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An overview of recycling and treatment of scrap computers

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Abstract

In order to recover valuable materials and to minimize the adverse effects of hazardous materials contained in scrap computers, a dismantling practice is commonly adopted to treat scrap computers. By using the dismantling process, both useful and hazardous materials can be manually separated and retrieved. On the basis of the properties of the retrieved materials, they can be sent to appropriate facilities for further recycling or treatment. Among the retrieved materials, the treatment of hazardous materials from cathode ray tubes (CRT) and printed circuit boards with integrated circuits have drawn considerable attention, thus implying that the proper treatment of such materials can greatly assure the successful recycling of scrap computers. For this reason, this study reviews the available technologies which can be applied to treat and recycle cathode ray tube components and printed circuit boards with integrated circuits. Actual recycling data from a scrap computer recycling plant located in Taiwan are also introduced. The data show that this recycling plant can recover 94.75 wt.% and 45.99 wt.% of useful materials from the main machines (i.e., CPU, power supplier, fan, IC boards, DVD drive, CD drive, hard disk, soft disk, shell casing, etc.) and monitors of scrap computers, respectively.

Keywords: Scrap; Computer; Recycling; Cathode ray tube; Printed circuit board; Integrated circuit; Recovery

1. Introduction

Due to rapid improvements in electronic manufacturing technologies, the personal computer (PC) can be regarded as a short-life-cycle electronic product. This phenomenon results in a large quantity of relinquished personal computers. The hazardous materials (i.e., phosphor coatings of cathode ray tubes (CRT), high-lead content in the CRT funnel glass, batteries, PCB capacitors, mercury-containing parts, and plastics containing flame-retardant bromine, etc.) contained in computers may seriously pollute the environment if they are not properly disposed of. In addition to the hazardous materials, some valuable materials (i.e., copper-containing motors, plastic or iron parts, gold-, silver- and copper-bearing printed circuit boards, etc.) contained in scrap computers make them worth being recycled. Generally, a personal computer consists of three major units: main machine (i.e., CPU, power supplier, fan, IC boards, DVD drive, CD drive, hard disk, soft disk, shell casing, etc.), monitor and keyboard. On the basis of a manual dismantling study, Tables 1 and 2 [1] and Table 3 presents the composition analysis of the three principal constituent units, respectively. From these tables, it can be seen that computers consist of many types of materials. Due to the complex composition of computers, a manual dismantling practice is usually adopted to recycle the valuable material from scrap computers. After dismantling, the simple items obtained (i.e., metal parts, plastic shell, etc.,) can be sold directly to a local secondary material recycler. However, some complex dismantled items have to be further treated before

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Table 1
Analysis of components main machine of an IBM 286 PC

Item	Material	Weight (kg)	wt.%
Shell	Plastic, iron	5.76	42.51
Face plate	Plastic	0.30	2.22
Front shell	Iron	0.35	2.58
Back shell	Iron	0.61	4.50
Top shell	Iron	2.02	14.91
Bottom shell	Iron	2.48	18.30
IC board	IC, resin, iron, copper	0.815	6.02
Main board	IC, resin, iron, copper	0.50	3.69
Display card	IC, resin, iron, copper	0.095	(0.70
Hard disk IO board	IC, resin, iron, copper	0.12	0.89
Soft disk IO board	IC, resin, iron, copper	0.10	0.74
Soft, hard disk	Plastic, iron	4.91	36.24
10 MB hard disk	Plastic, iron	2.00	14.76
5.5 soft disk, 2 sets	Plastic, iron	2.42	17.86)
Soft disk frame	Iron	0.49	3.62
Power supplier	Iron, copper	1.81	13.34
Amplifier	Iron, plastic, magnetite	0.20	1.48
Wire	Plastic, copper	0.015	0.11
Screw	Iron	0.04	0.30
Total		13.55	100.00

Table 2
Analysis of components in a 14 in. Philips color monitor [1]

Item	Material	Weight (kg)	wt.%
Shell	Plastic	2.032	17.38
CRT explosion–protection unit	Iron	0.213	1.82
CRT unit		5.638	48.23
Shadow mask	Steel	0.455	3.89
Panel glass	Glass	3.356	28.71
Funnel glass	Glass	1.731	14.81
Gun	Steel, glass, copper, plastic	0.096	0.82
Yoke	Copper, plastic, iron	0.589	5.04
Metal parts	Iron	0.542	4.64
IC board	IC, resin, copper, iron	1.676	14.34
Wire	Copper, plastic	0.661	5.65
Rubber parts	Rubber	0.048	0.41
Plastic parts	Plastic	0.291	2.49
Total		11.690	100.00

Table 3
Analysis of components in a typical PC keyboard

Item	Material	Weight (kg)	wt.%
Shell	Plastic	0.348	37.91
Top plate	Plastic	0.118	12.85
Bottom plate	Plastic	0.230	25.06
IC board	IC, resin, copper, iron	0.384	41.83
Button	Plastic	0.116	12.63
Wire	Copper, plastic	0.070	7.63
Total		0.918	100.00

they can be recycled or finally disposed of. According to the weight percentage analysis indicated in Tables 1–3, the CRT and printed circuit board with integrated circuit (IC board) are the major items in a scrap computer. These two items contain various hazardous materials which make recycling difficult. Thus, the possible technologies for the separation of the panel and funnel glass in a CRT, the removal of the fluorescent coatings from the panel glass and the recycling of the IC board are presented in this study.

On 1 June 1998, a producer responsibility recycling program for scrap computers was officially implemented in Taiwan. Under this program, several local recycling plants were established to treat and recycle scrap computers generated in Taiwan. The recycling practice and data of one of these recycling plants are also presented.

2. Recycling and treatment of CRTs

Table 2 shows that the CRT unit accounts for approximately 50% of the weight of the entire monitor, the largest component. The CRT of a color monitor with an evacuated glass envelope has five major components: (1) panel glass (faceplate), (2) shadow mask (aperture), (3) electronic gun (mount), (4) funnel glass and (5) deflection yoke. In order to avoid radiation exposure, the panel glass has a high barium content (up to 13%) and a low lead-oxide concentration. The funnel glass contains a high concentration of lead-oxide (up to 20%) and a small amount of barium [2]. Table 2 also indicates that the weight of the panel glass is about twice that of the funnel glass [1]. From an analysis by an electron dispersive spectrum (EDS) detection device (Noran 432C), Table 4 lists both the major (>5 wt.%) and the minor elements (<5 wt.%) which can be identified in the panel and funnel glass of a 14 in. Philips color monitor [3].

CRT glass may be considered hazardous waste due to its high-lead content. The hazardous characteristics of such glass can be determined by using a toxicity characteristic leashing procedure (TCLP), which has been adopted by the US EPA to determine the leaching toxicity of wastes. That is, waste exhibits the characteristic of toxicity if the concentration of any regulated contaminants in the TCLP leachate is greater than the regulatory threshold. According to the US EPA regulation, the TCLP regulatory thresholds of Pb, Cd, and Cr are 5.0 mg/l, 1.0 mg/l and 5.0 mg/l, respectively [4]. Table 5 lists the analytical results of the TCLP leachate of the panel and funnel glasses of color CRT glass [3]. This table indicates that CRT funnel glass can be

Table 4
Components of panel and funnel glass in a 14 in. Philips color monitor analyzed by EDS [3]

Type of glass	Major elements (>5 wt.%)	Minor elements (<5 wt.%)
Panel	Si, O, K, Ba, Al	Ti, Na, Ce, Pb, Zn, Y, S
Funnel	Si, O, Fe, Pb	K, Na, Ba, Ce, C

Table 5
TCLP analytical results for colored CRT glass [3]

Sample no.	Type of CRT glass	Pb (mg/l)	Zn (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)
A	Funnel	9.985	–	–	<0.1	<0.1
B	Funnel	14.17	–	–	<0.1	<0.1
C	Panel	1.272[a]	1.607[a]	0.002[a]	0.171[a]	0.002[a]
D	Funnel	20.2[a]	0.302[a]	0.097[a]	0.166[a]	0.097[a]

–: no data.
[a] Data provided by ITRI.

declared a hazardous waste since its TCLP lead concentrations (9.985 mg/l, 14.17 mg/l, and 20.2 mg/l) exceed the regulatory threshold (5.0 mg/l); whereas, the TCLP lead concentration (1.272 mg/l) of the CRT panel glass is less than the regulatory threshold (5.0 mg/l).

Four coating layers are applied to the inner surface of the panel glass. In the first, a mixture of carbon slurry and other surfactants produces carbon black and clear stripes on the interior of the glass panel. Then, three fluorescent colors (green, blue, and red) are filled into the clear areas produced by the carbon stripe process to form the second coating layer. A lacquer (a wax-like layer) is applied to the surface of the second coating layer to smooth and seal the inner surface of the panel, thus forming the third layer. The final layer applied to the inner surface is an aluminum film used to enhance brightness. The coating of fluorescent colors contains various metals which may seriously pollute the environment [5,6].

Since the composition and hazardous characteristics of the panel and the funnel glass are different, it is better to separate these components in order to treat and recycle each. Also, it is necessary to remove the harmful fluorescent color coating from the surface of the panel glass before further treatment. Since such coatings are attached to the inner surface, the separation of components (i.e., panel and funnel) can facilitate the removal of the coatings. Therefore, the technologies for the separation of panel and funnel glass and the removal of phosphor coatings are introduced below.

2.1. Separation of panel and funnel glass

If the panel and funnel glass can be separated and returned to CRT manufacturers to produce new panel and funnel glass, the procedure can greatly increase the recyclability of scrap CRTs. Currently, an electric-wire heating method can be obtained commercially. The principle and operational procedures of this method are briefly introduced below.

2.1.1. Electric-wire heating method

1. A special electrical wire is wound around the interface between the panel and the funnel glass. Depending on the degree of automation, the winding can be done manually or automatically.
2. The wire is heated by passing an electrical current through it. Since the wire is attached to the surface of the CRT, the generated heat is transferred to the surface of the glass.
3. After the glass surface is heated for a designated period of time, cool air (i.e., ambient air) is blown on the surface. Due to the thermal shock created by the cool air, the CRT breaks along the interface between the panel and funnel glass.
4. The broken panel and funnel glass can then be manually sorted into different containers.

Depending on the size and type of CRT, separation usually takes 1–3 min by this method.

Instead of the aforementioned technology, a gravitational-fall method can be used to separate the panel and funnel. The principle and operational procedures of this method are briefly introduced below.

2.1.2. Gravitational-fall method

1. The CRT is lifted to a designated elevation, with the funnel glass facing downward.
2. The tube is dropped so that the funnel glass breaks on impact with a surface.
3. The panel glass can be manually separated from the broken funnel glass.

The gravitational-fall method is relatively simple and cheap. However, the electric-wire method can achieve a clearer separation between the panel and funnel glass, thereby resulting in better recyclability of components. Table 6 presents comparisons of the different technologies for the separation of funnel and panel glass.

2.2. Removal of fluorescent coatings

A visual and manual examination reveals that the fluorescent coating is a thin layer loosely attached to the inner surface of the panel glass. This layer can be easily removed by manually scratching. To avoid possible contamination from the heavy metals contained in the fluorescent coating, it is necessary to remove this coating. Several possible technologies for removal are briefly introduced below.

2.2.1. Vacuum-suction method

By moving a vacuum-suction device over the inner surface of the panel glass, the loosely attached fluorescent coating can be manually removed. The function is identical to an ordinary household vacuum cleaner. This method is simple and easy to implement. Usually, vacuum-suctioning is used

Table 6
A comparison of different technologies for separation of funnel and panel glass

Method	Principles	Comparison
Electric-wire heating	1. An electric wire heats interface between panel and funnel glass; 2. Cool air is blown on heated interface to cause a sudden breakage along surface, due to thermal shock.	Broken surface is relatively regular, implying that recyclablity of separated glass is higher.
Gravitational-fall	1. CRT is lifted to a designated elevation, with funnel glass facing downward; 2. Tube is dropped so that funnel glass breaks on impact with a surface.	Broken surface is irregular, resulting in a relatively poor separation of glass.

in association with the aforementioned electric-wire heating method. After separating the CRT unit by electric-wire heating, the divided panel glass surface can be cleaned by vacuum-suctioning to immediately remove the fluorescent coating. For maximum cleaning efficiency, the panel glass size should be as large as possible. Due to manual agitation, many fine particles from the fluorescent coatings may be emitted during the suctioning process. Therefore, an air-pollution-control device should be used concurrently; otherwise, the working environment may be hazardous for on-site operators.

2.2.2. *Ultrasonic-cleaning method*

On the basis of research conducted by one of the present authors [3], the fluorescent coatings can be removed by an ultrasonic-cleaning process. In that study, the panel glass was broken into pieces between 5 cm and 10 cm in length. The broken glass was placed in a 1 l beaker and covered with 300 ml of cleaning fluids. Two types of cleaning fluid were used, namely, distilled water and concentrated sulfuric acid (36N H_2SO_4). Then, a beaker containing glass and cleaning fluid was placed in a Branson ultrasonic cleaner (model 5210) water bath. Each ultrasonic-cleaning test was operated under ambient conditions. The results indicated that all fluorescent coatings from the entire panel glass area can be removed within 20 min when water is used and 10 min when sulfuric acid is used [3]. However, this method creates a wastewater problem which needs further resolution.

2.2.3. *Wet-scrubbing method*

On the basis of the aforementioned author's research [3], the fluorescent coatings on the panel glass surface can also be removed by using a wet-scrubbing method, in which the panel glass is crushed to pieces less than 2 cm in length. Two kilograms of a crushed sample were mixed with water and blended in a 4 l ball mill. The weight ratios of the crushed glass to water ranged from 1 to 3. In order to increase efficiency in removing coatings, a few alumina balls were added to this experiment. The scrubbing time for this process was 2 h. On the basis of a visual examination of the scrubbed glass particles having a size larger than 100 meshes, the surfaces were clear and exhibited no distinguishing coatings [3]. Thus, it can be concluded that the wet-scrubbing method can effectively remove fluorescent coatings. Since no additional chemical is added, the generated wastewater can be reused in a similar process after filtration. However, a small portion of the panel glass is scrubbed off during this procedure, thereby resulting in an increase in solid waste. After wet-scrubbing, the final glass product has a round edge, which makes it easier to handle in later recycling or treatment processes.

2.2.4. *Sandblasting method*

Sandblasting technology is commonly used by the steel industry to remove rust from the surface of steel products. This technology can also be used to remove the fluorescent coating from panel glass. First, the glass must be crushed to a suitable size and placed in a sandblasting device. Inside the device, many small sand particles or iron balls are blasted off by a high-pressure air jet to strike the glass surface. Due to the high impact of the sandblasting, the fluorescent coating is then detached from the panel glass. Since no water is involved, there is no wastewater problem with this method. However, a lot of fine-dust needs to be collected to avoid air-pollution. During sandblasting, some of the glass and the blasting media are broken into fine-dust. Thus, the amount of solid waste also increases from the use of this method. After sandblasting, the final glass product also has a round edge, which makes it easier to handle in future recycling or treatment processes.

Table 7 presents comparisons of the aforementioned methods for the removal of fluorescent coatings. After removal of the surface coatings, the clean CRT glass can be used as raw material for the production of new funnel and panel glass (i.e., in a closed market) or for glassware, tile, glazing, etc (i.e., in an open market). Table 8 summarizes the advantages and disadvantages of open and closed CRT glass-recycling markets.

3. Recycling and treatment of scrap IC board

The IC board (i.e., a printed circuit board mounted with various integrated circuits and other electronic parts) is the key component of a computer, without which it cannot function properly. The typical circuit board is made of epoxy resin, fiberglass and copper. Usually, a bromine fire retardant is added to the resin to increase fire resistance. The integrated circuits and other electronic parts usually contain

Table 7
A comparison of various CRT coating-removal technologies

Method	Principles	Comparison
Vacuum-suction	A vacuum-suction device is manually applied to panel glass surface.	***Merits***: Low capital cost; simple operation; no associated wastewater problem. ***Problems***: Panel glass must remain in a large piece; rely on manual operation; is usually associated with fine-dust emission problem; effective only for fluorescent coating removal but not for other types of coatings.
Sandblasting	Fine steel balls are blasted onto glass surface by a high-pressure air jet.	***Merits***: Automation degree is high; no associated wastewater problem; other surface coatings can also be removed; round-edged final product is easy to handle. ***Problems***: Capital cost is relatively high; is usually associated with fine-dust emission and waste steel-ball disposal problem; coating removal efficiency may not be 100%.
Ultrasonic-cleaning	Broken CRT glass is immersed into a cleaning fluid (water + acid) and placed in an ultrasonic device for a period of time.	***Merits***: Automation degree is high; removal efficiency is high when acid is added to cleaning fluid; no additional solid waste is generated. ***Problems***: Usually associated with wastewater (containing acid) problem; removal efficiency is good for panel glass but not for funnel glass.
Wet-scrubbing	Broken CRT glass is placed in a tumbling mill device with water; coatings scrubbed off by self-scrubbing action of particles.	***Merits***: Automation degree is high; removal efficiency is high for fluorescent and other coatings; no additional chemical is needed; wastewater can be recycled; round-edged final product is easy to handle. ***Problems***: A portion of CRT glass is scrubbed off as solid waste.

Table 8
Comparisons of scrap CRT glass-recycling market

Type of market	Principles	Comparison
Open	Recycled glass can be used as raw material for production of glassware, tile, glazing, etc.	***Merits***: Scrap glass can be consumed. ***Problems***: Due to a high concentration of lead and barium in glass, it is difficult to find a successful market.
Closed	After removal of surface coating, clean glass can be used as raw material for production of new funnel and panel glass.	***Merits***: Given amount of scrap glass can be largely consumed; lead and barium in glass can be conserved. ***Problems***: Due to high quality demanded for this application, cost and effort for treatment is relatively high; CRT glass manufacturers do not exist in some areas, thus discouraging such utilization.

resin, silicon, gold, silver, nickel, iron, aluminum and other metals which, along with electronic parts, are attached to the board by a solder containing lead and tin. The typical composition of a scrap IC board is shown in Table 9 [7]. The copper and precious metals contained therein make it a potentially recyclable material. However, the lead in the solder and the bromine in the resin must be treated properly during the recovery of metals from the board. Several possible board recycling technologies are briefly introduced below.

Table 9
Typical composition of a scrap IC board [7]

Material	wt.%
Gold	0.035
Copper	22.0
Solder (tin)	1.5
Solder (lead)	2.6
Fiberglass	30.0
Epoxy resin	15.0
Other (Fe, Ni, Si,. . .etc.,)	29.0

3.1. Copper-smelting method

Since the IC board contains a high concentration of copper, it can be considered as high-grade ore for primary copper-smelting plants. Thus, the board can be sent to a smelting plant to recover its copper along with the ordinary ore. Depending on the facilities of the smelting plant, the precious metals (i.e., gold and silver) may also be recovered as by-products in this process. During the smelting process, the epoxy resin can be incinerated, and the fiberglass can be melted into slag. Thus, the smelting process can not only recover the valuable metals but also properly dispose of the non-recyclable materials in the IC board. Whether a board is worth being recycled by this method depends on the amount of valuable metals contained therein. Hence, it may be difficult to recycle a board containing low-grade metals by using this method, one which relies on the existence of a capital-intensive primary copper-smelting plant. Therefore, it may be difficult to find such recycling facilities in most areas of the world. On the basis of information

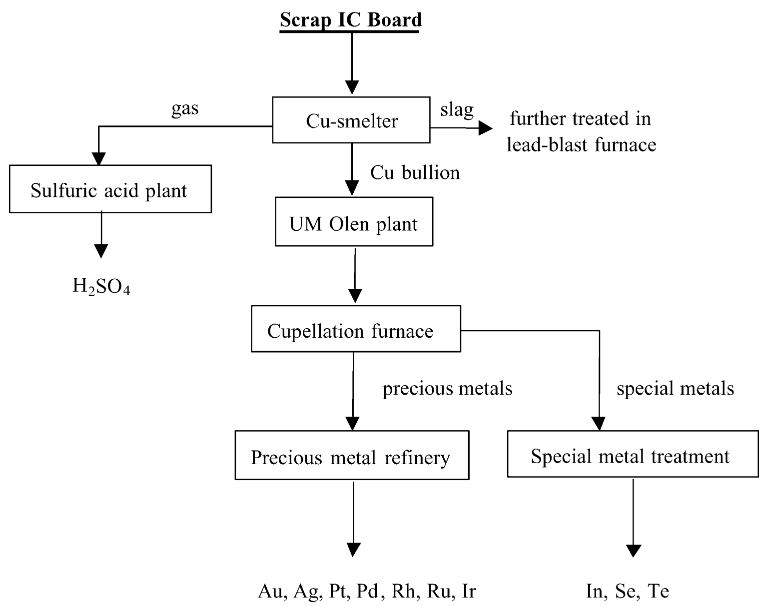

Fig. 1. Union Miniere Company's copper-smelting flowsheet for recycling of scrap IC board.

provided by the Union Miniere Company [8], Fig. 1 presents a copper-smelting flowsheet for the recycling of scrap IC boards.

3.2. Physical separation method

Although a primary copper-smelting plant is ideal for IC board recycling, such facilities are not well established in most areas of the world. Thus, it is reasonable to remove the non-recyclable material (i.e., epoxy resin and fiber glass) from the IC board to increase the value of the recyclable material. After separation, the recyclable materials have less volume and higher metal concentration. The enriched metal content can then be sold and transported to an appropriate recycling facility for further treatment. Generally, this type of separation plant consists of a series of physical treatment units devoted to processes such as crushing, grinding, screening, magnetic separation, air classification, eddy-current separation, electrical-conductivity separation, etc. Depending on the separation units used in this method, several metal fragments of various size and content are obtained. Except for iron, such fragments usually contain more than one kind of metal. Therefore, an effort should be made to find appropriate recycling markets for such mixed-metal fragments. Since no water or chemical additive is associated with this method, there is no wastewater problem in this type of operation. However, special attention should be given to dust emission and noise-control problems. The capital and operational costs of a physical separation plant for IC board recycling are much less expensive than those for a copper-smelting plant. On the basis of information provided by the Huei-Chia-Dien Company [9], Fig. 2 presents a physical separation flowsheet for the recycling of scrap IC boards.

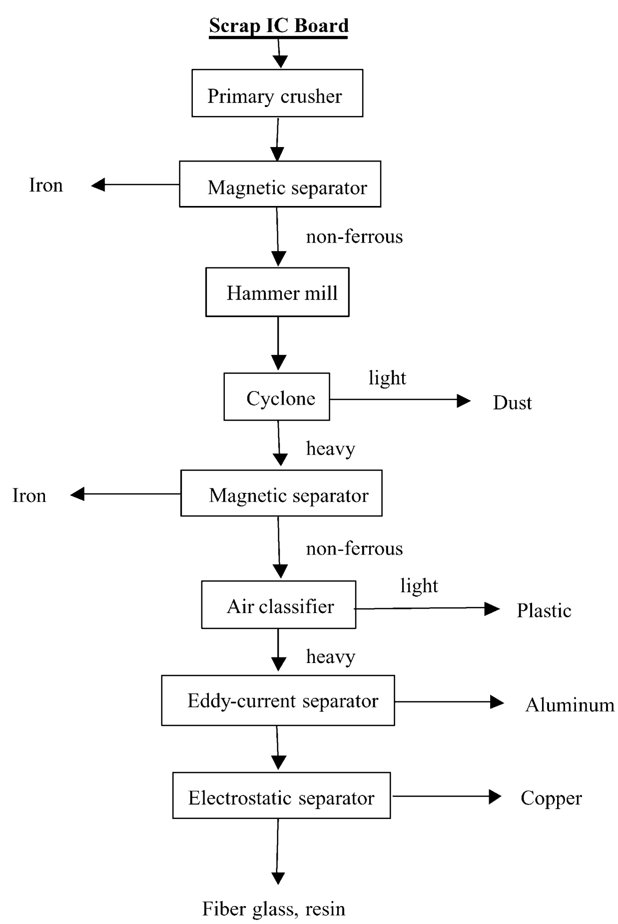

Fig. 2. Huei-Chia-Dien Company's physical separation flowsheet for recycling of scrap IC boards.

Table 10
Comparisons of various recycling technologies for scrap IC boards

Method	Principles	Comparisons
Physical separation	Scrap IC board is subjected to crushing, grinding, magnetic separation, eddy-current separation, air separation, etc., to separate metal from non-metal fragments.	***Merits***: No associated wastewater problem; high-grade metals can be recovered.
		Problems: Usually associated with dust emission and high-noise; recovered metals may also need further purification before they can be utilized.
Copper smelting	Scrap IC board can be sent to a copper-smelting plant to recover constituent copper and precious metals.	***Merits***: No additional facility needs to be built for treatment; constituent copper can be totally recovered; due to high-temperature smelting process, no associated solid-waste problem.
		Problems: Due to incineration of resin in board, special air-pollution problems may occur.
Scraping method	After solder is heated to a liquid state, mounted electronic parts can be mechanically scraped off; then, clean board and scraped-off parts can be processed separately.	***Merits***: Recycling efficiency may be increased, due to separate processing of clean board and scraped-off electronic parts.
		Problems: Economic efficiency is not well established.

3.3. *Scraping method*

This method utilizes a heating device to melt the solder on the IC board. After the solder is melted into a liquid, the mounted electronic parts can be mechanically scraped-off. Then, the clean board and the material scraped-off can be processed separately. IC board recycling efficiency may be increased by using this method, due to the separate processing of the clean board and the scraped-off parts. However, the economic efficiency of this process is not well established.

Table 10 presents comparisons of the different technologies for the recycling of scrap IC boards.

4. Scrap computer recycling practice in Taiwan

It is estimated that approximately 700,000 scrap personal computers are generated each year in Taiwan. The disposal of such a large number of these devices presents a difficult task due to the scarcity of landfills and incineration facilities available on-island. Thus, on 1 June 1998, Taiwan's EPA declared scrap computers to be a producer responsibility product, whereby manufacturers and importers of personal computers are responsible for the later recovery and recycling of their products sold in Taiwan. Under this regulation, five recycling plants have been established locally to treat the collected scrap computers. The recycling procedures of all these plants are similar. At the beginning of the process, the dismantling technology is used to retrieve various components from the scrap computers. Simple components such as plastic, iron, and metal parts can be sold directly to local recyclers; whereas, complex components such as CRTs and IC boards are further treated in the plants. The common recycling procedures of these plants are summarized below.

1. The collected main machines (7 kg/set) and monitors (8 kg/set) are manually dismantled.
2. After dismantling, the plastic or iron shell, hard disk, power supplier, and metal parts can be directly sold to the local recyclers.
3. The retrieved CRT is treated by an electric-wire heating device to separate the panel and funnel glass.
4. The fluorescent coatings on the surface of the panel glass are manually removed by a vacuum-suction device.
5. The removed fluorescent coatings are sent to a waste-treatment plant for solidification.
6. The separated panel and funnel glass are sent to a ceramic plant as raw material for the production of ceramic products. However, the scrap CRT glass-generators must pay for this application.
7. All the capacitors (possibly containing PCB) having a diameter greater than 1 cm and a height larger than 2 cm are manually removed from the IC board.
8. After removal of the capacitors, the IC board undergoes a series of physical separation units for crushing, grinding, magnetic separation, and air separation to recover the ferrous and non-ferrous metals contained therein.
9. The ferrous and non-ferrous metal fragments obtained can be sold to local metal recyclers; whereas, the non-metal fragments can be utilized as feed material for the production of statues or garden decorations.

Table 11 presents typical recycling data on main machine for a Taiwanese scrap computer recycling plant. Table 12 shows recycling data on monitors for such a plant. If the materials with positive sale value obtained from these procedures are considered recyclable, then the recovery rate can be defined as the summation of the weight percentage of the positive sale value materials (see Tables 11 and 12). According to the data presented in Tables 11 and 12, the calculated recovery rates for the recycling of main machines and monitors

Table 11
Data on scrap main machines from computer recycling plant

Capacity	Product	wt.(%)	Sale price (+)/disposal fee (−) (US$/t)
Main machine (7 kg/set, 15000 set/month)	Shell	70	+86
	Hard disk	5	+171
	Power supplier	15	+86
	Capacitor	0.03	−28
	IC board		
	Ferrous	0.5	+57
	Non-ferrous	1.5	+743
	Non-metal	2.75	+43
	Other (waste)	5.22	−28
Recovery rate: 94.75 wt.%			

Table 12
Data on scrap monitors from computer recycling plant

Capacity	Product	wt.%	Sale price (+)/disposal fee (−) (US$/t)
Monitor (8 kg/set 15000 set/month)	CRT glass		
	Panel	28.35	−28
	Funnel	16.65	−37
	Plastic	17	+86
	Capacitor	0.02	−28
	Ferrous	12	+57
	Copper	3	+171
	Aluminum	2	+343
	IC board		
	Ferrous	1.26	+57
	Non-ferrous	3.79	+743
	Non-metal	6.95	+43
	Fluorescent coating	0.01	−286
	Other (waste)	8.98	−29
Recovery rate: 45.99 wt.%			

are 94.75 wt.% and 45.99 wt.%, respectively. Thus, it can be seen that more effort is needed to enhance the recyclability of CRTs in order to increase the overall recovery rate of scrap monitors in Taiwan.

5. Conclusions

A commercially available electric-wire heating method can be utilized to separate the panel from the funnel glass. The fluorescent coating attached to the inner surface of panel glass can be removed by a vacuum-suction, an ultrasonic-cleaning, a wet-scrubbing or a sandblasting method. The scrap IC board can be sent directly to a primary copper-smelting plant for recycling. Or, the board can be treated by a series of physical separation units for crushing, grinding, air classification, screening, magnetic separation and eddy-current separation to enrich the metal content for further recycling. On the basis of actual practice in Taiwan, a high recovery rate of 94.75 wt.% can be achieved for the recycling of scrap main machines; whereas, a poor recovery rate of 45.99 wt.% for scrap monitors is obtained. The low recycling rate for monitors is due to the poor local recycling market for CRT glass, thereby indicating that more effort is needed to promote the recycling market for such glass.

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