7. Recommendations on reduction of waste amounts and emissions from WEEE

In order to reduce the amounts of WEEE and emissions of dangerous substances resulting from the disposal of such waste and in order to reintegrate valuable materials into the economy, ecological efficiency (not recycling at any price), economic aspects and social acceptability must be considered. Measures to minimise environmental impacts can focus on effective treatment and final disposal of reduced WEEE amounts and on long-term measures such as eco-design of EEE and changed consumer behaviour.

7.1. Waste management oriented measures

Collection infrastructure
Collection systems are one of the key issues concerning WEEE management. In Europe most WEEE is collected and disposed of together with municipal waste, especially small appliances and electronic goods. Refrigerators and freezers appear to be the exception, although their separate collection does not always lead to appropriate treatment. For waste management purposes it is important to collect and separate different types of WEEE according to the subsequent waste treatment and recycling processes.

For recycling purposes collection systems for categories of WEEE should be created:
- refrigerators/freezers to enable separate treatment of CFC;
- TV sets, monitors to enable special treatment of circuit boards and parts containing flame retardant;
- lighting equipment for mercury recovery;
- large white goods. After removal of capacitor that might contain PCB the ferrous, non-ferrous and plastic fraction can be recycled directly.

Dismantling and separation
Dismantling and separation constitute the important first step for reducing amounts of WEEE and emissions from WEEE treatment.

To improve the current situation several measures can be taken:
- Tools for dismantling should be developed and improved, in order to automate the dismantling process and to increase the segregation of materials in this first step.
- Information for the recyclers about the location of parts containing dangerous substance and how they can be recognised should be provided.
- The shredder process is the most problematic step in the pre-treatment chain, particularly when the input is not dismantled. Although this process is designed to facilitate material separation (ferrous material, non-ferrous and plastic) no pure fractions are obtained so that significant quantities of dangerous substances are dispersed to all fractions. This causes problems in the subsequent recycling facilities. Therefore efforts should be made to improve the process technology and to develop alternatives to this process.
- The shredder residues are not recyclable so this fraction should be incinerated in well-controlled plants or used after further treatment for energy recovery in plants with high standard flue gas cleaning systems.
- In order to reduce the amount of shredder residues, easily accessible parts should be removed before shredding.

Improvement of treatment processes
State-of-the-art incineration plants for hazardous waste are equipped with efficient abatement technologies, so that major environmental problems are not caused during

operation. Residues containing heavy metals have to be disposed of in properly operated landfills to avoid leaching of heavy metals.

A high percentage of WEEE is still treated in municipal waste incinerators and an increasing amount is processed in industrial facilities for recycling purposes. These facilities should be equipped with appropriate abatement technologies. Another way could be to improve the quality of the input materials. To realise this, the collection and separation systems should be improved to reduce the amount of dangerous substances transferred to thermal processes.

7.2. Product-oriented measures

Source-oriented measures are the most efficient way in the long term to reduce environmental problems by treatment of WEEE. Product design plays an important role because it can phase out dangerous substances such as heavy metals and halogenated organic compounds and improve the recyclability of the product. However, innovative product design is not a solution to the current problems, but an investment for the future.

Design
The trend towards increased recyclability of products has led to the concept of design for recyclability (DFR) and disassembly (DFD). The product design determines to a large extent how easily a product can be recycled. Intelligent design can therefore significantly improve the suitability of a product for disassembly and recycling.

Design for disassembly (DFD) and design for recyclability (DFR)
Dismantling of WEEE is the first and the most important step in the recycling chain. Currently, this process is very labour intensive. As a result only easily accessible parts, containing dangerous substances and precious metals are removed in this first step and various valuable and dangerous materials are transferred further on to the subsequent processes.

Because most electrical and electronic goods have a high value, computer-aided design (CAD) tools are used in the design process, so data on materials and rules for DFD and DFR should be incorporated into the CAD-software to enable the designers to take environmental aspects into consideration.

Material substitution
Examples of possible substitution of materials used in EEE manufacture are listed below:
- PCB-containing capacitors are no longer in use in Europe, so problems related to these dangerous substances will disappear over the next ten years;
- Hg switches are being phased out. The main sources of Hg and Cd are accumulators in electronic equipment and on circuit boards;
- a substitute for brominated flame retardants is currently being developed. Flame retardants for plastic can be avoided by using alternative construction measures, such as metal chassis and capsulated power supply;
- substitutes for lead in solders are currently being developed, but are not yet applicable;
- specifications of electronic devices have to be adapted to withstand higher temperatures.

7.3. Consumer-oriented measures

Eco-efficient services
A new approach to saving raw materials and resources is product leasing or selling services (the so-called eco-efficient service) instead of selling products.

The leasing approach is realised by producers of copiers, for example, Xerox and Kodak. The copier in use remains the property of the producer. It is therefore in the producers' interest to extend the life span of the product. End-of-life products are returned to the producer thus encouraging him to develop efficient re-use and recycling strategies. Xerox re-uses up to 60 % of end-of-life copiers in the production of new machines. Other parts of the old equipment are recycled so that the remaining waste from end-of-life copiers is reduced by 90 %. This could be expanded to other products.

Changing consumption patterns
Consumers represent the demand side in the market system. They can influence product design, increase the demand for eco-efficient services, buy long-life products or stop buying useless products.

First of all, consumers should be informed about the environmental impacts they cause by using and discarding EEE. They also should be informed about possibilities of reducing these impacts, such as existing take-back systems. Therefore information campaigns are useful and can be launched in cooperation with consumer associations and NGOs. Industry can support these activities by publishing product information about the environmental performance. Eco-labelling systems can be implemented to increase transparency on the market, that is, provide a common standard to compare eco-performance of products. Information on sustainable consumption patterns can be integrated in the education system.

8. Conclusions

8.1. WEEE potentials

A general conclusion is that the necessary data in order to carry out the calculations is rather poor. Especially data regarding sales, market saturation, import and export is lacking. The absence of reliable data implies that the estimated potentials of WEEE are of limited value and should be used only with great caution.

Furthermore, the appliances selected here only cover a fraction of the total WEEE potential included in the proposal for the WEEE directive. According to the proposal for the WEEE directive (COM(2000)347 final), various estimates of the quantity of WEEE indicate that the collection target of 4 kg per inhabitant constitutes only 25 % of the overall annual generation of this waste.

One of the objectives was to provide a first insight into the complex waste stream of WEEE, by trying to estimate current and future potentials. A large recycling potential exists, which, if thoroughly explored, can significantly contribute to a reduction of the amounts of dangerous substances emitted as well as the recovery of considerable quantities of valuable materials. This is in line with the proposal for the WEEE directive where targets have been established for recovery and component, material and substance reuse and recycling.

For EU15 the potential quantity of the five types of appliances shows a downward trend for 1990-99 from 3.6 - 3.3 kg per inhabitant. The projected potential for four types of appliances seems to rise steadily from 3.9 in 2000 to 4.3 kg per inhabitant in 2010. However, it is not possible to explain why the potential suddenly should be rising from 2000 and onwards.

Among the selected appliances, the highest potential amounts for EU15 are found for TV sets with figures of 1.2 - 1.7 kg and refrigerators with a potential of approximately 1.1 kg per inhabitant.

With respect to the projections, the most interesting factors are trends and tendencies of how each appliance as well as the total potential may develop in the future, as it is considered to be too unreliable to forecast the actual quantities.

8.2. Emissions of dangerous substances

The Topic Centre has calculated emissions from a number of dangerous substances from treatment of selected appliances with use of the state-of-art treatment methods present. The results of the calculation were:

The recycling quota (ratio of kg recycled material per average weight of appliance) is calculated for the selected appliances. This recycling quota shows that the EU minimum rate of component, material and substance reuse and recycling in the proposed WEEE directive has been achieved by using the so-called "state of the art" recycling schemes for all selected appliances except for PCs.

The air emission fraction (ratio of kg emitted dangerous substance per 1000 t input of appliance) is calculated for the selected appliances and shows that the lead emissions from recycling of PCs and TVs are the highest in comparison with the other appliances. Main contributors to these emissions are the copper and lead recycling plants. Given the fact that TVs and PCs account for approximately 55 % of the overall waste potential of these appliances, lead emissions from the treatment of TVs and PCs must be considered to be potentially significant. Among persistent organic pollutants the emission of PCB is highest. Incineration and metallurgical plants emit

PCBs. Relatively high emissions of PCBs result from the shredding of small appliances.

Additionally the study included a comparison between emissions produced by state-of-the-art recycling and emissions produced by incineration of a similar quantity of appliance. In most cases, emissions from incineration were lower than emissions from recycling. However, it is important to note that incineration means that resources such as metals are permanently removed from the economic cycle. Therefore, a comprehensive comparison of recycling and incineration must also take into account the emissions resulting from the primary production of materials destroyed by incineration.

To reduce the amount of WEEE and the emissions from the treatment of such waste, focus may be waste management oriented, product oriented and consumer-oriented.

Waste management oriented measures:
- Collection systems are one of the key issues concerning management and minimisation of WEEE. Separate collection of WEEE is the first and very important step to enable appropriate treatment.
- Dismantling and separation at pre-treatment facilities, where removal of parts containing dangerous substances takes place.
- Improvement of recycling technologies.

Product oriented measures:
- Product design plays an important role. The trend towards increased recyclability of products has led to the concept of design for recyclability (DFR) and disassembly (DFD). The product design determines to a large extent how easily a product can be recycled.
- Substitution of dangerous substances, especially brominated flame retardants, Cd, Hg, Pb and PCB is very important.

Consumer-oriented measures:
- A new approach to saving raw materials and resources is product leasing or selling service - the so-called eco-efficient services.

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Annex I. Methodology for potentials

For the calculations of waste potential of WEEE, various methods can be used. Table I.1 shows the methods of calculation used in the present report. The time step method is described in chapter 5. The other methods are described in this annex. The method in the last column - estimation - is simple estimations.

Table I.1: Methods of calculation used in the project

Appliance	Method of calculation				
	Time step	**Market supply**	**Approx. 1**	**Approx. 2**	**Estimation**
Refrigerators	X				
TV-sets	X				
PCs	X				
Photo copiers		X			
Fluorescent lamps				X	
Toasters				X	
Mobile phones			X		
Small appliances					X

I.1. The time step method

With this method the calculation of WEEE is made on the basis of private and industrial stock and sales data. The waste potential in phase III at time t is calculated from the difference in stock levels of private and industrial equipment (phase II), in the period between two points in time t, plus sales in that period (phase I) minus the annual waste produced in that time period up to time t-1. In a Fraunhofer ISI material flow study[12], this method was termed „the time step method".

The time step method

WEEE generation (t) =

$$[\text{Stock}(t_1) - \text{Stock}(t)]_{private} + [\text{Stock}(t_1) - \text{Stock}(t)]_{industry} + \underset{n=t_1+1 \text{ to } t-1}{\bullet} \text{Sales}(n) - \underset{n=t_1+1 \text{ to } t}{\bullet} \text{WEEE}(n)$$

with $t_1 < t$

$\text{Stock}_{private}$ = Number of households *saturation level of households / 100
= Population / average size of household *saturation level of households / 100

$\text{Stock}_{industry}$ = number of work places *saturation level in the industry / 100
= number of employees / number of users per appliance

Information about domestic sales required for this calculation can be obtained from production and export statistics. Domestic sales are the sum of domestic production and imports minus the number of exported appliances.

Appliance stock levels can be taken from ascertained saturation levels in the household. This information is available for some selected appliances in private households. Industrial stock levels however are rarely available and require assumptions.

The required input data are sales and stock data of appliance.

I.2. The market supply method

With this method the calculation of WEEE is made on from sales data, together with typical lifetimes. The waste potential in phase III at time t is calculated from sales figures from phase I and information about consumption patterns from phase II (see section 5.1). Disposal is seen as the

[12] Nathani, Carsten; *Materialfluß spezifischer Abfallarten und Abfallkennziffern bedeutender Bereiche*, Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Mai 1998.

opposite to the acquisition of appliances, but with a certain time delay in the subsequent process. In a study for DG ENV[13] this method, 'market supply method', was termed 'Phase method' in a Fraunhofer ISI[14] material flow study.

The market supply method

WEEE generation (t) = sales ($t - d_N$) + reuse ($t - d_S$)

with d_N - average lifetime of new items
d_S - average lifetime of second-hand items

Similar methods of calculation were also used in the so-called Toepfer study[15] and in Fraunhofer IPA[16] calculations. It should be pointed out that the average lifetime of new goods and second-hand appliances is different.

Information about domestic sales required for this calculation can be obtained from production and export statistics.

The phase difference corresponds to the average lifetime of the appliance. Assessing the average lifetime is to a large extent subjective, when one considers that EEE is often replaced and disposed of before it reaches its technical end-of-life, and WEEE is often stored for years in cellars or garages. For simplification purposes, it is assumed as a rule that all appliances produced in the same year will be in line for disposal after exactly the average lifetime. Closer to reality would be to assume a lifetime as a normal distribution with the average lifetime as average value and a certain variance. However, as the availability of data does not permit establishing distribution curves, the simplified method will be employed here.

Required input data: Sales data and assumptions about average lifetime of appliance.

The advantage of this method is that the necessary data need not be so wide-ranging and the calculation, using a simple formula, can be carried out without any great assistance.

Sales data is derived from official statistics from market research institutes or trade organisations and are of good quality and available for a large number of products. The assumption of an average lifetime, however, seems to be a problem and we will demonstrate this by taking the PC market as an example.

The assumption that a product has a fixed lifetime or period of use over a longer period of time, presupposes constant customer behaviour over this period. But there are several reasons to suggest that customer behaviour can change. Sudden events, such as changes in technology, may result in a temporary increase (or decrease) in discarded equipment. For example, in years of rapidly increasing sales, more PCs become obsolete before the average lifetime period assumed is over, because they are replaced with new ones. However, in this case, the market supply method predicts no increase in waste generation for this year, but x years (x = average lifetime) later.

It comes to an analogous conclusion for the example of a year showing weak sales corresponding with a prolongation of first use, i.e. reduction of waste generation, which is not predicted by the market supply method.

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13 Lohse, Dr J. *et al.*; *Collection targets for waste from electrical and electronic equipment (WEEE)* - Report compiled for EC DG ENV; Ökopol - Institut für Ökologie und Politik GmbH, Hamburg/Germany, 1998.

14 Nathani, Carsten; *Materialfluß spezifischer Abfallarten und Abfallkennziffern bedeutender Bereiche*, Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Mai 1998.

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Conclusion
The market supply method makes the assumption that the average variance in lifetime of items of EEE does not change very much, whereas, in reality, lifetimes may become shorter in the future. This means that this method is not especially useful in the calculation of WEEE for a dynamic market such as for PCs where technology and lifetimes are changing rapidly. The market supply-method, however, produces good results regarding saturated markets with no extreme changes in sales volume.

I.3. The Carnegie Mellon method

With this method the calculation of WEEE is made from sales data, assumptions about typical lifetimes, recycling and storage.

In 1997, the Green Design Initiative at Carnegie Mellon University[17] used a model which is a variation on the Market Supply method outlined above. The model attempts to examine further and take into consideration consumer behaviour when disposing of an end-of-life PC. The model may be applicable to other items of EEE as well.

The model used in the Carnegie Mellon study defines the pathways of computers from purchase to end-of-life. A new computer is purchased and eventually becomes obsolete. At this point there are four options available to the owner

- Reuse: Possibly resold or reassigned to another user without extensive modification.
- Storage: Not used.
- Recycled: Defined as the product being taken apart and individual materials or subassemblies being sold for scrap.
- Landfilled.

The model therefore allows for a computer to be purchased, reused, stored and finally recycled or landfilled. Some assumptions are made regarding the pathways and these are applied to the model. This model also requires a full coverage of sales data from as early as possible.

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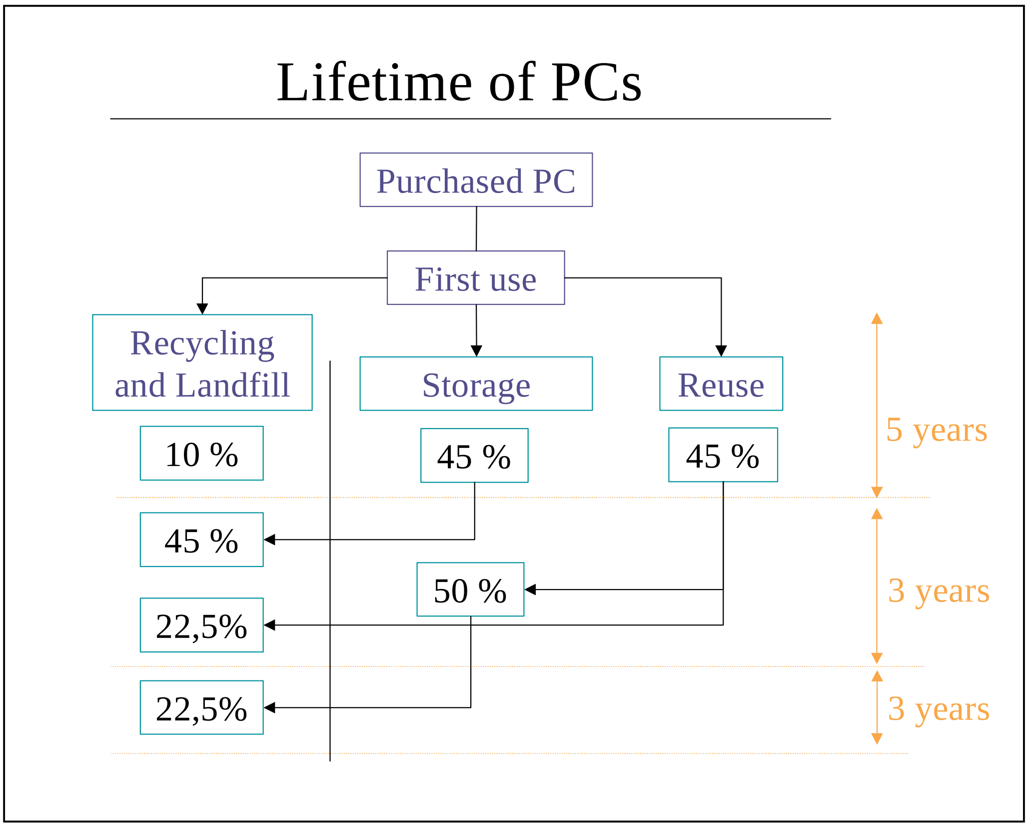
[17] Carnegie Mellon University, *Green design initiative*, 2000.

Figure I.1: Pathways of PCs from purchase to end-of-life



Required input data: Sales data and assumptions about average lifetime of appliance, reuse, storage, recycling and landfill.

Conclusion
The Carnegie Mellon method presents a refinement of the market supply method by carrying out a sophisticated examination of a product's total lifetime. For the possible options - reuse, storage, recycling, landfill - facing a product at the end of its first life, there are additional assumptions to be made regarding the probability of an option and, where necessary, the subsequent phase. These assumptions are both product and country specific and therefore demand a good knowledge of consumer behaviour and the disposal position. The Carnegie Mellon method is, in the first place, ideal for more extensive examination of individual products. Because of the larger amount of input data, the calculation of WEEE is clearly more extensively structured.

I.4. Approximate formula

Two methods are possible here: approximation 1 and approximation 2.

Approximation 1
The calculation of WEEE is estimated on the basis of stock and average lifetime data. This method has also been referred to as the 'Consumption and Use' method[18]. The same method was used to calculate WEEE in the Netherlands and was also used by NGS for WEEE estimations for the German Federal State of Lower Saxony. The method is represented by the following equation;

[18] Lohse, Dr J. *et al.*; *Collection targets for waste from electrical and electronic equipment (WEEE)* - Report compiled for EC DG XI; Ökopol - Institut für Ökologie und Politik GmbH, Hamburg/Germany, 1998.

Approximation 1

WEEE generation (t) = [Stock $_{private}$ (t) + Stock $_{industry}$ (t)] / average lifetime

Stock$_{private}$ = Number of households *saturation level of the households / 100
= Population / average size of household
*saturation level of the households / 100
Stock$_{industry}$ = number of work places *saturation level in the industry / 100
= number of employees/number of users per appliance

The method uses stock levels together with an assumption regarding the average lifetime of the appliance. As with the time step-method, stock levels are obtained by multiplying the number of households and work places by the degree of penetration for the appliance (i.e. percentage of households containing the particular appliance). Stock is then divided by the average lifetime to calculate the WEEE potential.

The required input data is: Stock data and assumptions about average lifetime of appliance.

Similar to the market supply-method, this method of calculation is based on the assumption of a product's constant mean lifetime. It is therefore suitable for estimating WEEE in widely saturated markets, where no great deviations from the mean lifetime are to be expected. This method is particularly sensitive to alterations in the average lifetime of the item being considered, and this is a somewhat subjective variable in the equation.

This method is particularly useful when reliable stock data for an appliance is available, but there is only limited information regarding sales figures.

Approximation 2
The calculation of WEEE is estimated on the basis of sales statistics assuming a saturated market. This method is based on the assumption, that with the sale of a new appliance, an old appliance has to be disposed of. It is represented by a very simple equation:

Approximation 2

WEEE generation (t) = sales (t)

The required input data is: Sales data.
This method is only suitable in a fully saturated market where the purchase of a product leads to the same quantity of waste from the old product. This method is therefore not sensibly deployed in dynamic, developing markets, as in these markets a larger part of the sales serves to increase stock and does not initially contribute to waste. In addition, this method should not be deployed if the temporary storage or second use of old appliances plays a significant role in consumer behaviour as this leads to a time delay in the emergence of waste.

One advantage of this method is the limited range of input data required. In contrast to the market supply method, no historical data is required, only sales figures for the period of time in question. This method is, therefore, suitable for carrying out an initial assessment requiring little data collection or calculation time.

I.5. Conclusion

The choice of a suitable method of calculation for WEEE is dependent on several factors. Leading questions have been formulated to make the classification of the appropriate method of calculation easier.

Character of the market segment to be considered
Are we concerned with a largely saturated statistical market or with a dynamic market, which is characterised by radical change and growth?

Behaviour of the product users
Are we dealing with product users from industry and the commercial sector or with private consumers?

- Which type of behaviour predominates with the users after the first use (continued use, storage, recycling, disposal)?
- To what extent is information on the product under investigation readily available, and how good is the quality of this data?

In Table I.2, the respective conditions for deployment of different methods of calculation and their characteristics are presented in summary form.

Table I.2: Demands and suitability for different methods of calculation of WEEE

Calculation method	Required database			Applicable to		Time consuming
	Sales	Stock	Average lifetime	Saturated markets	Dynamic markets	
Time step	X	X		X	X	high
Market supply	X [1]		X	X		medium
Carnegie Mellon	X [1]		X	X	(X)	high
Approximation 1		X	X	X		low
Approximation 2	X			X		low

[1] Sales data for previous years in accordance with assumed duration of use

The choice of a particular method of calculation requires a careful consideration of the aspects identified above and demands expertise. In every case, good results can only be achieved with a good quality database. This is especially true for the highly time-consuming calculations connected with the time step-method and the Carnegie Mellon method, which demand a more extensive database than the other methods of calculation.

If there were uncertainties concerning estimations about the market or quality of the database, the thing to do would be to implement several possible methods in parallel and then compare the results. The required values will most probably lie within the range of the results obtained.

Annex II. WEEE in the EEA member countries

II.1. Refrigerators

With regard to refrigerators, there is a saturated market determined by private consumers. The sales data from Euromonitor shows that these are, exclusively, sales to private households. An additional 10 % was added here to take the sales to industry and commerce into consideration.

For all EEA member countries, a value of between 97 and 99 % was reported for equipping households with a refrigerator. As the only information available regarding a second appliance in households was for Germany with 17 %, this value was taken as an approximation for the other countries. The specific waste potential varied between 20 and 40 units per 1 000 inhabitants for most countries.

II.1.1 Potential of WEEE 1990-99

Table II.1: Waste potential of refrigerators (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990									
1991	10 907	9 123	78 613	3 894	48 129	12 985	62 419	76 567	440
1992	11 504	9 013	108 756	3 477	49277	13 369	65 157	77 286	449
1993	11 611	8 989	110 795	3 645	51 067	13 436	64 050	64 194	410
1994	9 651	11 279	120 838	4 180	56 803	13 776	69 916	67 062	462
1995	10 123	10 933	128 436	5 094	56 021	13 934	68 414	74 815	476
1996	10 711	11 399	102 833	5 524	53 516	14 178	69 594	79 184	446
1997	13 767	12 001	170 006	5 899	61 474	14 919	72 514	73 595	438
1998	6 371	13 095	59 102	5 324	67 559	16 203	37 798	87 249	523
1999	7 954	13 735	84 483	9 521	64 623	15 151	75 601	82 677	463

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990									
1991	15 454	10 719	5 001	4 039	9 028	29 267			2 117
1992	15 122	10 804	7 389	3 771	7 651	28 631			1 998
1993	15 539	10 419	5 590	3 544	6 274	29 121			2 159
1994	16 008	10 840	6 269	3 335	6 164	29 319			2 349
1995	15 565	11 102	6 515	3 943	6 503	30 748			2 100
1996	14 023	10 784	6 747	6 125	5 746	33 685			2 113
1997	13 913	10 624	6 324	5 169	5 150	33 638			2 225
1998		8 242	6 915	5 496	4 494	71 210			2 215
1999	13 262	10 905	6 865	6 564	4 619	38 702			2 197

II.1.2 Forecast 2000-10

Table II.2: Waste potential of refrigerators (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	8 469	14 133	105 007	7 998	68 026	15 928	63 989	82 952	486
2001	8 105	14 746	104 589	8 563	70 332	16 271	63 777	84 373	492
2002	7 741	15 360	104 172	9 128	72 637	16 613	63 565	85 794	498
2003	7 377	15 974	103 754	9 693	74 943	16 955	63 352	87 215	504
2004	7 013	16 588	103 336	10 258	77 249	17 298	63 140	88 635	510
2005	6 649	17 202	102 918	10 823	79 555	17 640	62 927	90 056	515
2006	6 285	17 816	102 501	11 389	81 861	17 982	62 715	91 477	521
2007	5 921	18 430	102 083	11 954	84 167	18 325	62 503	92 898	527
2008	5 558	19 044	101 665	12 519	86 472	18 667	62 290	94 319	533
2009	5 194	19 658	101 247	13 084	88 778	19 009	62 078	95 740	539
2010	4 830	20 272	100 830	13 649	91 084	19 352	61 865	97 161	545

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
2000		9 944	7 067	6 442	3 700	50 942			2 236
2001		9 834	7 200	6 797	3 204	53 923			2 250
2002		9 725	7 333	7 152	2 708	56 904			2 264
2003		9 615	7 466	7 508	2 211	59 885			2 279
2004		9 505	7 599	7 863	1 715	62 867			2 293
2005		9 395	7 732	8 218	1 219	65 848			2 308
2006		9 285	7 865	8 573	723	68 829			2 322
2007		9 175	7 998	8 929	227	71 810			2 336
2008		9 066	8 131	9 284	- 270	74 792			2 351
2009		8 956	8 264	9 639	- 766	77 773			2 365
2010		8 846	8 397	9 995	- 1 262	80 754			2 380

II.2. Television sets

It was possible to use the sales data from Euromonitor for most EEA member countries. The missing values for 1991 as well as 1997-99 were added using the 'trend' linear function. For Ireland, for 1998 and 1999, data supplied by CEDA were used. For Spain, the sales data from Euromonitor did not seem consistent since they showed a dramatic fall from 1993-96, which did not correspond with an increasing degree of equipment in households. For this reason, an assumed annual rate of growth of 3 % was added for Spain for 1993-99.

The market penetration for equipping households with a first television set was taken to be 98 or 99 % over the whole period. In contrast, equipping with a second appliance had increased rapidly over the previous years, which was obvious from available values for Germany and Ireland. For example, the value for Germany more than doubled from 23 % in 1993 to 48 % in 1999 and in Ireland the increase from 27 % in 1994 to 46 % in 1999 was equally high. For every other country, values for only one year - normally 1998 - were available, so an approximate steady growth was assumed for 1990-99. The annual rate of growth was set individually for each country by taking the market penetration values for 1998 into consideration.

For most countries, the specific waste potential for 1990-99 showed a slight downward trend. In forecasts for 2000-10, this trend became stronger leading to values of around zero for some countries (e.g. Luxembourg) and in some cases negative values (Greece, Sweden, Belgium). The reason for these obviously inaccurate calculations must be deviations in future market penetration data for televisions, which were obtained by linear extrapolation of developments up to the present.

II.2.1 Potential of WEEE 1990-99

Table II.3: Waste potential of television sets (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990									
1991	9 594	9 461	175 102	3 400	67 366	5 660	96 876	83 054	440
1992	10 970	8 365	155 846	3 291	62 248	5 064	97 055	80 264	428
1993	10 974	7 765	134 464	3 484	62 666	4 520	100 649	69 196	380
1994	10 216	8 179	133 074	3 836	62 877	4 056	100 267	77 311	365
1995	10 348	8 728	138 159	3 783	62 840	3 628	100 446	78 622	348
1996	10 224	9 233	128 802	4 625	62 510	3 017	99 348	78 248	364
1997	13 595	8 461	180 069	4 417	62 378	2 184	99 413	73 537	314
1998	6 500	8 773	78 223	3 064	61 344	3 010	68 092	82 256	349
1999	7 291	8 906	120 474	6 580	58 048	598	94 272	73 524	276

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990									
1991	25 873	9 785	14 574	4 447	13 706	86 166			4 094
1992	17 975	9 475	14 563	2 286	11 922	82 938			4 370
1993	17 322	8 604	14 638	3 382	10 066	79 567			4 547
1994	16 485	7 935	14 021	3 706	9 879	74 206			5 391
1995	14 578	7 918	14 804	4 793	8 372	66 462			4 587
1996	13 162	7 846	13 476	5 413	6 584	58 540			4 229
1997	9 658	6 851	13 457	5 063	4 978	49 879			4 564
1998		4 221	13 825	5 684	3 436	76 398			4 321
1999	5 749	5 697	12 327	6 202	1 651	59 963			3 964

II.2.2 Forecast 2000-10

Table II.4: Waste potential of television sets (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	8 521	8 773	107 876	5 278	59 065	849	86 766	75 458	277
2001	8 231	8 798	101 802	5 523	58 383	314	85 088	75 083	260
2002	7 942	8 822	95 728	5 768	57 701	- 221	83 410	74 707	243
2003	7 652	8 846	89 654	6 012	57 019	- 757	81 731	74 332	226
2004	7 363	8 870	83 580	6 257	56 337	- 1 292	80 053	73 957	209
2005	7 073	8 894	77 506	6 502	55 655	- 1 827	78 375	73 581	192
2006	6 784	8 919	71 432	6 747	54 973	- 2 363	76 696	73 206	174
2007	6 494	8 943	65 358	6 992	54 291	- 2 898	75 018	72 831	157
2008	6 205	8 967	59 284	7 237	53 609	- 3 434	73 340	72 455	140
2009	5 915	8 991	53 210	7 482	52 927	- 3 969	71 661	72 080	123
2010	5 626	9 015	47 136	7 727	52 245	- 4 504	69 983	71 704	106

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
2000		4 617	12 789	6 409	582	53 834			4 302
2001		4 021	12 554	6 781	- 871	50 510			4 272
2002		3 426	12 319	7 152	- 2 323	47 185			4 242
2003		2 831	12 083	7 523	- 3 776	43 861			4 212
2004		2 236	11 848	7 895	- 5 228	40 536			4 182
2005		1 641	11 613	8 266	- 6 681	37 211			4 153
2006		1 046	11 378	8 637	- 8 133	33 887			4 123
2007		451	11 142	9 009	- 9 586	30 562			4 093
2008		- 145	10 907	9 380	- 11 038	27 238			4 063
2009		- 740	10 672	9 751	- 12 491	23 913			4 033
2010		- 1 335	10 437	10 123	- 13 943	20 588			4 003

II.3. Personal computers (PCs)

The sales data for personal computers provided by EITO (European Information Technology Observatory) was used in calculations for every country with the exception of Ireland. For Ireland, values from Gartner Group were used due to the fact that the scale and chronology seemed consistent. The missing values for 1990-95 assumed a steady growth rate of 25 %. The missing values for 1990-92 for Greece and Portugal were supplied by assuming exponential growth. Regarding market penetration of personal computers in private households, research results are available for most EEA member countries. These are, however, of only limited use, as there is no data available regarding the penetration in industry and, therefore, the total stock of personal computers cannot be deduced from the market penetration in private households. For a few countries, information on the ratio of the stock of privately used PCs to commercially used PCs is available. However, these ratios vary from one to four and therefore seem to be unreliable. To obtain the total stock of PCs, it was therefore necessary to fall back on market penetration data obtained from EITO, which does not differentiate between private and commercial use. This information is available for most EEA member countries for 1992-94 as well as 1998 and shows rapid growth. The missing information was supplied by using the assumption of exponential growth. As expected, a significant increase in waste potential from personal computers for the majority of EEA member countries was found.

For some countries, for example the Netherlands, a clear fall in the quantity of waste was seen which could not be explained. This demonstrates the problem of the rapidly growing number of appliances, which cannot be determined accurately enough for this method of calculation. Because deviations in the stock of appliances effect the resulting waste data over proportionally, dramatic deviations in the quantity of waste for individual years may even produce contradictory results.

II.3.1 Potential of WEEE 1990-99

Table II.5: Waste potential of personal computers (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990									
1991	2 345	1 865	40 146	267	12 092	427	24 983	16 344	
1992	2 676	1 697	41 767	405	12 749	536	26 030	17 153	
1993	3 955	4 433	43 232	589	12 097	689	29 766	15 201	
1994	5 773	6 644	63 905	901	11 223	887	35 093	17 195	
1995	4 675	4 382	58 949	1 251	13 678	1 058	24 537	15 630	
1996	5 356	5 063	68 309	1 835	16 986	1 452	31 484	19 439	
1997	4 165	2 230	83 317	2 463	26 456	1 727	48 006	25 888	
1998	2 155	683	73 312	4 077	33 918	2 331	46 808	32 189	
1999	7 843	5 895	85 834	6 353	39 515	2 594	60 223	33 489	

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990									
1991	10 656	5 358	1 591	3 074	5 353	30 663			3 171
1992	11 241	5 668	1 706	2 582	5 950	31 174			3 598
1993	12 005	6 619	2 000	3 437	7 770	47 244			4 120
1994	17 197	7 215	2 339	3 990	11 893	54 409			5 774
1995	10 897	5 068	2 537	2 740	7 201	35 216			4 430
1996	12 164	5 949	2 765	2 920	5 692	38 317			4 626
1997	9 367	6 868	3 032	3 000	15 018	36 679			3 688
1998	1 356	7 741	3 976	2 457	13 988	52 176			2 989
1999	3 218	9 146	4 549	3 208	26 760	43 380			4 712

II.3.2 Forecast 2000-10

Table II.6: Waste potential of personal computers (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	8 399	75 736	83 338	8 188	46 355	3 084	63 897	38 123	
2001	10 238	82 949	84 596	10 133	52 884	3 517	70 005	41 924	
2002	12 077	90 163	85 854	12 078	59 414	3 951	76 114	45 725	
2003	13 916	97 377	87 112	14 023	65 943	4 384	82 223	49 525	
2004	15 755	104 590	88 371	15 968	72 473	4 818	88 331	53 326	
2005	17 594	111 804	89 629	17 913	79 002	5 251	94 440	57 127	
2006	19 432	119 017	90 887	19 859	85 532	5 685	100 549	60 927	
2007	21 271	126 231	92 146	21 804	92 061	6 118	106 658	64 728	
2008	23 110	133 444	93 404	23 749	98 591	6 551	112 766	68 529	
2009	24 949	140 658	94 662	25 694	105 120	6 985	118 875	72 329	
2010	26 788	147 872	95 920	27 639	111 649	7 418	124 984	76 130	

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
2000	- 1 501	10 197	5 369	3 097	30 330	50 779			4 821
2001	- 4 576	11 336	6 127	3 201	36 201	54 129			5 333
2002	- 7 650	12 475	6 886	3 305	42 071	57 480			5 845
2003	- 10 724	13 614	7 644	3 409	47 942	60 830			6 357
2004	- 13 798	14 753	8 402	3 513	53 812	64 180			6 869
2005	- 16 873	15 892	9 161	3 617	59 683	67 531			7 381
2006	- 19 947	17 032	9 919	3 722	65 554	70 881			7 893
2007	- 23 021	18 171	10 677	3 826	71 424	74 231			8 405
2008	- 26 095	19 310	11 436	3 930	77 295	77 582			8 917
2009	- 29 169	20 449	12 194	4 034	83 166	80 932			9 429
2010	- 32 244	21 588	12 952	4 138	89 036	84 282			9 942

II.4. Photocopiers

There are comprehensive sales data on photocopiers available; however, there is no reliable information to allow the calculation of stock. Because of this, a calculation of waste potential was carried out using the market supply method. A mean appliance lifetime of four years was assumed. Using the available data, the waste potential for 1994-99 was calculated as well as a forecast to 2003. For almost every EEA member country, a falling emergence was revealed, which reflects the slight fall in sales over the last few years.

II.4.1 Potential of WEEE 1990-99

Table II.7: Waste potential of photocopiers (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1994	3 350	4 200	38 000	3 000	13 000	2 000	29 500	19 258	
1995	3 288	4 522	39 182	3 000	13 720	2 000	30 556	19 258	
1996	3 114	5 064	42 967	3 000	13 987	2 000	31 819	19 865	
1997	2 502	2 934	55 686	3 143	11 252	2 127	26 071	17 379	
1998	2 526	3 146	53 671	3 024	11 072	1 860	26 592	16 263	
1999	2 552	3 436	53 354	2 920	11 293	1 624	27 390	15 872	
2000	2 565	3 594	52 980	2 935	11 542	1 522	28 266	15 698	
2001	2 341	2 648	38 155	2 109	6 905	1 304	20 493	18 683	
2002	2 416	2 741	38 689	2 168	6 971	1 357	21 046	19 580	
2003	2 496	2 810	39 519	2 232	6 998	1 414	21 329	20 309	

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1994	13 500	5 000	2 200	3 700	7 800	33 000			2.022
1995	13 289	5 258	2 200	3 845	7 964	33 458			2.111
1996	13 070	5 549	2 200	4 231	8 150	34 108			2.201
1997	11 103	4 697	2 428	3 231	7 764	28 393			2.295
1998	11 525	4 871	2 126	3 261	7 640	29 245			2.380
1999	11 756	5 007	2 190	3 359	7 792	30 561			2.475
2000	12 073	5 147	2 295	3 436	7 940	31 814			2.566
2001	9 138	3 744	1 721	2 543	3 190	17 905			1.692
2002	9 422	3 897	1 802	2 678	3 247	18 460			1.729
2003	9 701	4 083	1 872	2 805	3 301	19 030			1.765

II.5. Fluorescent tube lights

Since sales data was only available for five countries, approximate values for the other countries were calculated. This was carried out as follows:

As 60 % of fluorescent tube lights are used in commerce and industry, the gross domestic product was taken as the basis for other countries. For the five countries for which sales data is available, ratios s, which were averaged out over the year, were calculated (s = number of sales/GDP). These lie between 40 and 83 and so seem fairly plausible. A mean value was created from these ratios and used for the other countries. This gives an annual emergence of fluorescent tube lights for EEA member countries of approximately 400 million pieces or 96 000 tonnes.

Table II.8: Calculation of waste, fluorescent tube lights in EEA member countries

a) Calculation sales average 1993-98 (units)

	Austria	Denmark	Germany	Ireland	Spain
1993		7 100 000		1 382 252	
1994		7 500 000		1 486 546	
1995	7 018 134	12 000 000		1 867 315	
1996	8 062 995	12 400 000		1 895 276	
1997	6 966 255	10 800 000		1 093 610	
1998			90 000 000	2 486 671	41 000 000
Average 1993-98	7 349 128	9 960 000	90 000 000	1 701 945	41 000 000

b) Calculation average sales / GDP 1997 (units / Euro)

	Austria	Denmark	Germany	Ireland	Spain
Sales	40.28	66.89	48.22	24.55	83.16

c) Calculation average sales / GDP 1997 (units / Euro)

Five countries
52.62

d) Calculation WEEE, EEA member countries

	mio units	tonnes
1997	399.6	95.892

II.6. Small appliances

II.6.1 Overall assessment

A survey carried out by Bundesverband Sekundärrohstoffe und Entsorgung[19] gives a total amount of 130 000 tonnes/year for Germany for 1998. Included in this are the following types of appliances: vacuum cleaners, power tools, kitchen appliances, electric heating appliances (toasters etc), electric lawn mowers, ironing machines, sewing machines, hairdryers, razors, hot-water appliances. This quantity represents an emergence of 1.6 kg per capita per year. When this value is compared with the empirical data provided by various pilot projects from the collection of end-of-life appliances (compare Table 5.1), the empirical data values with a range of 0.57 to 1.4 kg per capita per year lies clearly lower. This corresponds with the experience that only a small portion of the total waste potential can be collected by waste collection systems.

The value of 1.6 kg per capita per year given above is therefore acceptable and will also be used for estimating waste potential of small electrical appliances for the remaining European countries. With these assumptions there is an overall waste potential of small appliances in the EEA member countries of 593 000 tonnes/year. A backdated calculation of emergence in previous years as well as projections for the future will not be made due to the limited range of data.

Table II.9: Calculation of waste potential of small appliances in the EEA member countries

	WEEE (tonnes)	WEEE (kg/person/year)
Estimation BVSE Germany	130 000	1.6
Estimation EEA member countries	593 000	1.6

II.6.2 Toasters

The results for most of the EEA member countries show a nearly constant or slightly increasing waste potential between 1990 and 1999.

Table II.10: Waste potential of toasters (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990	218	81	2 026	170	452	40	1 120	462	8
1991	224	81	2 057	168	447	36	1 075	450	8
1992	231	86	2 261	171	473	48	1 340	445	8
1993	238	88	2 340	161	455	47	1 407	432	8
1994	245	89	2 421	158	460	44	1 435	410	8
1995	252	90	2 493	160	465	42	1 464	406	7
1996	240	92	2 560	161	469	49	1 494	402	8
1997	290	94	2 685	156	471	49	1 619	386	8
1998	277	95	2 745	154	469	47	1 628	375	7
1999	286	97	2 829	154	475	49	1 676	366	7

19 BVSE - Bundesverband Sekundärrohstoffe und Entsorgung e.V., 1998.

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990	461	210	246	101	259	1 981	170		78
1991	462	210	251	105	280	2 050	168		74
1992	457	200	256	108	240	2 111	171		86
1993	447	200	278	111	265	2 238	161		88
1994	442	202	282	114	265	2 328	156		76
1995	450	182	283	118	275	2 383	160		98
1996	447	197	288	120	275	2 414	161		81
1997	441	187	300	123	275	2 527	156		90
1998	440	185	306	126	287	2 600	153		88
1999	440	182	310	129	288	2 658	154		89

II.6.3 Mobile telephones

The available data on mobile telephones represents the total market well, but as there is no sales data for every EEA member country, a comprehensive calculation of waste potential using the calculation tool is not possible. For France, Germany, Italy, Spain and the UK, EITO provides data on market penetration for several years which, assuming a constant rate of growth in these countries, is supplemented for 1990-98. The growth in the stock of mobile telephones in each country can be calculated from this data and is identified as being dramatic (Table II.11).

The use of the calculation tool to create forecasts is not possible because of the data situation described. Besides, the market research carried out for EITO can be used for this[20]. The following illustrations show forecast values provided by EITO for market penetration and the associated rate of growth of stock of mobile telephones in Western Europe for 1995-2005. When one accepts this forecast, the market is seen to approach saturation in 2005. When this value is applied to all EEA member countries, it produces a total stock of approximately 230 million appliances in 2005. From this, an estimation of waste potential can be made for 2005. Taking into consideration the assumption that at that time there will be a relatively saturated market, the 'approximation 1' method is used. The average lifetime of an appliance is assumed to be four years. From this, a waste potential of approximately 57.6 million units or 14 400 tonnes of mobile phones is projected for 2005 for the EEA member countries.

Table II.11: Mobile phones, calculated data, stock total (units)

	Germany	Spain	France	Italy	UK
1990	824 101	143 407	297 412	758 665	1 193 405
1991	1 075 172	186 598	389 961	994 746	1 564 768
1992	1 415 325	242 796	511 309	1 304 292	2 051 693
1993	1 867 238	315 920	670 418	1 710 161	2 690 139
1994	2 458 565	411 067	879 039	2 242 329	3 527 256
1995	3 915 428	955 987	1 341 265	3 842 741	5 408 499
1996	5 405 745	1 598 784	2 201 166	5 349 395	7 200 616
1997	8 447 816	3 341 459	4 928 613	10 413 122	9 680 967
1998	13 999 436	7 000 736	11 332 134	20 115 680	12 693 120

20 EITO - European Information Technology Observatory 2000, European Economic Interest Group, 2000.

Annex III. Material flow in the recycling/recovery of WEEE

In the following, typical recycling and recovery processes for WEEE are described, stating input/output and environmental problems for each step.

III.1. Dismantling

Dismantling is an important step in the recycling/recovery chain. The main purpose is to remove parts containing dangerous substances that are hazardous in the subsequent processes and to segregate valuable parts in accordance with the material-specific recycle chains.

Dismantling is labour-intensive, so its extent is usually a compromise between ecological and economic aspects. It should be considered to remove parts and substances that might contain Hg, PCB, CFC, Cd and Pb.

Outputs

Material for recovery/recycling	• Steel, iron, plastic, copper, aluminium, printed circuit boards, cathode ray tubes
Waste	• PCB containing capacitors, Hg-switches, CFC
Environmental risks	• Contamination of soil through improper storage of WEEE, removed parts or improper handling of liquids (e.g. oil) • Emission of CFC to the atmosphere.

III.2. Separation by shredder process

Shredder processes are applied to separate ferrous metal, non-ferrous metal and plastic. The fractions obtained are not pure, all fractions contain a low percentage of the other substances, and dangerous substances in the input material are spread over all fractions. The ferrous and non-ferrous fraction can be recycled in smelting plants, whereas the shredder residue is a mixture of different plastics, ceramic, glass etc. and cannot be recycled.

White goods (refrigerators, etc.) are normally treated in large shredders together with cars. The environmental impacts from shredder residues depend on the input material, which means whether components containing dangerous substances were dismantled and the dangerous substances removed/recycled before shredding. In white goods such components are large capacitors with PCBs for refrigerators/freezers and in addition mercury switches, CFC and oil from the cooling circuit and the insulating foam if the shredder is not encapsulated. For other WEEE, it should be considered to remove batteries and accumulators before shredding.

Input	• White goods (often together with cars and other scrap)
Output	• Ferrous fraction • Non-ferrous fraction • Shredder light fraction • Filter dust
Environmental problems	• Shredder light fraction (large quantities and dangerous substances) • Volatile emissions

Ferrous metal fraction
The scrap metal after shredding has a 95-98 % iron content. Problems for steel production processes are caused by contamination with copper (app. 2 g/kg ferrous fraction).

Non-ferrous metal fraction
According to information from shredder operators the metal yield is about 50 %, the other half being plastic, rubber, stones etc. For non-ferrous metal recycling this fraction is treated in several further separation processes (for example, sink-float processes) and the separated non-metallic fraction is landfilled.

Shredder residues
The filter dust is, in most cases, disposed of together with the light fraction. The shredder light fraction is a mixture of plastics, rubber, wood, textiles, foam, glass, ferrous and non-ferrous metals and wires. The amount of shredder residues lies between 20 and 30 % of the input and depends on:

- the type and proportion of the input materials (cars, white goods, other scrap);
- the extent of dismantling;
- the operating conditions.

The calculated amount of shredder light fraction is 11-49 % by weight for washing machines, 23-51 % for dishwashers and 39 % for cooling appliances[21]. The percentage depends on type and year of production.

Disposal of shredder residues
Except for pilot projects there are currently no recycling/recovery treatment processes for shredder residues available. Normally the shredder residues are disposed of in landfill sites for municipal waste. From experiments on mono-landfilling of shredder residues the following conclusions were drawn:

- Despite their composition shredder residues are microbiologically degradable[22].
- The self-generated heat (up to 70°C) leads to emissions of light volatile compounds[23].

To reduce the volume of the shredder residues (and the disposal costs) extruders are used, reducing the volume by up to one seventh.

Pilot projects on minimising shredder residues (input: cars, white goods, other scrap) demonstrated that by mechanical treatment this fraction can be separated further: a plastic fraction which can be used for energy recovery, a metal fraction which can be recycled and a fraction consisting of glass, ceramics, metal containing dust which has to landfilled[24]. The method is not commonly used, because direct landfilling of shredder residues is cheaper.

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21 Institut für Siedlungswasserwirtschaft und Abfalltechnik, Universität Hannover, *Untersuchungen zur Herkunft, Zusammensetzung und zum Deponieverhalten von Shredderrückständen*, 2. Korr. Auflage, 1992.

22 Institut für Siedlungswasserwirtschaft und Abfalltechnik, Universität Hannover, *Untersuchungen zur Herkunft, Zusammensetzung und zum Deponieverhalten von Shredderrückständen*, 2. Korr. Auflage, 1992, Annex 1.

23 Institut für Siedlungswasserwirtschaft und Abfalltechnik, Universität Hannover, *Untersuchungen zur Herkunft, Zusammensetzung und zum Deponieverhalten von Shredderrückständen*, 2. Korr. Auflage, 1992, p. 117.

24 K.-U. Rudolph, T. Passvoss, H. Gotthelf, H.-F. Wilms, ‘Stand der Behandlung und Verwertung von Shredderrückständen aus Altautos’, *Müll und Abfall*, Volume 12, 1997, p. 745.

III.3. Recycling/recovery

Steel / iron recovery
Scrap is melted in electric arc, the waste gases are passed through a cooler which can also serve to recover heat. Gases are then dedusted by filters. In some cases the dust can contain considerable quantities of heavy metals such as zinc and lead, which can be recovered.

Input	• Scrap
Output	• Steel • Slag, dust from steel mill process, sludge contaminated with Pb, Cd, Hg, PCDD/F
Environmental problems	• Dioxin emission factors for electric arc steel plants depend strongly on operation conditions; if scrap preheating is applied, dioxin emissions are up to five times higher[25] • Electric arc furnaces contribute to the emission of Cd (13 % of the total Cd Emission in the 15 EU countries)[26].

Copper recovery
Most of the copper comes from printed circuit boards, cables and the non-ferrous fraction from shredder processes.

Printed circuit boards
All copper recycling processes require pre-treatment of the boards. Components for re-use and components containing dangerous substances (Ni/Cd, Li batteries, NiMH accumulators, PCB capacitors, mercury switches, Se-containing parts) are manually dismantled. Subsequently, the boards are crushed and copper can be recovered in (hydro-) metallurgic processes. Printed circuit boards with a high Au, Pd, Pt content are recycled separately.

The mechanical treatment (crushing, sifting, sieving magnetic and electrostatic separation) of printed circuit boards leads in the case of non-assembled boards to a copper fraction with about 95 % purity and to plastic fractions.

Input	• Printed circuit boards assembled without dangerous components
Output	• Al fraction (->Al recycling) • Ferrous metal fraction (->steel recycling) • Shredder residues (plastic, metal content 3 %): light fraction • Filter dust (->landfill) • Metal mixture • (Precious metal content > 0.02 % -> separating works; • < 0.02 %: -> copper recycling)
Environmental problems	• Dangerous substances are spread over all fractions • Crushing leads (depending on the plant and operation modus) to a thermal strain, which can cause emissions of dangerous substances • Filter dust is breathable and contains heavy metals (for industrial safety good exhausters are necessary).

Another mechanical process ('kryo recycling') uses liquid nitrogen to cool the circuit boards. Inputs and outputs are the same as in the conventional mechanical process, but the low temperature excludes the emission/generation of several dangerous substances.

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25 *The European dioxin inventory*, Final Report, LUA NRW, 1997.

26 *The European atmospheric emission inventory of heavy metals and persistent organic pollutants for 1990*, published by German EPA (Umweltbundesamt)

Metal reclamation from cables
Cable burning is a process in which copper and lead are recovered through burning of the insulating material. The gases are incinerated in a thermal afterburner and emitted into the atmosphere after wet scrubbing.

While these facilities have been shut down in Germany and the Netherlands, no information is available for other countries[27].

Environmental problems:
- All ingredients for the generation of PCDD/F are present;
- occasionally high flue gas concentrations and soil contamination at former plants were found.

Copper smelting plants
Copper can be recycled by pyrometallurgical or hydrometallurgical processes. It is recovered from copper scrap and copper alloy scrap, and substances containing oxidised copper. Pyrometallurgical treatment with a blast furnace and converter is preferred.

Primary copper smelting process
Circuit boards are often treated in the copper ore process. Plastic is burned, metals more precious than copper are transferred to the copper phase, less precious metals are transferred to the slag. The process requires flue gas cleaning.

Input	• copper ore, circuit boards
Output	• slag (contains Fe, Cr, Al, Mn, ceramic, glass) ->used for construction purposes • copper • anode sludge (Ag, after further treatment: Au, Pt, Pd recovery) • electrolyte (-> Ni recovery) • residues from exhaust gas cleaning (if applied) containing Hg, Pb, Cd (-> Pb recovery)
Environmental problems	• high temperature destroys organic hazardous compounds; • it is assumed that the ‘de novo’ synthesis (i.e. new generation) of PCDD/F is low because of the high SO_2 concentration • release of volatile heavy metals if flue gas cleaning not applied

Secondary copper production
Copper scrap is melted in small converters with coke and iron scrap during air blowing. Crude copper in the converter contains impurities and must be refined. The copper rich slag is processed by reducing blast furnace smelting to yield black copper.

Environmental problems	• volatile metals or their oxides are transferred to the exhaust gas and - if abatement technologies are present - in the gas cleaning residues • secondary copper production contributes significantly to the PCDD/F air emissions in Europe. In the case of printed circuit boards all ingredients for dioxin formation are present

Aluminium recovery
Secondary aluminium production in rotary furnaces:

27 *The European dioxin inventory*, Final Report, LUA NRW, 1997.

After preparation, such as milling, materials containing aluminium are melted and treated in converters for refinement. In rotary drum furnaces the re-melting process is carried out under a salt layer. Most of the contaminants are transferred to the slag.

Secondary aluminium production in open-hearth smelting furnaces:
In modern multi-chamber open-hearth smelting furnaces, clean grade materials such as wrought alloys are melted down without salt. Waste gas is post burnt.

The secondary aluminium production uses only 5 % of the energy used for primary aluminium production.

The most widespread method for waste gas cleaning is the dry sorption technique. Emissions of organic substances are low when the input contains low amounts of organic matters (paint, grease, oil).

Input	• Al scrap • (salt)
Output	• Al • Salt slag • Exhaust gas • Residues from gas cleaning
Environmental problems	• Salt slag • Emissions of PCDD/F • Emission of fluorides, SO_2, NO_x