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Disassembly and recycling of electronic consumer products: an overview

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Abstract

Discarded electronic consumer products cause enormous environmental problems as no thought has been given to their possible reuse. Some European governments have passed laws so that manufacturers and importers are being made responsible for their products when discarded by the consumer. Therefore, manufacturers have started to think about product designs which allow the reuse of components and the recycling of materials. Such designs have special requirements with respect to materials, fixings, and assembly and disassembly techniques.

From an economic point of view the disassembly and recycling of consumer products should be carried out with minimum costs. To fulfil governmental rules, certain operations have to be executed; therefore a disassembly strategy should include operations to separate out poisonous components.

Many techniques are available to separate and reduce materials, but it is clear that the working conditions of employees involved in the disassembly and dismantling processes should be improved.

1. Introduction

In the last decade the flow of discarded electronic consumer products has become tremendous and will result in big problems in the near future if no regulations are introduced.

Although some manufacturers are introducing the disassembly and recycling of friendly materials, the products which are available for recycling now were designed 15–20 years ago when no consideration was given to their future re-use. The absence of such consideration now causes enormous environmental problems as well as loss

of the value of products and materials which could be re-used for different purposes. For example, the gross electronic waste in Germany is more than 800 000 tons. Figure 1 shows the numbers and types of major electric appliances used in German households in 1990. This figure also shows the resulting volume of waste materials to be expected from washing machines in the near future [1].

As the figure shows, a number of components (and their added value) and materials can be salvaged. This example only shows the large flow of household appliances, but there are many other

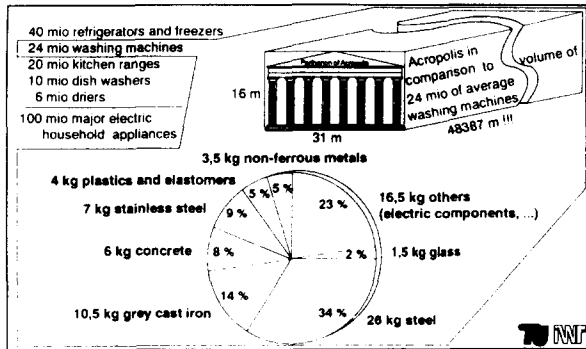


Fig. 1. The important types of discarded products in Germany and the expected waste and materials from a washing machine [1].

discarded products. For example, 1.5 million cars are transported to a dismantling plant every year in the UK, while more than 600 000 refrigerators are discarded every year in The Netherlands. In The Netherlands, the expected volume of electronic products has been calculated. This calculation is based upon the penetration degree, the average weight and the average life of each type of product. For the year 1992, it is estimated that 33 kilotons of electronic products were discarded, consisting of 20 ktons of TV sets, 8.5 ktons of audio apparatus, 3 ktons of computers and 1.5 ktons of telephone apparatus.

Of this total, 5 ktons comes from industry. To give an indication of probable growth, it is estimated that this will increase to 57 ktons in the year 2005. At the moment, a large proportion of these discarded products are not processed in any environmentally friendly way. The largest proportion of discarded electronic products has not yet been offered for waste treatment, but is stored in the home. Furthermore, much electronic apparatus goes for the landfill (8 ktons). Only a fraction is collected separately.

Concern about the environment has an increasing influence on companies, especially because of various governmental regulations. For instance, the Dutch government wants to reduce the amount of waste and to remove the remaining waste without leakages to the environment [2]. These objectives are realised by developing and

implementing courses of action and tools with the aim that companies will take care of such waste control. The results have to be:

- avoidance of the creation of waste during production and consumption processes;
- re-use of unavoidable waste as far as possible, perhaps after reprocessing, or its efficient use in the same or other production or consumption chains;
- removal of avoidable waste with negligible risk for the environment, where incineration with energy recovery is the preferred method if the waste cannot be re-used or used efficiently.

To execute this strategy, the following goals have been formulated.

1. Prevention:
 - (a) realising as far as possible quantitative prevention;
 - (b) realising as far as possible qualitative prevention.
2. Collection:
 - (a) a differentiated collection of 100% of electronic consumer products in the year 2000 to obtain optimal processing with regard to the environment.
3. Product re-use:
 - (a) realising as far as possible product re-use.
4. Material re-use:
 - (a) realising the most urgent material re-use;
 - (b) realisation of the following tasks with regard to material re-use in the year 2000:
 - (i) 90% material re-use for 'white' appliances;
 - (ii) 70% material re-use for electronic consumer products.
5. Remnant processing:
 - (a) only remnant processing by integral incineration if:
 - (i) the amount of environmentally harmful materials in the waste are negligible, and

- (ii) in this way a relevant volume reduction is obtained [3].

This kind of regulation is not only considered in The Netherlands; other countries have some similar ideas. One of the forerunners with regard to this problem is Germany. The German government wants to give manufacturers and importers responsibility for the discarded phase of products. For this purpose a bill has been proposed called 'Elektronikschrott Verordnung'. [4]. The first proposals for this bill were dated 11 July 1992 [5]. The bill states that manufacturers and importers of all electric and electronic apparatus have a duty to collect and reprocess that apparatus. The original timetable was that this bill should be operational in 1994, but this did not happen. By this bill, the German government aims to impose an integrated approach to discarded electric and electronic products. Such a concept includes the following steps:

- logistics for collection and transport;
- disassembly (dismantling) of apparatus;
- re-use of components and recycling of secondary materials;
- selling secondary materials to the market.

In this way, it is hoped that landfill with electronic consumer products can be avoided.

2. Recycling of electronic consumer products

2.1 The product

The starting point for the design of recycling processes is the product that has to be recycled [6, 7]. Components are hardly ever re-used, and therefore products have to be disassembled or dismantled to be able to separate materials in order to recycle them as secondary materials. It is not possible to recover 100% of all materials used. For instance, in printed boards many different materials are used which cannot be recovered in a pure state. This means that impure fractions are

created. Therefore it is important to know the composition of the product. From product analysis it is known that electronic consumer products contain the materials shown in Fig. 2. The large proportion of glass can be explained by the fact that glass makes up more than half the weight of a television set, and these are a significant part of the total number of products [8].

Important components found in electronic consumer products are:

- TV tubes;
- cases;
- printed boards;
- cables;
- coils;
- transformers;
- motors;
- frames.

These components are assembled from various materials and they are separated by means of manual disassembly, or mechanical or chemical separation methods.

The composition of the components of electronic consumer products will change in time; differences which have been predicted for the year 2005 in comparison with 1992 are:

- less ferrous material and more plastic and aluminum;
- an increase of metal coatings;
- less wood and more plastics;
- less precious metals.

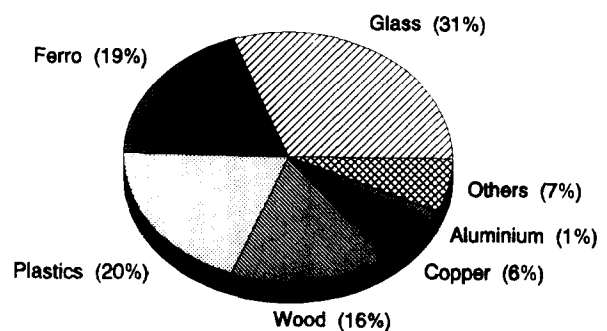


Fig. 2. The various materials that can be found in TV sets.

Recycling and re-use cause new requirements in product design [6, 9]. Products have to be designed so that they can be disassembled or dismantled easily and the materials used can be recycled. During the development phase of a product, consideration should be given to the disassembly and recycling of that product. Some requirements with respect to product design are [10]:

- improvements to make it easier to disassemble components;
- choosing the right fixing techniques;
- concentration of functions and problem materials;
- use of the right combinations of materials;
- attachment of characteristics and codes of components and materials;
- avoidance of harmful materials;
- use of fewer very different materials (especially for plastics);
- re-use of components.

2.2 The process

Re-use of components hardly ever happens as no market exists for second-hand components of electronic apparatus [4]. Siemens–Nixdorf is a company that uses secondary components on a small scale [7]. They disassemble components from their discarded products but do not use them themselves; the secondary components are sold to other parties, for example to East Europe.

If the components cannot be used, it is possible to re-use the materials as secondary materials. To sell them, the materials have to be separated and therefore dismantling techniques have to be applied.

First the materials are separated partly by disassembling the products manually with the aid of tools such as screwdrivers; the different components are removed from the device and collected separately. It is also possible to use destructive techniques (if permitted by the specifications) to shorten the disassembly times. With destructive activities, great care has to be

taken because of the risks for the employees [11]. At the moment mechanisation or automatization of disassembly is limited because of the large variety of products and their unsuitable design. In addition, more and more special tools are required to decrease the disassembly times.

The disassembled components are reduced by means of shredders or hammermills. The reduced materials from the shredder still contain the same mixed materials as before shredding. The aim is to recover the most pure materials by applying separation techniques. For instance, magnetic materials can be separated from non-magnetic materials, materials with a high density can be separated from those with low density, etc.

The purer the input materials of the shredder/separation line, the purer will be the output materials. It is not possible to obtain 100% separation; part of the impurity will remain in the material flow [6].

The disassembly level, i.e. the number of disassembly steps that need to be executed, determines the purity of secondary materials (and the price) but results in longer disassembly times (and higher costs). However, if the disassembly level is low, fewer disassembly steps are applied and the components are shredded relatively rapidly, resulting in low disassembly costs but more impure secondary materials. For instance, a TV set can be shredded as it is without any disassembly. The secondary materials which are obtained are impure, which means that the output flow contains many different materials and as a result the price will be low.

As the separation techniques used do not allow separation of all different materials, it is important to have an optimal disassembly level with regard to costs and selling price. To do so, a disassembly strategy has to be determined. This involves an optimal disassembly plan and the number of operations which need to be carried out.

3. Determination of a disassembly strategy

To determine a disassembly strategy, the first step is to analyze the structure of the product.

The relations between the product's components are determined and represented as a model of that product [12]. The analysis process establishes a distinct product structure. The product is represented as a tree graph in which all relevant components and the physical relations between them are displayed. In such a graph structure, one can see which components and/or materials are significant for determination of the disassembly sequence. First, valuable and poisonous components and/or materials should be determined. The poisonous components will define the number of compulsory disassembly operations, while the valuable components imply the number of desirable operations.

When the product's structure has been clarified, it will be found that not every disassembly operation is suitable. Some operations are not possible because there are no physical relations between the components, and other cannot be carried out because the joints are fixed and no physical separation is possible (welding, soldering, etc.). In addition, disassembly is not the reverse of assembly, and many operations can be omitted if they are not profitable.

If destructive methods are possible in order to retrieve a desired part more quickly various material flows are obtained. Another alternative is to send the product to a shredder for material recycling.

To establish a plan for optimal disassembly, one should find a balance between these options. This requires a systematic approach, which implies that suitable methods and theories should be used. To formulate the problem with respect to a disassembly strategy, the theory of graphs and the method of dynamic programming can be used for generation and evaluation of feasible disassembly plans, while a new economic model can be introduced to determine the optimal level of disassembly [12].

During the production process, input variables as raw materials, energy, information, etc., are transformed into valuable outputs (products). This means that the raw materials pass through a number of stages before the final useful products are produced. The value added to the product

increases after completing every operation and stage of the transformation process. This can be expressed as

$$V_{pr} = \sum_{i=1}^n (V_{r,i} + V_{m,i} + V_{a,i}) \quad (1)$$

where n is the number of components, V_{pr} is the value added to the product, $V_{r,i}$ is the value added to the raw materials of each component, $V_{m,i}$ is the value added during the manufacturing process of each component, and $V_{a,i}$ is the value added during the assembly process of each component.

The aim of disassembly is to regain the value added to products and materials, and to protect the environment. In this context, the term 'disassembly' involves a number of subprocesses, e.g.

- service,
- disassembly,
- dismantling,
- recycling,
- disposal.

Each of these processes represents a different disassembly level, which depends upon a number of economic considerations. The most important of these are

- the value added to products and materials,
- the disassembly cost per operation,
- the revenue per operation,
- the penalty if poisonous materials are not completely removed.

Before approaching disassembly, the value of the abandoned products should be determined. This value can be represented by

$$V_{ab} = (R_{dis} + R_{shr} - C_{tr} - C_m) \quad (2)$$

where V_{ab} is the value of the abandoned products, R_{dis} is the revenue from disassembled (dismantled) parts, R_{shr} is the revenue from recycling the remaining materials, C_{tr} is the transport cost, and C_m is miscellaneous costs (testing, remanufacturing, quality assurance, etc.).

One of the most important aspects which influence the optimal disassembly level is the product's

state with respect to its life cycle at the moment it is discarded. If a product is not completely out of its operational life cycle, it can be brought back into operation with minimum effort by changing a component which has worn out (service). A service operation is regarded as a segment of the entire disassembly process, the main task of which is to re-use the complete product by replacing a single or a few components. Such a policy is worth doing if the product is in the second phase of its life cycle (refer to the bath-tub curve) and the product can be recovered by a small investment. After service, the product can be sold to a secondary market. Service should be carried out only if the value of the product after repairing (remanufacturing) is higher than the sum of the total service costs and the value which could be obtained by disassembling. This condition can be expressed mathematically as

$$V_{pr} - (C_{dis} + C_{as} + C_c + C_m) > (R_{dm} + R_{shr} + R_{dis}) \quad (3)$$

where V_{pr} is the value of the product, C_{dis} is the disassembly cost to repair the product, C_{as} is the assembly cost to repair the product, C_c is the value of the component replaced, C_m is miscellaneous costs, R_{dm} is revenue from dismantling, R_{shr} is revenue from shredding, and R_{dis} is revenue from disassembly. If this requirement is fulfilled, the service task is justified. Otherwise, one should proceed with the next disassembly level.

Products which are completely exhausted can be regarded as an object for components or materials re-use. These considerations should be formulated in a mathematical way in order to make clear which solution is economic in each particular case.

Let us consider the following example (Fig. 3). It is supposed that a discarded product contains two types of material, ferrous and plastic. The revenue which can be obtained from a product is the revenue from disassembly (R_{dis}), the revenue from dismantling (R_{dm1} or R_{dm2}) or the revenue from shredding (R_{shr}). This can be expressed by

choosing among alternatives and selecting the best, i.e.

$$P_{max} = \max\{R_{dis} \vee R_{dm1} \vee R_{dm2} \vee R_{shr}\} \quad (4)$$

where P_{max} is the maximum revenue, R_{dis} is the revenue from disassembly, R_{dm1} and R_{dm2} are revenues from dismantling, and R_{shr} is the revenue from shredding.

The revenues obtained by disassembling valuable parts of a product can be expressed by

$$R_{dis} = \sum_{j=1}^n (P_j - C_{dis,j}) \quad (5)$$

where n is the number of valuable components which can be extracted from the product, P_j is the value of component j , and $C_{dis,j}$ is the disassembly cost of component j .

The dismantling revenue from valuable parts of a product is given by

$$R_{dm} = \sum_{j=1}^n (P_j - C_{dm,j}) \quad (6)$$

where n is the number of valuable components which can be extracted from the product, P_j is the value of component j , and $C_{dm,j}$ is the dismantling cost of component j .

The revenue from the separated shredded materials in the product is

$$R_{shr} = M \left(\sum_{j=1}^{k-1} (r_j \alpha_j - C_{sep,j}) + r_k \alpha_k - C_{shr} \right) \quad (7)$$

where k is the number of material fractions, M is the mass of the shredded part of the product, r_j is the revenue of a material fraction (negative if the material must be dumped), α_j is the mass of a fraction compared with the total mass of the shredded part, $C_{sep,j}$ is the separation cost of a material fraction, and C_{shr} is the operational cost of the shredder.

In eq. (7), α_k is the remaining mixed material fraction, where

$$\sum_{j=1}^k \alpha_j = 1 \quad (8)$$

As mentioned above, there are several disas-

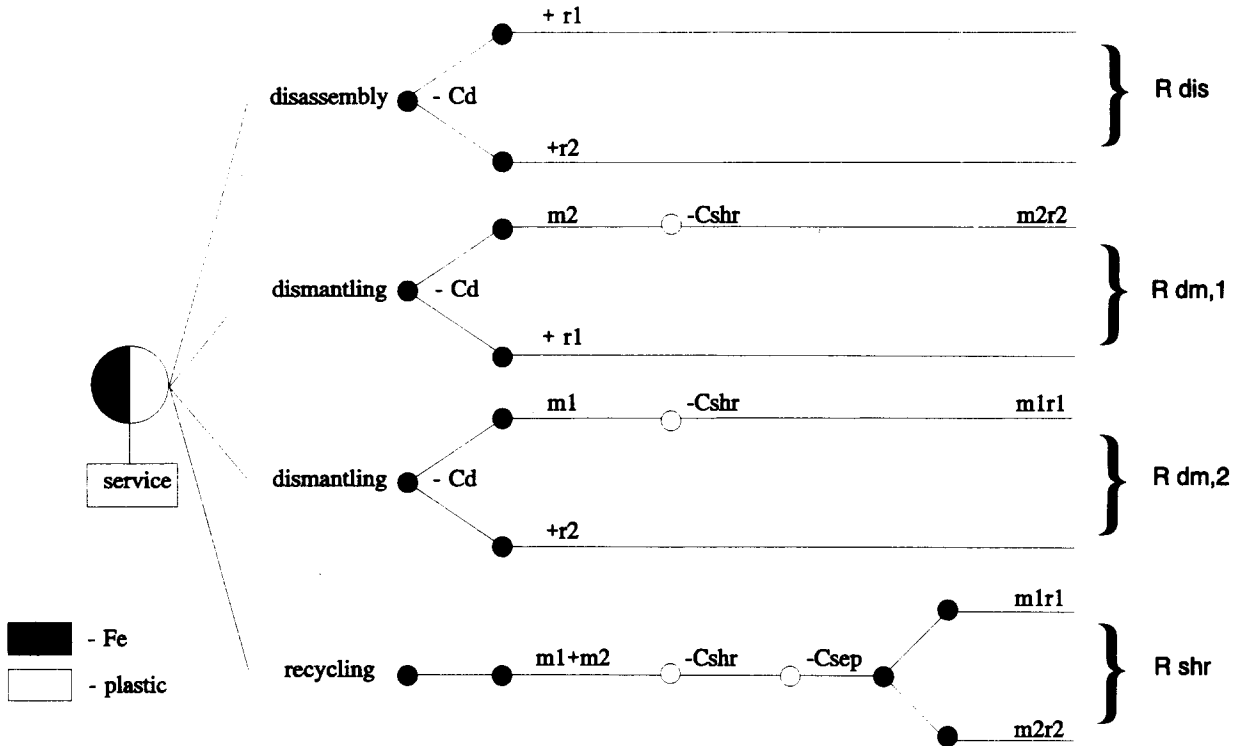


Fig. 3. Disassembly options.

sembly levels. Which of them is worth doing depends upon economic considerations as represented by the foregoing equations. Here, all levels are considered and it is clear what conditions should be fulfilled at every stage of disassembly.

Disassembly implies components (parts) re-use. It is applied if the disassembly revenue of a part i fulfils

$$R_{dis,i} > (R_{dm,i} \vee R_{shr,i}) \tag{9}$$

Proceeding with disassembly is also justified if the separation costs after shredding can be reduced by sending pure fractions to the shredder, which will facilitate segregation and increase the profit. This holds if the revenue from disassembling the i -th part is such that

$$C_{dis,i} < C_{sep,i} \tag{10}$$

Dismantling is executed when components as

well as materials re-use is worth doing. In the present example (in Fig. 2) two dismantling options are possible. The choice is made after assessing whether the following condition is met:

$$R_{dm,i} > (R_{dis,i} \vee R_{shr,i}) \tag{11}$$

In this case, proceeding with dismantling is also justified if pure fractions can be obtained which are more valuable; then, eq. (10) also holds.

Recycling is associated with the re-use of materials. If in the foregoing selection it has been found that the components do not have a high resale value, only material re-use is justified. To carry out this assessment the following condition must be considered

$$\alpha_i R_{shr,i} > (R_{dis,i} \vee R_{dm,i}) \tag{12}$$

When recycling is carried out, it is important to define to what extent one should proceed with

separation of the materials. The problem is similar to finding the optimal level of disassembly. This means that the revenues from shredding given in eq. (7) must be positive. In this case, it is very useful to represent the volume of materials which have to be recycled in a diagram. For this purpose a Shankey diagram can be introduced. This depicts the total volume of materials in a product, the number of separation operations and the volume after every step. It is clear that using eq. (12) a balance can be achieved at the optimal recycling level. It is suggested that as soon as the costs of recycling are higher than the revenues, the process should be terminated. In other words, continuing with recycling will never provide a higher revenue. This process is considered as a continuously decreasing function.

Disposal is the last stage of disassembly in which no revenue is generated. However, it influences the complete process since at this stage environmental issues must be addressed. As was stressed earlier, taxes for disposal have been increased drastically. This fact will push companies to deal with disassembly not only to generate positive revenues from discarded products, but also to decrease the costs of dumping, as these costs might be higher than all other costs associated with disassembly. Although in some cases revenue cannot be generated, disassembly will be justified if:

$$C_{dp} > C_{dis} + C'_{dp} \quad (13)$$

where C_{dp} is the cost for disposal without disassembly, C'_{dp} is the cost for disposal after disassembly (decreasing the negative revenue), and C_{dis} is the disassembly cost.

This means that by disassembling, it is possible to decrease the total disposal taxes. This is achieved by removing materials for which a penalty has to be paid if they are dumped. These penalties are imposed by legislation.

In practice, one should be very flexible in order to select the correct disassembly process and to determine to what extent it should be executed. The price of spare parts, secondary materials, disposal, etc., are dynamic variables which change

during a defined period. This makes the disassembly issue extremely difficult. By using the approach suggested, the problems can be solved in a systematic way which provides satisfactory results. This approach is the basis for a logical formulation, search and selection of the most worthwhile disassembly process. It should always be considered when dealing with issues in the field of disassembly.

4. Separation and reduction techniques

Before a mixture of different materials can be separated, the materials are usually reduced in volume. To reduce materials, a large range of apparatus is available. For the reduction of electronic consumer products, the following equipment is generally used.

Shredder

Reduction is obtained by hammers attached to a turnable by axes. The material is destroyed by the hammers and by collision with the wall of the shredder. A hammermill has a grid in the bottom where the material falls though after being sufficiently reduced. A shredder does not have a grid [8].

Cutting mill

Reduction is obtained by cutting the material using discs mounted on two axes turning in opposite directions. Often, there is a grid in the bottom. Cutting mills are especially suitable to reduce elastic materials [4].

Cryogrinding

Cryogrinding is a process to reduce materials by freezing to a very low temperature with the aid of liquid nitrogen. The increased brittleness of the material increases the efficiency of the mill and the separation of materials.

The output material from the reduction equipment is sorted to obtain purer fractions. This sorting can be executed by dry mechanical techniques which have the advantage of low cost, and avoid the use of waste water and the creation of harmful gases.

Separation equipment is usually in one of the following forms.

Riddle

The riddle process is used to classify particles according to their dimensions. When a mixture is separated into two parts, one size of particles pass through the riddle while the other size remain on the riddle. By using more riddles in cascade, separation into more than two size classes can be achieved. In practice, drum riddles, shake riddles and trill riddles are used.

Wind Sifter

By means of a wind sifter it is possible to separate solid particles in an air flow because of their different density, form and dimension; the particles are classified by gravity. Light particles are transported by the air flow, while heavy particles fall down. Wind sifters are available in different types which can vary from a vertical to a horizontal tube and from a straight to a zig-zag tube.

Gas cyclone

The gas cyclone separates solid particles from a gas by means of centrifugal forces because of differences of density and dimensions. They are used mainly to extract dust from the air.

Another type of equipment uses wet separation techniques where a liquid is used as the working medium. These techniques are based on the principle that solid particles can be separated from a mixture of solid particles and liquid by means of different particle dimensions and/or density. There are two particularly important techniques.

Float-sink technique

This technique is used to separate solid particles by means of differences in density. The particles which have to be separated are immersed in a liquid having a density value between the density values of the two components to be separated. The heavier particles sink to the bottom, while the lighter particles float at the surface.

Hydrocyclone

The hydrocyclone technique is used to separate

solid particles from a liquid based on differences of density and dimensions by means of centrifugal forces generated by the particles themselves as they whirl round. It is also used to separate contamination from a liquid.

To separate ferrous from non-ferrous materials, the specific electrical and magnetic characteristics of metals can be utilized. There are several separation techniques of this nature.

Ferromagnetic techniques

The ferromagnetic components from waste flows can be separated by directing the waste flow via a strong magnetic belt which removes the magnetic material from the flow. A magnetic belt consists of a conveyor belt around a permanent magnet. The ferromagnetic materials are drawn by the magnet to the conveyor belt. The conveyor belt transports the material outside the magnetic field, where it falls from the belt.

High gradient magnetic separation

High gradient magnetic separation can be used to separate paramagnetic materials from non-magnetic materials by directing the waste flow through a strong magnetic field with high gradients.

Eddy current

By using the conductivity of the material, ferrous and non-ferrous materials can be separated or non-ferrous material alone can be removed. By bringing a conducting particle into a fluctuating magnetic field, an eddy current is generated in that particle. The force acting on the eddy current by the changing magnetic field is used to separate the particles. Conducting particles are deflected while non-conducting particles are not deflected; in this way a separation is obtained.

Electrostatic techniques

Solid particles can be separated by means of differences in the attraction and repulsion of charged particles when influenced by an electric field. The reduced material flow is charged electrostatically. The particles go towards a surface with an opposite charge. Conducting materials reject their charge and will have a charge equal to that

of the surface; they are repulsed. Non-conducting particles are attracted by the surface.

5. Recycling in practice

Because of early publications concerning the 'Elektronikschrott Verordnung', German companies are the most developed with respect to recycling and disassembly. Siemens-Nixdorf collect their products from the early 1980s and used recycling techniques from 1988. They are using the following concepts.

1. First the re-use of the complete apparatus is considered. If this is possible the apparatus goes to the semi-professional market, and if it is not possible to the hobby market.
2. If the apparatus cannot be re-used, the re-use of components is considered. These components are not assembled in a new apparatus, but are sold to third parties.
3. If the components cannot be re-used, the materials are re-used as secondary materials. About 30 operators disassemble the apparatus to obtain pure fractions.

The raw material fractions are sold to different buyers:

- ferrous material is bought by traditional treaters;
- TV tubes are processed by a specialized company which separates the tubes into screen glass and conus glass. The screen glass can be used as a secondary material in the glass industry, while the conus glass is used for lead production;
- electronic waste such as printed boards is mechanically reduced and separated by third parties;
- cables are bought by specialized companies;
- plastics still are a problem with regard to recycling; the aim is to characterize all plastics in future so that pure separation is possible and they can be re-used.

In the last few years recycling at Siemens-Nixdorf has greatly increased: from 35% in 1988 to 79%

in 1992/1993. Only 20% remain for landfill or incineration.

Another company that recycles their discarded product is Digital Equipment Corporation. They use the following system.

1. Analysis of computer systems and other apparatus.
2. Criteria for the recycling process.
3. Determination of the recycling processes.
4. Development of disassembly strategy.
5. Recommendations for a complete recycling strategy.
6. Requirements for a recycling friendly product development.
7. The right information structure.

As well as their own apparatus, equipment from other manufacturers is also collected. Part of the disassembly/recycling activity is executed by Digital; further treatment is contracted out to Mirec BV in The Netherlands, the recycling department of Philips [13].

In Germany, specialized recycling companies have been established which are involved in the processing of discarded electronic consumer products as well as other electric consumer products. These include:

- RWE Entsorgung AG, which is located in 15 cities and has experience in the field of household appliances waste and re-use;
- Thyssen-Sonnenberg, which is located in various cities and is concerned with the processing of household appliances;
- Zerlegezentrums Grevbroich, which has different recycling lines to treat different products such as refrigerators, recovery of oil from radiators, recycling of TL tubes, battery separation, recycling of asbestos-containing apparatus, and processing of electronic waste (they cooperate with Trienekens Entsorgung GmbH, which is a subsidiary of RWE Entsorgung AG [14]);
- Zubling Umwelttechnik, which is the first company to recycle TV tubes mechanically (for Nokia Display Technics). The TV tubes are broken mechanically and reduced; the chemicals

are removed by water while the ferrous material is removed by means of magnetic belts. The clean glass is used to manufacture new conus glass.

In The Netherlands a number of companies specialize in recycling and disassembly.

- Mirec BV, a subsidiary of Phillips, treats electronic consumer products from Philips and other companies. They have a dismantling line for TV sets.
- Coolrec BV is a company which is owned by PNEM, the energy company of the county Noord Brabant and Van Gansenwinkel BV, which is a waste treater. Coolrec BV processes refrigerators and freezers.
- AVR started in 1993 to build a dismantling line for refrigerators and freezers. In the future they want to process electronic consumer products also.
- Prozon has a dismantling line for refrigerators and freezers.

The activities in Germany and The Netherlands, and also in other European countries (e.g. France and Italy) show the future demand for techniques to disassemble products in an environmentally sound and profitable way. It may be expected that other governments will follow the rules already established, and research and development with respect to the disassembly of discarded products will increase in the future.

5. Conclusions

Legislation now being developed in a few European countries forces companies to think about their product design as they are being made responsible for environmentally friendly recycling of their products discarded by customers. However, for the next 10–20 years products will have to be recycled which have not been designed with this aim.

Some processes for the recycling of electronic consumer products are already known, but have

to be developed further in order to hasten the design of a disassembly system which is economically more attractive and gives better conditions for employees.

A very important step in disassembling and recycling products is the determination of the disassembly strategy, as this strategy defines the costs for these activities.

The growth of companies specializing in disassembling and dismantling shows that these activities will be of strategical importance in the near future.

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