

European Portable Battery Association

Assessment of the Environmental Impacts Associated with the Transport of Waste Batteries in Europe

August 2001

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For and on behalf of
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SUMMARY

The implementation of the proposed Batteries Directive is likely to lead to additional transport of waste batteries between facilities as a result of the required increases in battery collection and recycling. This report assesses the environmental implications of this increase in transportation.

The European Portable Battery Association commissioned this study in order to understand the effects of the distance waste batteries are transported in terms of the wider environmental impacts and the development of sustainable practices in Europe. Our approach builds on previous work carried out by ERM for the UK Department of Trade and Industry (DTI) in 2000. Data relating to the transport of waste batteries was extracted from aggregated collection and transport data in the model, **BATMOD**, previously developed for DTI and then used in a discrete analysis for this study. This was first carried out for UK waste battery arisings and then extrapolated to all of the Member States.

The analysis was based on predicted waste arisings for 2004 for the UK and 2003 for Europe, these being drawn from sales data in 2001 and 2000 assuming a three year lifetime. At this time, the proposed Directive would be in force and so the 75% collection rate required in the proposal was applied in the model.

Three collection scenarios were examined:

- kerbside
- civic amenity site
- retail outlet take back

Annex B contains flow diagrams which illustrate the collection scenarios, the various disposal routes and the transport distances applied to each. It was assumed that the transport was undertaken in a 16 tonne truck or a 40 tonne truck depending on whether it is a short or long-haul transport step. Other assumptions included in the model were:

- battery lifetime was 3 years;
- the trucks were used to full capacity and were full on their return journeys; and
- transport impacts associated with shipping were assumed to be negligible.

The scale of the impacts associated with the transport of waste batteries are indicated in *Summary Table 1*. This table lists the impacts associated with the kerbside collection scenario for Europe. Impacts are shown by battery type, and as a total for all consumer batteries. The data is also represented in terms of a comparator to help visualise the scale of the impacts (the annual contribution to each impact category of an average European car travelling 750km/year).

Table S.1 Kerbside Europe (500 km)

Impact	General purpose 500 km (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	No. of car equiv.
TSP	15368	836	13550	29754	
NO _x	46139	278	4513	50930	
N ₂ O	81	1	24	106	
CO ₂ (unspecified)	3513771	63672	1031889	4609332	
SO ₂	8097	147	2378	10622	
non-renewable depletion (Oil equiv.)	2812662	50967	825994	3689623	686
GWP (CO ₂ equiv.)	3728421	67562	1094925	4890908	803
Acidification (kg SO ₂)	40483	734	11889	53106	1344
Eutrophication (kg PO ₄)	6080	110	1786	22034	
Ozone depletion (kg CFC 11)	4	0	1	5	
Summer Smog (kg ethylene)	8654	157	2542	11353	986

The kerbside scenario was shown to have fewer environmental impacts associated with it compared to CA / take back. This was largely due to the fact that no transport burden was included for the collection and movement to sorting facility transport step, since the marginal burden associated with battery collection as part of mixed recyclables was assumed to be insignificant. However, it must be considered whether this would be realistically achievable with current infrastructure and household recycling levels.

Two sensitivity tests were performed on the data. These were:

- assuming that the truck was empty on its return journey; and
- use of a 33t truck rather than 16t truck.

The sensitivity analysis showed that the resulting impacts do depend on the parameters chosen for the model. The importance of efficiency in the system, particularly the trucks being loaded to full capacity was highlighted.

It should be noted that the feasibility of attaining the 75% collection rate assumed may not be realistic with present levels of infrastructure and public participation. If the collection rate was not achieved there is potential for the collection vehicles to be running at less than their maximum capacity. Therefore the resulting environmental impacts associated with the transport of each kilogramme of waste batteries would be greater than reported.

1 INTRODUCTION

1.1 OBJECTIVE OF STUDY

The European Portable Battery Association has commissioned ERM to assess the potential environmental impacts associated with the transport of separated portable consumer batteries, at the end of their lifetime. This study builds on previous work carried out by ERM, which provided analysis of the environmental impacts and financial costs of the proposed Directive on batteries. The proposed Directive, if implemented, is likely to lead to an increase in transport of waste batteries between facilities. This study attempts to assess the environmental implications of this increase in transportation.

Data relating to the transport of waste batteries was extracted from the previous model, and then used in a discrete analysis of the environmental impacts relating to transport of the batteries under three different collection scenarios to the various treatment/disposal facilities. This was first carried out for UK waste battery arisings and then, using the same assumptions, extrapolated for waste battery arisings for the whole of Europe.

The proposed Batteries Directive is intended to achieve the aims of the Community Waste Strategy through targets for the collection and recycling of consumer, automotive and industrial batteries, accompanied by restrictions on or phasing out of batteries containing cadmium and provisions on battery and appliance marking. The proposed Directive is likely to specify the following collection and recycling targets for consumer batteries, to be achieved by 2003 at the earliest:

- collection targets of 75% of the weight of all spent consumer batteries, including at least 75% by weight of those containing cadmium and lead;
- a recycling target of 55% by weight of all separately collected spent batteries.

1.2 WASTE BATTERY ARISING

Portable consumer batteries are classified as primary or secondary (rechargeable). Portable primary batteries include general purpose batteries (such as cylindrical AA and prismatic 9V batteries), small button cells and less common cylindrical batteries including lithium technologies. They are used in numerous electrical consumer appliances that have high power demands, such as, portable stereos, torches, clocks and watches. Portable secondary (rechargeable) batteries were introduced as alternatives to primary batteries for longer term use in applications such as cellular

phones, laptops, power tools and emergency lighting. Rechargeable batteries were originally all nickel cadmium (NiCd) chemistry. However, since the mid-1990's, other alternatives have been developed such as nickel metal hydride (NiMH) and lithium ion (Li).

1.2.1 UK Waste Battery Arisings

Annex A provides a full breakdown for the *BATMOD* predicted waste arisings for the year 2004. The predicted total tonnage for 2004 is 26 183. This year was chosen for the study as the proposed batteries Directive is due to come into effect in 2003. Therefore, in 2004, the proposed collection targets would be mandatory across Europe. The waste arisings listing is broken down into three sub-sections to reflect the different disposal/treatment methods required. These are General Purpose, Button Cells and Secondary Rechargeable.

An average lifetime of 3 years is assumed for all portable consumer batteries. As a result, the predicted battery waste arisings in 2004 correspond with battery sales in 2001. Although lifetimes do vary between battery types, and particularly with secondary batteries, in order to simplify analysis an average of 3 years has been used in this report. This figure represents the arithmetic average of primary consumer battery lifetimes. It is also not unreasonable for secondary batteries whose lifetimes can vary between 1.5 years (cellular phones) and 6.5 years (video cameras). The length of time after purchase of the arrival of batteries into the waste stream is also dependent on the users' habits and tendency to hoard both spent batteries and appliances. Therefore, the 3-year assumption is not considered to present a significant over-simplification given the variability in appliance/battery lifetime due to different user habits.

1.2.2 European Waste Battery Arisings

Annex A also provides a breakdown by country for European waste battery arisings. This data reflects sales tonnages for 2000. Assuming the same average battery lifetime for Europe, this corresponds to waste arisings in 2003. Although this is a different year from the UK data used, it was still deemed satisfactory to use in this analysis. The proposed Batteries Directive would be in force and so the same collection target (75%) could also be applied. There is only one year difference between the data and so for simplicity in analysis it has been assumed that environmental impacts due to the transport of one tonne of batteries one kilometre would be the same in both cases. Furthermore, for the purpose of analysis it has been assumed that similar overall transport distances, truck sizes and thus transport burdens would be applicable across Europe.

1.3

PREVIOUS WORK – THE BATMOD MODEL

In 2000, ERM carried out an analysis of the environmental impact and financial costs of a possible new European Directive on Batteries on behalf of the UK Department of Trade and Industry.

In order to undertake the analysis, a model, BATMOD, was designed and run. The model incorporated data modules to predict waste arisings projections, financial costs and benefits, and environmental impacts. This project used the BATMOD model to extract the flows of environmental impacts that were specific to the transport involved in each scenario. This allowed a more detailed picture of the environmental impacts associated with increased battery collection and transport to be formulated.

1.3.1

Collection Scenarios

In the original model three collection scenarios were included. These were used again in this study and are as follows:

- ‘kerbside’ scenario - kerbside collection of batteries;
- ‘CA site’ scenario - collection of batteries deposited by consumers at Civic Amenity (CA) sites; and
- ‘take-back’ scenario - collection of batteries brought by consumers to retail outlets.

The *Kerbside* collection system assumes that batteries would be collected in a mixed recyclable collection or during a normal MSW collection round. Therefore, due to the relative weights of batteries collected in comparison to other wastes in either of these alternatives, it has been assumed that the impacts arising from battery transport during the round are negligible.

The *CA Site* and *Retailer Take-Back* scenarios’ transport impacts are assumed to be identical. In both cases, the transport of the batteries by the end user to either the CA site or the retail store have been excluded from the boundaries of the model. This is due to the improbability of either trip being dedicated solely to battery drop-off. The transport impacts would therefore be attributed to the other (and probably main) reason for the journey. In both cases, it is assumed that the collected batteries are transported by a truck (containing only batteries) to the sorting facility, from where they are then transported to their final destination.

Although some of the final treatment facilities are in mainland Europe, the transport impacts associated with shipping by sea are assumed to be negligible due to the relatively low tonnages shipped and the low frequency of journeys.

Collection scenarios were built into a combined structure, which also included the various disposal routes available. The combined models for each collection scenario are included in *Annex B*.

1.3.2 Disposal Options

The disposal options incorporated into the collection scenario models reflect the sources from which financial and environmental information was gained during research for the *BATMOD* model. The facilities used in the model included the following:

- ASW Sheerness (UK). Steel manufacture using an electric arc furnace, to recover the iron/steel fraction of general purpose batteries. Trials with mercury free general purpose batteries have been successfully conducted and are likely to be extended;
- Indaver Relight (Belgium). Mercury distillation to remove mercury from button cells. Metal fractions are subsequently sent for recovery;
- Revatech (Belgium). Sorting and separation of general purpose batteries at Liege, physico-chemical treatment at Engis. Ferrous and non-ferrous metal wastes are subsequently sent for recovery; and
- SNAM (France). Cadmium distillation of NiCd batteries and other cadmium containing wastes to recover cadmium. Ferrous and non-ferrous by-products are sold for subsequent recovery.

The models include two alternative routes for general purpose batteries. If the electric arc furnace (EAF) route is enabled (ie the mercury content of batteries is sufficiently low) then this is the preferred route for all general purpose batteries. If the EAF route is not available then general purpose batteries are assumed to go to the Revatech facility in Belgium. There are considerable differences in journey distances between these two options. Each is modelled separately for each collection scenario so that the effect of the EAF/non-EAF route can be discerned. Disposal options are included in the model diagrams found in *Annex B*.

2.1 THE MODEL SYSTEM**2.1.1 Waste Battery Tonnages**

Data on waste battery tonnages was taken from the original **BATMOD** model based on UK sales for 2001, which resulted in waste arisings for 2004. At this point, the proposed batteries Directive would be in force, and so a 75% collection rate has been applied. *Table 2.1* details the tonnages collected per disposal category.

Table 2.1 UK 2004 Consumer Battery Waste Arisings (75% collection rate)

Battery Type	Waste Arising (Tonnes)	Collected (Tonnes)
Total	26,183	19,637
General Purpose	22,652	16,989
Button Cells	205	154
NiCd/NiMH	3,326	2,494

2.1.2 Assumptions

Although collection vehicles would not be filled to capacity during a collection round (eg of CA sites), the additional environmental impacts associated with transporting batteries in a partly-filled vehicle have been excluded to simplify analysis.

It is assumed that the waste batteries are transported by two sizes of truck. A 16 tonne (axle weight) truck with a maximum load capacity of 9.5 tonnes was assumed to carry batteries from the CA site/retail outlet to the sorting facility and also to carry general purpose batteries from the sorting facility to the Electric Arc Furnace in the UK. A 40 tonne (axle weight) truck with a maximum load capacity of 27 tonnes was assumed to be used for all other routes in the scenarios.

It is assumed that the vehicle is also loaded to capacity on its return journey. The issue of loading to capacity is less important in transport from the intermediate storage of the sorting facility to the final processing destination. Transport will generally only occur when a vehicle has been filled to capacity.

Shipping transport has been assumed to be negligible due to the low tonnages involved and infrequency of journeys.

2.1.3

Fuel Use

ERM has been unable to attain the fuel use assumption used in the transport database in the PEMS™ software. However, an estimate can be made using the oil reserves input found in the impact inventory. It is assumed that 90% of the oil reserves used in the transport database are used in powering the vehicle. The impact inventory shows that 0.037 kg per tonne kilometre is used. Assuming the truck is loaded to full capacity (16t truck used as example) this equates to 0.316 kg km⁻¹. If the density of oil is taken as 0.95 kg l⁻¹, then a fuel consumption of 0.33 l km⁻¹ is reached. Although this is a crude estimate it is not thought as being unreasonable. Average fuel consumption data for generalised vehicles as listed in the Auto Oil II Database ⁽¹⁾ shows results within 19% of this estimate. For the purposes of this analysis, 0.33 l km⁻¹ is used as the transport vehicles' fuel use in order to estimate the total fuel use implications associated with the waste battery transport.

2.2

ANALYSIS OF IMPACTS

2.2.1

Calculation of weighted transport distances

Weighted transport distances, expressed as tonne kilometre were calculated for each transport step (as noted in the model diagrams in *Annex B*). The calculation used is as follows:

$$\text{Load} \times \text{Journey} \times \text{Max Load/Useful Load} = \text{tonne km}$$

Load = Actual tonnage of batteries carried per year

Journey = Distance in km of outward journey

Max Load = The maximum load able to be carried (ie 9.5t or 27t)

Useful Load = Actual tonnage of batteries carried per journey.

For example, in the UK, 16 tonne trucks carry 19 637 tonnes of mixed batteries from the CA site to the sorting facility, a distance of 75km, throughout 2004. The truck is filled to a maximum load of 9.5 tonnes for each outward and return journey:

$$19\ 637 \times 75 \times 9.5/9.5 = 1\ 472\ 775 \text{ tonne km}$$

Table 2.2 lists the resulting weighted distances and actual road distances for each disposal route used in the collection scenarios. A measure of fuel use is also indicated based on the estimate in *Section 2.1.3*.

(1) European Commission 1999. Auto Oil II Program - Cost Effectiveness Study. Draft Report.
<http://forum.europa.eu.int/Public/irc/env/aop2wg7/library>

Table 2.2 **Transport distances**

Disposal Route	Total Road km (assuming full capacity)	Weighted Distances (tonne km) (assuming full capacity)	Estimate of fuel consumption (l)
UK			
CA/Retail to sorting facility	155,029	1,472,775	46,509
General Purpose to EAF	357,663	3,397,800	107,299
General Purpose to Non-EAF	629,222	16,989,000	188,767
Button Cells	5,703	154,000	1,711
NiCd/NiMH	92,370	2,494,000	27,711
Total UK	1,239,987	24,507,575	371,997
Europe			
CA/Retail to sorting facility	893,368	8,487,000	268,010
General Purpose 200 km	2,061,031	19,579,800	618,309
General Purpose 500 km	1,812,944	48,949,500	543,883
Button Cells	32,851	887,000	9,855
NiCd/NiMH	532,407	14,375,000	159,722
Total Europe	5,332,601	92,278,300	1,599,779

2.2.2 **Environmental Impact Inventories**

Assessment of the environmental impacts associated with each transport step was developed using inventories produced using PEMS™ software. The inventories used in this report are based on the one shown below in *Table 2.3*, which reflects the impacts associated with one kg of batteries travelling one tonne km⁻¹ in each vehicle. This inventory contains selected environmental flows of relevance to transport such as NO_x emissions and Life Cycle Impact Assessment criteria such as Global Warming Potential and Eutrophication. Definitions for the impact categories used are listed in *Annex C*. Comparison was again made between the resulting data and the Auto Oil II Program data on vehicle emissions. Their predictive data for average vehicles was within the same order of magnitude as the data below.

Table 2.3 Inventory of Environmental Impacts Associated with Transport of Waste Batteries

Environmental Impact	16 tonne vehicle (kg per tonne km)	16 tonne vehicle (kg per km)	40 tonne vehicle (kg per tonne km)	40 tonne vehicle (kg per km)
TSP	0.00032	0.00304	0.00031	0.00837
NO _x	0.00178	0.01691	0.00094	0.02538
N ₂ O	2.89E-06	2.75E-05	1.66E-06	4.48E-05
CO ₂	0.07178	0.68191	0.12690	3.4263
SO ₂	0.00016	0.00152	0.00026	0.00702
Non-renewable resource depletion (oil equiv.)	0.10388	0.98686	0.05746	1.55142
GWP (CO ₂ equiv.)	0.13297	1.263215	0.07616	2.05632
Acidification (SO ₂ equiv.)	0.00150	0.01425	0.00012	0.00324
Eutrophication (PO ₄ equiv.)	0.00023	0.002185	0.00012	0.00324
Ozone Depletion (CFC 11 equiv.)	1.42E-07	1.35E-06	8.80E-08	2.38 E-06
Summer Smog (ethylene equiv.)	0.00030	0.00285	0.00018	0.00486

2.2.3 Calculation of Transport Burdens

The distance for each weighted transport step, listed in *Table 2.2* was multiplied by the inventory shown in *Table 2.3*. This represented the burden associated with each transport step. The resulting burdens are presented in *Section 3*.

2.3 EXTRAPOLATION FOR EUROPE

This model system was then applied to the waste arisings data for Europe. The total waste battery arisings data for Europe is presented in *Table 2.4*. Some changes were made between the UK and European model to allow for presumed differences in logistic arrangements on the continent.

The previous ERM report for the Department of Trade and Industry made simple assumptions appropriate to the UK with regards to transport logistics for the EAF and non-EAF disposal routes for general purpose batteries. When constructing the system for this study, it was decided that the closer proximity of EAF disposal facilities compared to non-EAF alternatives in the UK could not be assumed as representative of the situation throughout Europe. Therefore, rather than assuming different transport distances for EAF and non-EAF recycling, reasonable upper and lower bounds for transport distances would be used. These are shown in *Annex B*, with transport distances of 200km and 500km being used. The resulting transport burdens are presented in *Section 3*.

Table 2.4 2003 European Consumer Waste Battery Arisings

Battery Type	Waste Arising (Tonnes)	Collected (Tonnes)
Total	150,880	113,160
General Purpose	130,532	97,899
Button Cells	1,182	887
NiCd/NiMH	19,166	14,375

3.1 UK WASTE BATTERY ARISING

The transport burdens associated with each collection scenario are listed in *Tables 3.1 – 3.4*. For each scenario, the burdens with the Electric Arc Furnace route and without EAF are included so that the difference, if any, that the availability of this disposal route makes can be detected. In order to help visualise the scale of the impacts, a comparator has been included in the table. For global warming, acidification, and summer smog the impact burdens have been converted into the number of cars travelling 12 000 miles/year that would result in the same impact level.

Table 3.1 UK Kerbside (200km to EAF, 16t truck)

Impact	General Purpose EAF (kg)	Button cells (kg)	NiCd/NiMH (kg)	Total kg	car equiv.
TSP	1084	48	783	1916	
NO _x	6051	145	2351	8546	
N ₂ O	10	<1	4	14	
CO ₂ (unspecified)	431221	11055	179028	621304	
SO ₂	868	25	413	1307	
non-renewable depletion (Oil equiv.)	352989	8849	143306	505144	94
GWP (CO ₂ equiv.)	451832	11730	189965	653527	107
Acidification (kg SO ₂)	5111	127	2063	7301	185
Eutrophication (kg PO ₄)	795	19	310	1124	
Ozone depletion (kg CFC 11)	<1	<1	<1	1	
Summer Smog (kg ethylene)	1033	27	441	1502	131

Table 3.2 UK Kerbside (1000km to non-EAF, 40t truck)

Impact	General purpose non EAF (kg)	Button cells (kg)	NicCd/NiMH (kg)	Total Kg	car equiv.
TSP	5334	48	783	6165	
NO _x	16014	145	2351	18510	
N ₂ O	28	<1	4	33	
CO ₂ (unspecified)	1219532	11055	179028	1409615	
SO ₂	2810	25	413	3248	
non-renewable depletion (Oil equiv.)	976196	8849	143306	1128352	209
GWP (CO ₂ equiv.)	1294031	11730	189965	1495725	246
Acidification (kg SO ₂)	14051	127	2063	16241	411
Eutrophication (kg PO ₄)	2110	19	310	2439	
Ozone depletion (kg CFC 11)	1	<1	<1	2	
Summer Smog (kg ethylene)	3004	27	441	3472	302

Table 3.3 UK CA/Takeback (200km to EAF, 16t truck)

Impact	CA/retail to sorting (kg)	General purpose EAF (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	car equiv.
TSP	470	1084	48	783	2386	
NO _x	2622	6051	145	2351	11169	
N ₂ O	4	10	<1	4	18	
CO ₂ (unspecified)	186913	431221	11055	179028	808216	
SO ₂	376	868	25	413	1683	
non-renewable depletion (Oil equiv.)	153003	352989	8849	143306	658147	122
GWP (CO ₂ equiv.)	195846	451832	11730	189965	849373	139
Acidification (kg SO ₂)	2215	5111	127	2063	9516	241
Eutrophication (kg PO ₄)	344	795	19	310	1469	
Ozone depletion (kg CFC 11)	<1	<1	<1	<1	<1	
Summer Smog (kg ethylene)	447	1033	27	441	1949	169

Table 3.4 UK CA/Takeback (1000km to non-EAF, 40t truck)

Impact	CA/retail to sorting (kg)	General purpose non EAF (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	car equiv.
TSP	470	5334	48	783	6635	
NO _x	2622	16014	145	2351	21132	
N ₂ O	4	28	<1	4	37	
CO ₂ (unspecified)	186913	1219532	11055	179028	1596527	
SO ₂	376	2810	25	413	3625	
non-renewable depletion (Oil equiv.)	153003	976196	8849	143306	1281354	238
GWP (CO ₂ equiv.)	195846	1294031	11730	189965	1691572	278
Acidification (kg SO ₂)	2215	14051	127	2063	18456	467
Eutrophication (kg PO ₄)	344	2110	19	310	2784	
Ozone depletion (kg CFC 11)	<1	1	<1	<1	2	
Summer Smog (kg ethylene)	447	3004	27	441	3920	356

The UK Inventory results show that the presence of the shorter route to the EAF has a positive effect on the transport burdens associated with all collection scenarios, although a greater effect is seen with the kerbside scenario. When comparing scenario impacts directly, the CA/takeback scenarios have a greater transport impact than the Kerbside system. Of the impacts, the greatest difference between scenarios is seen in depletion of non-renewable resources and global warming potential, where CA/takeback has almost three times the impact.

3.2 EUROPEAN WASTE BATTERY ARISING

The tables below list the transport burdens associated with collection scenarios in Europe. These figures are an extrapolation of the UK data.

Table 3.5 Europe Kerbside (200 km, 16t truck)

Impact	General Purpose 200 km (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	car equiv.
TSP	6249	836	13550	20635	
NO _x	34866	278	4513	39658	
N ₂ O	57	1	24	82	
CO ₂ (unspecified)	2484909	63672	1031889	3580471	
SO ₂	5005	147	2378	7529	
non-renewable depletion (Oil equiv.)	2034095	50967	825994	2911057	541
GWP (CO ₂ equiv.)	2603680	67562	1094925	3766167	618
Acidification (kg SO ₂)	29451	734	11889	42073	1064
Eutrophication (kg PO ₄)	4583	110	1786	6479	
Ozone depletion (kg CFC 11)	3	<1	1	4	
Summer Smog (kg ethylene)	5955	157	2542	8653	751

Table3.6 Europe Kerbside (500 km, 40t truck)

Impact	General purpose 500 km (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	car equiv.
TSP	15368	836	13550	29754	
NO _x	46139	278	4513	50930	
N ₂ O	81	1	24	106	
CO ₂ (unspecified)	3513771	63672	1031889	4609332	
SO ₂	8097	147	2378	10622	
non-renewable depletion (Oil equiv.)	2812662	50967	825994	3689623	686
GWP (CO ₂ equiv.)	3728421	67562	1094925	4890908	803
Acidification (kg SO ₂)	40483	734	11889	53106	1344
Eutrophication (kg PO ₄)	6080	110	1786	22034	
Ozone depletion (kg CFC 11)	4	<1	1	5	
Summer Smog (kg ethylene)	8654	157	2542	11353	986

Table 3.7 Europe CA/Takeback (200 km, 16t truck)

Impact	CA/retail to sorting (kg)	General purpose 200 km (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	car equiv.
TSP	2709	6249	836	13550	23343	
NO _x	15113	34866	278	4513	54771	
N ₂ O	25	57	1	24	107	
CO ₂ (unspecified)	1077101	2484909	63672	1031889	4657572	
SO ₂	2169	5005	147	2378	9699	
non-renewable depletion (Oil equiv.)	881692	2034095	50967	825994	3792749	705
GWP (CO ₂ equiv.)	1128583	2603680	67562	1094925	4894750	803
Acidification (kg SO ₂)	12766	29451	734	11889	54839	1388
Eutrophication (kg PO ₄)	1987	4583	110	1786	8466	
Ozone depletion (kg CFC 11)	1	3	<1	1	5	
Summer Smog (kg ethylene)	2581	5955	157	2542	11234	976

Table 3.8 Europe CA/Takeback (500 km, 40t truck)

Impact	CA/retail to sorting (kg)	General purpose 500 km (kg)	Button cells (kg)	NiCd/ NiMH (kg)	Total kg	car equiv.
TSP	2709	15368	836	13550	32463	
NO _x	15113	46139	278	4513	66043	
N ₂ O	25	81	1	24	131	
CO ₂ (unspecified)	1077101	3513771	63672	1031889	5686433	
SO ₂	2169	8097	147	2378	12791	
non-renewable depletion (Oil equiv.)	881692	2812662	50967	825994	4571315	850
GWP (CO ₂ equiv.)	11258583	3728421	67562	1094925	16149491	2650
Acidification (kg SO ₂)	12766	40483	734	11889	65872	1666
Eutrophication (kg PO ₄)	1987	6080	110	1786	9963	
Ozone depletion (kg CFC 11)	1	4	<1	1	6	
Summer Smog (kg ethylene)	2581	8654	157	2542	13934	1210

The reduced transport distances used for general purpose batteries provide a reduction in the impact inventory. Non-renewable resource depletion and global warming potential are increased approximately by a factor of 1.5 in the CA/take back scenario in comparison to kerbside.

In order to test the sensitivity of the transport burdens calculated in this analysis two factors were varied. Firstly, the original scenario for UK Kerbside (200km with EAF) was re-run but the assumption that the trucks would return from the processing sites full was removed. In the test, it was assumed that the trucks would be empty on the return journey. In the second test, the same inventory was applied to the UK CA site (with 200km EAF) scenario with a 33t truck carrying the general purpose batteries from the CA site to the sorting facility and from the sorting facility to the recycler.

4.1 REDUCING USEFUL LOAD CAPACITY

When running the main model, it was assumed that the collection vehicles carrying the waste batteries would be fully utilised on their return journey. In reality this may be a conservative assumption and so this sensitivity test was employed to see how the impacts would change if the truck was empty on its return journey. Changing this assumption has the effect of doubling the distance travelled by the load. *Table 4.1* below illustrates the difference in environmental impacts resulting from the 16 tonne truck carrying general purpose batteries to the EAF site in the UK and returning to the sorting facility empty.

Table 4.1 Comparison of the Effect of Different Load Efficiencies on Environmental Impacts

Impact	Full Load on Outward & Return (kg)	Empty on Return (kg)	General Purpose 1000 km (Max. load) (kg)
TSP	1084	2169	5334
NO _x	6051	12101	16014
N ₂ O	10	20	28
CO ₂ (unspecified)	431221	862442	1219532
SO ₂	868	1737	2810
non-renewable depletion (Oil equiv.)	352989	705977	976196
GWP (CO ₂ equiv.)	451832	903664	1294031
Acidification (kg SO ₂)	5111	10222	14051
Eutrophication (kg PO ₄)	795	1591	2110
Ozone depletion (kg CFC 11)	<1	1	1
Summer Smog (kg ethylene)	1033	2067	3004

If the truck were to return empty from the EAF disposal route, the environmental impacts associated with this section of the model would double. However, as the third column in *Table 4.1* shows, the shorter EAF route still has fewer environmental impacts associated with it if the truck

does return empty. This is particularly true for CO₂ and global warming potential.

4.2 **USE OF A 33T VEHICLE RATHER THAN 16T**

This test was carried out in order to determine the effect of using a larger truck capacity to move the total waste battery arisings from CA site/retail outlet to the sorting facility. In the comparison, it was assumed that both trucks would be full on their return journey from the sorting facility.

Table 4.2 lists the transport distances and fuel consumed associated with each truck. Although the weighted distance stays the same, both fuel consumed and actual road km travelled are approximately halved by the use of the larger vehicle.

Table 4.2 Fuel Use Associated with a 16 t truck and 33 t truck

Impact	16 t truck	33 t truck
Tonne km	1,472,775	1,472,775
Actual road km	155,029	70,132
Fuel Used (<i>l</i>)	46,509	21,040

4.3 **FEASIBILITY**

It is important to note that this analysis assumes that the 75% collection rate imposed by the proposed directive is achievable in practice. However, the higher rates of collection modelled in this study are not demonstrated currently by any European scheme for consumer battery recovery, and are seldom achieved for other materials.

Bring systems such as Civic Amenity sites and Retail Take Back are the least expensive method of collecting consumer batteries for recycling but current experience suggests that 40% is the upper bound for public participation. Higher rate of participation can be achieved through kerbside collection, but at present only 40% of households in the UK are served by kerbside collection. ⁽¹⁾ Clearly, a much higher coverage would be required for the higher collection target modelled in this study to be achieved across the country. Although response of local authorities in the UK to the statutory recycling targets in, for example, *Waste Strategy 2000*, is likely to lead to a greater coverage of kerbside collection, inefficiencies and lack of public participation will continue to exist.

In order to initiate and implement the collection scenarios modelled in this study, significant improvements in infrastructure would be required. As explained above, at present it would be very doubtful whether a level of 75% collection would be achievable. Therefore, the potential exists for

(1) Municipal Waste Survey DETR 1998/99

collection vehicles carrying less than their maximum load on a regular basis. As the sensitivity analysis has shown, reducing the useful load of the vehicles would result in an increase in impacts associated with each kg of waste batteries collected and transported.

5 CONCLUSION

5.1 SENSITIVITY OF RESULTS

The sensitivity analysis has shown that the calculated environmental impacts associated with the transport of waste batteries are dependent on the parameters defined in the model. This report has shown that the details surrounding the transport vehicle are particularly important such as the size of truck used in transportation and the useful load of the truck whatever the size.

The feasibility of implementation of the collection scenarios must also be considered in terms of the sensitivity of these results. The results assume that the system would be run efficiently. At present levels of public participation and infrastructure there is doubt as to whether the 75% collection rate could be achieved. If not this would result in inefficiencies and so greater environmental impacts associated with the transport of each kg of waste batteries.

5.2 COMPARISON OF COLLECTION SCENARIOS

The UK data has shown that kerbside collection provides a reduced transport burden in comparison with the CA site collection or retail take-back routes. This is primarily due to the fact that the transport associated with the actual kerbside collection phase is assumed to be negligible, whereas transport from CA site or retail outlet is included. Kerbside collection would therefore seem to be a better option in terms of reducing the environmental impact of transport of waste batteries.

However, there are many other factors which have an impact on the environmental effect of kerbside collection, not least the provision of containers and the degree to which current infrastructure makes this realistically achievable. The Kerbside collection scenario, in order to achieve these reduced transport burdens, would need a comprehensive kerbside collection of recyclables service to be available to all households in the UK, and in Europe respectively.

In all collection scenarios, the most significant impacts in terms of tonnes produced were found to be CO₂, non-renewable resource depletion and global warming potential. This can be explained in terms of fuel usage and exhaust emissions associated with the use of the vehicles.

5.3 THE ELECTRIC ARC FURNACE ROUTE

For each UK collection scenario, the impact results show that the transport burden is significantly less when the shorter distance to the EAF disposal route is in operation for general purpose batteries.

This result was expected based on the assumptions used in the model. That is, the transport distances involved were less with the EAF disposal route for general purpose batteries than with the Revatech disposal route where all batteries must be transported to Belgium. The fact that the greatest proportion of waste battery tonnages is provided by general purpose batteries also adds to the effect that the EAF/non EAF route has on the scenarios. Clear benefits can therefore be seen in the use of this disposal option in the UK in terms of reducing the transport burden.

The use of the EAF and Non-EAF route was not considered appropriate for extrapolation throughout Europe. Instead a lower and upper bound for the transport of general purpose batteries was assumed. Again, benefits were seen in the transport distance for general purpose batteries being reduced.

Annex A

Battery Waste Arisings Data

Table A1 UK Battery Waste Arisings Predicted Data (2004)

Battery Type	Waste Arisings (tonnes)
Primary: Zinc Carbon - Main types (AAA)	239
Primary: Zinc Carbon - Main types (AA)	2,707
Primary: Zinc Carbon - Main types (C)	1,227
Primary: Zinc Carbon - Main types (D)	2,316
Primary: Zinc Carbon - Main types (9 V E-Block)	400
Primary: Zinc Carbon - Other types (Other)	195
Primary: Alkaline-manganese (AAA)	469
Primary: Alkaline-manganese (AA)	5,705
Primary: Alkaline-manganese (C)	3,005
Primary: Alkaline-manganese (D)	5,415
Primary: Alkaline-manganese (9 V E-Block)	962
Other Primary	12
Total Primary General Purpose	22,652
Primary: Button Cells - Mercuric oxide	0
Primary: Button Cells - Alkaline	9
Primary: Button Cells - Silver-oxide	10
Primary: Button Cells - Lithium	16
Primary: Button Cells - Zinc-air	39
Other Lithium	132
Total Button Cells	205
Portable Secondary - Nickel Cadmium (Emergency Lighting)	1,061
Portable Secondary - Nickel Cadmium (Mobile Phones)	40
Portable Secondary - Nickel Cadmium (Prof. Power Tools)	363
Portable Secondary - Nickel Cadmium (Cons Power Tools)	638
Portable Secondary - Nickel Cadmium (Dust Buster)	140
Portable Secondary - Nickel Cadmium (Laptops)	0
Portable Secondary - Nickel Cadmium (Cordless Phones)	393
Portable Secondary - Nickel Cadmium (Other)	389
Portable Secondary - Nickel Metal Hydride (Mobile Phones)	174
Portable Secondary - Nickel Metal Hydride (Laptops)	2
Portable Secondary - Nickel Metal Hydride (Cordless Phones)	52
Portable Secondary - Nickel Metal Hydride (Other)	11
Portable Secondary - Lithium Ion (Mobile Phones)	45
Portable Secondary - Lithium Ion (Laptops)	15
Portable Secondary - Lithium Ion (Other)	3
Total Secondary	3,326
Total Arisings	26,183

Table A2 **European Battery Waste Arisings Predicted Data (2003)**

Country	Waste Arisings (tonnes)	General Purpose (tonnes)	Button Cells (tonnes)	NiCd/NiMH (tonnes)
Austria	2916	2522	23	370
Belgium	5406	4677	42	687
Denmark	2540	2197	20	323
Finland	1848	1599	14	235
France	29316	25207	228	3701
Germany	29205	25267	229	3710
Greece	2708	2343	21	344
Ireland	791	684	6	100
Italy	15942	13792	125	2025
Netherlands	5436	4703	43	691
Norway	1789	1547	14	227
Portugal	2105	1821	16	267
Spain	16604	14365	130	2109
Sweden	3706	3206	29	471
Switzerland	4161	3600	33	529
UK	26586	23001	208	3377
Total	150880	130532	1182	19166

Annex B

Scenario Flow Diagrams

Figure B0.1 UK Kerbside Collection Scenario Structure (Combination of LCA Systems)

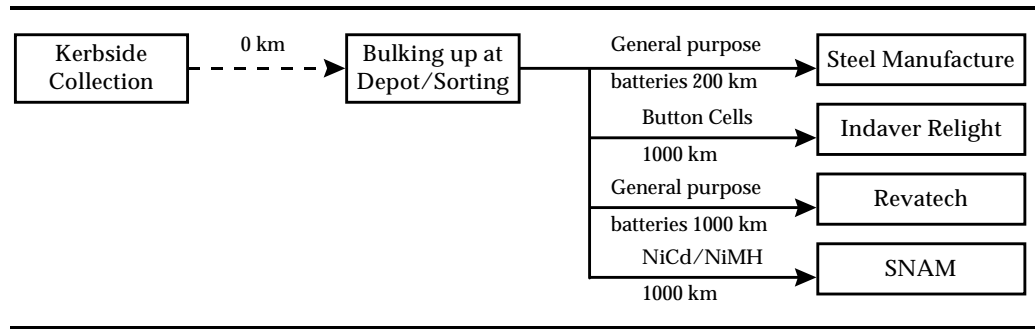


Figure B0.2 UK CA Site Collection Scenario Structure (Combination of LCA Systems)

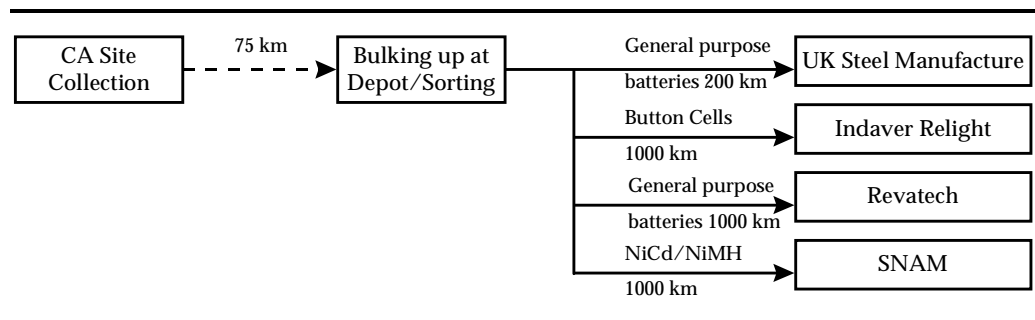


Figure B0.3 UK Take-back Collection Scenario Structure (Combination of LCA Systems)

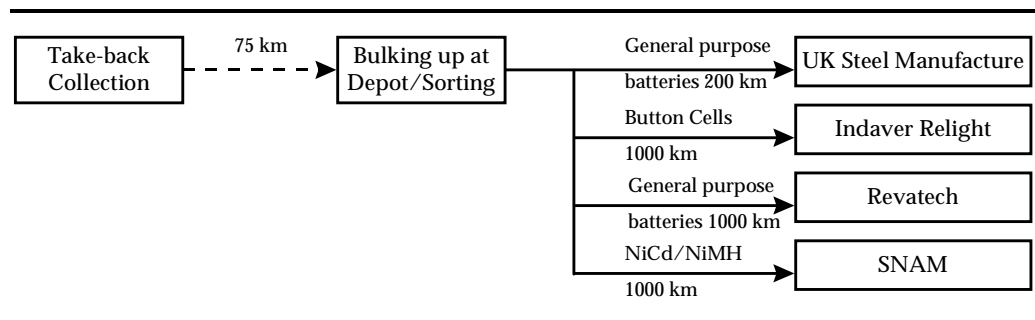


Figure B0.4 Europe Kerbside Collection Scenario Structure (Combination of LCA Systems)

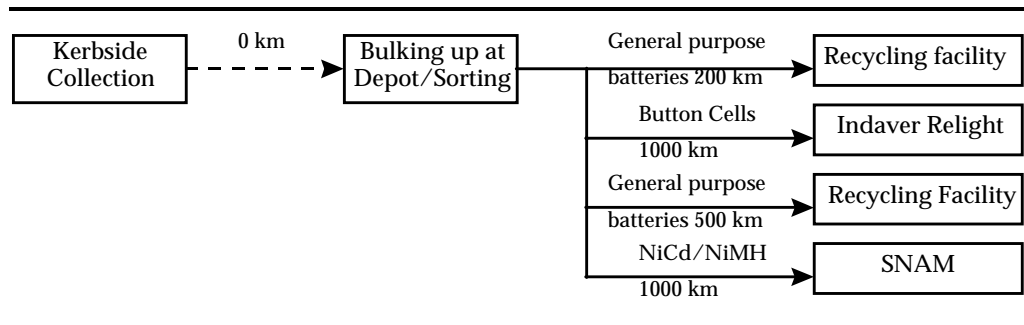


Figure B0.5 Europe CA Site Collection Scenario Structure (Combination of LCA Systems)

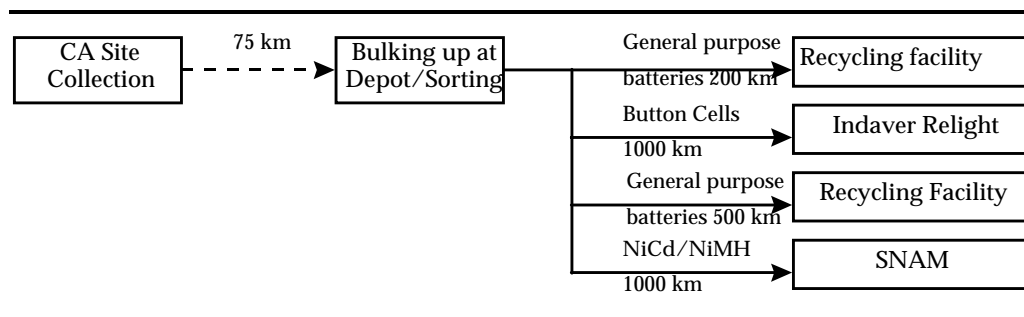
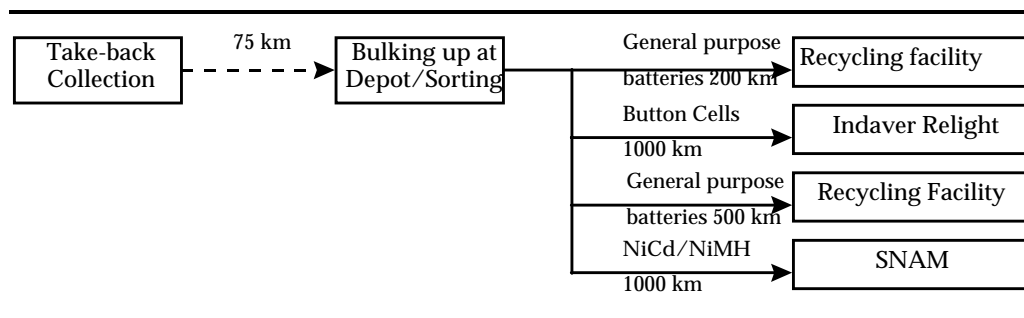


Figure B0.6 Europe Take-back Collection Scenario Structure (Combination of LCA Systems)



Annex C

Definition of Environmental Impact Categories

Definition of Environmental Impact Categories (as used in PEMS™)

Resource depletion

The classification of resource depletion is limited to non-renewable resources only, i.e. coal, oil, gas and minerals. Resource depletion is calculated by multiplying the amount of extracted resource (kg) by its individual classification factor. The classification factors are calculated by dividing the global oil reserves by the global reserves of the specific resource. The classification results in 'oil equivalents' can then be summed.

Global warming Potential

The gases involved in the greenhouse effect (e.g. carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), nitrous oxide (N₂O), sulphur hexafluoride (SF₆)) all have the property of absorbing energy and emitting thermal infra-red radiation. An increase in the atmospheric concentration of greenhouse gases will change the absorption of infra red radiation in the atmosphere. This may lead to changes in climatic patterns and higher global average temperatures.

Global Warming Potentials (GWP's) have been developed by the IPCC (Intergovernmental Panel on Climate Change) and can be used to express the potential contribution of different gases to the greenhouse effect.

The GWP is a relative parameter that uses carbon dioxide (CO₂) as a reference gas. The emissions of each greenhouse gas are multiplied by their GWP and the system's potential contribution to the greenhouse effect is expressed in a single score by summing the individual contributions.

Acidification

Acidification results from the deposition of acids that lead to a decrease in the pH, a decrease in the mineral content of soil and increased concentrations of potentially toxic elements in groundwater. These effects are caused by acid rain and the major gaseous pollutants associated with this are sulphur dioxide (SO₂) and nitrogen oxides (NO_x). These are dissolved in rainwater and subsequently deposited. The effects of acid deposition are very site specific and will vary depending on the receiving environment (i.e. the buffering capacity of the soil and any dilution effects which might occur).

Acidification Potential (AP) factors have been developed for potentially acidifying gases such as SO₂, NO_x, HCl, HF and NH₃. The AP of a substance is calculated on the basis of the number of hydrogen ions that can be produced per mole of a substance, using SO₂ as the reference substance.

Eutrophication

This is caused by the addition of nutrients (e.g. NO_x, nitrates, phosphates and ammonia) to a soil or water system that leads to an increase in biomass. Any nutrient can have a nutrifying effect however, nitrogen and phosphorous are the most important. Those substances that have the potential for causing eutrophication are aggregated using nitrification potentials (NP's) which are a measure of the capacity to form biomass compared to phosphate (PO₄).

There are various issues surrounding this category and as with acidification, the impact of pollutants will depend on the sensitivity of the receiving environment.

Ozone depletion

Changes in atmospheric ozone will modify the amount of harmful ultraviolet radiation penetrating to the earth's surface with potential effects on human health. For gases that contribute to the depletion of the ozone layer (e.g. chlorofluorocarbons), ozone depletion potentials (ODP's) have been developed. These can be used to express the potential contribution that these substances make to the depletion of the ozone layer. The ODP uses CFC 11 as a reference substance.

Summer (Photochemical) Smog

Low level smog contains irritants that can adversely affect human health. Photochemical oxidant formation potential (POCP) factors have been developed for substances (VOC's, CFC's) that contribute to the formation of photochemical oxidants/smog. The POCP is a measure of the capacity to form ozone in the lower atmosphere using ethylene as the reference substance.