, saline water	+			
Hydro-metallurgical process	Zimaval Technologies in Falaise (France)	steel, non-ferrous met., FeOH, Zn (particles, powder, & sulphite) $MgCO_3$, carbon residue and Hg amalgam			+	
	Revatech S.A. – Erachem, Tertre (Belgium)[a]	Metals scrap, plastics, Zn- and Mn-sulphate	+			
	Hydrometal, Liege (Belgium)[b]	Zn sulphate, filter cake for further treatment in e.g. Waelz process				+
	(new-since 2006) Revatech, Liege (Belgium)[c]	Zn sulphate and Mn dioxide				+
Revabat (mechanical sorting)	Revatech S.A. Liege (Belgium)	plastic, ferrous and non-ferrous metals, black mass (Zn, Mg, Fe) for recycling, paper and dust to landfill				+

[a] hydrometallurgical process operated in cooperation Revatech – Erachem until 2004

[b] hydrometallurgical process used by Revatech S.A. since 2004

[c] new hydrometallurgical process developed by Revatech S.A.

The overall LCA results indicate that the selection of the equivalent processes have a significant impact on the obtained LCA results. The complexity of the equivalent processes selected depends on the quality and quantity of the materials recovered from batteries. In the Sumitomo/Batrec technology, both Zn and ferro-Mn are recovered, while in the two other technologies only Zn. Therefore, the equivalent processes of the Sumitomo/Batrec technology show the highest complexity. The higher the environmental impacts of the equivalent processes attributed to a given technology, the better final LCA score of this technology. This partly explains the best environmental score of the Sumitomo/Batrec technology.

The results of the LCA on the treatment of spent batteries within the Dutch National Waste Management Plan (Afval Overleg Orgaan, 2002) indicate that the VALDI process leads in most cases to the lowest environmental burden. The Sumitomo-Batrec process shows a low environmental burden in many cases, but also leads to relatively little final waste disposal prevention. The Zimaval process shows a mixed view, because of its relatively high energy intensity it shows higher environmental burdens in some weighing methods and average results in others (the LCIA is performed according to the CML method). The Nedstaal process leads to the most environmentally unfavorable results. This is mainly due to the large effect score in normalized ‘terrestrial Eco-toxicity’, which is approximately 96% of the total score. This is mainly caused by emissions of Hg. For the Hg content, in the input batteries 36 mg/kg was assumed; this is the upper limit of battery acceptance of the process. Currently (2002) produced batteries contain a maximum 5 mg/kg Hg, so that the environmental performance of the Nedstaal process will gradually improve. Moreover, at the Nedstaal process only the Hg emissions were measured directly. In the other processes, they were calculated from the mass balances and emission factors.

The four processes all actually aim at a different typical input material (e.g., Nedstaal at Hg-free batteries as an additive only, Batrec at Hg-rich batteries), which leads to different gas/water cleaning technologies. Nevertheless, the same average input was modeled for all processes.

In the study, secondary products are assumed to directly substitute primary resources. It is uncertain whether or not the effects for, e.g., extra process additives or energy should be incorporated.

In the Belgian publication (Briffaerts, 2006) the assessment of four scenarios for recycling of AlMn and ZnC batteries was performed. These scenarios constitute a sequence of treatment technologies for batteries, including:

1) REVABAT scenario (technologies: Revabat – Hydrometal - Harz-Metall)
2) REVATECH scenario (technologies: Revatech – REVATECH - Harz-Metall)
3) BATREC scenario (technologies: Sumitomo/Batrec – Hydrometal - Harz-Metall)
4) VALDI scenario (technologies: Valdi – Hydrometal - Harz-Metall)

The method applied is the integrated analysis of waste treatment techniques (IAW-method), developed by VITO. For the LCIA the Eco-Indicator 99 methodology is used. A significant part of emissions occurring at the modeled processes is not included due to data gaps. According to the authors of this publication, the obtained results do not allow identification of the best scoring scenario. The REVATECH, BATREC en VALDI scenarios recycle approximately equal amounts of metals. The REVABAT scenario recycles approximately equal amounts of Zn and iron, but no Mn. According to the LCIA within this study, Zn is considered a scarce metal (which is contradictory to the opinion of Rentz *et al.* (Rentz et al, 2001). The evaluation of the environmental impacts does not provide a preferable option. All four scenarios have net environmental benefits for the criteria: damage to human health caused by carcinogens and because of respiratory effects caused by inorganic pollutants, ecotoxicity, damage to mineral resources and land use. Some scenarios also have net environmental benefits for other criteria.

Generally it can be concluded that transport has an important influence on the results of the environmental profiles; therefore, plants located in Belgium score better against some criteria. It can be also concluded that higher recycling rates for metals do not necessarily result in a better environmental profile. The efficiency of the Sumitomo/Batrec process increases with the Hg content. Since in this study, the assumed Hg content is relatively low, this has a negative influence on the environmental profile of the BATREC scenario, compared to the other treatment scenarios.

The results of the three LCA studies reviewed for the recycling of spent batteries can not be directly compared. First of all, only the Sumitomo/Batrec and Valdi processes have been evaluated by 3 and 2 LCA studies, respectively. Moreover the methodologies applied within the presented LCAs differ from each other. Each LCA applies a different LCIA method, which results in different impact categories and their calculation methods. As discussed before, the substituted processes (avoided impacts) proved to have a profound effect on the LCA results. In the publications described, different substitution processes were modeled, thus the degrees of environmental benefits due to replaced processes differ from each other. This may be a reason for a different score of the Sumitomo/Batrec technology in each LCA. Moreover, in each LCA a different average composition of the battery input is assumed. The differences are especially significant for the Hg content: 1.5 kg/ton in the first LCA (Bräutigam, 2001) for the Sumitomo/Batrec technology and far less for the other two; 0.036 kg/ton and 0.13 kg/ton for the second and third LCA (Afval Overleg Orgaan, 2002 and Briffaerts, 2006, respectively). Since emissions of Hg are a very important parameter for both human-toxic and eco-toxic effects, this may cause significant differences in the final LCA results (both because of process related emissions and because of avoided emissions of the substituted primary Hg production, mainly for the Sumitomo/Batrec process). Finally, the LCI data underlying each of the three LCAs differs significantly from each other. Examples of air emission values for the Sumitomo/Batrec process considered in the LCIs are listed in Table 3.49.

It is interesting that due to the highest Hg content in battery input assumed in Bräutigam, 2001, Hg air emissions are highest in the LCI by Briffaerts, 2006.

Generally, because the consideration of a basic scenario (co-disposal of batteries with household waste) is lacking in all three LCA studies, it is not possible to asses an overall net environmental impact of the recycling of AlMn and ZnC batteries.

Table 3.49 LCI data of the Sumitomo/Batrec process

Pollutant	Emissions to air [mg/ton of batteries]		
	Bräutigam, 2001	Afval Overleg Orgaan, 2002	Briffaerts, 2006
CO	11,250	270,000	447,000
CO_2	n.a.[a]	3.1E+08	8.4E+08
NO_x	875,000	791,000	770,000
SO_x	187,500	78	850 mg
Dust	625	1,380	17,000
Hg	109	16	1,017
Zn	4,800	40	4,198
Cd	50	2	5
Pb	n.a.	n.a.	79
HCl	49,500	970	n.a

[a] the data on CO_2 emissions is available within the up-stream process of electricity production (Bräutigam, 2001)

3.3 Conclusions

In this literature search articles, reports, and books written in German (including German, Austrian and Swiss sources), Dutch (including the Netherlands and Belgium) and Polish were reviewed. The most of identified publications stem from Germany and The Netherlands. Some Austrian and Belgian reports were reviewed. In the Polish literature, the environmental impacts of the management of spent batteries very superficially dealt with.

It turned out that, in general, very few publications are concerned with environmental impacts of the management of spent batteries. The majority of the publications identified provide data on the performance of battery collection systems or describe technical aspects of recycling processes. The environmental impacts are only marginally dealt with, mostly only qualitatively.

In the recent publications, co-disposal of batteries with household waste is not discussed at all. This is due to the EU and national legislation which prescribes separate collection and recovery/recycling of batteries. Thus, in the modern LCA studies on management of spent batteries, only alternative recycling scenarios are considered.

In the older literature (mostly from the 1980s), some research results on the behavior of batteries in landfill conditions and in waste incineration plants have been described. However, the results are mostly cited from other, even older, literature sources. These results refer to old battery systems with significantly higher contents of heavy metals (especially Hg) than the modern AlMn batteries. Thus, these results cannot be directly applied to the modern batteries.

Generally, it can be concluded that sound, scientific evidence on the environmental performance of modern AlMn batteries in the German, Dutch and Polish-language literature is lacking.

The list of sources used to identify relevant publications in the German, Dutch, and Polish literature is presented in Appendix B. The list of key words used in the search is presented in Appendix C.

4. Italian Literature

This section deals with a literature review on the impact of the disposal of alkaline batteries on landfills conducted in Italy and written in the Italian language.

4.1 Method of investigation

The literature review was carried out by checking the following sources:

a. Main Italian Environmental Journals
b. Libraries of the Universities active in Environmental Engineering
c. Masters and PhD thesis from the main Italian Universities
d. National and Regional Environmental Protection Agencies
e. Ministry for the Environment
f. Public and Private Organisations active in the field; and
g. Internet

The archives of the following environmental Journals in Italy have also been searched:

- “IA -- Ingegneria Ambientale”
- “Ambiente Italia”
- “Inquinamento”
- “RS Rifiuti Solidi”
- “Recycling”
- “Hi-Tech Ambiente”
- “Nuova Gea – I quaderni per l’Ambiente”

The search went on considering the list of PhD theses at the Italian Universities, the publications of the Environmental Ministry and of the ARPA (regional offices for the preservation of the environment).

The following web sites have been considered:

- ARPA sites
    - § www.arpa.fvg.it;
    - § www.arpalombardia.it;
    - § www.arpa.piemonte.it;
    - § www.arpalazio.it;
    - § www.arpa.emr.it;
    - § www.arpa.veneto.it;
    - § www.arpa.sardegna.it;

- university libraries
  - § www.unipd.it;
  - § www.unitn.it;
  - § www.unica.it;
  - § www.unina.it;
  - § www.uniroma.it;
  - § www.polito.it;
  - § www.polimi.it;

- institutional sites
  - § www.enea.it;
  - § www.cnr.it;
  - § www.apat.gov.it;
  - § www.miniambiente.it;
  - § www.regione.veneto.it;
  - § www.federambiente.it.

4.2 Summary

The search in the literature was not able to identify specific articles dealing with the disposal of alkaline batteries. It seems that the problem related to the disposal of household alkaline batteries has not been so far analysed or investigated in Italy. It is also possible that some of the investigations have been reported in English in international scientific journals.

At the present time, the only available information about the management of batteries in general, from the production to the disposal, comes from the national laws, which are related to the implementation of the European Directives.

5. Japanese and Korean Literature

This section deals with a literature review on the impact of the disposal of alkaline batteries on landfills conducted in Japan and Korean and written in the Japanese and Korean languages.

5.1 Results of the literature review

Yanase, Hirata, Matsufuji, 2007

Original title:	Behavior of Mercury from Used Batteries in Landfills Over 20 Years
Translation:	N/A
Author:	R. Yanase, O. Hirata, Y. Matsufuji
Institution:	Fukuoka University, Japan
Editors:	R. Cossu, L.F. Diaz, R. Stegmann
Publisher:	
Place, Year:	Sardinia, Italy
ISBN/ISSN:	N/A
Kind of publication:	Proceedings of Sardinia Symposium 2007
Additional information:	

In Japan, used batteries are collected as incombustible MSW and the major fraction is disposed in landfills. In 1983, it was determined that household batteries contained mercury, and since the batteries were disposed in landfills, fears were raised of environmental pollution due to mercury.

The amount of batteries produced in Japan in 1983 was about 2.9 billion units. The batteries used about 128 tons of mercury as zinc amalgam. Then the Battery Association of Japan manufactured mercury-free alkali manganese batteries and Zinc-Carbon batteries from 1992 and in 1997 entirely ceased manufacture of batteries containing mercury. The amount of primary batteries produced in 2005 was 4.27 billion units, using 1.8 tons of mercury.

However, batteries manufactured in 1990 or before, contained mercury in the form of zinc amalgam, and considerable amounts had been disposed in landfills. It was feared that the batteries would corrode in the landfill, releasing the mercury which would contaminate the groundwater.

To investigate the behavior of mercury in landfilled batteries, the authors performed basic experiments (absorption and desorption of mercury), mercury tracer experiments, battery corrosion experiments using a small lysimeter, and long-term mercury behavior experiments using a large lysimeter, clarifying the process of mercury behavior from landfilled batteries. For a 20-year period (from 1985 until 2005), a large lysimeter was used to investigate long-term mercury behavior characteristics and the mercury balance of a landfill.

This paper discusses the use of the large lysimeter filled with a mixture of batteries and solid waste since 1985, in a 20-year investigation of the characteristics of mercury behavior to leachate and the dissipation of the mercury into the atmosphere. After 20 years, the batteries and solid waste were removed from the large lysimeter and an investigation made of the mercury content of the recovered solid waste and the migration of mercury within the landfill. Based on the results of the investigation over the 20-year period, a comprehensive evaluation of the mass balance of mercury in the landfill was performed.

The lysimeter was operated as a semi-aerobic landfill (Figure 5.1), under the conditions indicated in Table 5.1. The experiment consisted of a lysimeter filled with solid waste and 436 batteries (mercury, alkali manganese, and zinc-carbon) labeled as lysimeter Se-1, and a second lysimeter filled with only solid waste as a control labeled lysimeter Se-4. Each lysimeter was filled with four tons of solid waste (wet), consisting of a mixture of 38% incineration residues, 20% glass and broken stone, 25% sludge (15% sewage sludge, 10% compost), 10% ferrous metals, 5% wood chips, and 2% plastic. Batteries were mixed with the solid waste, spaced uniformly in each 10 cm-thick waste layer. The total amount of mercury in each lysimeter is shown in Table 5.2 and was 10,707 mg which is 789 mg from solid waste-derived mercury and 9,918 mg of mercury from the batteries for lysimeter Se-1. Lysimeter Se-4 had the same amount of waste-derived mercury (789 mg).

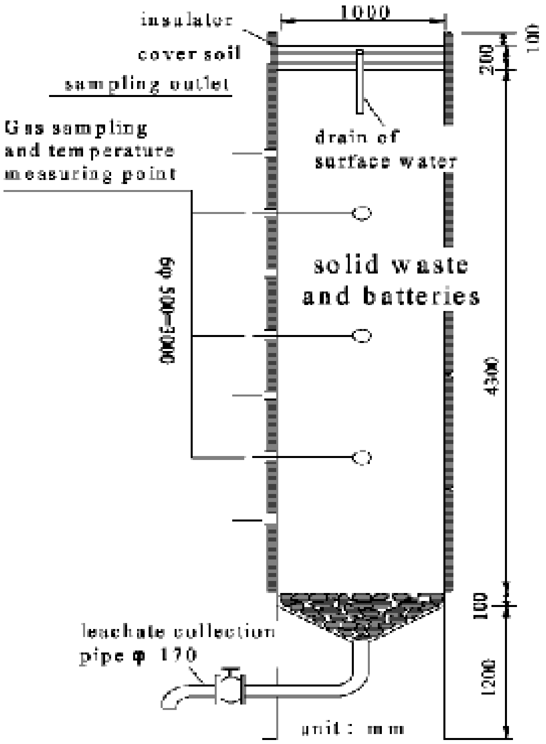

Figure 5.1 Experimental semi-aerobic lysimeter

Table 5.1 Experimental conditions

Lysimeter		Se-1	Se-4
Duration of reclamation		20 years	
Landfill type		Semi-aerobic landfill type	
Weight of solid waste (ton-wet)		4.0	
Water content (%)		18.4	
Weight of solid waste per unit volume (ton/m^3)		1.18	
Composition of solid waste		Incineration residues 38%, glass(broken stone) 20%, sewage sludge 15%, compost 10%, ferrous metal (empty cans 4%, sheets 6%), woods 5%, plastics 2%	
Weight of cover soil (ton-wet)		0.22	
Weight of cover soil per unit volume (ton/m^3)		1.41	
Number of batteries (piece)	MR9	4	0
	LR6	32	0
	SUM 1	80	0
	SUM2	80	0
	SUM3	240	0
	total	436	0

MR: Mercury Battery, LR: Alkaline Manganese Battery, SUM: Zinc-Carbon Battery

Table 5.2 Total amount of mercury in each lysimeter

Lysimeter	Se-1	Se-4
Solid waste (mg/lysimeter)	786	786
Cover soil (mg/lysimeter)	3	3
Batteries (mg/lysimeter)	9,918	0
Total (mg/lysimeter)	10,707	789
Per ton (mg/solid waste-wet)	2,677	197

Over the 20-year period (1985 to 2005) of the experiment, the concentration of mercury in the leachate and the emissions of vaporized mercury within the lysimeter were investigated on a monthly basis. On August 2005, 20 years after the lysimeters were filled; the solid waste was carefully removed from the lysimeter (starting from the top) and divided into 17 equal portions, each portion was approximately 25 cm thick. The total weight of the solid waste was measured for each layer, and all batteries were recovered. The solid waste material was analyzed for composition to determine the concentration of mercury. Mercury elution testing, mercury vaporized concentration, and others were determined using the samples with a high composition of solid waste (10 mm under). An investigation was also made of the batteries by amount of mercury remaining, mercury of atmospheric diffusion, corrosion and others.

Figure 5.2 shows the change in annual average concentration of mercury in the leachate over the 20-year period. During the primary stage of landfilling, the concentration of mercury in the leachate was 0.0002 to 0.0004 mg/L (the environmental standard in Japan is 0.0005 mg/L). The concentration of mercury in the leachate continued to decrease gradually over the first decade, reaching 0.0001 mg/L after 15 years, and from the 18th year the concentration of mercury in the leachate was below detection limits.

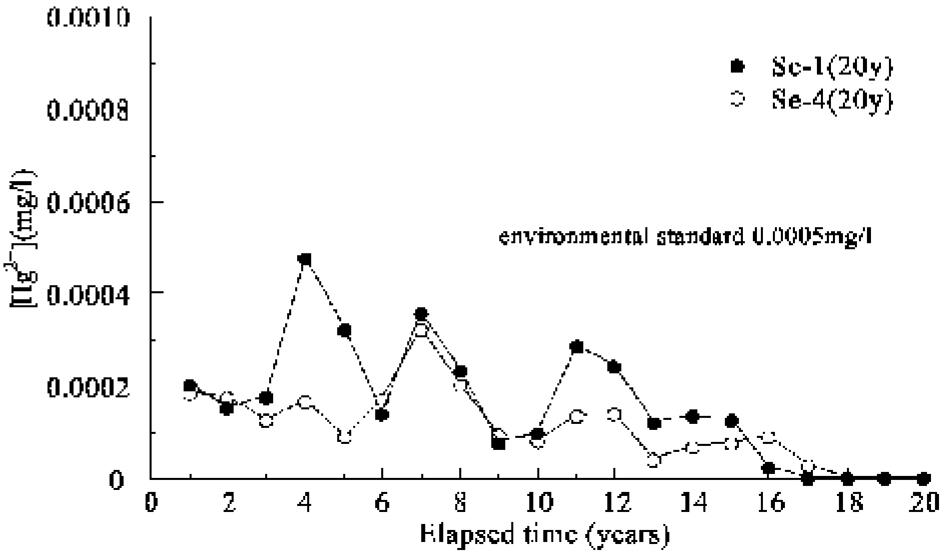

Figure 5.2 Change of mercury concentration in the leachate

A comparison was made of the lysimeter Se-1, filled with solid waste and batteries, and the other lysimeter (Se-4) filled with only solid waste. There was no discernable difference in the concentration of mercury in the leachate in the initial landfill period, but mercury levels in the leachate were slightly higher from the 3rd year through the 15th year in lysimeter Se-1 than the lysimeter Se-4. It is thought that the batteries in lysimeter Se-1 corroded during the initial landfill period due to electro corrosion from discharge, allowing transport of mercury from the batteries to the solid waste layers, and then to the leachate.

Mercury, unlike other heavy metals, vaporizes consequently, periodic measurements of concentrations mercury vaporization in the upper, middle and lower layers of the lysimeter were made. The results of the measurements are shown in Figure 5.3. The diagram indicates that the average concentration of vaporized mercury was 0.1 to 0.3 µg/m^3. Prior experiments were affected by seasonal temperature variation and generated a range of 0.01 to 1 µg/m^3.

The concentration of vapor mercury in the lysimeter was ten to one hundred times higher than the concentration levels of atmospheric mercury, but still only 1% to 10% of occupational environmental standards set by the WHO and Japanese agencies, representing an intermediate level of mercury behavior. In addition to mercury from batteries, vapor mercury also occurred from municipal solid waste, and there was no significant difference between the two of them.

Vapor mercury generated in the lysimeter, and therefore after 20 years it was dug up and investigated for each layer of recovered solid waste (10 mm under) and batteries. The vapor mercury generated from the solid waste material recovered from each layer and from the batteries was measured using a desiccator (at 20°C for 24 hours). The amount of vapor mercury generated in the desiccator was converted to vapor mercury per gram of mercury contained in the battery or solid waste material.

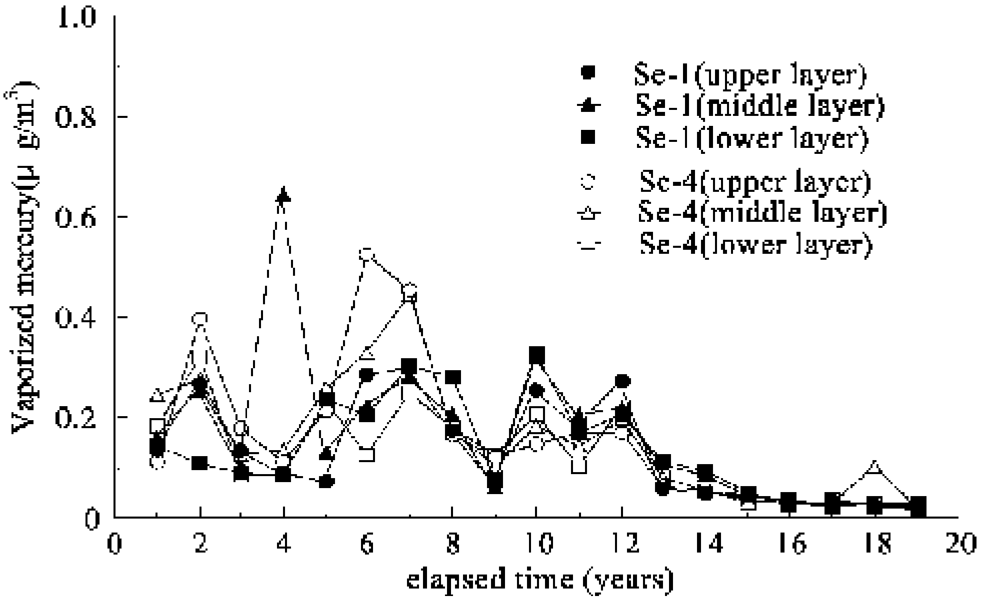

Figure 5.3 Change of vaporized mercury in the lysimeter

The batteries recovered from the layers of the lysimeter Se-1 generated 0.1 to 10 µg/g-vapor mercury. In other words, vapor mercury migrated from the landfilled batteries into the solid waste layers in lysimeter Se-1. There is considerable fluctuation in the amount of vapor mercury from the batteries, due to differences in battery corrosion, peel, etc.

Vapor mercury from solid waste material (10 mm under) in both lysimeters was between 0.00001 and 0.0001 µg/g, lower than the amount generated by the batteries, and there was no significant difference detected between the two lysimeters. Behavior of vapor mercury is higher in the top of the lysimeter, and smaller in middle and lower layers. This is thought to be due to the many anaerobic regions in the middle and lower layers, reducing the generation of mercury sulfides.

To evaluate the potential of mercury elution from solid waste after 20 years, an elution test was performed using waste (smaller than 10 mm) collected in accordance with the Japanese regulatory leaching test (JTL-13). Eluted mercury concentration was 0.00005 to 0.0001 mg/L for both lysimeters, significantly below the environmental standard of 0.0005 mg/L. Figure 5.4 shows the elution rate converted to eluted mercury per gram of mercury content in the solid waste. The elution rate for mercury for lysimeter Se-4 (solid waste only) was 0.05% to 0.15%, and for lysimeter Se-1 (solid waste and batteries) was 0.05% to 0.2%; in both cases, the elution was minimal. The rate was 0.15% to 0.2% in the upper layer of the lysimeter Se-1 (solid waste and batteries), however, showing the same trend as that found in vaporized mercury from solid waste (smaller than 10 mm) shown in Figure 5.4.

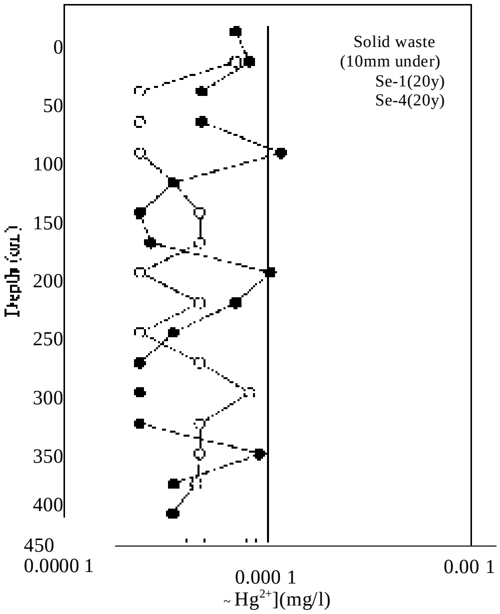

Figure 5.4 Distribution of elution mercury concentration

As a result, mercury elution is thought to be affected by: (1) the fact that vaporized mercury from the batteries in lysimeter Se-1 to the solid waste layers is absorbed in the solid waste layers as metallic mercury, and (2) the fact that the state of the mercury in the solid waste is different between the aerobic area and the anaerobic area of each layer, and the upper and lower layers contain mercury oxide and the middle layer contains mercury sulfide.

The lysimeter was disassembled in August 2005 after a 20-year period, and the recovered solid waste was analyzed for composition (wood chips, plastics, ferrous metals, inert materials, materials smaller than 10 mm). Mercury concentrations of the dried components were analyzed, and the amount of total mercury in the solid waste was determined. Figure 5.5 shows the distribution of mercury in solid waste within the lysimeter after 20 years.

The diagram indicates that the distribution of mercury in lysimeter Se-4 (solid waste only) is 0.2 to 0.3 mg/kg, which is slightly lower than the initial levels (0.28 mg/kg). And mercury has a tendency to migrate throughout the lysimeter. Concentration in lysimeter Se-1 (solid waste and batteries), however, is 0.2 to 0.5 mg/kg, which is slightly higher than initial levels, making it clear that the lysimeter with batteries had a higher mercury content than the lysimeter with solid waste only. This confirms the theory that corrosion of battery casings causes migration of battery mercury to the solid waste layers as vapor mercury.

A comparison of upper, middle, and lower layers shows that lysimeter Se-1 (batteries and solid waste) has a low mercury concentration in the upper layer and a higher level in the lower layer. This is thought to be due to the migration of mercury from batteries to solid waste (smaller than 10 mm), followed by dispersion of vapor mercury from the upper layer to atmospheric diffusion, while eluted mercury migrated to the lower sections due to the leachate.

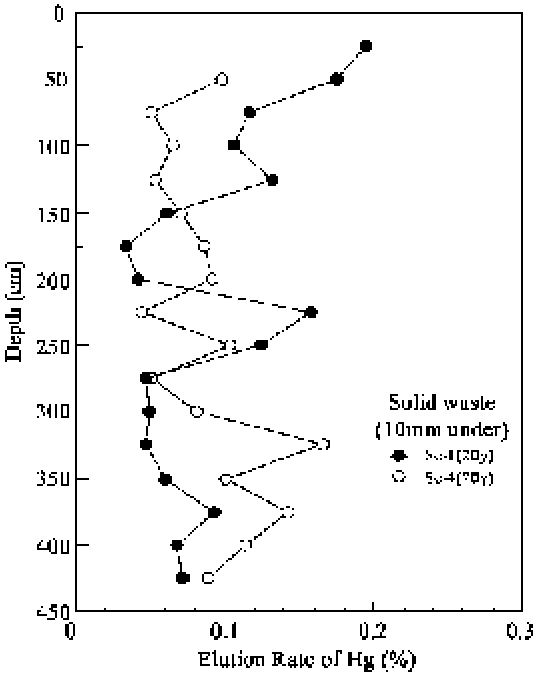

Figure 5.5 Distribution of mercury content by depth in solid waste (after 20 years)

Table 5.3 shows the results of the mass balance of mercury over the 20-year period. The data in the table show that the mercury that escapes in the form of leachate or atmospheric diffusion was 57.9 mg from lysimeter Se-1 and 11.1 mg from lysimeter Se-4, which is a low 0.5% to 1.4% of initial mercury levels. Almost no mercury escaped even after 20 years. Mercury levels in the solid waste of lysimeter Se-1 are higher than initial levels, confirming migration of mercury from batteries to solid waste layers (Figure 5.5). There was a minimal amount of mercury escaping from lysimeter Se-1 (filled with batteries and solid waste) outside the lysimeter, with approximately 95% remaining. Over 90% of initial mercury remained in the lysimeter Se-4 (filled with solid waste only).

The results of the 20-year investigation can be summarized as follows:

- Initial mercury concentration in the leachate was between 0.0002 and 0.0004 mg/L, which was below the environmental standard 0.0005 mg/L. The concentration of mercury in the leachate was reduced gradually during the first 10 years, stabilizing at 0.0001 mg/L, or essentially below detection levels. A comparison between the lysimeters with and without batteries showed that the lysimeter with mercury batteries tended to show a higher concentration of mercury in the leachate in the central period.

- Vaporized mercury concentration in the upper, middle, and lower layers of the lysimeter ranged from 0.01 to 1 μg/m^3, which is between 10 and 100 times higher than the atmospheric mercury concentration, but that is only from 1/100 to 1/10 of standard levels by the WHO. Vaporized mercury was generated by both batteries and other wastes, but there was no difference observed between the lysimeter with and without batteries.

Table 5.3 Measured release of Hg from lysimeters (during 20 years)

Lysimeter	**Se-1**	**Se-4**
Total Hg in lysimeter :		
Mass of Hg in Waste (mg)	786	786
Mass of Hg in Cover soil (mg)	3	3
Mass of Hg in batteries (mg)	9,918	0
Total Hg in lysimeter initial (mg)	10,707	789
Total Hg mass released in 20 years:		
Hg in leachate (mg)	1.5	1.3
Hg in surface water (mg)	< 0.1	< 0.1
Hg diffused to atmosphere (mg)	56.4	9.8
Hg adsorbed in cover soil (mg)	3.5	2.0
Hg remaining in waste (mg)	925.0	745.0
Hg remaining in batteries (mg)	9,258.0	-
Subtotal (mg)	10,244.4	758.1
A rate of initial Hg released for lysimeter after 20 years (%)	0.5	1.4
A rate of initial Hg remaining in lysimeter after 20 years (%)	95.2	94.7
A rate of in batteries remaining in batteries after 20 years (%)	86.5	-
A rate of initial Hg accounted for lysimeter (%)	95.7	96.1

Chamber Methods for Measuring the Vaporized mercury Mercury Level

- The concentration of mercury in the wastes and in batteries after 20 years of landfill was measured. The concentration of mercury in the wastes in the lysimeter which also held batteries was found to be higher than the initial value, indicating migration of mercury from corroded batteries to the wastes.

- The mercury balance over the 20-year period showed that the amounts of mercury lost through leachate or through diffusion to the environment from the lysimeter surface ranged between 0.5 and 1.4% of the initial value, indicating that a minimum of 95% of the mercury was still retained in the landfills after 20 years.

As a result of a 20-year study of the dynamics of mercury in a landfill, the migration of mercury outside the lysimeter was extremely low, at only about 1%, with the majority of the remaining mercury retained inside the lysimeter. It can be expected that even if mercury from solid waste or batteries is landfilled, the majority of the mercury will remain in the landfill and not escape to the surrounding environment.

Yang, Shin, Sohn, Yoo, 2007

Original title:	Physical Treatment of Spent Lithium Batteries for Recycling of Nickel
Translation:	N/A
Author:	Dong-Hyo Yang, Shun-Myung Shin, Jeong-Soo Sohn, Kyoung-Keun Yoo
Institution:	Minerals and Materials Processing Division, Korea Institute of Geoscience & Mineral Resources
Editors:	
Publisher:	
Place, Year:	Korea, 2007
ISBN/ISSN:	
Kind of publication:	The 2007 Environmental Societies Joint Conference
Additional information:	

The main objective of this research project was to develop a process for dismantling lithium primary batteries such that the main components of the battery could be recovered. The process involved manual, chemical, and mechanical steps to remove unnecessary parts, discharge the cells, and eventually separate the units into magnetic and non-magnetic components.

Karnchanawong, Limpiteeprakan, 2006

Original title:	Heavy Metal Contamination in Leachate Caused by Spent Household Batteries in Municipal Wastes
Translation:	N/A
Author:	Somjai Karnchanawong, Pawena Limpiteeprakan
Institution:	Chiang Mai University and Chulalong University, Thailand
Editors:	
Publisher:	
Place, Year:	APLAS, Shanghai, China, 2006
ISBN/ISSN:	
Kind of publication:	Proceedings of Asia-Pacific Landfill Symposium
Additional information:	

A research program was carried out to assess the potential environmental impact of disposing household batteries in landfills. Simulated municipal solid waste generated in Chiang Mai was placed into three lysimeters. Spent household batteries were added to the solid waste at 0%, 1%, and 5% by weight of waste. The lysimeters were operated for a period of 6 months. Unfortunately, the researchers did not specify the types of batteries that were added to the reactors and whether or not the batteries were cut, shredded, or bent prior to the placement in the lysimeters. The results of the work indicated that among the three lysimeters, Fe had the highest concentration in the leachate. The lysimeter that had 5% batteries produced significantly higher concentrations of Cd, Mn, Zn, Ni, Pb, and Fe than the lysimeter filled with only MSW (the control) and the lysimeter containing MSW mixed with 1% batteries.

Sohn, Ahn, Park, Kim, Yoon, 2006

Original title:	Leaching Characteristics of Spent Batteries Containing Heavy Metals
Translation:	N/A
Author:	J.-S. Sohn, J.-G. Ahn, K.-H. Park, H.-I. Kim, O.-S. Yoon
Institution:	Korea Institute of Geoscience and Mineral Resources & Han Bat University
Editors:	N/A
Publisher:	
Place, Year:	APLAS, Seoul, Korea, 2006
ISBN/ISSN:	
Kind of publication:	Proceedings of Asia-Pacific Landfill Symposium
Additional information:	

This study involved the performance of leaching tests on various types of spent batteries. The types of batteries included: alkaline, zinc-carbon (AA, AAA, C, and D), mercury, silver-oxide, and Ni-Cd. In the test, 1,200 g of each battery were selected and ground to less than 5 mm in size. After size reduction, the crushed batteries were mixed uniformly prior to grabbing a 400-g sample. The leaching tests were carried out in a batch process in 2-L glass flasks. A 110 g sample of battery was mixed with 1,000 ml of distilled water at a pH between 5.8 and 6.0 (the pH was adjusted with a dilute solution of hydrochloric acid). The flask was closed, and shaken horizontally over a 6-hr period. After shaking, the residue was filtered through a glass fiber filter of 1 µm. The concentration of heavy metals in the solution was determined by means of ICP spectroscopy, and the concentration of Hg was determined using cold-water technique.

The results of the leaching tests indicated that the concentration of mercury in silver-oxide batteries was 1.24 mg/l, in mercury-oxide batteries was 25.0 mg/l, in conventional carbon-oxide batteries was 0.008 mg/l and in alkaline manganese batteries was 0.13 mg/l. On the other hand, the concentrations of Hg in the leaching solution of mercury-free zinc carbon batteries and alkaline batteries were below 0.001 mg/l. The pH of the solution of mercury-free alkaline batteries was on the order of 13.1.

Yanase, Matsufuji, 2005

Original title:	Migration of Mercury Tracer (^{203}Hg) in Solid Waste Layer of Landfill
Translation:	N/A
Author:	R. Yanase, Y. Matsufuji
Institution:	Fukuoka University, Japan
Editors:	N/A
Publisher:	
Place, Year:	Korea, 2005
ISBN/ISSN:	
Kind of publication:	Proceedings of the 9th Korea-Japan Joint International Session
Additional information:	

This publication reports on an investigation conducted to assess the transfer and diffusion of mercury into landfill leachate using a ^{203}Hg solution (a radioactive isotope of mercury) under non-destructive methods. The investigation was performed in an experimental column filled with waste materials (two types of incineration residue and crushed incombustible residue), to clarify the motion of water and non-absorbed/desorbed solutes, tritium (^{3}H) was used to compare to ^{203}Hg.

The results of the research indicate that the concentration of ^{203}Hg was less than 0.0001 mg/l for the three types of residues. The concentration of Hg was below the detection limit of the analyzer. The leaching rate of ^{203}Hg in both types of residues was 1% or less. The ^{203}Hg tracer experiment confirmed that soluble Hg is absorbed in the landfill and it is unlikely to escape into the leachate. Thus, the investigators conclude that mercury would not leak from the landfill that contains the types of residues investigated.

Yanase, Hirano, Matsufuji, 2004

Original title:	Characteristics of Mercury Behavior in Solid Waste: Adsorption, Desorption and Dissolution into Leachate
Translation:	N/A
Author:	R. Yanase, F. Hirano, Y. Matsufuji
Institution:	Fukuoka University, Japan
Publisher:	
Editors:	N/A
Place, Year:	APLAS, Kitakyushu, Japan, 2004
ISBN/ISSN:	
Kind of publication:	Proceedings of Asia-Pacific Landfill Symposium 2004
Additional information:	

This paper reports on experiments performed at the Fukuoka University in Japan to evaluate the leaching characteristics of Hg from dry batteries and solid waste in landfills. The waste used in the experiment consisted of incineration residues (2 mm maximum size). Sand (2 mm maximum size) was used as the control. The experiment consisted of three parts: (1) adsorption of Hg eluted in leachate from the waste and desorption of the Hg from the waste; (2) leaching of vaporized Hg into leachate; and (3) absorption of vaporized Hg into the wastes and desorption of Hg from the waste.

The dissolved Hg was unaffected by coexistent ions, with at least 90% being adsorbed into the incineration residues. Vaporized Hg adsorption by incineration residues was 5 to 8 µg/g, and was not released again as gaseous Hg. Dissolution of gaseous Hg into leachate was stable at about 1%, exhibiting no dependence on Cl^- concentration. These results indicated that the Hg is unlikely to escape from landfills.

Musselman, Shimaoka, Yanase, Sills, 2001

Original title:	Assessing the Behaviour and Fate of Mercury in a Municipal Waste Combustor Ash Landfill
Translation:	N/A
Author:	C. Musselman, T. Shimaoka, R. Yanase, M. Sills
Institution:	CMA Engineers, Fukuoka University & New Hampshire Dept. of Environmental Services, N.H.
Editors:	
Publisher:	
Place, Year:	Sardinia, Italy 2001
ISBN/ISSN:	
Kind of publication:	Proceedings, Sardinia Symposium 2001
Additional information:	

This article reports the results of a work conducted at a full-scale ash landfill (monofill) from a municipal waste combustor located in Franklin, New Hampshire, USA. The tests indicated that Hg vapor was detected in convective air currents in the leachate collection piping systems in concentrations below applicable occupational exposure and ambient air quality limits for Hg. These analyses corroborated the work conducted by Yanase et al. at Fukuoka University, Japan, which indicated that Hg is predominantly immobile in an MWC ash landfill environment.

Yanase, Matsufuji, Hanashima, 2000

Original title:	Battery Corrosion and Mercury Migration in Landfill Site
Translation:	N/A
Author:	R. Yanase, Y. Matsufuji, M. Hanashima
Institution:	Fukuoka University, Japan
Editors:	N/A
Publisher:	
Place, Year:	APLAS, Fukuoka, Japan 2000
ISBN/ISSN:	N/A
Kind of publication:	Proceedings of Asia-Pacific Landfill Symposium 2000
Additional information:	

This experiment deals with the evaluation of the possible migration of mercury from household batteries disposed in landfills. Typically, it is assumed that the migration of mercury from batteries is due to the dissolution of mercury vaporized from corroded batteries into the leachate. The researchers measured the extent of corrosion of batteries and the amount of Hg that migrated from the batteries into the waste layers at 0.5, 1, 2, and 7 years after filling the experimental lysimeters. The lysimeters consisted of cylinders 300 mm in diameter and 1200 mm in length. The results of the experiment showed that the corrosion of batteries was primarily of the electrolytic type and proceeded rapidly during the first 2 years. The concentrations of Hg in the leachate were less than 0.0003 mg/l. The migration of Hg from batteries to the waste layer was caused by the vaporization of Hg from the corroded batteries, and the concentrations of Hg in the waste layer surrounding the areas where the batteries had been placed. The results of this research program indicated that the Hg from batteries hardly migrated in the landfill site during 7 years.

5.2 Conclusions

Much work has been carried out in Japan and in Korea. The majority of the work dealt with the behavior of household batteries in landfills and, more specifically, the fate of heavy metals contained in the batteries.

Most notable is the experimental work carried out by researchers at Fukuoka University to assess the behavior of mercury contained in the batteries. This study lasted over 20 years. The results of the studies point out that any mercury contained in household batteries would not escape from landfills.

Appendix A. List of Abbreviations

A	Austria
AlMn	alkaline manganese primary (if not otherwise stated) batteries
B	Belgium
BAFU	Swiss Federal Environment Agency
BMU	German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety
C.R.C.	Collection & Recycling Contribution (Belgium)
CH	Switzerland
D	Germany
DtT	Distance to Target
EIA	Environmental Impact Assessment
EPBA	European Portable Battery Association
EU-10	the 10 new EU Member States since 01.05.2004
EU-15	the 15 EU Member States until 01.05.2004
EU-25	the 25 EU Member States since 01.05.2004
F	France
GRS	Joint Collection System for Batteries (Germany)
inh.	inhabitant
inh. eq.	inhabitant equivalent
LCA	Life Cycle Assessment
LCI	Life Cycle Inventories
LCIA	Life Cycle Impact Assessment
Li battery	Lithium battery
Li-ion battery	Lithium ion battery
MBP	Mechanical-Biological Pretreatment
MP	Mechanical Pretreatment
n.a.	not available
NGO	Non Governmental Organization
NiCd	nickel cadmium secondary batteries
NiMH	nickel metal hydride secondary batteries
NL	The Netherlands
NWMP	National Waste Management Plan
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenyls
PL	Poland
REBA	(Polish) Battery Recovery Organisation
TLV	Threshold Limit Value
UBA	(German) Federal Environment Agency
VAT	Value Added Tax
VEG	product disposal fee (Switzerland)
VROM	(Dutch) Ministry of Housing, Spatial Planning and the Environment
WMS	waste management system
ZnC	zinc carbon primary batteries, also referred to as Leclanché batteries

Appendix B. List of Sources Used to Identify Relevant Publications

Sources in German-language

Professional German-language magazines

Title	Publisher	Internet access
Wasser und Abfall	**Vieweg Verlag**	**http://www.vieweg.de**
Müll und Abfall	**Erich Schmidt Verlag**	**http://www.muellundabfall.de/**
Österreichische Wasser- und Abfallwirtschaft	**Springer Wien New York**	**http://www.springer.co.at/periodicals/contents.jsp?periodicalID=0945-358X&supplement=false**
Entsorgungspraxis, Umweltpraxis renamed to Entsorga Magazin	**Deutscher Fachverlag**	**http://www.entsorga-magazin.de/**
Müllhandbuch	**Erich Schmidt Verlag**	**http://muellhandbuchdigital.de/homepage.html**
Euwid Recycling & Entsorgung	**EUWID Europäischer Wirtschaftsdienst**	**http://www.euwid-recycling.de/**
Umweltmagazin	**Springer VDI Verlag**	**http://www.umweltmagazin.de/**

German-language databases

Database	Description	Access data
Datenbanken des Umweltbundesamtes (UBA)	**Databases of the German Federal Environment Agency**	**http://www.umweltbundesamt.de/uba-datenbanken/index.htm**
Veröffentlichungen des Umweltbundesamtes (UBA)	**List of publications of the German Federal Environment Agency**	**http://www.umweltbundesamt.de/uba-info-medien/publikationsliste-drucken.php**
Umweltforschungsdatenbank UFORDAT des Umweltbundesamtes	**Database on research the environmental field maintained by the German Federal Environment Agency**	**http://doku.uba.de/**
Bibliothekskatalog OPAC+ULIDAT des Umweltbundesamtes	**Database the library of the German Federal Environment Agency on environmental publications in German-speaking countries**	**http://doku.uba.de/**
Deutsche Nationalbibliografie online	**Database of the German National Library**	**http://z3950gw.dbf.ddb.de/z3950/zfo_get_file.cgi?fileName=DDB/searchForm.html**
ASK-Access to sustainable knowledge	**Internet database on publications related to environmental issues**	**http://www.ask-eu.de/default.asp**
BMU - Themenauswahl	**Database of the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety**	**www.bmu.de** **http://www.bmu.de/fb_abf/index.php?fb=3004**
Abfallinfodienst	**Internet database on waste related issues**	**http://www.abfallinfodienst.de/**
Österreichischer Umwelttechnik Datenbank	**Austrian database on environmental technologies**	**http://www.umwelttechnik.co.at/**

Database	Description	Access data
Österreichischer Umwelschutz Datenbank	**Austrian database on environment protection**	**http://www.umweltschutz.co.at/index.cfm**
Hinweise zum Thema Ökobilanzen im Internet	**Links about Lifecycle Assessment (LCA), collected and annotated by G. Doka**	**http://www.doka.ch/lca.htm**
Fraunhofer Geselschaft	**Publications of the Fraunhofer Institutes**	**http://www.fraunhofer.de/fhg/publications/index.jsp**
Öko-Institute	**Projects and publications of the Öko-Institute (Institute for Applied Ecology)**	**http://www.oeko.de/forschungsergebnisse/dok/228.php**
ifeu	**Projects and publications of the ifeu (Institute for Energy and Environment Research)**	**http://www.ifeu.org/index.php?seite=referenzenundpublikationen**
Stiftung Gemeinsames Rücknahmesystem Batterien (GRS)	**Publications of the German Battery Recovery Organisation**	**http://www.grs-batterien.de/**
Vfw-Rebat	**Publications of the German Battery Recovery Organisation**	**http://www.ctm.at/vfw/index.html**
Umweltforum Batterien (UFB)	**Publications of the Austrian Battery Recovery Organisation**	**http://www.batteriensammeln.at**
DeponieOnline	**Database on Landfill projects, publications, laws, etc.**	**http://www.deponie-stief.de/suchen.html**
Umweltbundesamt Österreicht	**Database of the Austrian Environment Agency**	**http://www.umweltbundesamt.at/fuer_wissenschaft/suche.html**
Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft	**Database of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water**	**http://publikationen.lebensministerium.at/**
Technische Universität Wien	**Projects and publications of the Vienna University of Technology**	**http://www.iwa.tuwien.ac.at/iwa226/publikationen.html**
Waste database	**Swiss database on waste related publications**	**http://www.abfall.ch**
Schweizer Bundesamt für Umwelt (BAFU)	**Batabase of the Swiss Federal Office for the Environment (FOEN)**	**http://www.bafu.admin.ch**
ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e.V.	**Database of the Central Association of The German electrical and electronics industry**	**http://www.zvei.org/index.php?id=10**
Envirocat	**Swiss Environmental Database in the internet**	**http://www.envirocat.ch/**
Deutsche Bundesstiftung Umwelt (DBU)	**Database of the German Federal Environmental Foundation**	**http://www.dbu.de/datenbank**
Hochschulschriftenserver der Universität Stuttgart	**Database of the Stuttgart University of Technology**	**http://elib.uni-stuttgart.de/opus/suche/**
Geoökologie an der Universität Karlsruhe	**Database of the research projects and publications of the Geo-Ecology at Karlsruhe University**	**http://www.bio-geo.uni-karlsruhe.de/ifgg1/lehre/diplthe.htm**

Database	Description	Access data
Institut für Umwelt- und Verfahrenstechnik, HSR Hochschule für Technik Rapperswil Switzerland	**Database on the research projects and publications of the Institute for Environmental and Process Engineering, Rapperswil University of Applied Sciences**	**http://www.umtec.ch/**
INOBAT «Interessenorganisation Batterieentsorgung». Swiss Battery Disposal Organisation	**Database on the collection and recovery quota in Switzerland**	**http://www.inobat.ch**

German, Austrian and Swiss institutions contacted (by email or telephone)

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Fraunhofer-Institut für Materialfluss und Logistik IML Joseph-von-Fraunhofer-Str. 2-4 44227 Dortmund Tel.: 0231 / 97 43-0 (Zentrale) Email: peter.meyer@iml.fraunhofer.de	Dr. **Meyer,** Peter	D
Umweltbundesamt (Österreich) Spittelauer Lände 5 1090 Wien/Österreich Tel: +43-(0)1-31304 Fax: +43-(0)1-31304/5400 Email: chemikalien@umweltbundesamt.at Email: sabine.cladrowa@umweltbundesamt.at	Dr. Sabine **Cladrowa**	A
Federal Ministry of Agriculture, Forestry, Environment and Water Management Stubenring 1 A-1010 Vienna Tel.: +43/1/71100-0 Fax: (+ 43 1)711 00-0 Email: mathilde.danzer@lebensministerium.at christian.keri@bmlfuw.gv.at	DI Mathilde **Danzer** Dr. Christian **Keri**	A
Amt für Gewässerschutz und Abfallwirtschaft des Kantons Bern (Water Protection and Waste Management Agency Canton of Berne) Reiterstrasse 11 3011 Bern Tel: 031 633 39 15 Fax: 031 633 39 20 Email: info.gsa@bve.be.ch martin.k.meyer@bve.be.ch	Martin K. **Meyer**	CH
Institut für Geographie und Geoökologie Institute for geography and geoecology, Karlsruhe University Email: annabarlinn@yahoo.de	Dipl.-Geol. Anna **Barlinn**	D

Institution, Address	Name	Country
Institut für Umwelt- und Verfahrenstechnik, Institute for Environmental and Process Engineering, Hochschule Für Technik, Rapperswil Switzerland University Of Applied Sciences Oberseestrasse 10 8640 Rapperswil Tel +41 (0)55 222 48 60 Fax +41 (0)55 222 48 61 Email : umtec@hsr.ch	Prof. Dr. Rainer **Bunge**	CH
Wien Energie - Fernwärme Wien Spittelauer Lände 45 1090 Wien Tel: (01) 313 26-0 Fax: (01) 313 26-2200 http://www.fernwaermewien.at/ Email: thomas.strauss@fernwaermewien.at	DI Thomas **Strauss**	A
Björnsen Beratende Ingeniure Maria Trost 3 D-56070 Koblenz Tel.: ++49 (0)261 / 88 51 0 Fax.: ++49 (0)261 / 80 57 25 Email: J.Dach@bjoernsen.de	Dr.-Ing. Joachim **Dach**	D
IFAS - Ingenieurbüro für Abfallwirtschaft Prof. R. Stegmann und Partner Schellerdamm 19-21; D - 21079 Hamburg Tel.: 040 / 7711 0741 Fax: 040 / 7711 0743 Email: info@ifas-hamburg.de	Dr. Ing. Kai-Uwe **Heyer**	D
IGW Ingenieurgemeinschaft Witzenhausen Fricke & Turk GmbH Bischhäuser Aue 12 D-37213 Witzenhausen Tel: +49 05542/9308-0 Fax: +49 05542/9308-20 Email: t.turk@igw-witzenhausen.de	Dipl.-Ing. Thomas **Turk**	D

Institution, Address	**Name**	**Country**
Universität Duisburg-Essen Fakultät für Ingenieurwissenschaften Abteilung Maschinenbau Abfalltechnik Lotharstraße 1 47057 Duisburg Germany Tel.: +49/ (0)203/ 379-3006 Fax: +49/ (0)203/ 379-3119 Email: herbell@uni-duisburg.de http://www.abfall.tk	Prof. Dr. rer. nat. Jan-Dirk **Herbell**	D
Umweltforum Batterien The Austrian Batteries Collection Organisation Injteressengemeinschaft der Batterienimporteure Wiedner Hauptstraße 63, Postfach 440 A-1045 Wien Tel. 05 90 900 - 3352 od. 3324 Telefax (01)505 38 51 Email: der-elektrohandel@wko.at http://www.batteriensammeln.at Email: office@dr.bannert-pr.at	Dr. **Bannert**	Austria
Vfw-REBAT The German battery Collection Organisation Vfw AG Max-Planck-Str. 42 D-50858 Köln Tel.: 02234 – 9587 - 176 Email: karl.semlitsch@vfw-ag.de Tel.: 02234 – 9587 – 150 Email: hans.j.nevermann@vfw-ag.de	Karl-Georg **Semlitsch** Hans-Jürgen **Nevermann**	D
BMU German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety	Contact person	D
Zentralverband Elektrotechnik- und Elektronikindustrie (ZVEI) e.V. Stresemannallee 19 60596 Frankfurt/Main Tel. 069 6302-256 Fax. 069 6302-279 Email:batterien(at)zvei.org	Contact person	D
Schweizer Bundesamt für Umwelt (BAFU) 3003 Bern Tel. 031 324 94 13 Email: hansjoerg.buser@bafu.admin.ch	Hansjörg **Buser**	CH

Sources in Dutch-language

Professional Dutch-language magazines

Title	Publisher	Internet access
Magazine Recycling Benelux	**MrB Uitgevers**	**www.recyclingmagazine.nl**
Recycling	**MrB Uitgevers**	**www.recycling-online.nl**
Journaal Afval	**SDU**	**www.sdu.nl/afval**
Toegepaste Wetenschap		
Milieu Magazine	**Kluwer**	**www.milieumagazine.nl/**
Milieu Compact		
De Ingenieur		
Energiebeheer en Afvalbeheer		
Civiele techniek : vakblad voor weg- en waterbouwers		
Gemeentereiniging en Afvalmanagement (GRAM)	**NVRD**	**www.nvrd.nl/nvrd/gram**
		www.afvalonline.nl

Dutch databases

Database	Description	Access data
Bebat	**Organises the collection and treatment of batteries in Belgium**	**www.bebat.be**
Stibat	**Organises the collection and treatment of batteries in The Netherlands**	**www.stibat.nl**
Indaver	**Main waste treatment company in Belgium**	**www.indaver.be**
VROM	**Ministry of Environment in the Netherlands**	**www.vrom.nl**
MilieuLiteratuurBestand	**The Environmental Literature Database contains descriptions of all forms of environmental publications (articles, books, reports, in print or digital), with special emphasis on environmental knowledge and information generated in, or concerning the Netherlands.**	**www.allesovermilieu.nl**
DAREnet	**Contains scientific publications and research output from all Dutch universities, scientific institutes, KNAW and NWO.**	**http://www.darenet.nl/nl/page/language.view/search.page?name=search.page&searchset=dareset**
Cream of Science	**Database of publications of appr. 200 Dutch top-researchers**	**http://www.darenet.nl/nl/page/language.view/search.page?name=search.page&searchset=keurset**

Database	Description	Access data
Promise of Science	**Database of Dutch doctoral theses**	**http://www.darenet.nl/nl/page/language.view/search.page?name=search.page&searchset=promiseset**
Scopus	**General scientific database**	**www.scopus.com**
Kennislink	**General knowledge database**	**www. kennislink.nl**
Libis	**Joint literature database of over 20 research institutions**	**http://www.libis.be/nl/**
Academische Bibliografie	**Publications of the Katholieke Universiteit Leuven**	**http://librivision.libis.kuleuven.be/KULab/**
Antilope	**Belgium article database**	**http://biblio.vub.ac.be/vubissmartweb/Vubis.csp?Profile=ANT**
OVAM	**Database of the Public Waste Agency of Flanders**	**www.ovam.be**
Publicaties van de Vlaamse Overheid	**Database of all publications of the Flemish government**	**http://publicaties.vlaanderen.be/ebl-web/do/start/publiek**
Departement Leefmilieu, Natuur en Energie	**The Environment, Nature and Energy Department (ministry of Environment)**	**www.lne.be**
VITO	**Publications and projects of the Flemish Institute for Technological Research**	**www.vito.be**
VUBIS, Vrije Universiteit Brussel	**University library collection**	**www.vub.ac.be/biblio**
Erasmus Hogeschool Brussel	**University library collection**	**http://www.ehb.be/biblio/**
NV Afvalzorg – waste disposal and treatment company	**Projects and publications of NV Afvalzorg**	**www.afvalzorg.nl**
Vereniging Afvalbedrijven – Organisation of Waste treatment & disposal companies	**Projects and publications of Vereniging Afvalbedrijven**	**www.verenigingafvalbedrijven.nl**
CE-research on energy and environment	**Projects and publications of CE**	**www.ce.nl**
TNO-research on health and safety	**Projects and publications of TNO**	**www.tno.nl**
RIVM – National Institute for Public Health and Environment	**Projects and publications of RIVM**	**http://rivm.openrepository.com/rivm/**
HBO Kennisbank	**The HBO Knowledge Bank makes the products of the Universities of Applied Science available**	**http://www.hbo-kennisbank.nl/nl/page/page.view/hbo.page**
Energy research Centre of the Netherlands (ECN)	**Projects and publications of ECN**	**www.ecn.nl**

Database	Description	Access data
Uitvoering Afvalbeheer (previously: Afval Overleg Orgaan, AOO)	**National centre for waste policy. Publications and information material**	**http://www.senternovem.nl/uitvoeringafvalbeheer/**
Koninklijke Bibliotheek Nederland	**Dutch national library collection**	**http://opc4.kb.nl/**
Koninklijke Bibliotheek Belgie	**Belgium national library collection**	**http://www.kbr.be/catalogues/catalogues_nl.html**
University Twente Library Catalogue	**University library collection**	**http://opc4.utsp.utwente.nl/LNG=EN/DB=1/**
Wageningen UR Library Catalogue	**University library collection**	**http://library.wur.nl/desktop/catalog/**
RU Groningen Library Catalogue	**University library collection**	**http://opc.ub.rug.nl/LNG=NE/DB=1/**
Library TU Delft	**University library collection**	**http://aleph.library.tudelft.nl/F/2MNY5DK1II1IFB16B4QFESGERHTYT7ANAC9TA9A9VE8BLSTKP7-00376?func=file&file_name=find-b&local_base=tud01**
U-CAT Library catalogue of Universiteit Leiden	**University library collection**	**http://ub.leidenuniv.nl/index.php3?m=4&c=52&garb=0.7059813025613331&session=**

Dutch institutions contacted (by email or telephone)

Institution, Address	**Name**	**Country**
Wageningen University Team Urban Environmental Management Gen. Foulkesweg 13 6703BJ Wageningen http://www.ue.wur.nl/ Email: adrie.veeken@wur.nl	Dr. Adrie **Veeken**	NL
IVAM research and consultancy on sustainability Roetersstraat 33 1018 WB Amsterdam Tel: +31 (0)20 - 525 5080 Fax: +31 (0)20 - 525 5850 Email: hvewijk@ivam.uva.nl	Ir. Harry **van Ewijk**	NL
Bebat FONDS OPHALING BATTERIJEN - VZW Woluwe Garden B Woluwedal 28 b7 1932 St-Stevens-Woluwe Tel. 02/721 24 50 Fax 02/721 07 20 Email : carine@bebat.be	Carine **Engelborghs,** Office Manager	B

Institution, Address	Name	Country
Stichting Batterijen (Stibat) Postbus 719 2700 AS Zoetermeer Tel. +31 79 3632090 Fax.: 079 363 20 91 Email: info@stibat.nl frans.de.buck@stibat.nl	Sander **Broers** Frans **de Buck**	NL
Indaver Dijle 17 a B-2800 MECHELEN Tel. + 32 15 28 80 40 Fax + 32 15 28 80 45 Email : contact webform	Contact person	B
EIM bv Italiëlaan 33 Postbus 7001 2701 AA Zoetermeer Tel.: 079 343 02 00 Fax 079 343 02 02 Email info@eim.nl	Contact person	NL
Stratus Marktonderzoek Stratus marktonderzoek bv Italiëlaan 33 Postbus 7001 2701AA Zoetermeer Tel: +3179 343 06 30 Fax: +3179 343 06 31 Email: azy@stratusbv.n	André **Zijdenbos**	NL
Vlaams Instituut voor Technologisch Onderzoek (VITO) Integrale milieustudies Boeretang 200 BE-2400 MOL Tel. + 32 14 33 58 66 Fax + 32 14 32 11 85 Email: roger.dijkmans@vito.be	Roger **Dijkmans**	B
Tauw Deventer Handelskade 11 Postbus 133 7400 AC Deventer Tel.: + 31 (0)570 69 99 11 Fax: +31 (0)570 69 96 66 Email info.deventer@tauw.nl	Contact person	NL
AVR - Bedrijven (Holding) Seattleweg 17 (havennr 2801) 3195 ND Rotterdam/ Pernis Tel.: +31 (0)181 - 275 275 Email: info@avr.nl	Contact person	NL

Institution, Address	Name	Country
Essent Milieu, locatie Wijster VAMweg 7, 9418 TM Wijster Postbus 5, 9418 ZG Wijster Tel.: 0593 - 56 3939 Fax: 0593 - 56 3993 Email: info.milieu@essent.nl	Contact person	NL
RU Groningen Chemiewinkel Nijenborgh 4 9747 AG Groningen Tel. 050 - 363 4132 / 4436 Fax 050 - 363 7526 Email: H.A.J.Mulder@rug.nl	Henk **Mulder**	NL
RU Groningen **Centrum voor Energie- en Milieukunde** Nijenborgh 4 9747 AG Groningen Tel.: 050 - 3634609 Fax 050 - 3637168 Email: a.a.bellekom@rug.nl r.m.j.benders@rug.nl d.t.van.den.Berg@rug.nl	Sandra **Bellekom** Rene **Benders** Dick **van den Berg**	NL
Vrije Universiteit Brussel Dept. Of Engineering sciences Chair of Chemical Engineering Pleinlaan 2 1050 Elsene Tel : +32-2-6293247 Fax : +32-2-6293333 Email: abuekens@vub.ac.be	Prof. Alphons **Buekens**	B
VROM-ministry of environment Rijnstraat 8 2515 XP DEN HAAG 070 - 339 50 50 Email: vrominfo@postbus51.nl	Dorine **Verschoof** Publieksvoorlichter	NL
NV Afvalzorg Nauerna 1 1566 PB Assendelft Telefoon: 088 - 801 08 01 Fax: 088 - 801 08 08 Email: j.renkers@afvalzorg.nl j.jacobs@afvalzorg.nl h.scharff@afvalzorg.nl	Jeroen **Renkers** Joeri **Jacobs** Heijo **Scharff**	NL
Library of the ministry for environment VROM Rijnstraat 8 2515 XP DEN HAAG 070 - 339 30 00 Email: bibliotheek@minvrom.nl	Annemieke **Flinterman**	NL

Institution, Address	**Name**	**Country**
Vereniging Afvalbedrijven Postbus 218 5202 CD 's-Hertogenbosch Tel.: 073 – 627 94 44 Fax: 073 – 627 94 49 Email: kok@verenigingafvalbedrijven.nl	Jeanne **Kok**	NL
Syncera Delftechpark 9 2628 XJ Delft Tel.: 015 751 23 00 Fax: 015 262 53 65 Email: cbe@syncera.nl	Ir. Clemens **Berntsen**	NL
CE Oude Delft 180 2611 HH Delft Tel: +31 15 2150150 Fax: +31 15 2150151 Email: boer@ce.nl	Ir. Eelco **den Boer**	NL
Sita Belgium Gatti de Gamondstraat 254 B-1180 Brussel Tel: +32 (0)2 370 66 11 Email: martine.vanesch@sita.be	Martine **Van Esch**	B
Revatech Engis Zoning industriel d'Ehein B-4480 Engis, België Tel.: +32 (0)4 275.00.93 Fax: +32 (0)4 275.69.93 Email: michel.bauduin@revatech.be	Michel **Bauduin**	B
Uitvoering Afvalbeheer Catharijnesingel 59 Postbus 8242 3503 RE Utrecht Tel. (030) 214 79 00 Fax (030) 231 64 91 Email : contact webform	Contact person	NL
RIVM Antonie van Leeuwenhoeklaan 9 3721 MA Bilthoven Tel.: (030) 274 91 11 Fax: (030) 274 29 71 Email: info@rivm.nl RIVM.Reports@rivm.nl	Kimberley **van Alphen** Joost **de Gorter**	NL
Ademe, Brussels office 53 avenue des Arts 1000 BRUXELLES Belgium Tel.: 00 32 2/ 545 11 41 Fax: 322 513 91 70 Email : ademe.brux@ademe.fr	Contact person	B

Institution, Address	Name	Country
TNO Milieu en Leefomgeving Tel: 055 549 35 22 henk.buijtenhek@tno.nl	ir. H.S. (Henk) **Buijtenhek**	NL
Department Environment and Health TNO Built Environment and Geosciences Tel: 015 269 47 33 henk.miedema@tno.nl toon.ansems@tno.nl	dr. H.M.E. (Henk) **Miedema** Toon **Ansems**	NL

Sources in Polish-language

Professional Polish magazines

Title	Publisher	Internet access
Przegląd Komunalny	**ABRYS**	**http://www.abrys.pl/pk/index.php?r=pk_o_tytule**
Ekopartner	**Ekopartner**	**http://www.ekopartner.com.pl/**
Recykling	**ABRYS**	**http://www.abrys.pl/pk/index.php?r=rec_o_tytule**
Kropla	**Dolnośląska Fundacja Ekorozwoju**	**http://eko.org.pl/kropla/newkropla/index.php?pismo=33**
Przemysł chemiczny	**SIGMA-NOT**	**www.sigma-not.pl**

Polish databases

Database	Description	Access data
Główny Inspektor Ochrony Środowiska (Main Inspector of the Environment Protection)	**Database of environmental studies**	**http://www.gios.gov.pl/index.php**
The Warsaw University Centre for Environmental Studies	**Database on publications on the ecology and the environment protection**	**http://ucbs.geo.uw.edu.pl/kanon/search.php http://ucbs.geo.uw.edu.pl/**
The National Library, Poland-Warsaw	**Database of the Polish National Library**	**http://www.bn.org.pl/index.php**
The Institute for Ecology of Industrial Areas (IETU)	**Projects and publications of the institute**	**http://www.ietu.katowice.pl/eng/index.htm**
Dolnośląska Fundacja Ekorozwoju	**Publications of the Lower Silesian Foundation of Sustainable Development**	**http://baterie.eko.org.pl/baterie3.php**
Institute for Mechanised Construction and Rock Mining in Warsaw, Centre of Waste Management	**Projects and publications of the Institute**	**http://www.imbigs.org.pl/imbigs/cgo/index.html**
Institute of the Basic Environmental Engineering, Polish Academy of Science	**Projects and publications**	**http://www.ipis.zabrze.pl/index.php?option=com_content&task=view&id=117&Itemid=155**
Institute of waste management	**Projects and publications**	**http://www.odpady.biz.pl/**
Forum of the Environment Protection	**Environmental publications**	**http://www.srodowisko.e-firma.pl**

Database	Description	Access data
Industrial Chemistry Research Institute	**Projects and publications**	**http://www.ichp.pl/pl/elektrochemia.htm#baterii**

Polish institutions Contacted (by email or telephone)

Institution, Address	Name	Country
Departament Gospodarki Odpadami – Department of Waste Management Ministerstwo Środowiska – Ministry of the Environment ul. Wawelska 52/54 00-922 Warszawa +48 (22) 5792798 Email: Beata.Klopotek@mos.gov.pl Email: Pawel.Sosnowski@mos.gov.pl	Beata **Kłopotek**, Arkadiusz **Dzierżanowski**, Paweł **Sosnowski**	PL
REBA Organizacja Odzysku S.A. ul.Kubickiego 19 lok. 16, 02-954 Warszawa Tel: +48 (22) 550 61 08 Tel: +48 801363373 Email: biuro@reba.pl	Contact person	PL
Dolnośląska Fundacja Ekorozwoju - Lower Silesian Foundation of Sustainable Development ul. Białoskórnicza 26 50-134 Wrocław Tel/Fax: +48 (71) 343 08 49, +48 (71) 344 59 48 Email: baterie@eko.wroc.pl mariusz@eko.org.pl	Mariusz **Szykasiuk**	PL
Institute for Mechanised Construction and Rock Mining in Warsaw, Centre of Waste Management ul. Kossutha 6 40-844 Katowice Poland Tel.: +48(32) 2517-454 Fax: +48(32) 2517-591 Email: i.baic@imbigs.org.pl	Ireneusz **Baic**	PL
The Institute for Ecology of Industrial Areas (IETU) ul. Kossutha 6 40-844 Katowice Polska – Poland Tel.: +48 32 2546031; +48 32 2540164 Fax: + 48 32 2541717 Email: ietu@ietu.katowice.pl l.sieja@ietu.katowice.pl	Prof. Lidia **Sieja**	PL

Institution, Address	**Name**	**Country**
Institute of the Basic Environmental Engineering, Polish Academy of Science ul. M. Skłodowskiej-Curie 34 41-819 Zabrze Tel.: +48 32 271 64 81, +48 32 271 7040 Fax: +48 32 271 74 70 Email: zkow@ipis.zabrze.pl	Prof. dr hab. inż. Zygmunt **Kowalski**	PL
Industrial Chemistry Research Institute Team of batteries disposal and recycling im. prof. Ignacego Mościckiego ul. Rydygiera 8 01-793 Warszawa Tel. centrala 0 22 568 20 00, Email : piotr.piela@ichp.pl andrzej.czerwinski@ichp.pl	dr Zbigniew **Rogulski** prof. dr hab. Andrzej **Czerwiński**	PL
Instytut Systemów Inżynierii Środowiska Wydział Inżynierii Środowiska Politechnika Warszawska Institute of Environnemental Engineering Systems Department of Environmental Engineering Warsaw University of Technology 00-653 Warszawa, ul. Nowowiejska 20 Tel: +48 (22) 621-89-93, Fax: +48 (22) 625-43-05 piotr.manczarski@is.pw.edu.pl	dr inż. Piotr Maciej **Manczarski**	PL
Wydział Inżynierii Procesowej i Ochrony Środowiska Politechnika Łódzka Faculty of Process and Environmental Engineering of the Technical University of Lodz Email: barbakoz@wipos.p.lodz.pl	dr inż. Barbara **Kozłowska**	PL
Dział Ochrony Środowiska, Huta Cynku "Miasteczko Śląskie" Spółka Akcyjna Department of Environment Protection, Zn Smelter "Miasteczko Śląskie" ul. Woźnicka 36 42-610 Miasteczko Śląskie tel. (+48 32) 2888 444 - centrala fax (+48 32) 2888 687, 2888 885 dos@hcm.com.pl http://www.hcm.com.pl/	Contact person	PL

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PROEKO Grupa Polska ul. Millennium 26, 05-503 Głosków Tel. +48 (22) 757-92-12, Fax +48 (22) 757-82-46 Email: proeko@proekogp.com.pl http://www.proekogp.com.pl/baterie2.htm	Contact person	PL
Politechnika Wroclawska Wroclaw University of Technology Wydział Inżynierii Ochrony Środowiska Institute of Environmental Protection Engineering Wybrzeze Wyspianskiego 27 Wroclaw Tel. +71 320 40 88 Fax: +71 32082980 Email: ryszard.szpadt@pwr.wroc.pl	dr inż. Ryszard **Szpadt**	PL

Appendix C. List of Keywords Used in the Search

No	English term	German	Dutch	Polish
1	**battery, batteries**	**Batterie, Batterien**	**batterij, batterijen**	**bateria, baterie**
2	**primary+1**	**primäre+1**	**primaire+1**	**1+pierwotne**
3	**household+1**	**Haushhalt+1**	**huishoudelijke+1**	**1+z gospodarstw**
4	**alkaline+1**	**Alkali-Mangan+1**	**alkaline+1**	**1+alkaliczne**
5	**Zn +1**	**Zn+1**	**zink+1**	**1+cynkowe**
6	**Equipment[23] (portable) +1**	**Geräte+1**	**ingebouwde+1**	**Sprzęt (przenośne) +1**
7	**old+1**	**Alt+1**	**oude+1**	**stare+1**
8	**used+1**	**gebrauchte+1**	**gebruikte+1**	**zużyte+1**
9	**dry+1**	**Trocken+1**	**droge+1**	**suche+1**
10	**1+environment**	**1+Umwelt**	**1+milieu**	**1+środowisko**
11	**1+environmental impact**	**1+Umweltwirkung**	**1+milieu-effect**	**1+wpływ na środowisko**
12	**1+lifecycle assessment (LCA)**	**1+Ökobilanz**	**1+levenscyclusanalyse**	**1+ocean cyklu życia**
13	**1+ecological balance**	**1+ökologische Bilanzierung**	**1+ecologische balans**	**1+bilans ekologiczny**
14	**1+segregation**	**1+Zusammensetzung**	**1+indeling**	**1+skład**
15	**1+intermediate storage**	**1+Zwischenlagerung**	**1+tussenopslag**	**1+magazynowanie**
16	**1+storage**	**1+Lagerung**	**1+opslag**	**1+składowanie**
17	**1+treatment**	**1+Behandlung**	**1+verwerking**	**1+przetwarzanie (1+obróbka)**
18	**1+recovery**	**1+Verwertung**	**1+terugwinning**	**1+odzysk**
19	**1+recycling**	**1+Recycling**	**1+recycling**	**1+recykling**
20	**1+disposal**	**1+Entsorgung**	**1+verwijdering**	**1+unieszkodliwienie**
21	**1+final disposal**	**1+Beseitigung**	**1+eindverwijdering**	**1+utylizacja**
22	**1+landfill**	**1+Deponie**	**1+storten**	**1+składowisko**
23	**1+incineration**	**1+Verbrennung**	**1+verbranden**	**1+spalanie**
24	**1+lysimeter**	**1+Lysimeter**	**1+lysimeter**	**1+lizymetry**
25	**1+landfill reactors**	**1+Deponiereaktoren**	**1+reactordeponie**	**1+reaktory składowiskowe**

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[23] In the German literature term “equipment batteries” is used for the „portable batteries”