MATERIAL & HEAVY METAL BALANCE IN A RECYCLING FACILITY FOR HOME ELECTRICAL APPLIANCES

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Abstract

Collection and recycling of home electrical appliances was started in Japan in 2001 under a new recycling law. The law is aimed at promoting material recycling and at reducing the amount of waste to be landfilled. End of life products are processed by manual disassembly, shredding, and separation in 38 recycling facilities. The authors conducted a questionnaire survey and interviewed at some facilities to obtain information on process flow and material balance. By using the detailed records offered by one facility and by estimating the composition of recovered components, the material balance in the facilities was determined for four typical recycling processes. The heavy metal content of the recovered components was analyzed, then metal flow in the process was determined for each scenario. As a result, it was concluded that emissions to the environment of most heavy metals have been substantially reduced by the new recycling system, while a modest improvement in the rate of material recovery has been achieved.

Key Words:

Home electrical appliances, Recycling, Material flow, Heavy metal.

1. Introduction

In Japan, collection and recycling of home electrical appliances was started in April 2001 under the Electrical Household Appliance Recycling (EHAR) Law (METI 2002). The law is one of a number of new recycling laws issued to establish a “Recycle-based society”. The other target wastes are food waste from business sectors, construction waste, and packaging material. Among these laws, EHAR law is ground breaking in that it puts into practice the concept of Extended Producers Responsibility (EPR), i.e. this law forces manufacturers to take responsibility for recycling their own used products for the first time in Japan. Four products are specified as targets: TV sets with cathode ray tube, refrigerators, washing machines, and air conditioners. These are called the “Four major products” because of their large product volume and large number of sales .

Before the law was passed, these four products were collected as bulky items by a municipality, or were returned to retailers when a citizen bought a new one. In both cases, the end of life products were simply shredded, and landfilled after minor recovery of metals, as shown in Figure 1(a). The residue of the breaking up process at private shredding companies was called shredder dust (or residue) and designated as hazardous waste because of its high heavy metal content.

Under the new law, end of life products are taken back by retailers and transferred to regional storage places as shown in Figure 1(b). There are 380 of these, located all over the country. The citizen has to pay a collection fee and a recycling fee to retailers when the end of life products are collected. While the collection fee varies in each case, a flat fee for recycling is charged: 4600JPY (Japanese yen) for a refrigerator, 2400JPY for a washing machine, 2700JPY for a TV set, and 3500JPY for an air conditioner, regardless of size (1 US$ is equivalent to about 125 Japanese Yen.) Then, the collected products are transported to recycling facilities, where they are disassembled and parts are recovered, mostly by hand, before shredding. It is expected that this process will increase the rate of material recovery and reduce the amount of waste. It is also hoped that it will lessen detrimental impact on the environment.

When the EHAR law was in the preparatory stages, Association for Electrical Home Appliances(AEHA) built a test plant to develop technologies and to study the performance of material separation and recovery. Based on the data collected in the project, a couple of LCA (Life Cycle Assessment) studies were done. Ueno et al.(1998) showed that new recycling system can reduce GWP (global warming potential) and other six impacts are significantly reduced compared with landfilling or conventional shredding treatment. Nakamura(2000) estimated the effect of the EHAR recycling on waste production in other industrial sectors by using Input-output analysis of waste management. Nagata(2000) calculated ELP (Environmental Load Point), which is the unit of environmental impact weighed by Nagata, for individual process in the plant or a recycle process of each kind of product. No study was done for the detailed analysis of the plant itself.

In this paper, in considering the question of resource recovery and the reduction of adverse environmental impact, the material balance and the heavy metal balance in a recycling facility were estimated. This was done through interviews at the facility and through chemical analysis of recovered parts and material. Finally, several scenarios of home electrical appliance recycling, including the conventional shredding scenario, were evaluated.

2. Method of survey

2.1. Questionnaire survey

The recycling law orders manufacturers of home electrical appliances to recycle their own products. However, there are many manufacturing corporations in the electronics industry. For efficiency in collection and recycling, two groups were formed. Group-A is made up of 19 companies, of which Matsushita and Toshiba are most important, and Group-B is made up of 21 companies, of which Sanyo, Sharp, Sony, Hitachi, and Mitsubishi are foremost. Their strategies are different. Group-A consigns products to private shredding companies for recycling. In order to achieve the material recovery rates set by the law, some additional equipment has been installed in the contracted companies, especially for TV sets, as mentioned later. Although other products such as automobiles and automatic vending machines are treated in the same process, home electrical appliances are processed separately in order to keep track of recovery rates. On the other hand, in Group-B, facilities have been newly constructed to exclusively process home electrical appliances, funded by joint capital investment from member companies with financial support from the Government. Group-A has 24 plants, and Group-B has 14, spread across the country.

In September 2001, Questionnaire sheets were sent to 14 recycling plants from Group-B (numbered B-1 to B-14) to get information regarding plant operation, material flow, power consumption etc. The questionnaires were returned from nine plants, but only a pamphlet was attached in most cases. This just gave information on process flow. Three of the plants presented some figures, but they were not detailed enough for a system analysis. For Group-A, not even the names and addresses of the 24 plants were published. Only one recycling company, named A-1, was interviewed. The information obtained from the questionnaires will be used to show the variation of process flow in 2.3, calculation of mass balance in 4.3, and the result of the interview with A-1 will be used to describe the processing scenario in 4.1.

From plant B-1, where the authors conducted an interview, detailed data on material flow and consumed energy were obtained, and samples of recovered components and material could be taken. These data contribute to the main body of analysis in this paper. All recycling plants in Group-B have a similar process flow to B-1, with minor variations as shown in the next section.

2.2. Process flow of end of life products

Process flows in B-1 are shown in Figure 2. Components which can be reused or should be removed before shredding are disassembled by hand. Each type of product is processed in a separate line as follows.

(1) TV sets

Components such as power cords and deflection yokes are removed, then the cathode ray tube (CRT) is separated from the outer casing. The front panel glass and the funnel glass, which are made of lead glass, are separated, then crushed into cullet. The outer casing is shredded, and metal and plastics are recovered.

(2) Refrigerators

Refrigerant CFCs (ChloroFluoroCarbons) and freezer oil are recovered first. After removing other components, the outer casing is shredded. Air pressure is used to separate the urethane insulation, which is then ground to fine particles. CFCs contained in the urethane are absorbed by activated carbon, evaporated, and cooled to condense. The ground urethane is compressed in the form of pellets.

(3) Washing machines

After the salt water used as a liquid balancer (in fully automatic washing machines) is drained, the components are removed. The outer casing is shredded, then the metal and plastics are recovered.

(4) Air-conditioners

The refrigerant CFCs and freezer oil are recovered, then components are removed. Shredding and recovery of metal and plastics follow.

At the time the interview in plant B-1 was conducted, the plastic packing of refrigerators, and drain hoses were landfilled as waste. CFCs and freezer oil were sent to waste disposal companies. The destinations of other components will be mentioned in 3.3.

2.3. Variation of process flow in Group-B plants

According to pamphlets collected from Group-B recycling plants , other types of process flow exist among different plants as follows:

(1) Shredder: (a) four kinds of products are shredded by an identical shredder (4 plants), (b) TV sets are shredded in a separate line (2 plants), (c) refrigerators are separately shredded (1 plant), and (d) air-conditioners and refrigerators are shredded together, and TV sets and refrigerators are shredded in an independent shredder (3 plants, including B-1).

(2) Treatment of plastics: (a) an infrared spectrometer is used for separation by material, (b) the plastic coating is removed from copper wires by gravity separation, (c) plastics are compressed for volume reduction, and (d) plastics are pelletized to produce RDF (refuse derived fuel) (1 plant each).

(3) Decomposition of CFC (1 plant).

Despite the different process flows, the recovered components are the same for these plants. Therefore, an analysis of plant B-1 can give unbiased information regarding all the recycling plants in Group-B.

3. Results of survey and analysis

3.1. Material balance

The primary objective of home electrical appliance recycling is to increase the material recovery rate of end of life products. The material balance in plant B-1 was estimated as shown in Figure 3, in which the process flows are in the same order as in Figure 2, i.e. manual disassembly is followed by shredding and recovery of metal and plastics. Numerical values in the figure are normalized by setting the weight of each kind of product as 100 on the weight basis. The estimation was done in the following way.

As well as the weight of each kind of end of life product when received, plant B-1 also records the weight of recovered components, material, and residue. In Figure 3, all values, except composition, of each component were calculated using these data. Since small components are shipped from the plant only when they have accumulated to a certain level, data for three months, July, August, and October 2001, were used.

The composition of recovered components were estimated by several methods, which are represented by #1 to #5 in Figure 3. #1 to #3 were obtained from literature reviews. The composition of printed circuit boards was available only for TV sets, so the same values were used for washing machines and air-conditioners. #4 was determined by the authors, i.e. components were collected from plant B-1, then disassembled and weighed. #5 was judged by appearance.

Figure 3 enables us to estimate the material flow in any process with or without recovery of specific components. The material flows will be estimated later in section 4.3.

3.2. Heavy metal contents in components

Printed circuit boards and cathode ray tubes of TV sets contain lead (Pb) in high concentrations. Sekito (2001) estimated that home electrical appliances account for more than 90 percent of the lead in bulky waste in the conventional disposal method illustrated in Figure 1(a). Therefore, the recovery of these components before shredding treatment will reduce environmental load. In order to evaluate the effect, recovered components and output material in plant B-1 were sampled, and the heavy metal content was analyzed. Analyzed samples are listed in Table 1. Motors, compressors, speakers, and power transformers were not analyzed because they were difficult to disassemble and break up by hand. Components numbered 1 and 2, e.g. dust-1 and dust-2, were sampled on different days. The plastic cabinets of TV sets contain fire retardant material, so they were sampled independently from other plastics. Two types of collected dust were sampled, i.e. fine black particles with aluminum flakes, and ones composed mostly of plastics.

Some components were analyzed after removing parts which were hard to cut up or whose composition could be obviously identified. For a printed circuit board, after removing parts on the board such as the aluminum radiant and condensers, only the board was analyzed. Solder, which contains lead, is widely used in such boards. In refrigerators, circuit boards are used only for new products, so their weight is a negligible proportion of the total refrigerator weight. In washing machines, circuit boards could not be disassembled because they are coated with resin for water proofing. Components analyzed for specific composition are shown in the far right column in Table 1 with weight percentage.

Pre-treatment of samples and chemical analysis were carried out as follows.

1) Samples were shredded using a cutting mill (Mitamura Riken 182900/SM-1) or manually, using a hammer. Flexible material was cut as small as possible using scissors.

2) 0.5g samples were acid-digested by a microwave method at 130psi for 50 minutes. Nitric acid, 2ml of hydrochloric acid, and 5ml of hydrofluoric acid was added.

3) When the sample had cooled down, it was further digested by adding 30ml of boric acid at 50psi for 10minutes.

4) The sample was then filtrated by an aspirator using a 5B filter.

5) The filtrate was analyzed by atomic absorption spectrometry (Hitachi A-2000 or Z-8200).

The results are shown in Table 1. For each sample, two sub samples were acid-digested and analyzed, then their average was used. Cu(copper) in power cords is obviously due to copper wire, and is also found in printed circuit boards in a high concentration. The highest content of Pb(lead) is found in the funnel glass of TV sets because lead glass is used. Color picture tubes and glass dust also contain Pb in high concentrations. Pb in circuit boards is obviously attributed to solder. A high level of Zn (zinc) is found in collected dust, and urethane insulation contains the next highest level. A high content of Sn (tin) in printed circuit boards is attributed to solder, as with Pb. Collected dust and printed circuit boards contain Cd (cadmium) and Cr (chrome). Cd is also found in TV cabinets, and power cords contain Cr. Sb (antimony) was detected in power cords, printed circuit boards, glass, and collected dust.

For comparison, the heavy metal content of shredder dust of home electrical appliances (Ogawa 1990) is shown in Table 1. The study was done 12 years ago for conventional shredding plants. The Cu content of collected dust in this study is lower than in Ogawa's work, but the levels of Pb, Cd, and Cr are the same.

3.3. Recycling and disposal of recovered components

In order to understand the fate of recovered components, (e.g. the recycling or disposal process) and the recovery yield, users of components recovered from plant B-1 were telephone interviewed. Figure 4 shows the findings.

1) Ferrous metal, copper, and aluminum are submitted to the smelting process without any pre-treatment. Therefore these recovered metals are considered to be raw materials when shipped out of the recycling plant. Yield rates to refined metal are 95 percent or higher for these metals.

2) Motors and compressors are exported to China, and disassembled by hand. Recovered metals are then submitted to the smelting process, and the residue is landfilled.

3) Copper is recovered from coated copper wire by a stripping process, then smelted. Residual plastics are landfilled.

4) Printed circuit boards are smelted, then non-ferrous metal and noble metals are recovered.

5) Cullet from panel glass and funnel glass is recycled into new products by mixing with raw materials in a ratio of 15 to 25 percent.

6) Other parts are shredded or hand sorted to recover metals.

7) Plastics are pelletized to RDF, then used as a fuel. The yield of RDF is 60 to 70 percent in weight.

4. Evaluation of home electrical appliance recycling

4.1. Evaluated recycling scenarios

Material balances and heavy metal balances are compared for several processes which were considered typical before and after the home appliances recycling law. Four scenarios of process flow are assumed as shown in Figure 5, considering three typical processes investigated through interviews and questionnaire surveys with plants in Groups A and B.

1) Type C : conventional

This is the conventional treatment process before the law was issued. The primary objective is volume reduction. In this process all products are indiscriminately shredded in one shredder without the recovery of any components except for refrigerant CFCs in refrigerators and air conditioners. Ferrous and non-ferrous metals are recovered by a magnetic or eddy current separator.

2) Type A

Here, the recycling process of Group-A plants is assumed. The process flows for refrigerators, washing machines, and air conditioners are the same as Type C. TV sets are processed in a separate line because cathode ray tubes have to be recovered to meet the required recovery rate set by the law. The standards are 55% for TV sets, 60% for air conditioners, and 50% for refrigerators and washing machines.

3) Type B

This is the typical process flow of Group-B plants. In this scenario, components of end of life products are recovered to the greatest degree possible. A smaller shredder machine is used than Type C because motors and compressors are excluded, and not only refrigerant CFCs, but insulating chlorofluorocarbons are recovered.

4) Type B_{MP}

Plastics and urethane insulation are used as fuels in plant B-1, but some plants in Group B do not recover these materials. This process is called Type B_{MP}.

4.2. Assumed input conditions for calculation

Assumed conditions for calculations are shown in Table 2 and Table 3.

The number of end of life products are shown in Table 2, where data for 7 months are used for B-1, and 5 months for other plants. The different quantities of air conditioners, i.e. very low in B-1 and very high in B-4, reflect the different regional climates. (The plants are numbered from the north to the south. Their regional locations are B-1 in Hokkaido, B-3 in Tohoku, B-4 in Kanto, and B-13 in Kyushu.) The average values of the four plants, both for the number of products and for average weight, are used for the input conditions shown in Table 2.

Recovery rates of material by shredding and separation are set out in Table 3. Recovery outside the recycling plants which was mentioned in 3.3 are also taken into account.

1) Literature values on shredding companies (Kanaya 1999) are employed for recovery rates of ferrous metal, copper, aluminum, and brass in the process of shredding and separation. Copper in copper wire cannot be recovered because of coating.
2) The recovery rate of plastics is assumed to be 95 percent by considering that drainage hoses and packing of refrigerators are removed in B-1 because they are made of PVC.
3) The recovery rate of urethane insulation of refrigerators is 99.8 percent according to the report of a pilot study by AEHA (1999).
4) 96.4 percent of cathode ray tubes are recovered in B-1 plant.
5) Recovery rate of metals from components, after shipping to users, are set by the AEHA report (AEHA 1999), which assumes advanced technology such as low-temperature shredding.

Based on the assumption mentioned above and estimated compositions of components shown in Figure 3, a material balance for any combination of manual assembly can be calculated. In order to show the precision of the estimation, Figure 6 compares the calculated amount of output materials with the actual amounts for plants B-4 and B-13, from which output data could be obtained. Input amounts to these two plants have already been shown in Table 2. Output items are categorized according to the record format of each plant. The large error of glass for B-13 is because only glass plate is included, not cathode ray tubes. The smaller amount of collected dust may be due to the different definition of the category in plant B-13 compared to the authors'. Good agreements were obtained for other categories for B-14, and most categories for B-4.

4.3. Material balance for four scenarios

For the four scenarios in Figure 5, material balances were calculated. Table 4 shows the balance for each scenario by product. In this calculation, the yield rate to recycled products is taken into account, i.e. the yields of metal and glass are 95 % and 100 % respectively according to Figure 4. The yield of RDF is 60 to 70 % in Figure 4, but 100 % is assumed to be used as fuel here. It is noted that the calculated recovery rate is different from the rate defined by the law, which assumes a yield of 100% for recovered components.

When compared with the Type-C scenario, the material recovery rate of TV sets increases considerably through cathode ray tube recovery. However for other products, from the comparison of Type-B and Type-A, manual disassembly of various components contributes to only a minor increase in material recovery rates.

Figure 7 shows the balance in a recycling plant, calculated using input data in Table 2. Of the material recovered, the highest proportion is metal. The recovery of plastics contributes to a reduction of waste, but even so, 20 percent of input product becomes waste, even in the Type B scenario. It is because, of components recovered in the plant, only metals and glass are recovered in the subsequent recycling process as shown in Figure 4.

4.4. Heavy metal balance

By combining Table 1 and Figure 2, the heavy metal content of product components was estimated and is shown in Table 5. Contents are shown in mass per unit weight for each kind of product. All components, including those not analyzed for metal content (and shown in italic letters), are given in the table to show their contribution in weight. When multiple samples were analyzed - collected dust for example - the average value was used. Printed circuit boards were all averaged for TV sets and refrigerators. The copper content of unanalyzed components were as shown in Figure 3. The “Other” category includes mostly ferrous metal and aluminum.

The metal balance for each scenario was estimated and is shown in Table 6. Considering metal in a waste stream as emissions to the environment, the quantity of emissions avoided through recovering components was calculated for each scenario. Almost 100 % of Pb is removed from waste by the recovery of cathode ray tubes. Sb is also reduced by recovering CRT and other components. Another significant reduction is achieved for Zn - 90%, by the recovery of plastics, particularly urethane insulation. Cd and Cr are reduced by excluding TV cabinets and power cords, though content is not high. Sn can be excluded from waste by the recovery of printed circuit boards. Although heavy metal emission in the recycling process of recovered components has not yet been assessed, it is safe to conclude that the recycling of home electrical appliances can effectively reduce the impact of heavy metals on the environment,.

5. Conclusion

Recycling of home electrical appliances was primarily intended to reduce the volume of waste and to increase material recycling rates. Because of high contents of heavy metals in some components of products, it is also expected that the recycling will lessen environmental impact on the environment. In order to evaluate these effects, the material balance and heavy metal balance in a recycling facility were estimated.

By using a material balance model, which was made up mainly by using collected data in one of recycling plants, four typical processes of recycling, including the conventional process before the recycling law was enacted, were assessed. The model was proved to be reliable by the examining the estimated amounts with actual amounts of output components in two facilities. As a result of the comparison between scenarios, the recovery of cathode ray tubes can increase the recovery rate for TV set since CRT accounts for more than 50 percents in total weight of the set. However manual disassembly and recovery of components, which are the main processes in a new recycling facility, contributes to only a minor improvement in recycling rates. That is because most of metals have already been recovered by a conventional shredding & separation system and newly recovered components account for small fraction of total weight, besides not 100 percents of materials can be recovered from the components. Without plastic recovery, reduction of waste is not sufficient.

On the other hand, recovering components leads to a significant reduction of heavy metal emissions to the environment. The estimation was carried out by combining the material balance model with the heavy metal analysis of collected components in a recycling facility. Heavy metals were identified to be concentrated in some components, so excluding such components from waste stream has considerable benefit to reduce environmental risks even their weigh fraction is small. Most heavy metal emissions can be reduced to 10 percent or less compared with the conventional simple shredding process. This effect should be emphasized as one of the main objectives of home electrical appliance recycling.

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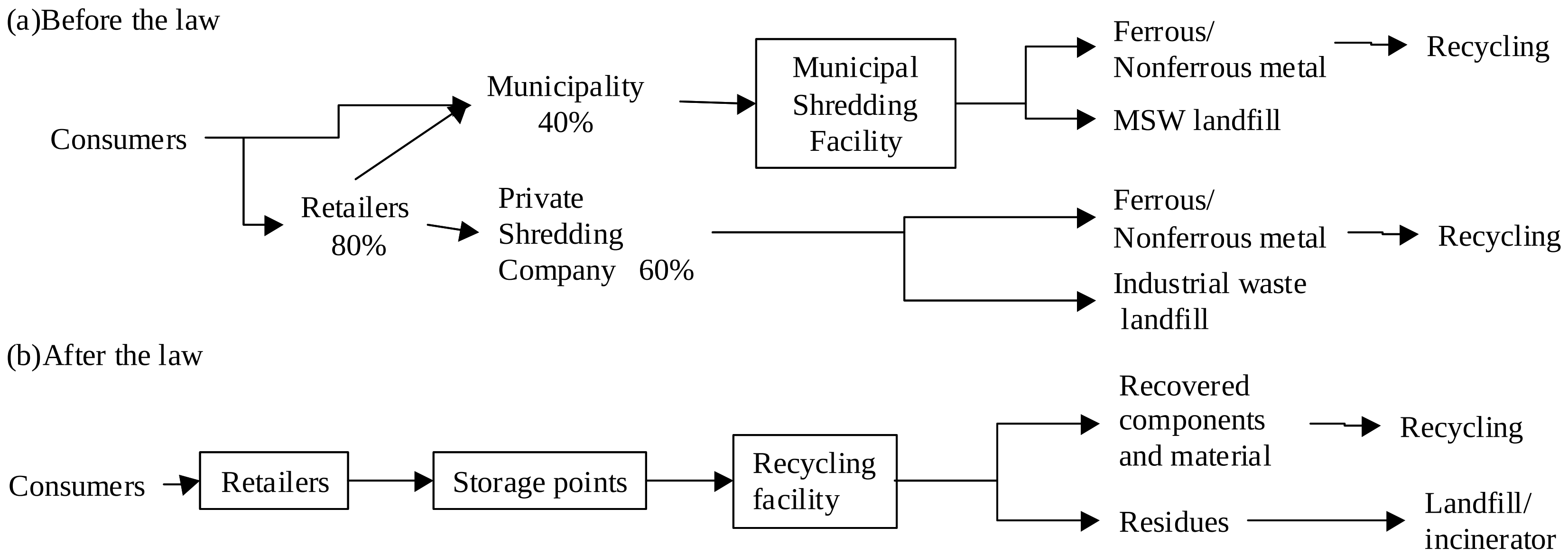

Figure 1 Flow of end of life electrical appliances before and after the recycling law was enacted

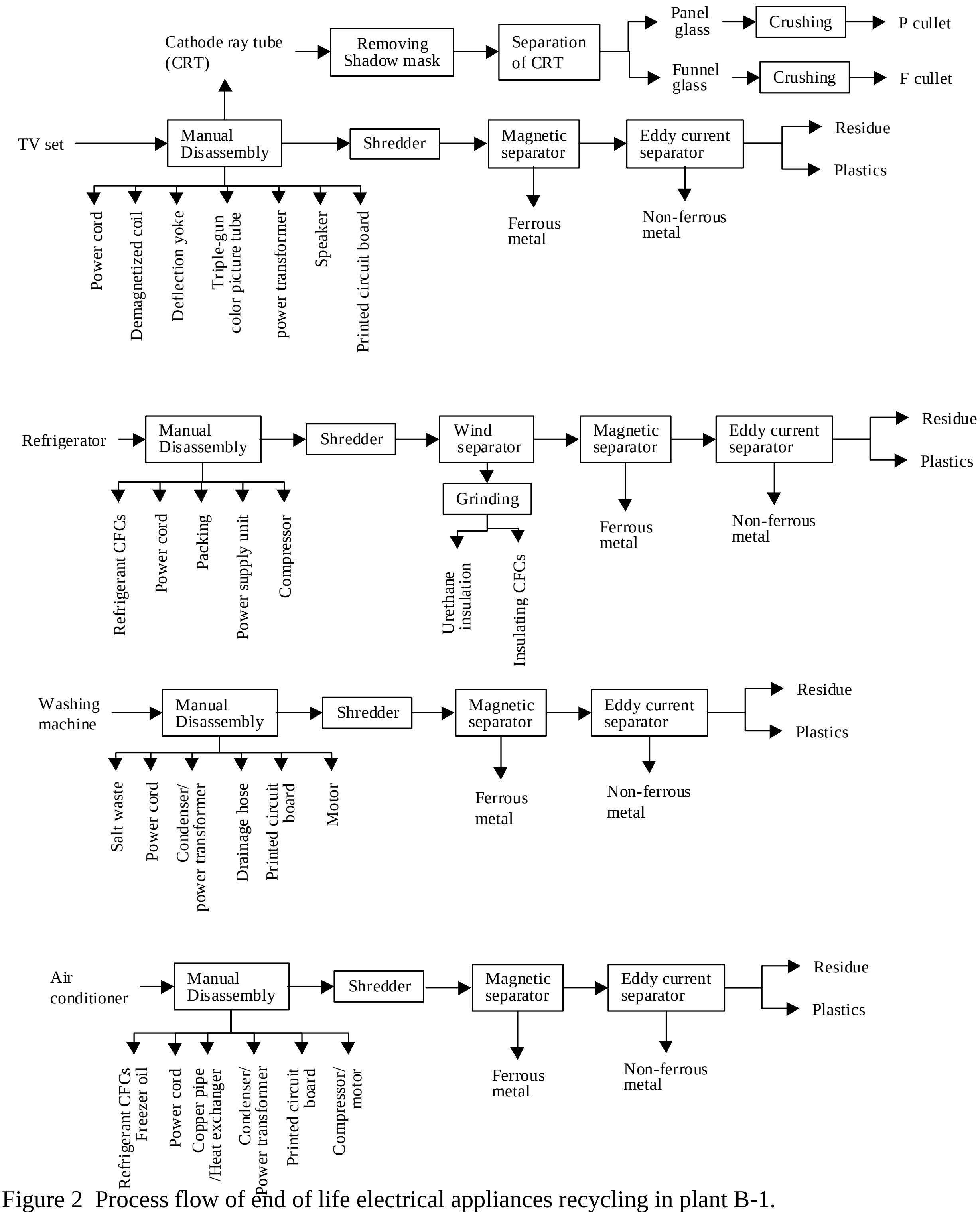

Figure 2 Process flow of end of life electrical appliances recycling in plant B-1.

TV set 100

	Power cord	Demag. coil	Deflec. yoke	color pict tube	Power transf.	Speaker	Pr. Circ. board
Ferrous metal			1.08		0.23	3.39	0.04
Copper	0.25	0.36	1.21				0.97
Aluminum				0.07			1.72
Glass				0.24			
Plastics	0.48	0.69		0.03			1.70
Other			0.22				0.59
Wt. of component	0.72	1.05	2.51	0.35	0.23	3.39	5.02
	#4	#5	#2	#4	#5	#5	#3

(Sub total 13.27)

+

Ferrous metal	6.15
P cullet	36.93
F cullet	18.75

Sub total 61.83

(Waste)

Glass dust	2.09

+

Ferrous metal	6.60
Aluminum	1.20
Plastics	13.10

Sub total 20.90

(Waste)

Dust	0.02
Wood cabinet	1.85
Sound abs.	0.04

Sub total 1.91

Refrigerator 100

	CFCs/ oil	Power cord	Packing	Power unit	Compr.
Ferrous metal				0.09	10.89
Copper					0.10
Copper wire		0.06		0.03	0.59
Aluminum					0.14
Brass					0.01
Plastics		0.04	2.80	0.05	0.35
Rubber					0.04
Urethane					
CFC	0.15				
Oil	0.25				
Other					0.44
Wt. of component	0.40	0.10	2.80	0.17	12.56
		#4	#5	#4	#1

(Sub total 16.03)

+

Ferrous metal	43.50
Copper	2.58
Aluminum	0.11
Plastics	25.87
Urethane	10.70

Sub total 82.76

(Waste)

CFC	0.35
Drain water	0.85
Dust	0.01

Sub total 1.21

Washing machine 100

	Salt water	Power cord	Power transf.	Conden- ser	Drain. hose	Motor	Pr. Circ. board
Ferrous metal			0.04			14.62	
Copper						0.28	0.07
Copper wire		0.35				1.61	
Aluminum				0.09		0.36	0.13
Brass						0.04	
Plastics		0.67		0.28	1.31	0.91	0.13
Rubber						0.09	
Salt water	2.40						
Other				0.40		1.18	0.04
Wt. of component	2.40	1.02	0.04	0.76	1.31	19.09	0.37
		#4	#5	#4	#5	#1	#3

(Sub total 24.99)

+

Ferrous metal	35.98
Copper	1.13
Aluminum	0.30
Plastics	37.30

Sub total 74.71

(Waste)

Rubber	0.25
Dust	0.04

Sub total 0.29

Air conditioner 100

	CFCs/ oil	Power cord	Copper pipe	Heat exchang.	Pr. Circ. board	Power transf.	Condense	Motor/ compr.
Ferrous metal					0.01	0.78		28.25
Copper			4.77	7.45	0.14			1.68
Copper wire		0.78						1.37
Aluminum				7.92	0.25		0.14	0.59
Brass								0.03
Plastics		0.34			0.24		0.44	0.78
Rubber								0.08
CFC	0.49							
Oil	0.11							
Other				0.13	0.04		0.63	1.18
Wt. of component	0.6	1.12	4.77	15.50	0.68	0.78	1.20	33.96
		#4	#5	#2	#3	#5	#4	#1

(Sub total 58.61)

+

Ferrous metal	25.36
Copper	0.28
Aluminum	0.50
Plastics	14.08

Sub total 40.22

(Waste)

Dust	0.19
Sound abs.	0.95

Sub total 1.22

Estimation method of composition
#1 (AEHA 1999) #2 (Shinko Research 2000) #3 (Iwasaki 2000)
#4 Determined by authors #5 Estimated by appearances

Figure 3 Output components, material,and residues in a home electrical appliance recycling plant B-1. Compositions of components are estimated by method #1 to #5 shown in the figure. All values are normalized by the weight of input product as 100.

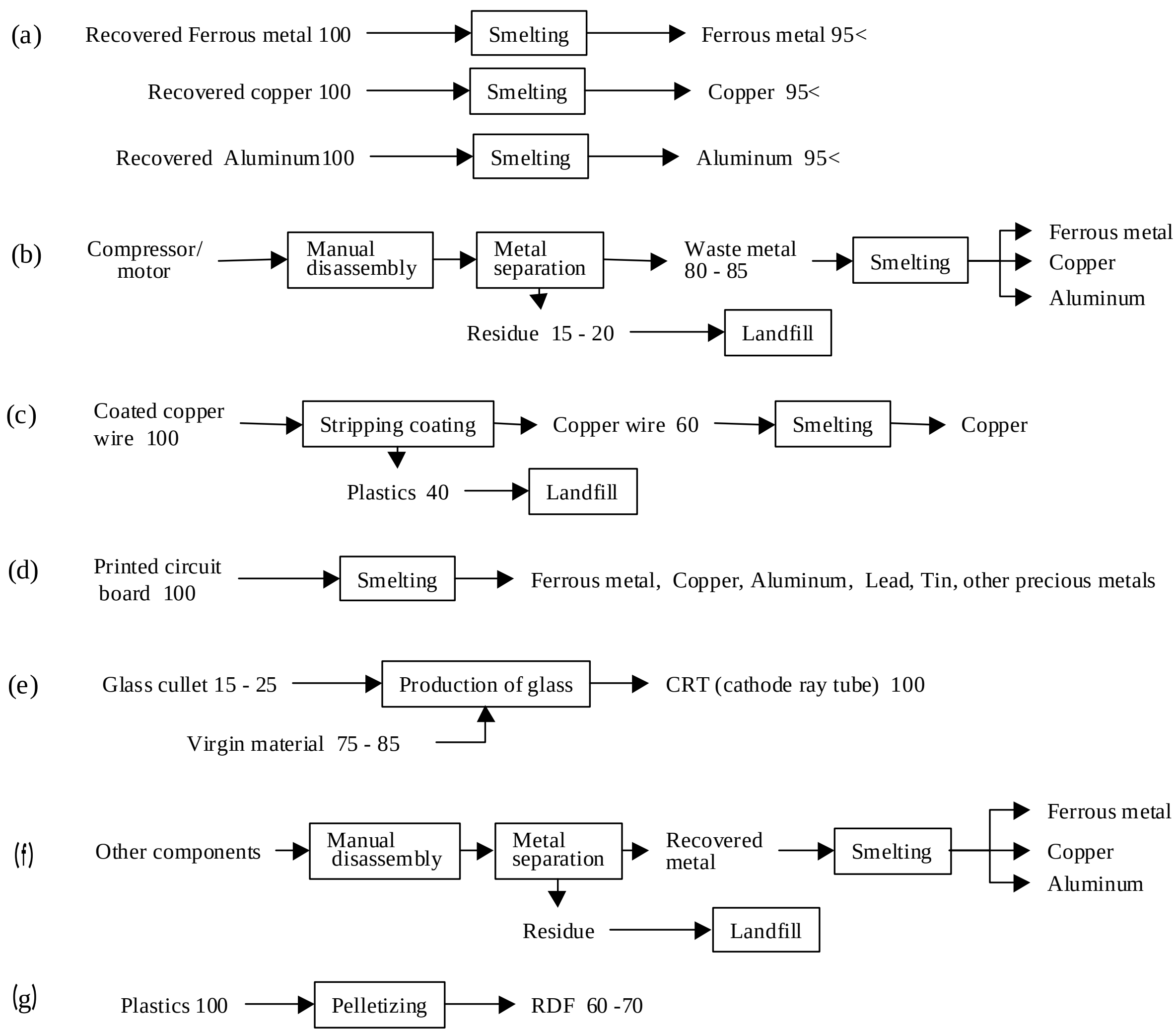

Figure 4 Subsequent uses of components and material recovered in a recycling facility.

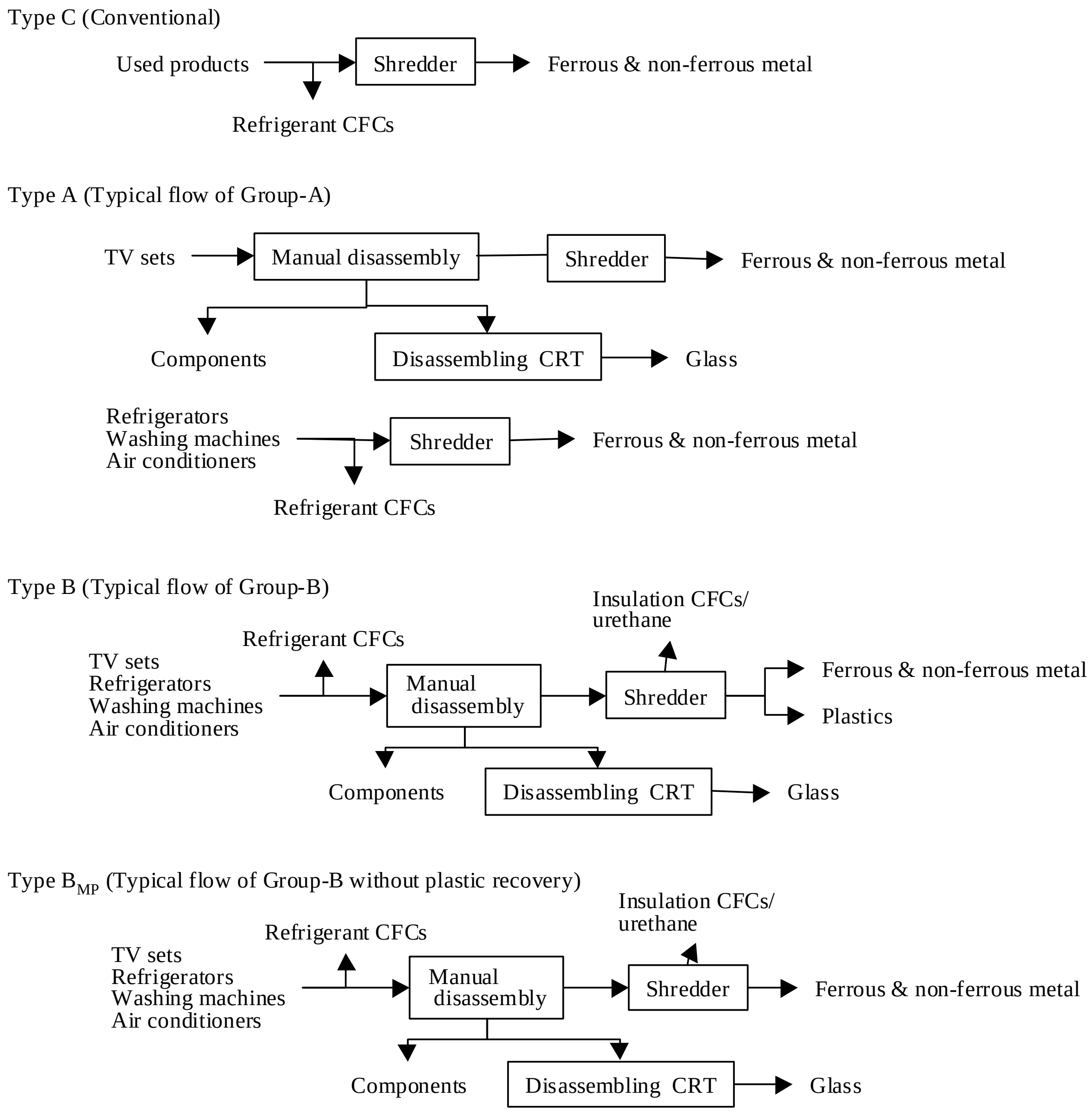

Figure 5 Assumed scenarios of home electric appliance recycling. Material balance and heavy metal balances are calculated for these scenarios.

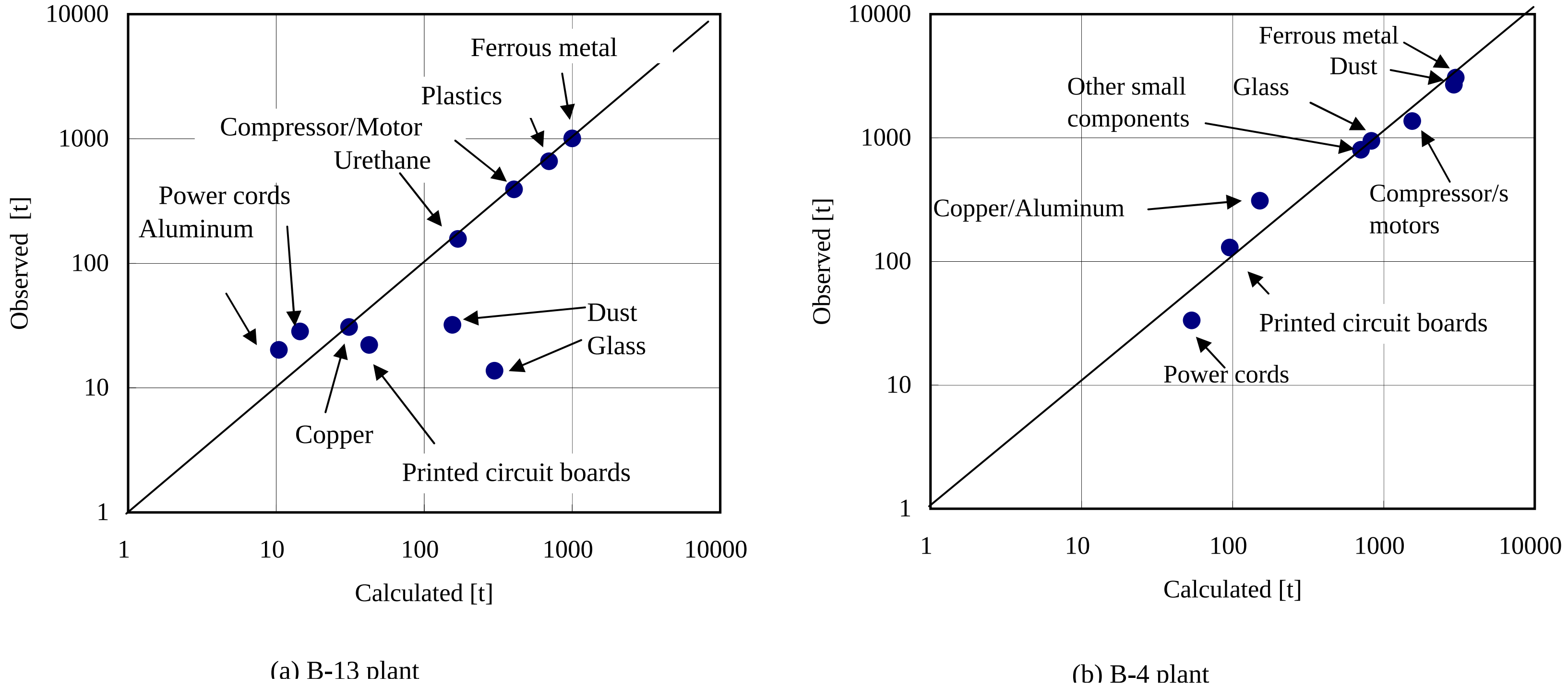

Figure 6 Output components or material. Calculated amount versus observed amount for recycling plant B-13 and B-4.

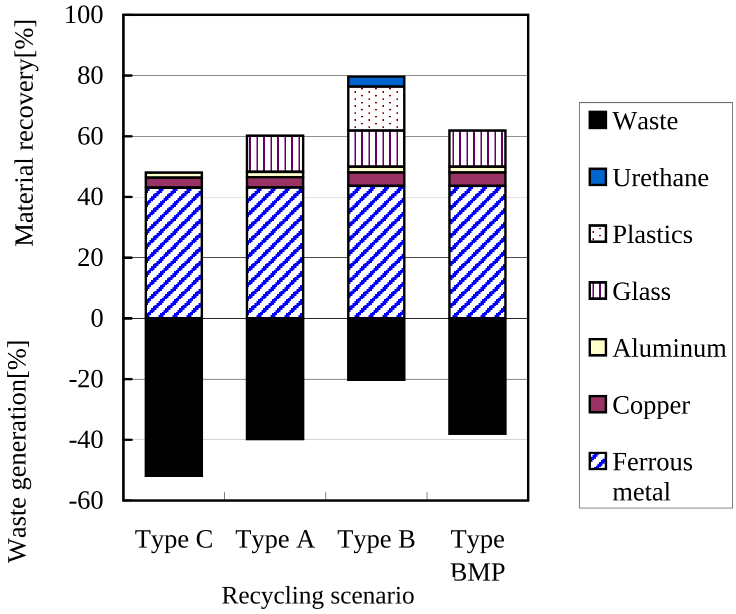

Figure 7 Calculated material recovery and waste generation rates for four typical recycling scenarios in Figure 5. Assumed input products are shown in Table2

Table 1 Heavy metal content of components. Blank cells indicate readings under detection limit except for shredder dust from literature.

component	Heavy metal content [mg/kg]							Partly analyzed composition
	Pb	Cu	Zn	Sn	Cd	Cr	Sb	
Power code (TV)	7500	504000	47.3	24100		223	8240	
Wiring on Printed circuit board (WM)	5050	342000	43.6	447		17.8		
Demagnetized coil (TV)	4200		73.0				8860	Plastics 27.5% (the rest is copper)
Printed circuit board (TV)-1	9530	97200	4240	91000	5.31		1500	Board 14.2%
Printed circuit board (TV)-2	7820	130000	2700	31700		36.4	619	Board 27.3%
Printed circuit board (R)-1	7280	159000	1470	93600			5630	Board 29.3%
Printed circuit board (R)-2	8050	161000	1020	68700			4330	Board 36.9%
Triple-gun color picture tube (TV)	14100	177	59				2640	Glass 80.8% (the rest is aluminum)
Funnel glass (TV)	265000		708				1960	
Glass dust	18400		2240				2420	
Packing (white:R)	3.35		275					Plastics 58.2% (the rest is magnet)
Packing (brown:R)	619		327					Plastics 52.7% (the rest is magnet)
Packing (gray:R)			680					Plastics 59.8% (the rest is magnet)
Drainage hose (WM)-1	1360	7770	1060					
Drainage hose (WM)-2			231					
Sound absorbing material (wool: AC)-1			684					90.1%
Sound absorbing material (rubber: AC)			4130					9.9%
Sound absorbing material (wool: AC)-2		111	186					9.8%(the rest is rubber)
Urethane insulation (R)	186	4500	15400					
Plastics-1	249	7210	803					
Plastics-2	254	576	779					
Plastic cabinet (TV)	2250	2990	574	2020	51.2			
Aluminum	318	859	834					
Collected dust-1	904	5140	107000		9.8	181		<1mm 95.1%(the rest is aluminum)
Collected dust-2	5010	2100	102000	2330	15.4	159	1340	<1mm 93.0%(the rest is aluminum)
Collected dust(plastics)	1130	8990	5880				3720	
Shredder dust (from Ogawa 1990)	3,300	130000			22.7	418		
	3100	28800			8.3	8.3		

Symbols for products TV: TV set WM: Washing machine R: Refrigerator AC: Air conditioner

Table 2 End of life products processed by the recycling plants. The upper value is the number of used products processed during April to October for B1, and April to August 2001 for other plants. The lower value is average weight per product in kg.

	Plant ID				Average*
	B1	B3	B4	B13	
TV sets	38434	21022	76082	20606	39036
	29.7	26.7	19.6	26	25.5
Refrigerators	37754	19143	73622	26645	39291
	57.7	57.2	58.2	59.5	57.1
Washing machines	28047	12526	50376	20260	27802
	27.5	27.6	26.5	28	27.4
Air conditioners	858	5178	44543	7804	14596
	44.2	45.5	49.8	37.1	44.2

* Average values will be used for later calculation

Table 3 Assumed material recovery rates by percentage weight.

	In recycling plants		
	Shredding and separation	CRT separation	Outside recycling plant
Ferrous metal	98.6		99.8
Copper	82.7		89.9
Copper wire	0		89.9
Aluminum	82.7		92.2
Brass	82.7		89.9
Glass	0	96.4	
Plastics	95		
Urethane insulation	99.8		

Table 4 Calculated material recovery rates, thermal recycling rates, and waste generation rates for the four assumed recycling scenarios.

		Recycling scenario			
	Rate	C	A	B	B_{MP}
TV sets	Material recovery	20	78	78	78
	Thermal recycle			8	
	Waste generation	80	22	14	22
Refrigerators	Material recovery	53	53	55	55
	Thermal recycle			23	
	Waste generation	47	47	22	45
Washing machines	Material recovery	49	49	52	52
	Thermal recycle			23	
	Waste generation	51	51	25	48
Air conditioners	Material recovery	70	70	74	74
	Thermal recycle			9	
	Waste generation	30	30	17	26

Table 5 Heavy metal content of each component. Contents are shown in mg per 1 kg of product. Components noted in italics were not analyzed for heavy metal content. Values under the detection limit are shown by " "(blank) except for components in italics.

(a) TV set

Competent	Ratio[%]	Pb	Cu	Zn	Sn	Cd	Cr	Sb
Power cord	0.72	45	3047	0	88		0.9	30
Printed circuit board (board)	1.04	85	1424	25	742	0.0	0.1	31
Parts on printed circuit board	3.98							
Cabinet box	13.11	295	392	75	265	6.7		
Collected dust	0.02	0	1	13	0	0.0	0.0	0
Glass dust	2.08	383		46				50
Panel glass	36.94							
Funnel glass	18.75	44000		133				368
Demagnetized coil(coating)	0.28	12		0				25
Demagnetized coil (Cu wire)	0.75		7513					
Deflection yoke	2.51		12147					
Triple-gun color picture tube (glass)	0.28	39	0	0				7
Triple-gun color picture tube (aluminum)	0.07							
Power transformer	0.24							
Speaker	3.39							
Shadow mask	6.15							
Sound absorbing material (rubber)	0.04		0	1				
Sound absorbing material (wool)	0.00		0	0				
Wood casing	1.84							
Non-ferrous metal	1.20	4	10	10				
other	6.60							
Total	100.00	44864	24535	305	1095	6.7	1.0	512

(b) Refrigerator

Component	Ratio[%]	Pb	Cu	Zn	Sn	Cd	Cr	Sb
Power cord	0.10	6	433	0	13		0.1	4
Rubber packing	2.12	4		9				
Plastics	25.88	65	1007	205				
Urethane	10.70	20	481	1653				
Collected dust	0.01	0	1	8	0	0.0	0.0	0
Compressor	12.51		6882					
Power supply unit	0.17		349					
Inner shelves	0.68							
Non-ferrous metal	0.11	0	1	1	0	0.0		
other	47.71		25673					
Total	100.00	96	34827	1875	13	0.0	0.1	4

(c) Washing machine

Competent	Ratio[%]	Pb	Cu	Zn	Sn	Cd	Cr	Sb
Power cord	1.02	64	4322	0	125		1.2	42
Printed circuit board (board)	0.12	10	169	3	88	0.0	0.0	4
Parts on printed circuit board	0.25							
Discharge hose	1.31	9	51	8				
Plastics	37.59	95	1463	297				
Collected dust	0.05	1	2	32	0	0.0	0.1	1
Motor	19.10		18910					
Condenser	0.76							
Power transformer	0.05							
Non-ferrous metal	0.29	1	3	2				
other	39.46		9922					
Total	100.00	180	34842	344	214	0.0	1.3	47

(d) Air conditioner

Competent	Ratio[%]	Pb	Cu	Zn	Sn	Cd	Cr	Sb
Power cord	1.12	70	4745	1	138		1.4	46
Printed circuit board (board)	0.24	20	327	6	170	0.0	0.0	7
Parts on printed circuit board	0.48							
Plastics	14.14	36	550	112				
Collected dust	0.19	4	10	137	1	0.0	0.2	3
Compressor	27.05		17309					
Motor	7.04		13300					
Heat exchanger	15.57		74833					
Copper pipe	4.36		43617					
Condenser	1.20							
Power transformer	0.78							
Sound absorbing material (rubber)	0.86			35				
Sound absorbing material (wool)	0.09		0	0				
Non-ferrous metal	0.51	2	4	4				
other	26.36		2851					
Total	100.00	132	157548	296	309	0.0	1.6	57

Table 6 Rate of avoidance of heavy metal emission to the environment for the four assumed recycling scenarios. Values show percentage of total contents of end of life product processed in a recycling plant.

Recycling scenario	Pb	Cu	Zn	Sn	Cd	Cr	Sb
C	0.0	73.8	0.3	0.0	0.1	0.0	0.0
A	97.4	78.8	3.4	50.2	0.3	26.1	71.1
B	98.9	90.0	94.1	90.7	94.7	83.7	83.1
B_{MP}	97.6	87.8	3.5	73.8	0.3	83.7	83.1