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Ministère de l'Ecologie et du Développement Durable

# Working Paper

STUDIES -- METHODS -- SYNTHESES

D4E

# EFFICIENCY OF THE BATTERY CHANNEL

SERIE ETUDES
05 – E02

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## Translator's notes

1 In European French, "pile" refers to a primary cell, or a non-rechargeable battery that produces electricity from its own components. "Accumulateur" refers to a secondary (or rechargeable) battery that stores electricity generated elsewhere. This latter term includes NiCd batteries as well as lead/acid automobile batteries, for example. In this paper, for some reason, the term "pile&accumulateur" (spelled as one word) is used to cover a variety of situations.

I have translated this combined term as "batteries" which more closely corresponds to general usage in the trade and the battery business in North America. I have translated it as "automobile batteries" where it clearly is limited to wet cell batteries, which in North America are generally a totally separate business category. I have translated it as "Dry Cell batteries" when the paper is clearly referring to household, or non-automotive batteries. I have translated this term as the specific battery types only when needed for clarification.

2 Factual errors have been translated as they were presented in this paper. For example, on page 7, the atomic mass of lead (Pb) is in fact 207.2, not 270 as given in this paper.

3 An effort has been made to conform to the pagination of the original document in order to facilitate direct reference to the original, if required.

4 The titles in the Bibliography and in the list of Published Papers (Annex 4) have not been translated, but left in their original language (mostly French), to facilitate any reference back to the original.

5 In the original document the following numbered pages are blank: 2 (this page), 4, 44, 45 (header only), and 46. Pages 47 – 51 (inclusive) are not present. It does not, however, appear that any content is missing.

## CONTENTS



## SUMMARY


Containing numerous and varied chemical substances, batteries constitute a heterogeneous product category. At the end of their product life there are a variety of environmental impacts, with the incineration of heavy metals being the major pollutant. Having been the subject of European regulation since 1991, this category is one of the first in France to experience the application of the principle of Extended Producer Responsibility (EPR). A combination of controls was used: upstream restrictions on products brought to market, and selective downstream collection. After beginning with only those used batteries containing toxic materials, the scope of the exercise was expanded to include the entire category.

In 2003 more than 820 million batteries (not including lead-acid automobile starter batteries) were sold in France – or more than 30,000 tons. Alkaline and Zinc Carbon batteries represent the vast majority of this volume. Given the extremely low mercury content of today's product, they represent virtually no threat to the environment at the end of their use. During the same year, nearly 7,200 tons of used batteries wound up in recycling installations.

An analysis of the economics of the category of used dry cell batteries shows that the cost of recycling varies from 1,500 €/t for NiMH rechargeable batteries to 4,100 €/t for button cells. The cost for the remainder of the category is less than 140 €/t. Externally the costs consist primarily of heavy metal emissions in the case of incineration, and other emissions caused by recycling. Taking a cost – benefit analysis into account enables us to arrive at the best mode to responsibly manage the issue.

It appears that, for the majority of dry cell batteries, collection and recycling are not required. The level of their environmental impact in the household waste stream does not justify the high costs of recycling. Also, the treatment of mercury button cells and NiCd rechargeable batteries is very expensive regardless of how they are handled. Restriction or even elimination of their use altogether, would seem to be called for. Lastly, the regulated threshold of mercury content (5 ppm) appears to be too strict and does not bring any substantial environmental benefit.

Finally, the combination of tools employed today to manage used dry cell batteries can be used to reinforce the "upstream" controls which would have the effect of eliminating higher cost "downstream," controls. Future policy should focus on strictly limiting the use of those dry cell battery systems containing mercury or cadmium. Substitutes are available, and this would eliminate the need for selective collection. This change in focus, however, should not discourage the general public from sorting in general.

## I – INTRODUCTION AND CONTEXT OF THE STUDY

For many years, batteries have been one of the categories used to make the general public aware of the problems surrounding waste. The dangerous toxicity of some of these batteries, and the relative ease of sorting them from the rest, probably explains this. It is not surprising that this category was one of the first to face European legislation, in 1991. The principle of Extended Producer Responsibility (EPR) was often the tool utilized by EU member states to apply this legislation. It deals with making those who produce, or bring to market, a product support all, or part, of the cost of collecting and recycling their product.

On the technical level, batteries are a mixed bag. At the end of their useful lives, some are hazardous waste, and some are not. Evolution of battery technology has been relatively rapid, with technological progress, and the emergence of newer electro-chemical systems combined with legislative constraints on the use of certain toxic contents. The technologies available today are totally different from those available when the original legislation was passed in 1991. New legislative initiatives are currently being discussed, taking into account current technologies. The question now is to determine what is the best way to handle used dry cell batteries after their use.

From an economic standpoint, the best way to deal with the problem is that which minimizes the cost to society. Obviously this calculation must include external costs, and any environmental impact. A cost – benefit analysis will make it possible to take into account all of these costs in order to determine if recycling is socially desirable, taking into account direct costs as well as any environmental impact which is avoided. The purpose of this study is to present the results of this analysis.

In the first part, we will describe the environmental impact of used batteries. The legislative and organizational aspects of the battery category and its disposal channel(s) will also be reviewed.

The second part will consist of the cost-benefit analysis itself. It will begin by listing the management and environmental costs, before determining for each type of used battery whether or not collection and recycling are preferable to disposal into the normal household waste stream. Special attention will be paid to Nickel-Cadmium (NiCd) rechargeable batteries.

## II – DESCRIPTION OF THE CATEGORY

### 1. Batteries

1.1 Definition and classification.

Directive 91/157/EEC of March 18' 1991 defines a primary battery or a secondary (rechargeable) battery as “a source of electrical energy composed of one or several primary elements (non-rechargeable) or secondary elements (rechargeable)”.

Dry cell batteries can be classified according to various criteria:

- End use. Portable batteries, Industrial rechargeable batteries, Automobile batteries
- Type of User. Household or industrial
- Whether rechargeable or not
- Whether toxic or not (as defined by legislation)
- Whether or not the battery is user-replaceable

Table 1: Example of classifying batteries according to whether or not they are rechargeable and by end use.

| | Technology | Examples of Use | Type | Household |
|---|---|---|---|---|
| **Non-rechargeable** | Alkaline and Zinc Carbon | Radios, toys,lights | Portable Dry Cell Batteries (< 1 kg) | **X** |
| | Lithium | Photo applications remotes | | **X** |
| | Button cells (zinc air, silver oxide, manganese dioxide, and lithium) | watches, hearing aids calculators | | **X** |
| **Rechargeable** | Nickel Cadmium (NiCd) | Cordless phones emergency lighting | | **X** |
| | Nickel Metal Hydride (NiMH) | cordless and portable phones | | **X** |
| | Lithium Ion (Li-ion)<br>Lead Acid | phones and laptops PDA's recreation equipment | | **X**<br>**X** |
| | Lead Acid | car batteries | car batteries | **X** |
| | Fixed Lead Acid batteries | Alarm systems Emergency lighting | Industrial Rechargeables | |
| | Mobile Lead Acid batteries | Elevators | | |
| | Fixed Nickel Cadmium | satellites, railroads | | |
| | Mobile Nickel Cadmium | Electric vehicles | | **X** |
| | Industrial Nickel Metal Hydride | Hybrid vehicles | | **X** |

Source: European Commission (2003b)

### 1.2 Technical characteristics of batteries

Depending on the end use, one looks for different technical characteristics. For example, certain industrial applications require strong constant power, while the majority of household uses are intermittent, and require good shelf life or maximum recharging cycles. The variety of applications explains the variety of dry cell battery types, and the variety of electro-chemical systems in use. (see Table 2).

Table 2. Technical characteristics of some portable rechargeable systems

| | NiCd | NiMH | Lithium-ion |
|---|---|---|---|
| Average weight | 25 – 45 g | 26 – 46 g | 26 – 46 g |
| Energy density | 48 – 60 Wh/kg | 64 – 90 Wh/kg | 104 – 130 Wh/kg |
| Number of cycles | 500 – 1000 | 300 – 800 | 100 – 600 |
| Energy over cycle life | 24 – 60 kWh/kg | 19 – 64 kWh/kg | 10 – 78 kWh/kg |

*source : CJ Rydh, B Svard (2003)*

1,3 Chemical characteristics of batteries

Batteries consist primarily of metals. Some of them, heavy metals, are dangerous for health and the environment. Used batteries can be treated in specific cases to recover a portion of these metals. (see Table 3). We distinguish between hydrometallurgical, pyrometallurgical, and thermal treatments.

Table 3. Composition of some dry cell batteries and their recycling possibilities

| Round Cells | | Button Cells | |
|---|---|---|---|
| 20% zinc<br>20% manganese<br>20% iron<br>1% copper | recyclable : 61% | 26% zinc<br>34% mercury<br>30% iron | recyclable : 90& |
| + between 5 & 10% paper/plastic<br>Between % & 10% water<br>electrolyte (KOH, $ZnCl_2$, $NH_4Cl$), mercury, heavy metals… | | + electrolyte (KOH, $ZnCl_2$, $NH_4Cl$), eau, mercure, heavy metals… | |

| NiCd Rechargeable | | NiMH Rechargeable | | Lithium-ion Rechargeable | |
|---|---|---|---|---|---|
| 15% cadmium<br>25% nickel<br>35 % steel | recyclable : 75 % | 40% nickel<br>18 % steel | recyclable : 58 % | 22 % steel<br>17% cobalt | recyclable : 39 % |
| + 25% plastics, water… | | + 42% cobalt, rare metals,,<br>Plastics, water | | + 7% aluminum<br>7% copper<br>3% lithium<br>44% plastics, solvents | |

Source SCRELEC

**2. Pressures on the Environment**

5.1 Heavy metals in batteries

The pressure on the environment from used dry cell catteries comes essentially from the heavy metals that they contain, in particular Cadmium (Cd), Mercury (Hg), and Lead (Pb), the characteristics of which are set out in Table 4.

Table 4. Chemical characteristics of Lead, Cadmium, and Mercury

| | Lead | Cadmium | Mercury |
|---|---|---|---|
| Atomic Mass | 270 | 112 | 200 |
| Mass/volume | 11,35 $g/cm^3$ | 8,6 $g/cm^3$ | 13,6 $g/cm^3$ |
| Melting point | 327°C | 320,9°C | – 38°C |
| Boiling point | 1740°C | 765°C | 357°C |
| Chemical symbol | Pb | Cd | Hg |
| Obtained form | galena | Zinc refining | Cinnabar ore |

*source : office parlementaire d'évaluation des choix scientifiques et technologique (2001)*

The manufacture of dry cell batteries is the principle use of Cadmium (NiCd batteries) and Lead (Automobile batteries) as shown in Table 5.

Table 5. Battery share of worldwide consumption of certain heavy metals.

| | Worldwide Consumption | Use in Batteries (%) |
|---|---|---|
| Cadmium (Cd) (1) | 16 000 - 18 000 t | ~ 2/3 |
| Mercury (Hg) | 3 000 t (1999)(2) | na |
| Lead (Pb) (3) | 6,25 Mt (1999) | 72,5 % (1997) |

*Na: not available*
*sources : (1) : « substitution of rechargeable NiCd batteries », août 2000, D. Noréus pour la DG environement ; (2) : « global mercury assessment », UNEP (décembre 2002) ; (3) : « Risks to health and the environment related to the use of lead in products », TNO (sept. 2001) pour la DG entreprises.*

These heavy metals are clearly found in used batteries. If they are not selectively collected, they will be mixed in with the general household waste stream and treated by incineration or landfill. In each of these treatments, heavy metals can have an important impact on the environment either by emission into the atmosphere or leaching into subsoil waters.

### 2,2 Waste processing and heavy metal pollution

Table 6 illustrates, in the case of air pollution in France, the contribution of waste processing to the total pollution by heavy metals. It should be noted that the incineration of household waste contributes significantly in the case of cadmium, mercury, lead, and zinc. Moreover it is much more concentrated here than in other areas. Thus in 1998, among the top twenty sources of atmospheric emissions, incineration of household waste accounted for fourteen of lead, fifteen of cadmium, and sixteen of mercury, [1]

Table 6. Contribution of certain heavy metals to atmospheric emissions by waste processing in France in 2002.

| | Total Emissions | Waste Processing | | Incineration Units of Household Waste | |
|---|---|---|---|---|---|
| | | in kg | in % des total emissions | in kg | in % des total emissions |
| Arsenic (As) | 24500 kg | 425 kg | 1,7 % | 239 kg | 1,0 % |
| Cadmium (Cd) | 9600 kg | 2 608 kg | 27,2 % | 1 882 kg | 19,6 % |
| Chrome (Cr) | 242000 kg | 2 502 kg | 1,0 % | 1 327 kg | 0,5 % |
| Copper (Cu) | 178000 kg | 6 202 kg | 3,5 % | 3 512 kg | 2,0 % |
| Mercury (Hg) | 11700 kg | 3 501 kg | 29,9 % | 1 826 kg | 15,6 % |
| Nickel (Ni) | 192000 kg | 4 116 kg | 2,1 % | 2 425 kg | 1,3 % |
| Lead (Pb) | 217000 kg | 24 713 kg | 11,4 % | 21 063 kg | 9,7 % |
| Selenium (Se) | 14200 kg | 18 kg | 0,1 % | 18 kg | 0,1 % |
| Zinc (Zn) | 1 339000 kg | 205 495 kg | 15,3 % | 186 183 kg | 13,9 % |

*source : CITEPA / CORALIE format SECTEN – updated February 2004*

Table 7 shows how heavy metals that are incinerated along with the household waste stream contribute to different residues (including atmospheric emissions) of the incineration. The share of emissions and

[1] Office parlementaire d'évaluation des choix scientifiques et technologiques (2001).

the REFOIM [2] depend on the boiling point of the metal concerned and the effectiveness of the treatment of the smoke. Obviously translating this to a simple percentage is only a rough estimate. In any case, we will use these percentages to estimate the source of heavy metals entering the incineration system from used batteries.

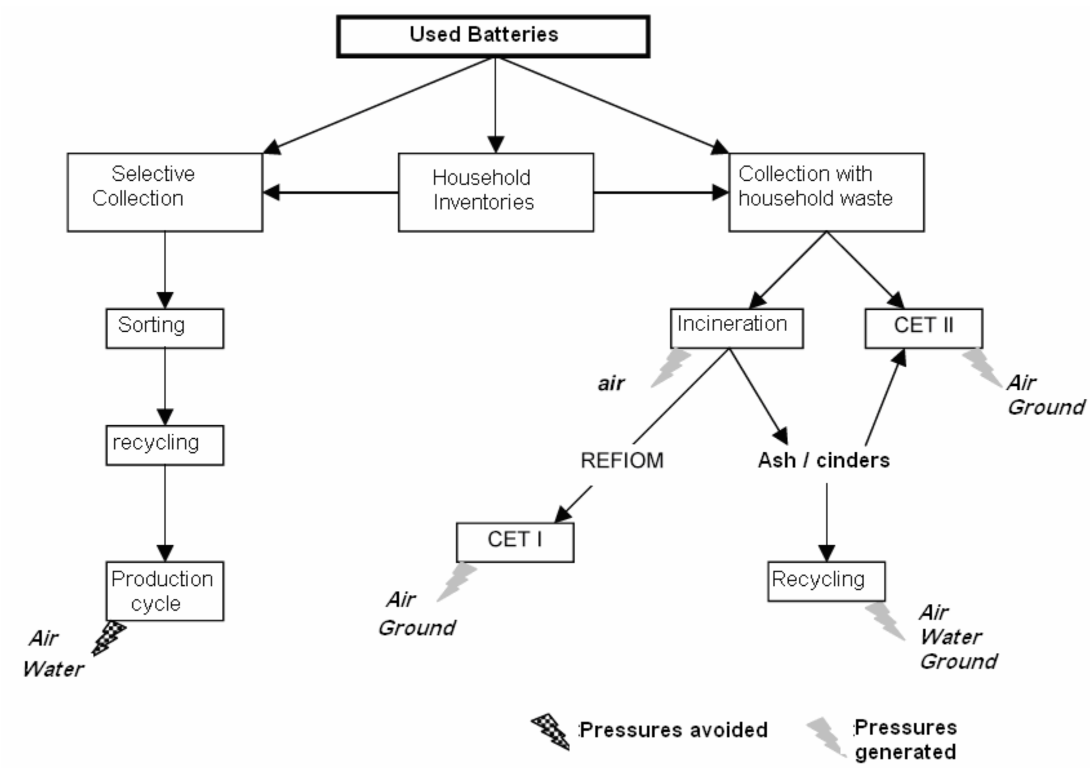
Table 7. Distribution of heavy metals in incinerator output (source: European Commission, 1999).

| | Mercury (Hg) | Lead (Pb) | Cadmium (Cd) |
|---|---|---|---|
| Emissions | 72 % | 5 % | 12 % |
| REFIOM | 24 % | 37 % | 76 % |
| Ash / cinders | 4 % | 58 % | 12 % |
| Total | 100 % | 100 % | 100 % |

2.3 The emissions of heavy metals linked to used Dry Cell Batteries

In order to evaluate the importance of used batteries in heavy metal pollution, it is necessary to quantify their flows (Figure 1) from the end of product life through the emissions from various waste treatments.

Figure 1. Flow of heavy metals linked to used batteries.




CET I = Landfill centre for hazardous waste
CET II = Landfill centre for non-hazardous waste
CET III = Landfill centre for inert waste

[2]. REFIOM = Résidus d'épuration des fumées d'incinération d'ordures ménagères (Smoke residue from the incineration of household waste).

Environmental pressures can occur, *a priori*, at all stages of collection, treatment, and recycling. Nevertheless, the major pressures result from the incineration of waste and the consequent atmospheric emissions. During the other stages of the process, heavy metals are contained (except for accidents) and not emitted into the environment. In the case of cadmium, a European study (European Commission, 2003b) shows that emissions related to incineration and landfill are at least 200 times greater than emissions related to recycling.

On the other hand, recycling of the metals back into the production cycle makes it possible to avoid the environmental pressures related to the extraction of virgin raw materials. Indeed, this raw material extraction, which can be avoided by recycling, causes pollution and power consumption. (see Table 8).

Table 8. Emissions and energy consumption during the extraction and processing of different metals.

| *Per kg of metal* | **Emissions of Metal (mg)** | | **Greenhouse Effect (kg $CO_2$)** | **Acidification (kg $SO_2$)** | **Energy (MJ)** |
|---|---|---|---|---|---|
| | **water** | **air** | | | |
| Cadmium | Cd : 6,75 | Cd : 9,5 | 3,8 | 0,037 | 70 |
| Nickel | Ni : 0 | Ni : 82,5 | ? | ? | 159 |
| Zinc | ? | ? | 4,5 | 0,053 | 47 |
| Lead | ? | ? | 2,2 | 0,023 | 21 |

*sources : Cd et Ni : d'après Rydh, C.J. (2001) ; Zn, Pb : Norgate, T. E. et Rankin, W. J. (2002)*

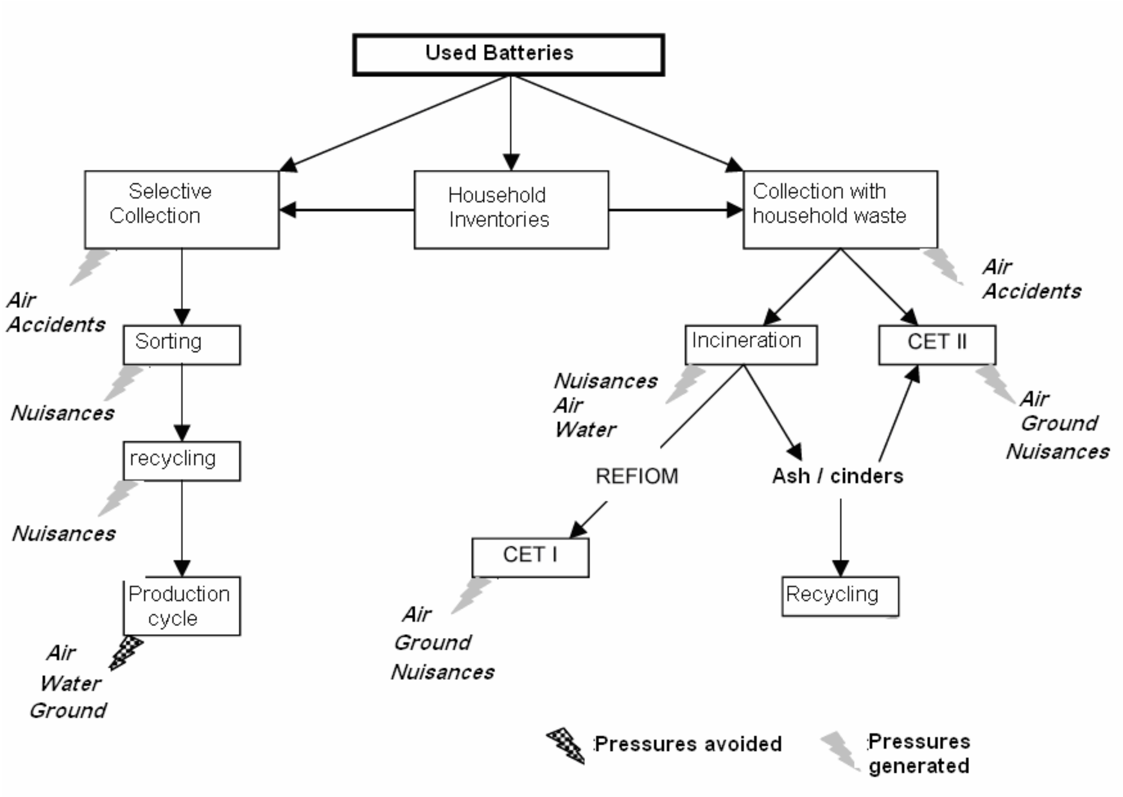
### 2.4 Other environmental concerns on used batteries

Like all other waste, used batteries are subject to environmental pressures that have nothing to do with their heavy metal contents. These pressures are mainly concerned with collection (including transportation), to incineration and disposal. (see Figure 2).

All of the installations dealing with used batteries can be considered as sources of pollution.[3] Since batteries do not contain organic matter, their contribution to the production of biogas is nil. Consequently, their storage in landfills does not have an impact on air pollution.[4] Also since their share of combustible material is relatively small (see Table 3), we will consider that used batteries do not contribute to energy production, nor to greenhouse gas emissions. Finally, the recycling of batteries makes it possible to reintroduce to the manufacturing process certain heavy metals, as well as some less hazardous materials (steel …). This operation makes it possible to avoid the pollution emitted in the extraction and refining of the virgin raw materials.

In conclusion, we will consider that all of the environmental pressures caused by used batteries are covered by Figure 1 (pressures related to heavy metals) and Figure 2 (General pressures other than heavy metals).

3. Nuisances caused to neighbours of treatment facilities (odors, noise, unsightly landfills).
4. The impact of discharge to the air is primarily greenhouse gas emissions.
5. Figure 2. Non-specific environmental pressures (excluding heavy metals) associated with the management of used batteries




CET I = Landfill centre for hazardous waste
CET II = Landfill centre for non-hazardous waste
CET III = Landfill centre for inert waste

### 3. Regulation

The battery category is subject to regulation, with its origins in European legislation. This was put in place with the aim of limiting the pressures put on waste treatment by diverting from the household waste stream hazardous elements, in particular mercury, cadmium, and lead. In order to ensure that these three toxic elements used in the manufacture of batteries are not found in the household waste stream, two complementary approaches were implemented. First, upstream limitations were placed on the content of certain hazardous materials in batteries that were being brought to market, and downstream separated collection of used batteries containing mercury, cadmium, or lead. This is an example of a combination of controls put in place from the same environmental point of view.

In France, the application of the European legislation was difficult since the translation to French law did not take place until 1997, after a judgment by the Court of Justice of the European Communities. France then added the concept of Extended Producer Responsibility (EPR) which had not been referred to in the European legislation in order to ensure that the collection and treatment of household products containing hazardous materials. Quickly it became evident that a major obstacle was the inability of the consumer to differentiate between batteries containing hazardous materials and those that did not. France then extended to collection to all batteries. This extension is being considered today at the European level.

The Directive 91/157/EEC of March 18, 1991

It came into effect on January 1, 1993. On one hand it prohibits the marketing of Alkaline/Manganese batteries containing more than 0.025% mercury by weight. Those batteries "intended for a prolonged use under extreme conditions"[5] can, however, contain up to 0.05% mercury by weight. Button cells are excluded from these restrictions. Additionally it requires the marking and separate collection of the following categories:

- Dry cell batteries containing:
  - More than 25 mg of mercury, with the exception of Alkaline/Manganese batteries
  - More than 0.025% cadmium by weight
  - More than 0.4% lead by weight
- Alkaline/Manganese batteries containing more than 0.025% mercury by weight

Moreover, batteries in the above categories that are incorporated in various devices must be easily removable by the consumer after use.

This directive also requires the member states (of the EU) to establish programs aimed at reducing the harmfulness of used batteries such as their presence in household waste.

### 3.1 The Directive 93/86/EEC of October 4, 1993

This establishes the marking requirements for dry cell batteries set out in the Directive 91/157/CEE. The mark consists of one of the roll-out containers covered with an "x" indicating that this battery must be the object of a separate collection. The chemical symbol of the heavy metal concerned must also appear.

### 3.2 The Decree N° 97-1328 of December 30, 1997

The Directives 91/157/EEC of March 18, 1991 and 93/86/EEC of October 4, 1993 were to be enacted by the member states before September 18, 1992 and December 31, 1993 respectively. France, not having respected these deadlines, was the subject of a procedure of observation of failure by the European Commission. A finding condemning France was brought down on May 29, 1997 by the Court of Justice of the European Communities.

In order to put itself in conformity with the European legislation, on December 30, 1997 France adopted the Decree N° 97-1328. Besides the limitations on marketing and marking required by the European Directives, this decree adds the principle of Extended Producer Responsibility (EPR) to address her community obligation on separate collection:

- Dry cell batteries containing:
  - More than 25 mg of mercury, with the exception of Alkaline/Manganese batteries
  - More than 0.025% cadmium by weight
  - More than 0.4% lead by weight
- Alkaline/Manganese batteries containing more than 0.025% mercury by weight

[5] The directive cites, for example, temperatures below 0° C or above 50° C, or exposure to "shocks".

This mechanism forces distributors to take back without charge used batteries that are returned to them by householders. In the same way, producers[6] must begin to, or continue to, take back used batteries recovered by distributors or by local communities limited only by the quantities that they themselves have put into the market (the objective of this selective collection being 100%). Users other than households are required to ensure the collection, accounting for, and disposal of any used batteries that they may hold.

The some total of these obligations can be satisfied by the signing of conventions between the various parties involved in the category: manufacturers, distributors, recyclers, or refiners. These conventions require prior approval of the authorities.

### 3.3 The Directive 98/101/EEC of December 22, 1998

This takes effect from January 1, 2000, prohibiting the marketing of the following categories of batteries, as required by the Directive 91/157/EEC:

- Batteries, other than button cells, containing more than 5 ppm of mercury
- Button cells containing more than 2% mercury

### 3.4 The Decree N° 99-374 of May 12, 1999

Less than 18 months after entering into force, the decree N° 97-1328 of December 30, 1997 was repealed and replaced by the Decree N° 99-374 of May 12, 1999, which mandates collection of all used batteries, not just those containing hazardous materials. The separate collection required by the decree No 97-1328 very quickly came up against the difficulty for householders to differentiate between the batteries that required collection and those that did not.

This went into effect immediately for rechargeable batteries, and from January 1, 2001 for primary cells.

### 3.5 The Decree N° 99-1171 of December 29, 1999

This modified the Decree N° 99-374 in implementing the Directive 98/101/EEC.

### 3.6 Order of June 26, 2001

Taken pursuant to Article 11 of the Decree N° 99-374, it defines the reporting requirements of the system. Four types of reporting are foreseen:

- The manufacturers, importers, and distributors of their own brands are required to declare the quantities put on the market.
- Industrial users who import batteries for their own use are required to report the quantities concerned.
- The manufacturers, importers, and distributors are required to declare the quantities to which they have added value or eliminated.
- Persons or entities that may develop or eliminate batteries on their own account are required to report the quantities concerned.

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[6] The term producer is understood in the broad sense including importers and distributors of their own brands

ADEME (The French Agency for the Environment and Energy Management) is responsible for managing the information system and establishing an annual report (ADEME, 2002c; ADEME, 2003a; and ADEME, 2004)

### 3.7 Regulatory situation as of January 1, 2005

Marketing of the following categories is forbidden:

- Batteries, other than button cells, containing more than 5ppm of mercury
- Button cells containing more than 2% mercury

All used batteries accumulated in households may be returned without charge to the distributor, who in turn may return this product without charge to the producer or manufacturer.

These obligations can be satisfied by the signing of conventions between the parties covered by the regulations and their various partners in the collection and recycling process. These conventions must specify:

- Objectives of collection, valorization, and elimination.
- The respective responsibilities of the signing parties (collection points, frequency of collection, types of containers, etc.) as well as financial.
- Means of communicating this information to householders.

Implicitly the regulation requires 100% collection, however less ambitious objectives may be set within the various conventions.

### 3.8 Perspectives

On November 21, 2003, the European Commission adopted a proposal for a Directive to replace the current legislation on batteries. This proposal passed first reading in front of the European Parliament, and then the Council on December 20, 2004.

At this stage of the procedure, the principal characteristics of the proposal are as follows:

- Extension of the legislation to encompass all batteries. This is the major evolutionary change in the proposal.
- A partial prohibition on the use of cadmium in portable rechargeable batteries. The exception is for cordless tools (and a few other specific applications) and applies only to a very small part of the overall cadmium-containing batteries.
- Definition of quantitative objectives
    - Recycling of 100% of collected batteries within one year of the Directive's going into effect.
    - Within three years of the Directive's taking effect, achievement of the following recycling results:
        - All lead and at least 65% of the average weight of lead-acid batteries.
        - All cadmium and at least 75% of the average weight of material contained in NiCd rechargeable batteries.
        - At least 55% of the average weight of the materials contained in all other used batteries.
    - With four years and eight years respectively after the Directive goes into effect, collection levels of 25% and 45% respectively of all used portable batteries.
- Introduction of the principle of EPR for the treatment, recycling, and disposal of portable batteries, as well as for the collection, treatment, and recycling of industrial and automobile batteries. Financial guarantees (recycling insurance, blocked funds) must be in place before the producer can market the product.

This draft Directive pulls together numerous elements (EPR, financial guarantees) from the Directive on electronic and electrical equipment waste management. The Parliament and the Council have strongly amended the Commission's original proposal. At this stage, the collection objectives do not appear to be very ambitious.

### 4. The functioning of the Battery Collection Channel in France

In order to comply with their regulatory obligations, some producers formed eco-organizations, others set up individual mechanisms. Each one, whether collective or individual, presented to the authorities for approval a convention (or agreement) describing their methods of recovery and valorization. As of September 1, 2004, 10 conventions had been approved and were in force:

- Collectives
    - SCRELEC
    - COREPILE

- Individual
    - E. Leclerc
    - Intermarché, Ecomarché, Bricomarché
    - FNAC et SURCOUF
    - Leroy Merlin
    - Hypere U, Super U, Marché U
    - Groupe Boulanger
    - Décathlon
    - Distribution Casino France

The principal points contained in these conventions are:

- Collection objectives: the collective mechanisms envisage a rate of collection between 45% and 50% by 2006.
- The upstream contribution scale (for the Collectives) for batteries has member's contributions defined either by unit (detailed by cell size, and system), or by weight. They amount to 0.30 – 0.50 €/kg for Alkaline/Manganese and Zinc/Carbon batteries, and from 1.00 to 2.00 €/kg for lithium batteries. For other rechargeable batteries, contributions are based on weight and rise to 1.80 €/kg. In general these amounts represent less than 1% of the selling price.
- Means of communication with the public. This is primarily used to increase the collection rate. Media expenditures are forecast to amount to 30€ to 40€ per ton of product sold in the marketplace. Schools are particular media target markets.
- Contracts with collectors and recyclers.

These producers have signed contracts with distributors to provide collection points for the consumers. Local communities can also partner with the producers in setting up collection points at local dump sites.

In the case of the individual entities, the producer is also the distributor[8] and ensures the installation of its own collection points. These producers have also signed contracts with companies specializing in collecting, sorting, and recycling (see Figure 3) the used batteries.

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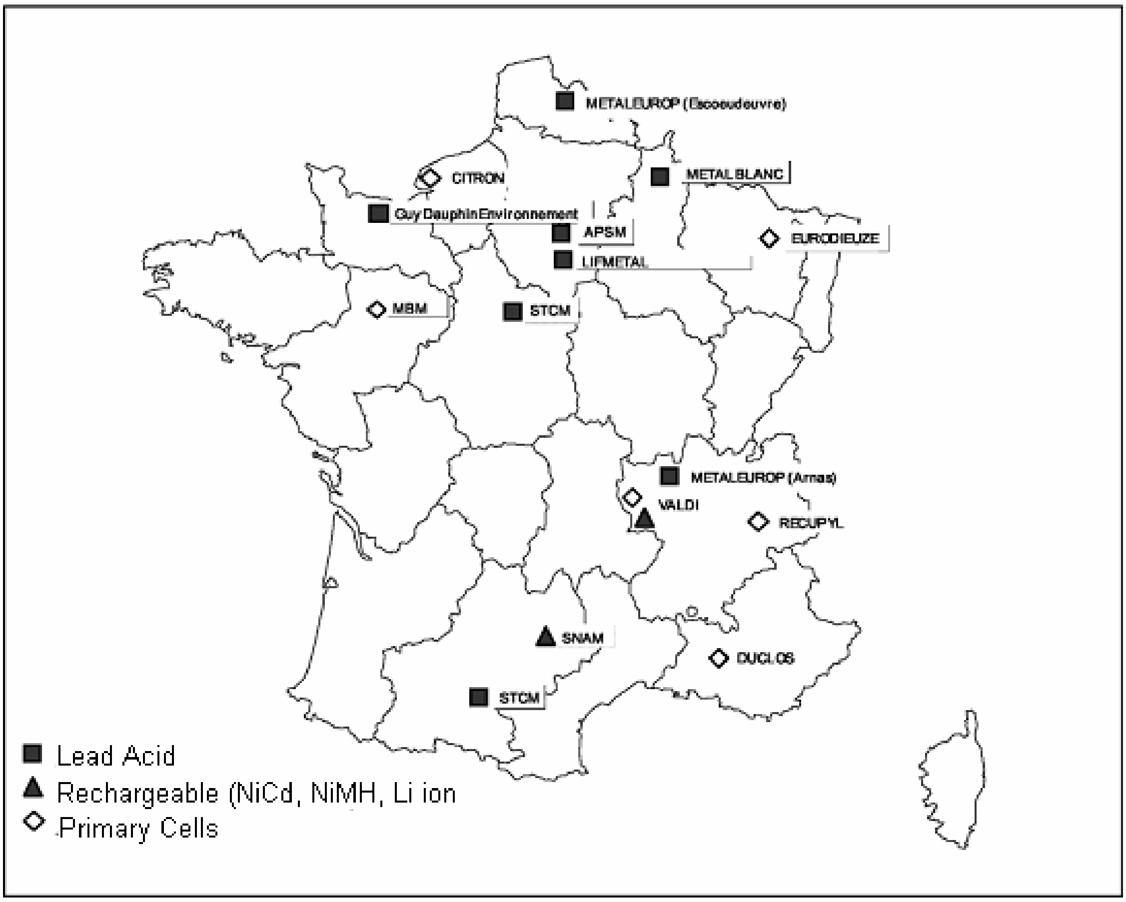
[8] This refers to distributors marketing batteries under their own brands.

Parallel to this, the printed public information produced by CERFA (Centre d'Enregistrement et de Révision des Formulaires Administratifs) 11801, 11802, and 11803 comes to support the findings of ADEME.

Figure 3. Sites for the pre-treatment and treatment of used batteries in France (source: ADEME, 2004)




The collection of used household batteries is strongly influenced by a particular phenomenon: household storage after use. Indeed, when they arrive at the end of their product life, a considerable portion of used batteries remain with their final user – whether or not they are built into the electrical appliance. The European Commission study (2003b) estimates that this applies to 30% of primary cells and up to 60% of rechargeable batteries.

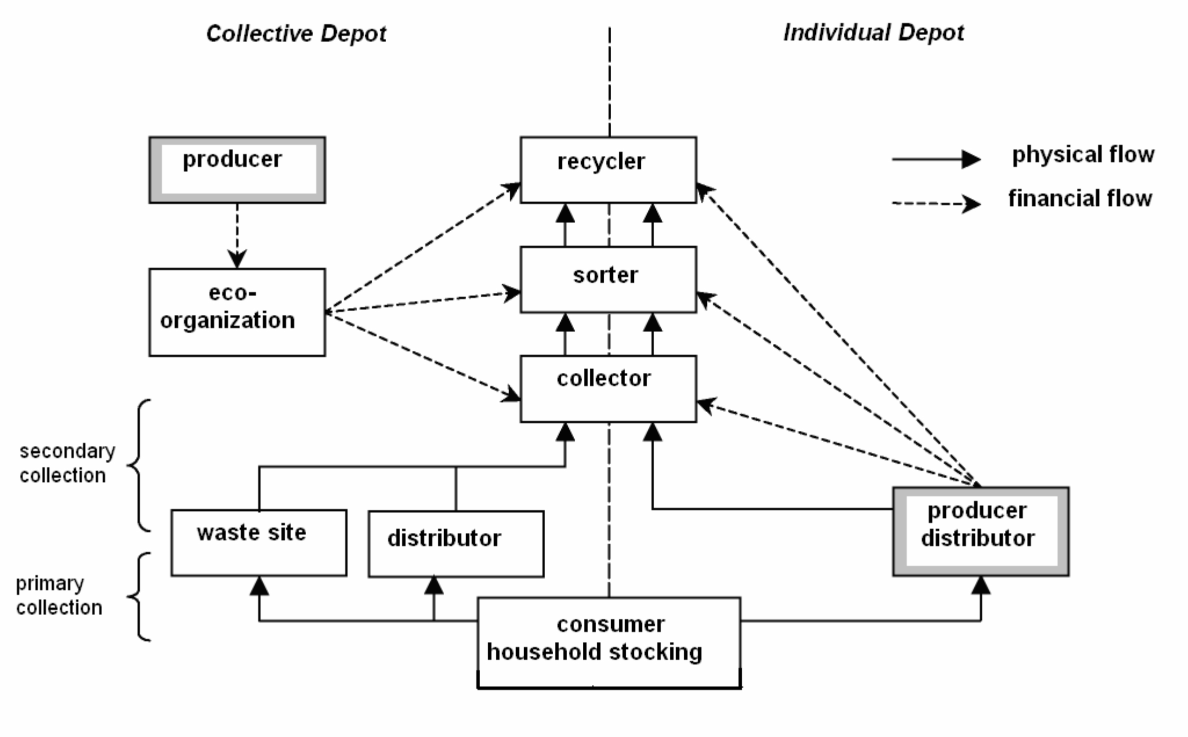
There are three possible explanations for this phenomenon:

- Awareness of the hazardous potential of spent batteries
- Ease of storing (small volumes)
- Failure to adapt to collection, and lack of information

Thus household storage reduces the amount available for collection. On the other hand, establishment of addition collection facilities can eventually contribute to a reduction in household stocking which would increase the amount available for collection. This phenomenon makes it very difficult to calculate the quantity of used batteries contained in the household waste stream. Only periodic physical studies are able to evaluate it precisely.

Finally the organization of the battery channel is presented in Figure 4.

Figure 4. Organization chart of the collective and individual depots for the collection and processing of used batteries




5. **Batteries as part of the EPR sector**

Taking into account the specifics of the battery category and the regulations described below, it is possible to establish the characteristics of this category.

- Specifics of the products concerned:
  - It only concerns used batteries coming from households.
  - They have a variety of design features (lifespan, environmental impact, recycling value).
  - The come from many and varied manufacturers (automotive, hi-fi, appliance, cordless tools, photography, general purpose … )
  - Their distribution network is quite dense and diversified (convenience stores, photography outlets, department stores, specialized shops … ).

- Legal mechanisms:
    - It is a mandatory régime, imposed by regulation.
    - No legal objective is explicitly laid down, but the obligation of recovery is implicitly set at a collection rate of 100%
    - The EPR is assumed by several collective collection services and by certain individual entities (major chain stores, etc.).

- Tools used
    - Distributors assume the responsibility of no-charge recovery, as do the manufacturers from the distributors.
    - No financing device is set out in the regulations.
    - Prohibition of marketing certain products is used as a complimentary tool.

- Shared responsibilities
    - Primary collection is the responsibility of the distributors.
    - Local communities can set up their own basic collection systems, but they are not so mandated by the regulations.
    - The manufacturers are responsible for the secondary collection and the recycling or disposal.

- Information and control systems
    - Annual reporting by l'ADEME*.
    - A priori control during the approval process.
    - A posteriori control to come gradually.
    - Consumer information to be introduced gradually.

Overall, we can conclude that the battery channel in France falls within the EPR régime, is characterized by a wide variety of products, manufacturers, and distributors, and by a fully responsible set of manufacturers and distributors. Additionally, we can also note that the involvement of governmental authority is relatively weak, and is limited to the approval of conventions.

## 6. Quantitative Data

### 6.1 Available sources

L"ADEME* was charged by the governmental authorities (Decree of June 26, 2001) with the management of the information and reporting system on batteries. To this end, a controlling office was established. Each year it publishes an analysis and the entirety of all of the reporting required by the Decree of June 26, 2001. It has thus become the source for all of the published data concerning the marketing, collection, and treatment of batteries.

The year 2001 marked the beginning of this reporting system. It is also an important year, since it marks the first year that the requirements of Decree N$^{o}$ 99-374 modified on May 12, 1999 were applied to all batteries. The 2002 report was published in November 2003. Although it was the second full year of mandatory reporting, the 2002 data remain incomplete (the case of lead-acid batteries).

The conventions and agreements validated by governmental authorities also remain a source of information, in particular concerning the methods of organizing the collection systems, the objectives of the contracting parties, and their methods of financing.

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l'ADEME is the French Agency for the Environment and Energy Management

### 6.2 Overall data

Table 9 presents the overall data for the marketing, collection, and treatment of batteries in 2002.

Table 9. Marketing, collection, and treatment of batteries in 2003*

| | Marketing | | Collection[(6)] | | Treatment | |
|---|---|---|---|---|---|---|
| | Number of Units | Tonnage[(1)] | Tonnage[(1)] | Collection Rate[(2)] | Tonnage[(1)] | Rate of Treatment [(3)] |
| **Dry Cell Batteries** | 776132 824 | 25 791 t | 6152 t | *23,8 %* | 8 210 t | *133,4 %* |
| Button or mercury | 220 340 | 0,6 t | 41 t | *(4)* | 20 t | *48,3 %* |
| Zinc carbon | 126 816 170 | 6 364 t | 5 223 t | *20,5 %* | 6 339 t | *121,4 %* |
| Alkaline | 587 745 193 | 19 169 t | | | | |
| Zinc-air | 21 742 051 | 57 t | 757 t | *1328,1 %* | 1 695 t | *223,9 %(5)* |
| Lithium | 22 291 099 | 185 t | 131 t | *70,8 %* | 156 t | *119,1 %* |
| Others | 17 317 971 | 15 t | | | | |
| **Rechargeables** | 56 558 022 | 190 088 t | 170 412 t | *89,6 %* | 170 715 t | *100,2 %* |
| Ni – Cd | 12 535 827 | 1 675 t | 938 t | *56,0 %* | 894 t | *95,3 %* |
| Ni – MH | 13 521 684 | 545 t | 55 t | *10,1 %* | 58 t | *105,4 %* |
| Lead - Acid | 12 133 226 | 185 501 t | 169 389 t | *91,3 %* | 169 753 t | *100,2 %* |
| Lithium | 18 206 013 | 705 t | 30 t | *4,3 %* | 10 t | *33,3 %* |
| Others | 161 272 | 1 662 t | | | | |
| **Total batteries** | 832690 846 | 215 879 t | 176 564 t | *81,8 %* | 178 925 t | *101,3 %* |
| **Total Batteries less Lead – Acid batteries** | 820557 620 | 30 378 t | 7 175 t | *23,6 %* | 9 172 t | *127,8 %* |

(1) Tonnage is estimated by multiplying the number of units by the average weight in each category.
(2 Calculated by dividing the tonnage collected by the tonnage marketed
(3) The treatment rate is calculated by dividing the tonnage treated by the tonnage marketed.
(4 All button cells, not just mercury cells, are included in this category.
(5) This very high rate is explained by old inventories being treated at ZIMAVAL (in 2002, 314 tos were treated).
(6) This counts only stocks received at treatment sites during the year, and does not take into account stocks already there, that amounted to about 1,800 tons.

* The conflict in dates (2002/2003) is the way it is presented in the original.

A first analysis makes it possible to identify several larger trends:

- Alkaline and Zinc-Carbon batteries (classified as non-hazardous waste when used) account for 92% of the number of units and 99% of the weight of all dry cell batteries on the market. Only about 20% of them were collected (15% in 2001 and 28% in 2002).
- Lead-Acid batteries, primarily automotive batteries account for 98% by weight of all rechargeable batteries put on the market, and 86% of all batteries. They (lead-acid batteries) have a very effective collection system (the vast majority is collected separately) that existed well before the implementation of these regulations. Indeed, it is the resale of the lead that makes this collection and recycling profitable
- By and large the used batteries that were collected were recycled promptly. Except for a couple of specific categories, there were no cases of storage or massive destocking (except for the case of considerable stocks remaining when ZIMAVAL went into bankruptcy).

## III – ECONOMY OF THE USED PORTABLE BATTERY SECTOR

The economic model of recycling lead-acid automotive batteries presents some unique economic characteristics, and its older establishment is linked to its profitability. Consequently this chapter is devoted only to other used portable batteries.

### 1. Management costs

The management costs for the recycling of used portable batteries can be broken down as follows:

- Primary selective collection
  - Dump / landfill
    - Share of overhead
    - Share of equipment costs
  - The distributor level
    - Share of overheads
    - Share of equipment costs
- Selective secondary collection
  - Collection from collection points
  - Replacement of containers
  - Transportation to sorting centre
- Sorting operations and transportation to the recycling centre
- Recycling operations
- Administrative and communications costs

In the same way, management costs for used portable batteries collected in the household waste stream can be broken down as follows:

- Collection with household waste
- Incineration with household waste
- Landfilling with household waste

#### 1.1 Sources of data

Concerning the costs of the recycling of used portable batteries, the various conventions approved by governmental authorities contain the contracts binding the manufacturers to the various parties involved in the collection, sorting, and recycling. The rates invoiced by these various parties are available in the conventions. These rates are not very different from one party to another performing similar work, or from one (national) convention to another. Additionally, the study undertaken by BIO IS for the European Commission (European Commission 2003b) brings together all of the data on the cost of recycling in the battery sector for the various countries of Europe. For France the data comes from an analysis of the mechanism set up by SCRELEC. It is about the only study that covers all of the costs for the entire battery sector. Finally, the study on “The Balance Sheet and the Outlook for a Decade of Recycling” (ADEME 2002d) incorporates a number of elements to the costs of recycling used batteries. These costs are also included in a study undertaken by ADEME in 1998.

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SCRELEC is a French organization primarily concerned with collecting and recycling WEE (Waste Electrical and Electronic Equipment.

As far as the household waste stream is concerned, numerous sources can be utilized, including:

- ADEME: "Thermal Treatment of Household Waste – Study of 42 French Operations Assisted by ADEME." (September 2002.
- ADEME: "The Waste Market and Associated Activities: Situation in 2002 and Outlook for 2003/2004." (December 2003).

### 1.2 Determination of management costs

The costs for householders to bring their used portable batteries to the points of collection may be regarded as negligible. Indeed, we can make the assumption that there is no specific inconvenience taking into account the ease of transporting waste batteries (low volumes).

The BIO IS Study does not provide any data on equipment costs at the collection points, because these costs are covered by the distributors, or the local communities. Nevertheless the estimates for Belgium and Germany come to 56 €/t and 150 €/t respectively. We will use an average of 100 €/t with the understanding that this important estimate is uncertain.

The analysis of the SCRELEC model by the BIO IS data for the secondary collection gives us an estimate of 457 € per collected ton. We should note that this amount is definitely lower than that proposed the the ADEME 2002d study, namely a cost for sorting and transportation of 969 €/t.

Table 10. Costs of recycling for different types of used batteries

| Types of Used Batteries | Recycling Costs |
|---|---|
| Alkaline and Zinc-Carbon batteries | 1 000 €/t |
| Button cells | 2 600 €/t |
| Lithium batteries | 2 000 €/t |
| Lead-Acid Rechargeables | 1 000 €/t |
| NiMH Rechargeables | 0 €/t |
| NiCd Rechargeables | 300 €/t |
| Li-ion Rechargeables | 1 000 €/t |

*Source : European Commission (2003b)*

As far as recycling costs are concerned, there are considerable disparities between the various types of used batteries (see Table 10). These disparities are explained by the resale prices of the recovered metals, and by the hazardous (or not) character of them (example: mercury content), and of the nature of the recovery processes employed. Thus, for example, the resale value of nickel, makes it possible to fully finance the recycling costs of those systems utilizing this metal. All in all, the average cost of recycling used batteries is about 1000 €/t.

Table 11 recapitulates all of the costs involved and very clearly shows the advantages to using the normal household waste stream. The report on cost differential between the two methods of dealing with used batteries varies by a factor of 11 to 30 times according to the battery system type. Consequently, in the absence of some legal restraint, no used portable battery would be recycled.

Table 11. Management costs for used batteries

<table>
<tr><th>Recycling Model</th><th colspan="2">Househould Waste Stream Model</th></tr>
<tr><td>Primary collection<br>***100 €/t***</td><td colspan="2" rowspan="2">Collection of normal household waste<br>***60 €/t***</td></tr>
<tr><td>Secondary collection<br>***457 €/t***</td></tr>
<tr><td>Sorting and transportation<br>*152 €/t*</td><td rowspan="3">Incineration<br>***78 €/t***</td><td rowspan="3">Landfill in CET II<br>***70 €/t***</td></tr>
<tr><td>Recycling (see Table 10)<br>***0 €/t à 2 600 €/t***</td></tr>
<tr><td>Administration – communication<br>***790 €/t***</td></tr>
<tr><td>**TOTAL**<br>**Alkaline & Zinc-carbon 2 500 €/t**<br>**Button cells 4 100 €/t**<br>**Lithium batteries 3 500 €/t**<br>**Lead-Acid Rechargeables 2 500 €/t**<br>**NiMH Rechargeables 1 500 €/t**<br>**NiCd Rechargeables 1 800 €/t**<br>**Li-ion Rechargeables 2 500 €/t**</td><td>**TOTAL**<br>**138 €/t**</td><td>**TOTAL**<br>**130 €/t**</td></tr>
</table>

*source : European Commission (2003b), ADEME (2003b)*

## 2. External costs

### 2.1 Data sources

Specific sources of information on the environmental costs related to used batteries do not exist. The external costing must be traced through other external data sources such as those on atmospheric heavy metal emissions.

The determination of external costs requires three principal input elements, which are relatively easy to come by:

- Pressures (physical emission of pollutants): atmospheric emissions on incinerators (easily measurable), long-term leaching from discharges into subsoil waters (largely unknown[9]).
- Impacts (relationship between the pressures and their health and environmental consequences): dose relations – response with or without the threshold effects, or long-term impacts from very low doses.
- The monetary value of the health and environmental impacts: value of lifestyle, value of the harmful effects (odors, etc.).

The reconstitution of each one of these stages in order to obtain their monetary values goes beyond the boundaries of this study. This study will be content in using the monetary values presently in the existing literature. A review of the latter has made it possible to readily identify available and reliable data sources. Table 12 displays these sources while distinguishing:

- The monetary value from the impact of the heavy metals contained in the used batteries (pressures described in Figure 1): for example, heavy metal emissions at the time of incineration of used batteries.

[9] The European Commission study 2000b qualifies as "immeasurable and uncertain" the impact on health and the eco-system of leached discharges into subsoil waters.

- They monetary values of the overall impacts, excluding that of heavy metals (corresponding to the pressures descried in Figure 2): emissions by transporters during the collection process, harmful effects of the incinerators and other discharges …

Table 12. Data sources of the monetary values of external factors related to the management of used batteries

| Sources and External Impacts | | Sources Chosen from Available Data Bases | Comments |
|---|---|---|---|
| ***Monetary value of impacts specific to heavy metals*** | | | |
| Incineration | air | Rabl & Zoughaib, 2004 | Values recalculated within the framework of the ExternE Project |
| | water | No data available | |
| CET I | water<br>soils | No data available | |
| CET II | water<br>soils | No data specific to heavy metals available | |
| Ash Recycling | air<br>water<br>soils | No data available | |
| ***Monetary value of overall impacts (except for heavy metals)*** | | | |
| Selective collection of batteries | air | Commissariat Général du Plan (2001) | Calculations based on these sources suggest that a ton of used batteries yields « 25 km en PL et 225 km en VL » (what this means, is not understood by translator) |
| | accidents | European Commission (1996a), Commissariat Général du Plan (2001) | |
| Household waste | air<br>accidents | Commissariat Général du Plan (2003b) | Values calculated in European Commission study (1996a) |
| Incineration | Nuisances noise | Very little or no data available | Few specific studies |
| | air | Commissariat Général du Plan (2003b) | Normal emissions used : |
| | water | Very little or no data available | |
| CET I | nuisances | MEDD/D4E (2003)<br>DEFRA (2003) | |
| | water<br>soils | No data available | |
| CET II | nuisances | MEDD/D4E (2003)<br>DEFRA (2003) | |
| | water<br>soils | No usable data | Analysis by le Commissariat Général du Plan (2003b) shows that the little data available is inconclusive |
| Sorting – Recycling of used batteries | nuisances | No available data | Values obtained from waste data |

The least reliable of the available data deals with the atmospheric pollution from incinerators. A study undertaken on behalf of ADEME (Rabl & Zoughaib, 2004) shows the values used within the ExternE project. The monetary value of other impacts is much less obvious, because of the absence of data, lack of values of transfers of hazardous materials, and a lack of detail (which doesn't allow us to calculate the external costs specifically related to used batteries).

Concerning the monetary values of the overall impacts, we will use primarily a study carried out in 2003 to evaluate the public service policies of waste managers (Commissariat du Plan, 2003b) which was a general review of the available knowledge in this field.

The insufficiency of data is not an insurmountable obstacle to calculating the external costs of used batteries, provided that it is possible to identify and assign a monetary value to those impacts that carry significant environmental costs.

### 2.2 Principal external costs that are specific to heavy metals

Air pollution caused by the emission of heavy metals from incineration was the subject of studies done within the framework of the ExternE Project. The costs to the environment were estimated to be 18,000 €/t for cadmium and 2,530 €/t for nickel. Taking into account the total emissions of cadmium and nickel by the UIOM (Usines d'incinération des ordures ménagères – Household Waste Incinerators) (see Table 6) the national external costs rise respectively to 33,200 €/t and 4,200 €/t, used batteries being obviously not the only source.

The impact of incineration on water pollution depends on the technology employed in cleaning the smoke. In the absence of precise data on these external costs, we will not take it into account, since they are probably not significant.[10]

The impact of heavy metal leaching into ground water from CET I (hazardous material landfills) was not evaluated. Taking into account the strong legal restrictions surrounding this activity in France, we will assume that any leaching is negligible, and that the corresponding costs will be nil.

As far as CET II (non hazardous waste) sites are concerned, there are no studies evaluating the cost of heavy metal leaching into ground water. The only existing data – sparse and of dubious value – relates only in a general way to leachates. Additionally, heavy metals contained in the leachates can have an environmental impact even if there is no underground leaching. Indeed, the treatment of recovered leachates is not 100% effective. But there is no data that permits us to quantify this impact.

The recycling of incinerator slag or ash consists in using this residue in public works (i.e. roadbeds). To this end they must respect certain standards on the leaching of heavy metals. These standards make it possible to limit this use of incinerator residue if the standards on heavy metal leaching are not respected. Consequently, we will not take into account the possible environmental impact of the recycling of incinerator residue – at least as far as heavy metals are concerned.

### 2.3 Principal external costs for general impact (not heavy metals)

The harmful effects of the CET landfills were the subject study done on a French site (MEDD/D4E, 2003) and an evaluation of the overall costs on all of the sites in Great Britain (DEFRA, 2003). The first study, which has the advantage of having been done on a French site, yields a cost ranging between 0.30 and 1.50 € per ton of buried waste. The second study, which has the advantage of covering a great number of sites, yields a range of 2.16€/t to 3.10€/t[11]. We will use 2.00 € per ton. The choice

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10 The report "Economic Evaluation of the Draft Incineration Directive" (European Commission, 1996b) also estimates that impacts on water are probably negligible, but does not present and studies that support this assertion.

11 Conversion rate as at December 23, 2003 1.00 € = 0.703 £.

of this cost can be justified by two arguments: the French site has been extremely well managed from an environmental perspective, and the British sites generally have lower environmental standards than their French counterparts.

We will use this same cost for the harmful effects of other installations (incinerators, sorting stations, and recycling facilities) because there are very few specific studies on this topic.

The external costs of collecting household waste in the general waste stream are estimated at approximately 11.00 €/t (Commissariat Général du Plan, 2003b). We should note that accidents account for more than 90% of this amount, with the balance coming from air pollution.

No study has been done on the subject of evaluating the external costs of the selective collection of used batteries. It is very specific (i.e. collection from distributors and other collection points) and it is not possible to use data on selective collection of traditional recycled materials, such as packaging. A specific calculation was carried out. Data provided by Corepile (*a French battery recycling firm*) estimate an average collection run of 225km/t in a light vehicle and 25 km/t in a large truck [12]. The impact on the air per kilometer driven comes from the Boiteux Report (Commissariat Général du Plan, 2001), and that for accidents comes from the Boiteux Report and the European Commission (EC 1996a). We thus obtain a cost of 11.00 €/t for air pollution and 30.00 €/t for accidents.

The impact of incineration on air pollution and global warming depends on the standards of emissions that are applied. We will take into account the directive of 2000[13]. As specified above, we will ignore any contribution made by used batteries to $CO_2$ emissions or to energy generation. We then come up with an external cost of approximately 28.00 €/t (Commissariat Général du Plan, 2003b) for atmospheric emissions from incineration. It should be noted that this cost drops to 16.00 €/t if we apply a limit of 80 $mg/Nm^3$ to $NO_x$.

In the same way as for heavy metals, the impact of incineration on water is regarded as being negligible.

The impact of CET I on ground water is unknown. We will ignore this source because of the tight environmental controls in place.

The impact of CET II is also far from known. The Commissariat Général du Plan (2001) considers that the available data are not very reliable coming from only one source, and having been arrived at by an "approximative method". Consequently we will not take into account any pollution or risks of pollution from this source.

### 2.4 Summary of the external costs

Table 13 recapitulates the external costs contained in the cost – benefit analysis

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12 Light vehicle from the collection point to the sorting centre and heavy truck from the sorting centre to the recycling centre.

13 Directive 2000/76/EC of December 4, 2000 (JOCE of December 28,2000)

Table 13: monetary values of the external costs associated with managing used batteries

***Monetary value of impacts of heavy metals***

| Sources and directions Of pollution | | External costs | Source of data |
|---|---|---|---|
| incineration | air | Cd : 39.00 € /kg of emissions<br>Ni : 3.80 € /kg of pollutants emitted<br>Pb : 1600 € /kg of pollutants emitted<br>Hg : 1000 € /kg pollutants emitted | Rabl & Zoughaib, 2004 (ExternE method) |
| ***Monetary value of overall impacts (excuding heavy metals)*** | | | |
| Selective Collection | air | 11.00 € per ton of collected batteries | As per the Commissariat Général du Plan (2001) |
| | accidents | 30.00 € per ton of used batteries collected | As per the Commissariat Général du Plan (2001) and the European Commission 1996a) |
| Household waste collection | air | 1.00 € /ton of collected waste | Commissariat Général du Plan (2003b) |
| | accidents | 10.00 € / ton of collected waste | |
| Incinération | nuisances | 2.00 € /ton of incinerated waste | Costs transferred |
| | air | 28.00 € /ton of incinerated waste | Commissariat Général du Plan (2003b) |
| CET I | nuisances | 2.00 € /ton of landfilled waste | Costs transferred |
| CET II | nuisances | 2.00 € /ton of landfilled waste | MEDD/D4E (2003)<br>DEFRA (2003) |
| Sorting & recycling of used batteries | nuisances | 2.00 € per ton of recycled batteries | Costs transferred |

## 3. External benefits

The benefits associated with the recycling of used batteries are found in the environmental impacts that are avoided by the extraction and refining stages of the virgin raw materials. The monetary values that correspond to these impacts are summarized in Table 14.

Table 14. Monetary values of the external benefits associated with the recycling used in the manufacture of batteries.

| Metal recycled | External benefits from recycling | Source of the monetary value data |
|---|---|---|
| Cd | 1,56 € / kg | From the « avoided impacts » shown in Table 8 and the monetary value data give by Rabl & Zoughaib, 2004 (ExternE method) |
| Ni | 3,09 € / kg | |
| Zn | 1,18 € / kg | |
| Pb | 0,53 € / kg | |
| Fe | 0,54 € / kg | Commissariat Général du Plan (2003b) |
| steel | | |

The Commissariat Général du Plan (2003b) estimates that the external benefits from recycling ferrous and non-ferrous metals are in the neighbourhood of 540.00 € /t and 1,700 € /t respectively. These values come from a single study (European Commission, 1996a) on recycling municipal waste and were obtained almost exclusively on steel and aluminum. For other metals, Table 8 gives, for some of them, the environmental costs that can be avoided by recycling. The corresponding external benefit was obtained by using the unit costs of Rabl & Zoughaib (2004), except for the saved energy, for which we used the external cost of the production of electricity from burning coal[14].

For mercury, the lack of data leads us to ignore any external benefit from its recycling. We will reconsider this point in our sensitivity analysis.

## 4. Cost – Benefit Analysis

### 4.1 Methodology

The cost – benefit analysis is calculated on the basis of batteries currently (2003) being put onto the market, in accordance with current regulations. It is thus an analysis of the current state of the business and not necessarily of current real costs. Older batteries, with much higher levels of mercury, whose marketing is prohibited today, but are still entering the waste stream, are not taken into account.

In addition, the cost parameters used are based on current estimates. They are the result of current selective collection. However the more this rate increases, the more the cost of selective collection is expected to increase. But for this analysis we have assumed that both the management and external unit costs will not vary according to the rate of selective collection.

Two arguments justify using this simplifying assumption:

- It would be very difficult to estimate what the costs might be if the rate of selective collection were different than what we see today.
- The average cost of managing battery recycling probably does not vary greatly according to the rate of selective collection; the essence of the cost derives from the process of recycling and not from the selective collection itself.

Consequently this cost – benefit analysis does not enable us to determine an optimal rate of selective collection. At most it helps us determine the best case scenario, that is to say the one that has the lowest social cost.

### 5.2 Overall results

Table 15 shows the management costs and the external costs and/or benefits of the household waste stream model as well as for the recycling model (selective collection, sorting, and recycling).

It would appear that the managing costs of the recycling model are extremely high, far higher than those of the household waste stream model. From the point of view of social costs, recycling is not justified for any type of battery other than mercury button cells, even if, for a few, the external benefits of recycling exceed 1000 €/t.

We can distinguish a relatively homogeneous group with the battery sector. It is the zinc-carbon, alkaline, zinc-air, and lithium batteries. Their environmental impacts are limited when they are randomly distributed within the general household waste stream, whereas the cost of recycling these types is very high.

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[14] The extraction and refining of these metals takes place mostly in the developing world, where the principal source of electricity is coal-fired generators.

Table 15. Cost of managing the battery models (the calculation of the costs is detailed in Annex 3).

| | | Collection model | | | Recycling model | | |
|---|---|---|---|---|---|---|---|
| | | Management cost | External cost | Social cost | Management cost | External cost | Social cost |
| | Button or mercury | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | Zinc-carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | Alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | Zinc-air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | Lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| * | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 | 650 €/t |
| * | NiM H | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 | 210 €/t |
| * | Lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

* Rechargeable

Mercury button cells show such an extremely high social cost, that whichever handling model is used, recycling is definitely called for. The external cost of the collection model comes primarily from the atmospheric emissions of mercury from incinerators[15]. These results make a very strong case for an outright ban on the sale of this battery system. Current regulations are moving correctly in this direction. The question remains nevertheless: what is the optimum threshold rate for mercury; was it necessary to reduce it to 5 ppm? The sensitivity analysis will answer this question.

The social cost of managing used NiCd batteries is relatively high. Whatever the model considered, the social cost exceeds 450.00 €/t. Atmospheric emissions of incinerated cadmium and nickel explain these costs. We will look at these results again later.

Finally in looking at NiMH rechargeable batteries, it is not possible to favour one or the other model. Indeed, the social costs are close and the uncertainties in the underlying data do not really permit a decision. Also these costs remain at relatively low levels, which do not justify significant efforts to restrict the use of this system.

### 5.3 Sensibility analysis

Much of the data underlying the cost – benefit analysis are characterized by considerable uncertainties. An analysis of the sensitivity of the results to these data was carried out. The detailed results are presented in Appendix 2.

- External benefits on the recycling of mercury: its value lies only in the external cost of recycling the mercury, but without calling into question a comparison of the management models. For all other types of batteries, the trace mercury present (< 5ppm) is too low. The cost-benefit analysis made by ignoring the external benefit of recycling mercury thus remains completely valid.

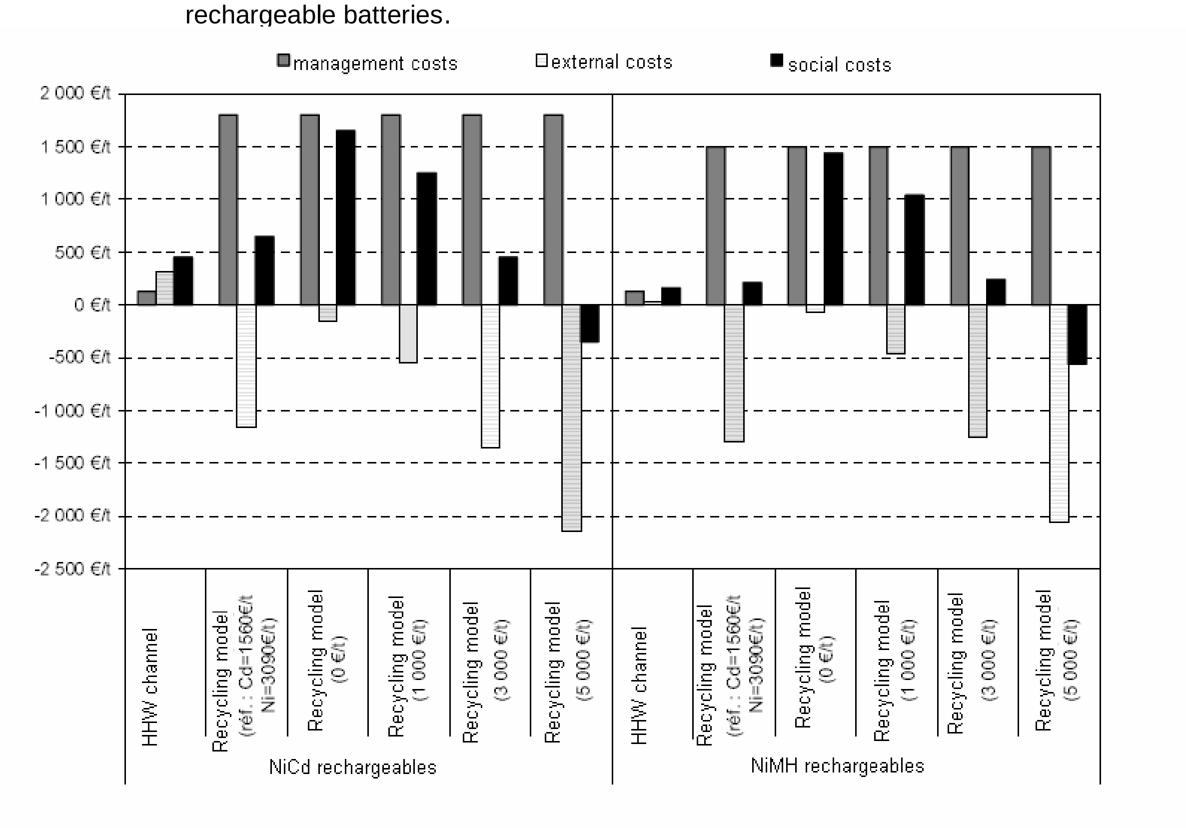
[15] We should remember however, that these heavy metal emissions were not taken into account owing to a lack of data on the subject.

Table 16. Influence of the external benefits of recycling mercury on the cost-benefits analysis of managing mercury button cells.

| External benefits of mercury recycling | Social costs of the household waste model | Recycling model | | |
|---|---|---|---|---|
| | | Management costs | External cost | Social cost |
| 0 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 900 €/t |
| 1000 €/t | 6 200 €/t | 4 100 €/t | - 220 €/t | 880 €/t |
| 3000 €/t | 6 200 €/t | 4 100 €/t | - 260 €/t | 840 €/t |
| 5000 €/t | 6 200 €/t | 4 100 €/t | - 300 €/t | 800 €/t |

- External benefits on the recycling of cadmium and nickel: Figure 5 shows that the influence on the cost – benefit analysis of the management of used NiCd and NiMH batteries is fundamental. As long as the benefits remain less that 3000 €/t, utilizing the household waste stream is socially preferable, above that amount recycling is desirable.

Figure 5. Influence of the external benefits of recycling cadmium and nickel (value in parentheses) on the comparison of management models of NiCd and NiMH rechargeable batteries.



- Mercury content of alkaline batteries (other than button cells): it is limited today to 5 ppm. But is this threshold justified from an economic point of view?

Figure 6. Influence of the mercury content on the social cost of the management channels for alkaline batteries.

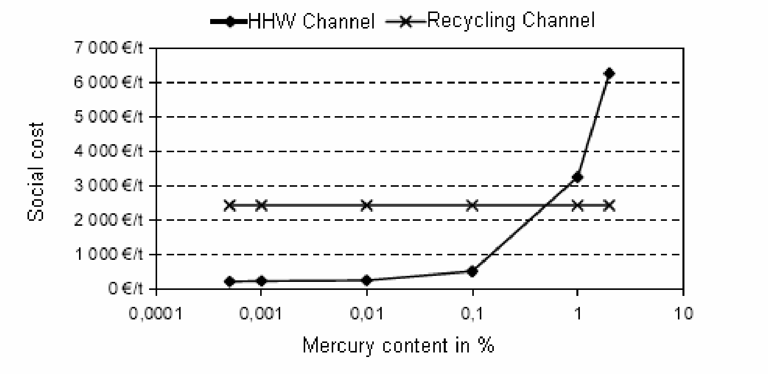
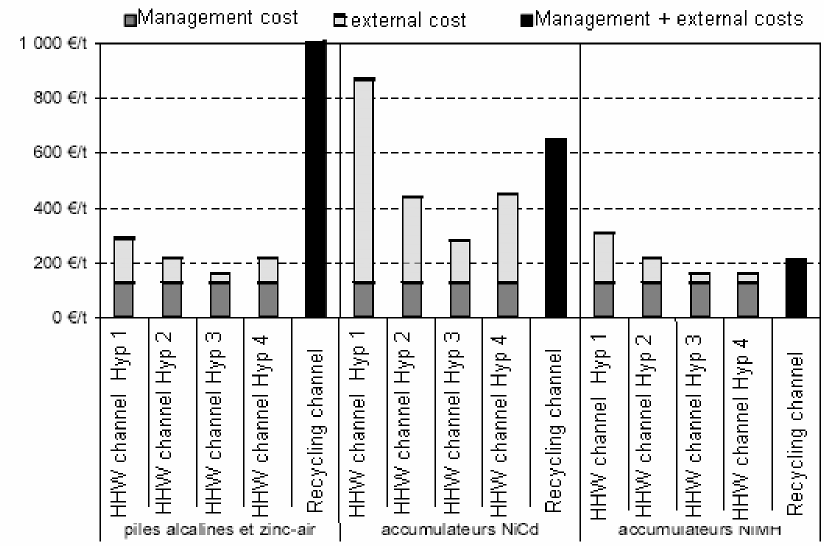



Figure 6 shows that until a rate of approximately 0.5%, the HHW collection model is preferable, but all the same generates a social cost which can rise to nearly 2,500 €/t. Below 0.01% (100 ppm), the social cost of the HHW model remains almost constant. The legal threshold of 5 ppm thus appears to be very strict when taking into account the environmental profit that it gets ( passing from 5 ppm to 100 ppm yields a 30 €/t gain on the social cost of the HHW model, or 12%). The analysis would need nevertheless to calculate the economic interest in moving the threshold from 5 to 100 ppm. Indeed, if the 5 ppm limitation does not involve production costs greater than a 100 ppm limit, then the current threshold remains justified.

- Distribution of heavy metals in the output of incinerators: the environmental impact of the HHW model comes primarily from the atmospheric emissions of the incinerators. The assumptions made on the share of heavy metals found in the air are important (see Figure 7). It is particularly true for NiCd rechargeable batteries. With an assumption of the acceptability of raised emission limits, the recycling of NiCd and NiMH rechargeable batteries is no longer justifiable.

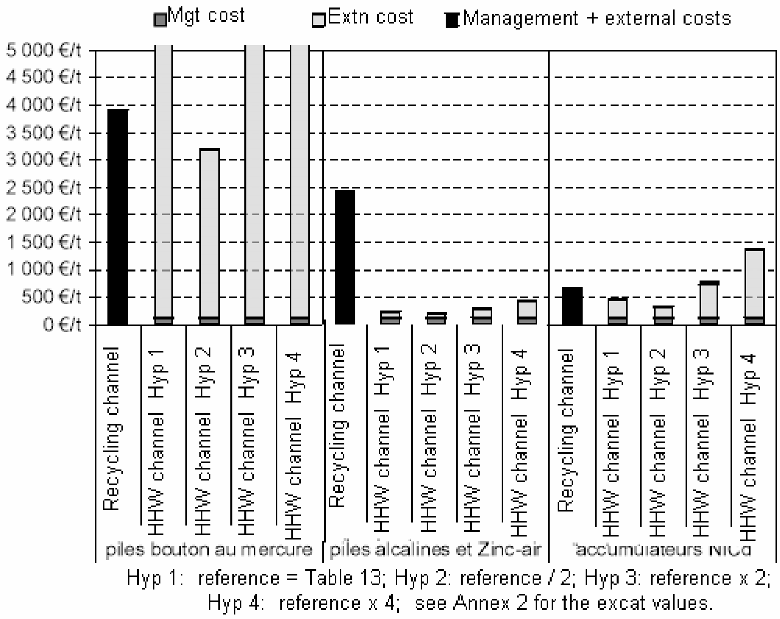
Figure 7. Influence of the distribution of heavy metals in incinerator residue on the social cost of different channels.




Hyp 1: elevated atmospheric emissions; Hyp 2: medium atmospheric emsiisons; Hyp 3: low atmospheric emissions; Hyp 4: reference = Table 7; see Annex 2 for exact values.

- External cost of heavy metal emissions by incinerators: calculating the monetary cost of air pollution from heavy metals is subject to some uncertainties. It is thus useful to examine how the results change when the unit costs (euros per kg of emitted pollutants) selected are different. Figure 8 shows that the desirability of the HHW channel for the disposal of alkaline and zinc-air is very strong. For mercury button cells, it would be necessary to make an assumption of very low external costs in order to justify not recycling. For the NiCd rechargeable batteries, multiplying the external costs by 2, is enough to change the desirability from one channel to the other.

Figure 8. Influence of the external cost of atmospheric heavy metal emissions on the social costs of different waste channels.




### 5.4 Conclusion

In summary, the cost-benefit analysis shows that collecting and recycling batteries is not economically justified, except for mercury button cells, and under certain conditions, NiCd rechargeable batteries.

The recycling of mercury button cells is always preferable, unless we make an assumption of very low external costs for mercury atmospheric emissions. But in all cases, the social cost of managing the end of lifetime of this battery system exceeds 3,000 €/t. It is desirable to restrict the use of mercury button cells to a bare minimum.

For zinc-carbon, alkaline, and zinc-air, as well as lithium batteries and rechargeables the recycling channel is not justified from an economic standpoint. This might only be called into question by the presence of an elevated level of mercury (greater than 0.5%). But in that case, the cost to society is high (approximately 2,500 €/t.). The limitation on mercury levels contained in the regulations is important, even if the threshold is quite strict in view of the environmental benefit that it yields. In addition, it is interesting to note that the conclusions of the cost-benefit analysis coincide neatly with the first European regulations on batteries (directive 91/157/EEC of March 18, 1991) which mandated only the collection of batteries containing mercury, cadmium, or lead.

Management of the end of product life for NiMH rechargeable batteries is relatively inexpensive. But the social cost of their recycling depends to a great degree on the external benefits of recycling nickel. Lastly, it appears best to leave the NiMH rechargeable batteries in the normal household waste stream, which guarantees a limited social cost. This conclusion might be modified if it could be shown that the recycling of nickel would bring a greater benefit than assumed in this study.

Table 17. Total social cost of different scenarios of managing used batteries.

| total social cost | | Current situation | Collection with 100% recycling | No selective collection | No collection but a ban on NiCd |
|---|---|---|---|---|---|
| dry cells | mercury button cls | ? | 2 300 € | 3 700 € | 3 700 € |
| dry cells | zinc-carbon | 4 052 000 € | 15 464 500 € | 1 018 200 € | 1 018 200 € |
| dry cells | Alkaline | 13 113 500 € | 46 580 700 € | 4 217 200 € | 4 217 200 € |
| dry cells | zinc-air | 138 500 € | 138 500 € | 12 500 € | 12 500 € |
| dry cells | lithium | 459 100 € | 634 500 € | 29 600 € | 29 600 € |
| rech | NiCd | 941 300 € | 1 088 700 € | 753 700 € | - |
| rech | NiMH | 89 900 € | 114 400 € | 87 200 € | 355 200 € |
| rech | lithium | 176 500 € | 1 706 100 € | 112 800 € | 112 800 € |
| | **Total** | **18 970 800 €** | **65 729 700 €** | **6 234 900 €** | **5 749 200 €** |

In order to quantify the overall issue of used batteries, Table 17 shows the total social costs for three scenarios of product management,

- Current situation with the 2003 rate of selective collection (see Table 9).
- Collection and recycling of all batteries.
- No collection.
- No collection, but with NiCd rechargeables replaced by NiMH rechargeables.

The extreme objective of collection and recycling of all batteries would result in multiplying the social cost by three and half times over the current situation. On the other hand, applying cost-benefit recommendations of this study would reduce it to a third of current costs, thus saving 13 million euros each year. The bulk of this saving would come from not recycling zinc-carbon and alkaline batteries.

### 5. The particular case of NiCd rechargeable batteries

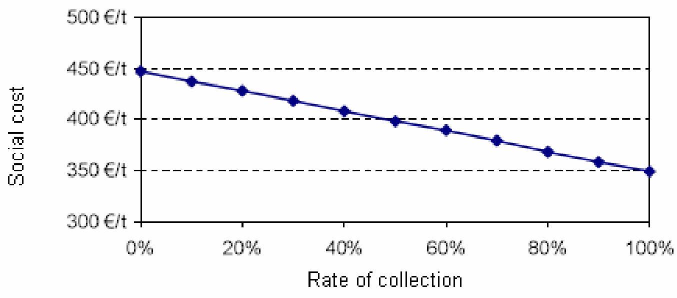
Mixed in with household waste, NiCd batteries have a large impact on the environment essentially from incinerator emissions of cadmium. The social cost of this channel comes to 450 €/t. In spite of substantial benefits arising from the recycling of nickel and cadmium, the high management costs of the recycling channel do not make it worthwhile, as its social costs come to 650 €/t.

The end of the product life for this type of battery is very expensive for society, except in the case of the minimum assumptions on atmospheric emissions of incinerators (see Figure 7). In this case the cost of the HHW channel falls to 280 €/t. Consequently, it is the right approach to limit sale of these batteries (on the same basis, but to a lesser degree, as for mercury button cells) and to encourage substitution by NiMH rechargeable batteries, since the cost of this system is less than 290 €/t.[16] This substitution is taking effect already because of the operation of market factors (European Commission, 2000a).

Nevertheless, it might be interesting to look at a ”third way” of handling used NiCd rechargeable batteries. It would consist of selectively collecting them only in jurisdictions where household waste is being incinerated. This solution would avoid the external cost of atmospheric cadmium emissions. The social cost of using this channel would come to 350 €/t if the rate of collection were 100% in the jurisdictions concerned. But as this rate decreases, the cost of this channel increases (see Figure 9). Additionally the public would have to be made to understand why collection of used NiCd batteries was only being undertaken in some areas, and not in others. Given all these difficulties, the benefit to society is likely reduced to zero. Finally, this “third way” does not appear to be more desirable than the two traditional channels.

16 This is the difference in social costs between optimal management of NiCd and NiMH rechargeable batteries at the end of their product lives.

Figure 9: Influence of the rate of collection on the social cost of managing used NiCd rechargeable batteries by selectively collecting them only in jurisdictions where household waste is incinerated.




Finally, placing restrictions on the use, or even the prohibition of NiCd rechargeable batteries should be a priority issue. Substitution by other types of rechargeable batteries (NiMH, Li-ion … ) is possible for the majority of applications (see European Commission, 2000a).

## IV – CONCLUSION

Historically, batteries are products that have contained several highly toxic metals. Managing the end of their product life first became the object of European legislation in 1991. It was one of the first waste management products to be dealt with by the European Union, even before packaging materials. Applying the legislation, which really only concerned itself with regulation and not communication, posed problems for consumers in identifying which batteries contained mercury, cadmium, or lead. Widening the scope to progressively include all battery systems was felt to be essential by several member states, including France, which currently has a new directive under discussion.

The organization put in place by France is based on the principle of Extended Producer Responsibility (EPR). Responsibility falls entirely on distributors and manufacturers, who may form eco-organizations. Local communities are only slightly involved in the process. Involvement of public authorities remains peripheral, and is mainly limited to approving the various contracts among the other parties. This system does not result in very effective selective collections: only about a quarter of the batteries (with the exception of automobile batteries) put on the market in 2003 were collected in that year.

The cost-benefit analysis, considering all of the management and environmental costs, makes it possible to determine which modes of collection and treatment are best for each type of battery system. Supplemented by a sensitivity analysis, the results appear to be satisfactorily reliable despite some weakness in the underlying data sources. The principle conclusions are as follows:

- For the majority of batteries, collection and recycling is not desirable from the standpoint of social cost. The environmental impacts related to their management in the household waste stream do not justify the high costs of recycling them.
- The treatment of batteries containing high levels of mercury or cadmium (mercury button cells, NiCd rechargeable batteries) is very expensive whether it is through HHW or recycling. The restriction or prohibition of these battery types can be justified, since there are alternatives which do not present the same exorbitant costs, which is the case for numerous applications of NiCd product.
- The lawful threshold of mercury content (5 ppm) seems excessively strict. Indeed, the avoided social cost does not exceed 30 €/t when the limit rises from 5ppm to 100 ppm. This saving needs to be compared with whatever costs may be needed to meet the threshold.

The implementation of only the first two of these points would make it possible to save up to 13 million euros each year, primarily from the costs of recycling alkaline and zinc-carbon batteries.

During the 1990's the management of used batteries was the object of a two-pronged approach. The first tool was applied upstream to restrict the amount of toxic material being used in manufacturing the product being sent to market, and the second approach was aimed downstream at extracting these hazardous substances from the household waste stream. This approach was effective, but today the best management of used batteries is trending towards abandoning the downstream approach in favor of reinforcing the upstream controls. Indeed, it appears that the initial justification for the selective collection and recycling of used batteries has today lost its validity. Since 1991, legal restraints and the evolution of battery technology have allowed, or will allow, the elimination of batteries containing mercury or cadmium. Public policy should henceforth be directed towards strictly restricting the latter, and abandoning the collection and recycling of all batteries, which was only being done to collect these two hazardous substances. The upcoming directive would be an opportunity to progress in this direction, but current efforts appear to be insufficiently attentive to restricting hazardous materials, and run counter to what constitutes a desirable collection policy.

However, some considerations not taken into account in our analysis might support the argument for maintaining the current system of collecting all batteries. We could take account of older batteries (alkaline batteries with significant mercury content, for example) still entering the household waste stream, or of the importance of batteries in the overall dialogue on waste control.

As far as the first point is concerned, the sensitivity analysis indicates that the household waste stream channel is preferable up to the point where the mercury content exceeds 0.5%. This means that our conclusion remains valid, even if a quarter of the alkaline batteries in the household waste stream are old alkaline batteries containing 2% mercury.

As far as the second point is concerned, a bit of prudence is called for. Because of the early passage of regulations controlling the flow of used batteries, they became central to public discussion of waste control – particularly of hazardous household waste. To change this position might be perceived by the public as a change on the position of sorting and recycling in general. But this difficulty could be turned to an advantage. Indeed, prevention of pollution is the objective of the initiative. Batteries can be used as an example of successful pollution prevention[17], thanks in particular to the combination of upstream and downstream initiatives that were implemented. The efforts carried out (or in the case of cadmium being carried out) by the manufacturers have made possible the elimination of collection.

[17] For example, the national plan on waste prevention alluded to this in the chapter on qualitative prevention.

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## ANNEX 2: DETAILED RESULTS OF THE SENSITIVITY ANALYSIS

Sensitivity of the external benefits from the recycling of mercury: the table below presents the external cost – benefit analysis from 0 to 5,000 euros/ton

| 0 €/t | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

| 1 000 €/t | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 220 €/t | 3 880 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

| 3 000 €/t | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 260 €/t | 3 840 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

| 5 000 €/t | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 300 €/t | 3 800 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

Sensitivity of the external benefits to the recycling of **cadmium**, **nickel**, and **lead**: the table below displays the benefits of the external cost-benefit analysis from 0 to 5,000 euros per ton (for each of the three heavy metals).

| **0 €/t** | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 150 €/t | 1 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 60 €/t | 1 440 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

| **1 000 €/t** | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 550 €/t | 1 250 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 460 €/t | 1 040 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

| **3 000 €/t** | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 350 €/t | 450 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 260 €/t | 240 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

| **5 000 €/t** | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 2 150 €/t | - 350 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 2 060 €/t | - 560 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

Sensitivity of the mercury content of alkaline batteries and of the external benefits of recycling mercury: the Table below displays the results of the cost-benefit analysis on the management of used alkaline batteries.

| External benefits from recycling Hg | Content of Hg in alkalines | Household waste channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt cost | External cost | Social cost | Mgt cost | External cost | Social cost |
| **0 €/t** | 0 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,0005 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,001 % | 130 €/t | 100 €/t | 230 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,01 % | 130 €/t | 120 €/t | 250 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,1 % | 130 €/t | 390 €/t | 520 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 1 % | 130 €/t | 3 120 €/t | 3 250 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 2 % | 130 €/t | 6 140 €/t | 6 270 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| **1 000 €/t** | 0 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,0005 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,001 % | 130 €/t | 100 €/t | 230 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,01 % | 130 €/t | 120 €/t | 250 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,1 % | 130 €/t | 390 €/t | 520 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 1 % | 130 €/t | 3 120 €/t | 3 250 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| | 2 % | 130 €/t | 6 140 €/t | 6 270 €/t | 2 500 €/t | - 90 €/t | 2 410 €/t |
| **3 000 €/t** | 0 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,0005 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,001 % | 130 €/t | 100 €/t | 230 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,01 % | 130 €/t | 120 €/t | 250 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,1 % | 130 €/t | 390 €/t | 520 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 1 % | 130 €/t | 3 120 €/t | 3 250 €/t | 2 500 €/t | - 100 €/t | 2 400 €/t |
| | 2 % | 130 €/t | 6 140 €/t | 6 270 €/t | 2 500 €/t | - 130 €/t | 2 370 €/t |
| **5 000 €/t** | 0 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,0005 % | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,001 % | 130 €/t | 100 €/t | 230 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,01 % | 130 €/t | 120 €/t | 250 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 0,1 % | 130 €/t | 390 €/t | 520 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | 1 % | 130 €/t | 3 120 €/t | 3 250 €/t | 2 500 €/t | - 120 €/t | 2 380 €/t |
| | 2 % | 130 €/t | 6 140 €/t | 6 270 €/t | 2 500 €/t | - 170 €/t | 2 330 €/t |

Sensitivity to the distribution hove heavy metals in incinerator residue: four assumptions on this distribution are simulated.

| | Hypothesis 1 Major atmospheric emissions | | | | Hypothesis 2 Moderate atmospheric emissions | | | |
|---|---|---|---|---|---|---|---|---|
| | Hg | Cd | Ni | Pb | Hg | Cd | Ni | Pb |
| Atm emissions | 90 % | 25 % | 25 % | 10 % | 70 % | 10 % | 10 % | 5 % |
| Smoke residue | 10 % | 65 % | 25 % | 35 % | 25 % | 80 % | 10 % | 35 % |
| Ash/cinders | 0 % | 10 % | 50 % | 55 % | 5 % | 10 % | 80 % | 60 % |
| | Hypothesis 3 Weak atmospheric emissions | | | | Hypothesis 4 Base assumptions | | | |
| | Hg | Cd | Ni | Pb | Hg | Cd | Ni | Pb |
| Atm emissions | 50 % | 5 % | 0 % | 0 % | 72 % | 12 % | 0 % | 5 % |
| Smoke residue | 40 % | 90 % | 0 % | 40 % | 24 % | 76 % | 0 % | 37 % |
| Ash/cinders | 10 % | 5 % | 100 % | 60 % | 4 % | 12 % | 100 % | 58 % |

The table below displays the results for these four assumptions:

| | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| **Hypothesis 1** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 7 590 €/t | 7 720 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| dry cells | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | alkaline | 130 €/t | 160 €/t | 290 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | zinc - air | 130 €/t | 160 €/t | 290 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 740 €/t | 870 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| rechg | NiMH | 130 €/t | 180 €/t | 310 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| rechg | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| **Hypothesis 2** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 5 910 €/t | 6 040 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| dry cells | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 310 €/t | 440 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| rechg | NiMH | 130 €/t | 90 €/t | 220 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| rechg | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| **Hypothesis 3** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 4 230 €/t | 4 360 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| dry cells | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | alkaline | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | zinc - air | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 150 €/t | 280 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| rechg | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| rechg | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| **Hypothesis 4** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| dry cells | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| dry cells | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| rechg | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| rechg | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

Sensitivity of the external cost to heavy metal emissions by incinerators: four assumptions on cost levels are made:

| | External costs (€/kg) from emissions of ... | | | |
|---|---|---|---|---|
| | Hg | Cd | Ni | Pb |
| **Hypothesis 1: base assumptions** | 1 000 | 39 | 3,8 | 1 600 |
| **Hypothesis 2: low external cost** | 500 | 20 | 2 | 800 |
| **Hypothesis 3: moderate external cost** | 2 000 | 80 | 8 | 3 200 |
| **Hypothesis 4: major external cost** | 4 000 | 160 | 15 | 6 400 |

The table below sets out the results for these four assumptions

| | | HHW channel | | | Recycling channel | | |
|---|---|---|---|---|---|---|---|
| | | Mgt costs | External cost | social cost | Mgt costs | External cost | social cost |
| **Hypothesis 1** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 6 070 €/t | 6 200 t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 90 €/t | 220 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 320 €/t | 450 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| **Hypothesis 2** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 3 050 €/t | 3 180 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 60 €/t | 190 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 60 €/t | 190 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 180 €/t | 310 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| **Hypothesis 3** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 12 120 €/t | 12 250 €/t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 160 €/t | 290 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 160 €/t | 290 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 630 €/t | 760 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |
| **Hypothesis 4** | | | | | | | |
| dry cells | mercury button cells | 130 €/t | 24 220 €/t | 24 350 t | 4 100 €/t | - 200 €/t | 3 900 €/t |
| | zinc - carbon | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | alkaline | 130 €/t | 300 €/t | 430 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | zinc - air | 130 €/t | 300 €/t | 430 €/t | 2 500 €/t | - 70 €/t | 2 430 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 3 500 €/t | - 70 €/t | 3 430 €/t |
| rechg | NiCd | 130 €/t | 1 230 €/t | 1 360 €/t | 1 800 €/t | - 1 150 €/t | 650 €/t |
| | NiMH | 130 €/t | 30 €/t | 160 €/t | 1 500 €/t | - 1 290 €/t | 210 €/t |
| | lithium | 130 €/t | 30 €/t | 160 €/t | 2 500 €/t | - 80 €/t | 2 420 €/t |

:**ANNEX 3: COST CALCULATION SHEETS**

## ANNEX 4. LIST OF PUBLISHED WORKING PAPERS

### 1. Studies

05 - E03 Modélisation du découplage des aides et environnement en agriculture
Elsa LAVAL

05 - E02 Efficacité de la filière piles et accumulateurs Olivier ARNOLD

05 - E01 Les régulations environnementales ont-elles un effet sur le commerce extérieur de l'industrie française ?
Sébastien RASPILLER, Nicolas RIEDINGER, Céline BONNET

04 - E10 Les politiques environnementales ont-elles un impact sur la croissance ?
Nicolas RIEDINGER

04 - E09 Estimation des nuisances pour la collectivité générées par les éoliennes de Sigean
Sébastien TERRA

04 - E08 Stratégies d'échantillonnage et modèles de comptage dans la méthode des coûts de transport
Sébastien TERRA

04 - E07 Bien public global et instruments des politiques nationales unilatérales
Christine CROS, Sylviane GASTALDO

04 - E06 Principe de précaution et décision médicale
Dominique BUREAU, Emmanuel MASSE

04 - E05 Préservation des ressources globales et développement économique
Dominique BUREAU

04 - E04 Evaluation du coût subi par EDF suite à une mesure en faveur de la vie piscicole sur la Dordogne
Franck FREDEFON

04 - E03 Valorisation économique d'une amélioration de la qualité de l'eau de l'étang de Berre
Franck FREDEFON

04 - E02 La prise en compte du changement technique endogène affecte-telle l'équivalence entre taxes et permis ?
Gilles SAINT-PAUL

02 - E03 Typologie des modes de gestion des déchets ménagers par les collectivités locales
Anne-Claire BOITEL, Christine LAGARENNE

02 - E02 Evaluation économique des pertes d'usage dues aux tempêtes Lothar et Martin de décembre 1999 : le cas de la forêt de Fontainebleau
Sylvie SCHERRER

02 - E01 Régulation de la durée des contrats dans le secteur de le l'eau
Patrick DERONZIER

01 - E07 Effet de serre document de base de la maquette
SAGESSE Eve ROUMIGUIERES

01 - E06 Déterminants de la consommation en produits de l'agriculture biologique
Sylvie SCHERRER

01 - E05 Effet de serre : quantification de l'effort économique par les parties du protocole de Kyoto
Eve ROUMIGUIERES

01 - E04 Déterminants des comportements de tri des ménages
Christine LAGARENNE, Séverine WILTGEN

01 - E03 Combinaison des instruments prix et quantités dans le cas de l'effet de serre
Boris COURNEDE, Sylviane GASTALDO

01 - E02 Politiques nationales de lutte contre le changement climatique et réglementation de la concurrence : le cas de la fiscalité
Jérôme RIEU

01 - E01 Effets économiques du Protocole de Kyoto : une maquette internationale
Jean-Pierre BERTHIER, Martin GUESPEREAU, Eve ROUMIGUIERES

## 2. Méthods :

05 - M03 L'utilisation des méthodes d'options réelles
Emmanuel MASSE, Stéphane GALLON

05 - M02 Guide pour l'élaboration de CCTP d'études de valorisation
Sébastien TERRA

05 - M01 Guide pour la mise en œuvre de la méthode des prix hédoniques
Sébastien TERRA

04 - M07 Maquette ECHEANCES : Epuisement des Combustibles selon Hotelling et Application Naturelle au Contingentement de l'Effet de Serre
Hélène OLLIVIER

04- M06 Articulation entre quotas échangeables et mesures de gestion des ressources halieutiques : éléments pour l'évaluation économique d'aires marines protégées
Dominique BUREAU

04 - M05 Qu'est-ce qu'un marché de permis ? Adaptation du jeu de simulation de l'ENSAE à un marché de crédits « Azote »

04 - M04 Tourisme, loi littoral et économie de l'environnement
Dominique BUREAU

04 - M03 Fiches DPSEEA élaborées à partir du rapport final de la commission d'orientation pour le plan santé Environnement
Camille FEVRIER.

04 - M02 Arbitrages intertemporels, risque et actualisation
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04 - M01 Le cycle de la prévention et de l'information sur les risques
Patrick MOMAL

03 - M03 La culture du risque et de la sûreté
Patrick MOMAL

03 - M02 Rapport du groupe de réflexion environnement et applications de l'espace
Bertrand GALTIER, Michel LEBLANC

03 - M01 Le système d'information environnementale français
Armelle GIRY

02 - M02 Santé environnement : problèmes et méthodes
Benoît VERGRIETTE

02 - M01 Intérêts et limites des variables biologiques en écotoxicologie aquatique
Patrick FLAMMARION

01 - M02 Indicateurs environnementaux : méthodes et utilisation pour l'évaluation des politiques publiques
Xavier DELACHE

01 - M01 Méthodologie de valorisation des biens environnementaux
Sylvie SCHERRER

**3. Syntheses**

05 - S02 Plan National d'Affectation des Quotas : retour d'expérience
Sébastien MERCERON

05 - S01 Les différentes gestions du dossier de l'amiante
Grégoire LAGNY

| | | |
|---|---|---|
| 04 - S07 | Mécanismes économiques à l'œuvre sur la biodivesité dans les secteurs de l'agriculture, la forêt, l'eau, la pêche, le tourisme et les transports<br>Christine CROS |
| 04 - S06 | Evolution du régime d'indemnisation des catastrophes naturelles<br>Annie ERHARD-CASSEGRAIN, Emmanuel MASSE, Patrick MOMAL |
| 04 - S05 | Développement durable et aménagement routier : le cas de la RN88<br>Stéphanie ANTOINE |
| 04 - S04 | L'économie de l'effet de serre : point sur les engagements internationaux de lutte contre le changement climatique<br>Aurélie VIE ILLEFOSSE |
| 04 - S03 | Entreprises et développement durable<br>Irène CABY |
| 04 - S02 | Références méthodologiques pour la prise en compte de l'environnement dans les projets routiers<br>Stéphanie ANTOINE |
| 04 - S01 | Déchets ménagers en France. Financement du service et recyclage : Exemples de travaux d'évaluation économiques utiles à la décision publique<br>Patrick DERONZIER, Olivier ARNOLD |
| 03 - S06 | L'évaluation des aménités et des dommages environnementaux<br>Sylvie SCHERRER |
| 03 - S05 | Les enseignements pour la France des régimes de responsabilité environnementale en vigueur à l'étranger : l'exemple des Etats-Unis et du Brésil<br>Catherine SCHLEGEL, Laurent VERDIER |
| 03 - S04 | Les engagements futurs dans les négociations sur le changement climatique<br>Séminaire D4E |
| 03 - S03 | Economie de l'environnement et décision publique<br>Dominique BUREAU |
| 03 - S02 | Biens publics mondiaux et négociations internationales<br>Hélène FRANCES, François NASS |
| 03 - S01 | Axes pour la recherche en environnement et en développement durable dans le sixième programme cadre de recherche et développement de l'union européenne<br>Groupe thématique national français « recherche européenne, environnement et développement durable » |
| 02 - S02 | Marchés de droits : expériences passées et débuts pour l'effet de serre<br>Christine CROS, Sylviane GASTALDO |

| | |
|---|---|
| 02 - S01 | Microéconomie du développement durable : une introduction<br>Dominique BUREAU |
| 01 - S05 | L'impact économique des tempêtes de décembre 1999<br>Annie ERHARD-CASSEGRAIN |
| 01 - S04 | Ouverture des marchés de l'électricité et environnement<br>Dominique BUREAU, Sylvie SCHERRER |
| 01 - S03 | La responsabilité environnementale<br>Patrick MOMAL |
| 01 - S02 | Gouvernance mondiale et environnement<br>Dominique BUREAU, Marie-Claire DAVEU, Sylviane GASTALDO |
| 01 - S01 | Les rapports environ nementaux des entreprises<br>CHRISTINE LAGARENNE, MARC AVIAM |