CHAPTER II
BACKGROUND AND LITERATURE REVIEW

2.1 E-waste

2.1.1 What is E-waste

In common speech in industrialized countries, "e-waste" is regarded as being an electrical or electronic device, which has no further (economic) value to the user. However, when an electrical or electronic device becomes useless for the primary user it can still have a value for the next holders. The owner can sell it and then it follows a chain where it is reused, recovered or finally disposed of. Consequently, "e-waste" is a very difficult term to define said by Widmer *et at,* (2005).

The risky part of e-waste is that it contains over 1,000 different substances and metals. Many of these substances and metals are toxic. According to Widmer *et al.* (2005), hazards such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium and flame retardants in casings and circuit boards are present. The printed circuit boards (PCB) (or = printed wiring boards, PWB) contain polychlorinated and polybrominated biphenyls that create dioxin-like emissions when burned. All these hazardous substances can threaten human health and the environment unless they are disposed of properly (Li and Richardson, 2006). Corresponding to Pucket *et al.,* 2002, "About 70 % of heavy metals (including mercury and cadmium) found in landfills came from electronic discards in E-waste".

Using home computer as an example, its Cathode Ray Tube (CRT) computer monitor contains many valuable but also many toxic substances. One of these toxic substances, cadmium, is used in rechargeable computer batteries and contacts and switches in older CRT monitors. Cadmium can collect a bio-accumulate in the environment and is extremely toxic to humans, in particular kidneys and bones. In addition, mercury used in lighting devices within flat screen displays can cause damage to the nervous system, kidney and brain.

2.1.2 Amount of E-waste

In year 2014, amount of electronic wastes as a part of discarded refrigerator, television, washing machine, vacuum cleaner and other electrical appliances discarded around the world in 2014 was 41.8 million tons around the world which included refrigerators, televisions, washing machines, vacuum cleaners and other electrical appliances. This number had moved up from 39.8 million in 2013 (United Nations University, 2015).

More specifically, E-waste was discarded from;

- 12.8 million tons of small equipment (such as vacuum cleaners, microwaves, toasters, electric shavers and video cameras);
- 11.8 million tons of large equipment (including washing machines, clothes dryers, dishwashers, electric stoves, and photovoltaic panels);
- 7.0 million tons of temperature-exchange (cooling and freezing equipment);
- 6.3 million tons of screens;
- 3.0 million tons of small ICT equipment; and
- 1.0 million tons of lamps.

However, on a per capita basis, Norway is on top of the world's electronic waste mountain, generating 62.4 lbs per inhabitant. Switzerland is in second position with 58 lbs while Iceland rounds off the top three with 57.3 lbs. The United Kingdom comes in fifth with e-waste per capita amounting to 51.8 lbs while the United Sates is in ninth position with 48.6 lbs as shown in Figure 2.1.

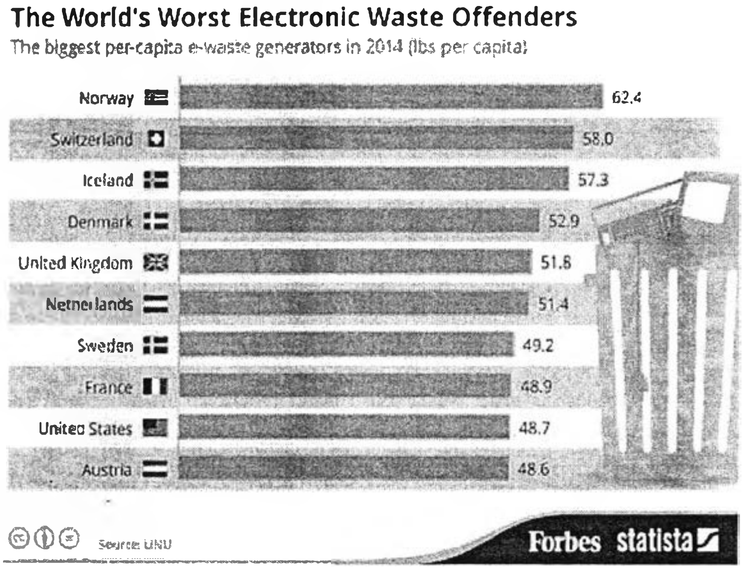


Figure 2.1 The world's worst E-waste offenders in 2014, in lbs per capita (United Nations University, 2015).

2.2 Overview TV Waste in Thailand

Nowadays technology revolutions in image displays for has been changed from the cathode ray tube (CRT) type to LCD (liquid crystal display), LED (light emitting diode) and PDP (plasma display panel). The mismanagement of CRT-TV waste rises a several concerns about the environmental problems and human health of television that cannot be ignored. As a consequence, the important challenge posed by the revolution is the need of discarded CRT television which is classified as an E-waste disposal.

2.2.1 Current Status of Electric Equipment Waste in Thailand

According to The Pollution Control Department (PCD) showed that the forecast quantity of electronic equipment wastes in Thailand from 2014-2018 increases sharply as shown in Figure 2.2. While, most of the television waste in 2012 and 2013 was generated from CRT-TV, waste as shown in Table 2.1. The amount of television waste in 2012 and 2013 was about 2 million sets and 2.4 million sets as shown in Table 2.1.

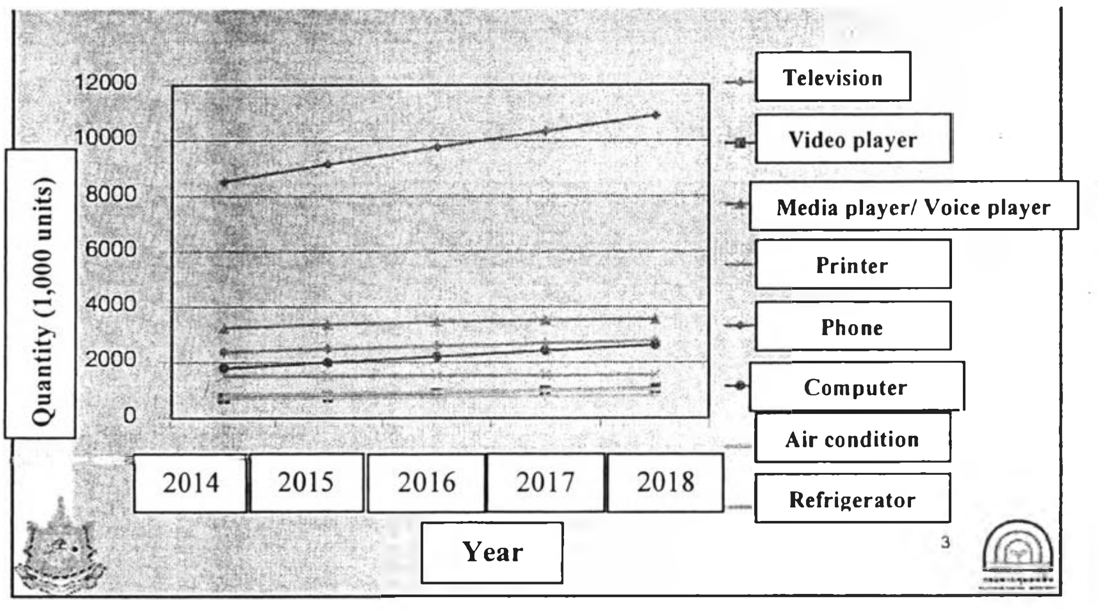


Figure 2.2 The expectation of quantity electric equipment waste in Thailand (2014 - 2018) (Pollution Control Department, 2011).

Table 2.1 Amount of television waste in Thailand (OIE, 2013)

Year	Set (x1000)	Weight (ton)
2012	2000	50,000
2013	2400	60,000

2.2.2 CRT-Television Production in Thailand

Figure 2.3 shows the amount of television production in Thailand from 2000-2013. The production of CRT television tended to decrease after 2007, vice versa the new technologies known as LCD and plasma television increased steadily from 2006-2013. The mass flow of electric equipment production and its waste generation are showed in Figure 2.4.

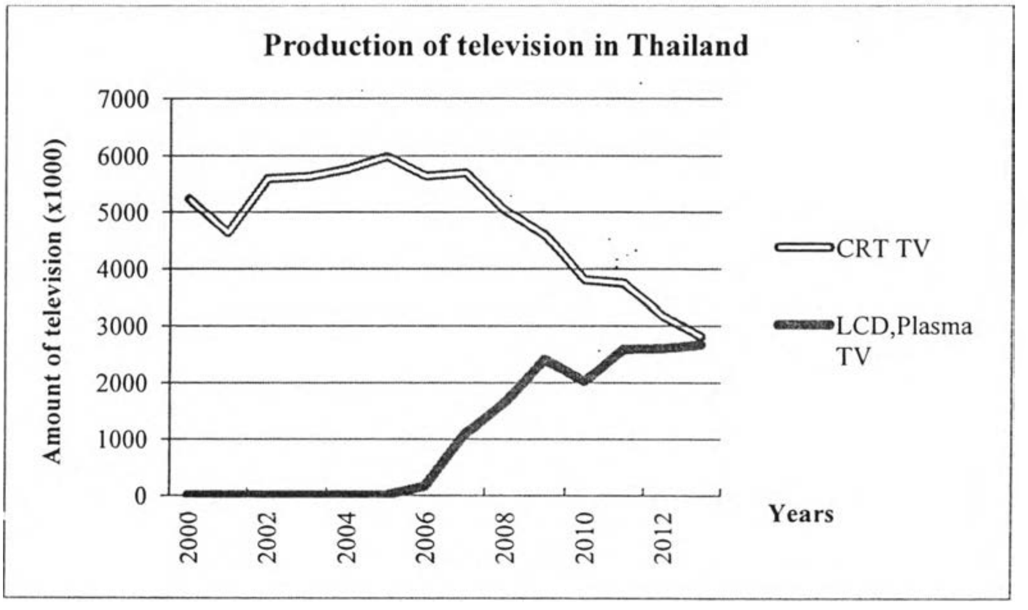


Figure 2.3 The amount of television production in Thailand (OIE, 2013).

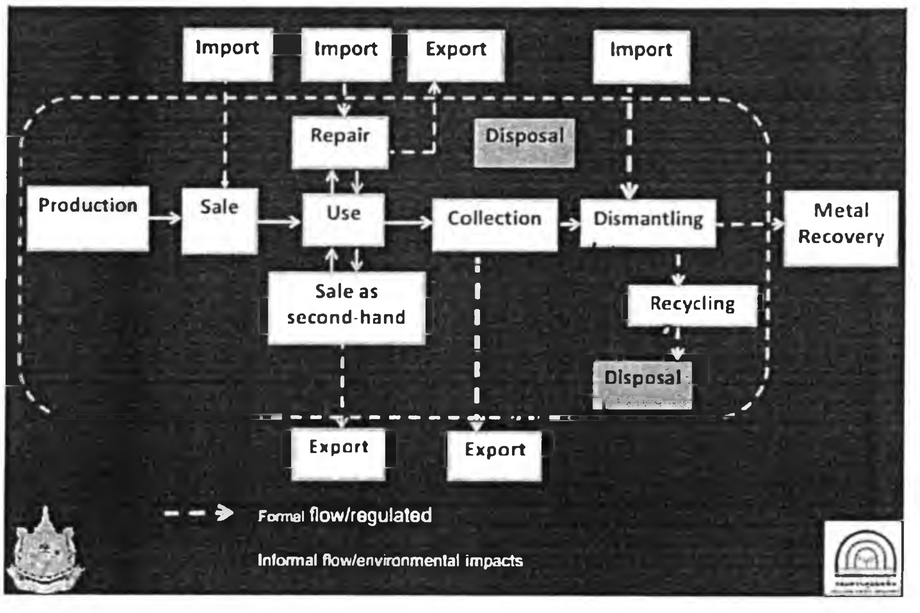


Figure 2.4 The flow of electric equipment production and waste in Thailand (Pollution Control Department, 2011).

2.2.3 TV Waste Disposal in Thailand

In Thailand, one of the largest television waste disposal facilities is located in Khok Sa-at, Khong Chai, Kalasin and SueYai Uthit, Bangkok. The process includes various activities including separation and disposal - consisting of landfilling, incineration and recycling. Figure 2.5 shows the current mass flow of CRT-TV waste disposal in Thailand. The major disposal method throughout the waste of flow are recycling and landfilling. In addition, some wastes are incinerated by open burning such as copper cables to get rid of plastic insulator/sheath (PVC).

The current end-of-life management of CRT-TV is showed in the diagram below. Based on the data collection from site visited, the percentages of dismantling and treatment of CRT-TV parts are estimated and used as a reference case in this study as shown in Table 2.2. Based on this, the amount and percentage of each part of CRT-TV being disposed are listed in Table 2.3.

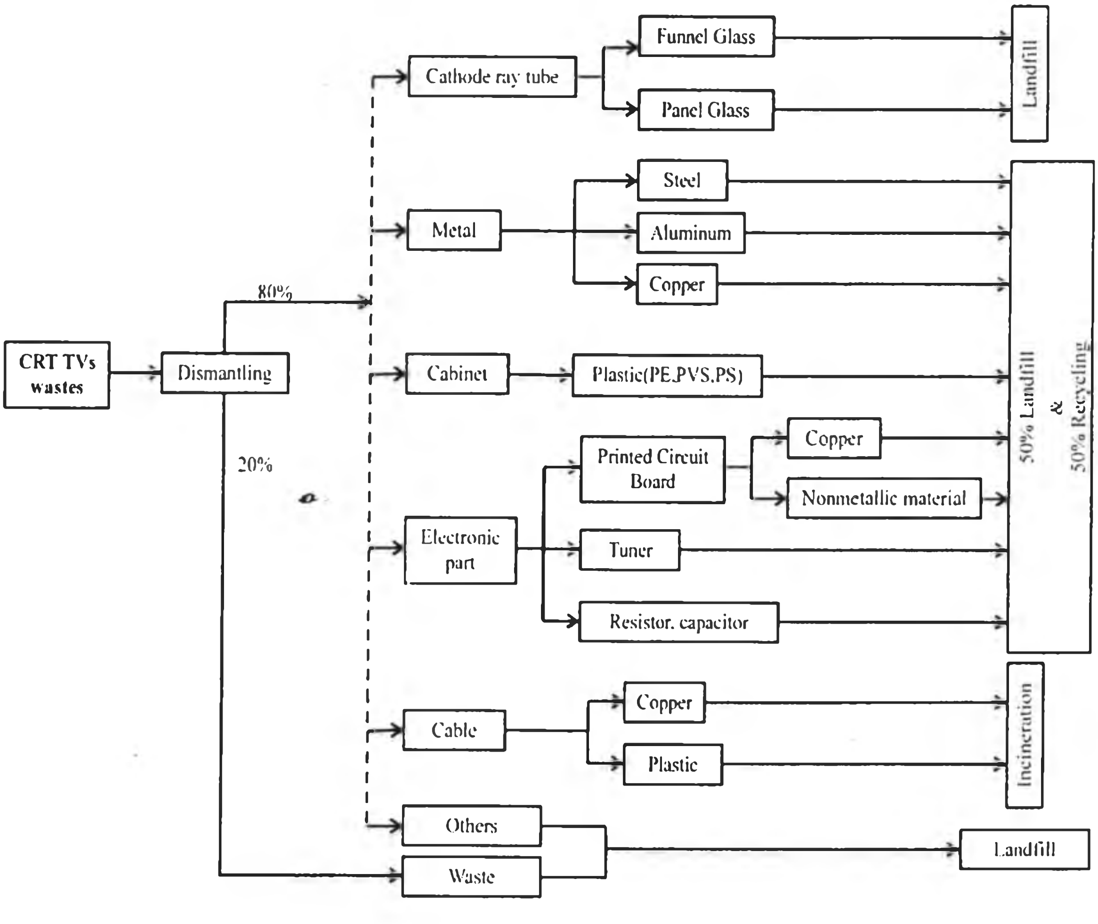


Figure 2.5 The waste management in Thailand (Interview in SueYai Uthit, October 2014)

Table 2.2 Percentage of dismantling and treatment of CRT-TV parts based on current waste management (Interview in SueYai Uthit, October 2014)

Component of CRT TV	%Dismantling	%Landfill	%Recycling	%Incineration
Cathode ray tube				
- Funnel Glass	80	100	0	0
- Panel Glass		100	0	0
Metal parts	80	50	50	0
Cabinet (Plastics)	80	50	50	0
Cable	80	50	0	50
Electronic parts	80	50	50	0
Others (Waste)	100	100	0	0

Table 2.3 Components of CRT-TV and current end-of-life treatment of wastes (Interview in SueYai Uthit, October 2014)

Component of CRT-TV	%Wt	Mass (kg)	Mass of Waste (for Disposition) (kg)	Disposal (End-of-Life)
Cathode ray tube*				
- Funnel Glass	19	5.7	4.56	Landfill
- Panel Glass	38	11.4	9.12	Landfill
Metal parts				
- Steel	10	3	1.2	Recycling
			1.2	Landfill
- Aluminum	2	0.6	0.24	Recycling
			0.24	Landfill
- Copper	5	1.5	0.6	Recycling
			0.6	Landfill

Table 2.3 Components of CRT-TV and current end-of-life treatment of wastes (Interview in SueYai Uthit) (cont.)

Component of CRT-TV	**%Wt**	**Mass (kg)**	**Mass of Waste (for Disposition) (kg)**	**Disposal (End-of-Life)**
Cabinet (Plastics)				
- Polyethylene (PE)	1	0.3	0.12	Recycling
			0.12	Landfill
- Polyvinyl chloride (PVC)	3.5	1.05	0.42	Recycling
			0.42	Landfill
- Polystyrene (PS)	6	1.8	0.72	Recycling
			0.72	Landfill
Cable	4.5	1.35	0.54	Incineration
			0.54	Landfill
Electronic parts	3	0.9	0.36	Recycling
			0.36	Landfill
Others(Waste)	8	2.4	2.4	Landfill
Remaining	-	-	5.52	Landfill
Total	**100**	**30**	**30**	

*Cathode ray tube: Funnel glass = 1/3 of the total glass, Panel glass = 2/3 of the total glass

2.2.4 CRT-TV Disposal Facility in Thailand

2.2.4.1 Kalasin Province

Kalasin site is one of the voluminous E-waste disposal facilities in Thailand as shown in Figure 2.6. The major of waste were managed in improper ways, especially the CRT-TV waste which has highest amount of waste.

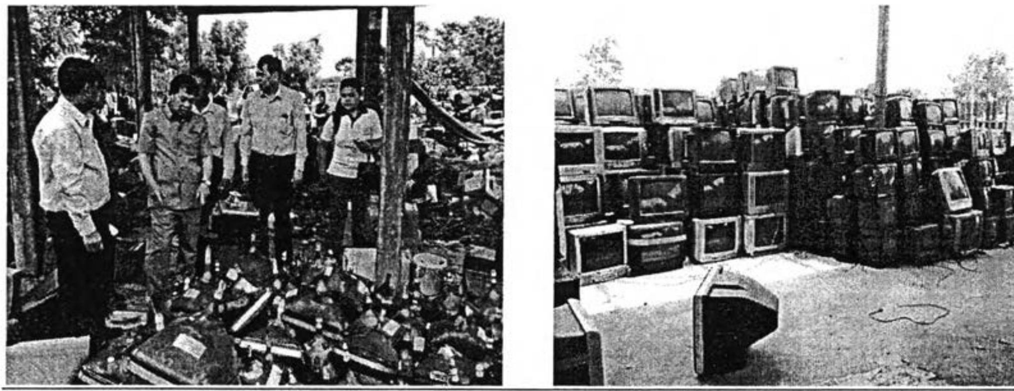


Figure 2.6 CRT-TV waste disposal site in Kalasin province (Pollution Control Department, 2011).

2.2.4.2 SueYai Uthit (Bangkok) Site

Based on site visited, One of the major recycle shops in Bagkok is located in SueYai Uthit area where all kinds of e-waste are treated such as CRT-TV, refrigerator, light bulb, washing machine, microwave etc. as shown in Figure 2.7. The CRT-TV wastes are dismantled by recycle shop and sell to recycling manufacturer. The funnel glass and panel from CRT-TV monitor are typically disposed to landfill. Some copper wire cables are burnt to recover copper which has high value for sell. However, about 50 % of the others parts of CRT-TV such as plastic, metal, electronic and panel glass are recycled and used as a new material. In this study, the data for Thailand's case can be estimated by extrapolation from this facility.

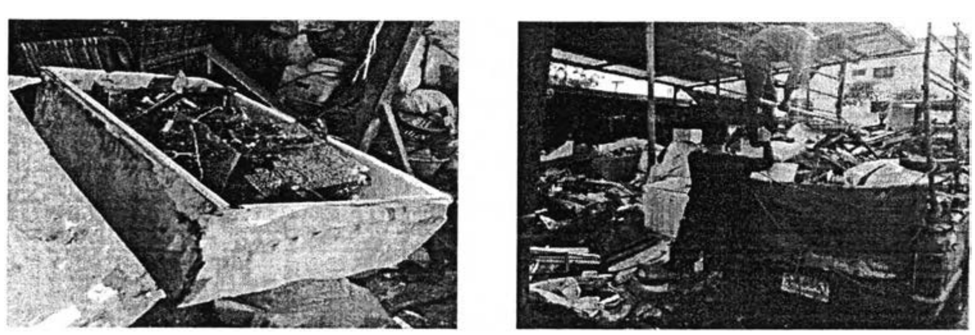


Figure 2.7 CRT-TV waste disposal site in SueYai Uthit (Bangkok).

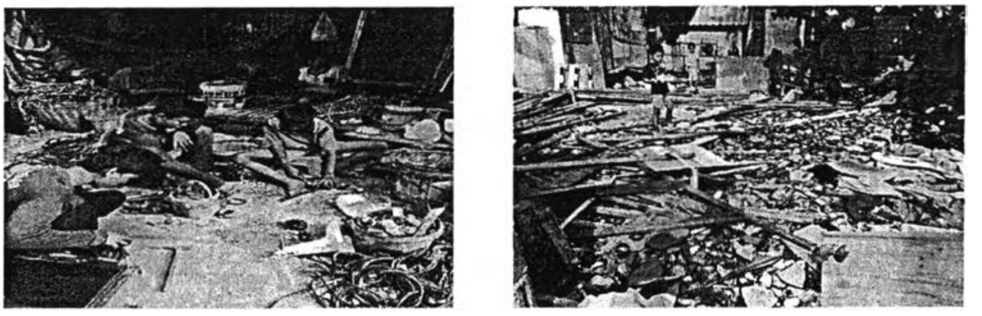


Figure 2.7 CRT-TV waste disposal site in SueYai Uthit (Bangkok) (cont.).

2.3 Background of Cathode Ray Tube Television

This research focuses one set of a discarded 25" CRT-TV as a functional unit and involved in the waste management of discarded CRT-TV. A CRT-TV is typically composed of four major parts; a panel glass (or faceplate), a shadow mask, a funnel glass, and an electron gun.

2.3.1 Cathode Ray Tube

A cathode ray tube, often called as CRT, is an electronic display device in which a beam of electrons can be focused on a phosphorescent viewing screen and rapidly varied in position and intensity to produce an image. The well-known application of a cathode-ray tube is a picture tube in a television. Other applications are used in oscilloscopes, radar screens, computer monitors, and flight simulators.

2.3.1.1 Characteristics of Cathode Ray Tube

The CRT is a vacuum tube containing one or more electron guns (a source of electrons or electron emitter) and a fluorescent screen used to view images. It has a means to accelerate and deflect the electron beam(s) onto the screen to create the images. The images may represent electrical waveforms (oscilloscope), pictures (television, computer monitor), radar targets or others. CRTs have also been used as memory devices, in which case the visible light emitted from the fluorescent material (if any) is not intended to have significant meaning to a visual observer (though the visible pattern on the tube face may cryptically represent the stored data) (Beill, 2008).

The CRT uses an evacuated glass envelope which is large, deep (i.e. long from front screen face to rear end), fairly heavy, and relatively fragile. As a matter of safety, the face is typically made of thick lead glass so as to be highly shatter-resistant and to block most X-ray emissions, particularly if the CRT is used in a consumer product.

CRTs have largely been superseded by newer display technologies such as LCD, plasma display, and LED, which have lower manufacturing costs, power consumption, weight and bulk. The vacuum level inside the tube is high vacuum on the order of 0.01 Pa to 133 Pa (Goldwasser, 2011).

2.3.1.2 Distinct Types of CRTs

There are two general categories of CRTs: (1) monochrome (single color or black & white) CRTs, and (2) color CRTs (ICF Incorporated, 1999). There are two different designs of monochrome CRTs, including low voltage CRTs for direct view and high voltage CRTs for the projection of images onto large screens. Color CRTs, including direct view and projection, all require high voltages.

2.3.1.3 Composition of Cathode Ray Tube

A CRT is composed of four major parts; a panel glass (or faceplate), a shadow mask, a funnel glass, and an electron gun. Figure 2.8 illustrates the structure of a typical color CRT. The glass panel is the front of the CRT that is seen when viewing a TV or monitor. The shadow mask is a thin metal sheet with apertures, positioned immediately behind the glass panel. The glass funnel is shaped like a funnel and is attached to the back of the glass panel. The glass panel and glass funnel are connected using a glass frit solder. The glass funnel holds the electron gun and forms the back end {neck) of the CRT. The electron gun produces the electrons that strike the glass panel and produce images that are seen on the TVs or monitors. Compared to monochrome CRTs (as shown in Figure 2.9) and color CRTs have slightly more complicated construction with additional components, such as internal magnetic shield.

In addition, a CRT is assembled into a display that includes several other parts, including a plastic cabinet, electromagnetic shields, circuit boards, connectors, cabling, and other discrete components.

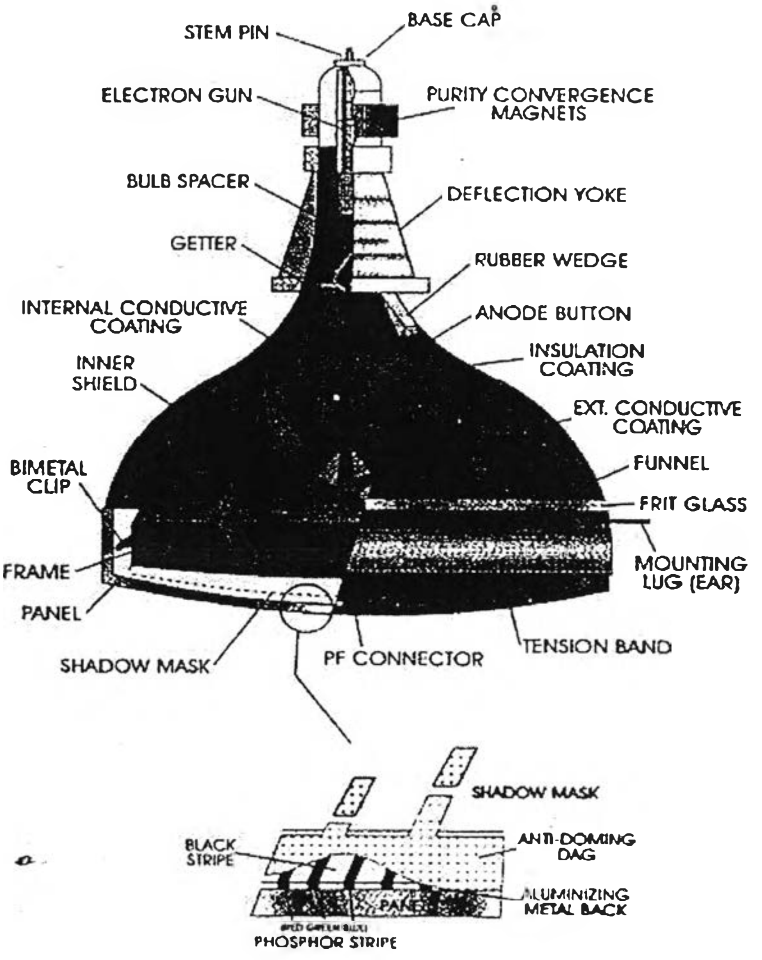


Figure 2.8 Structure of a typical color CRT (Toshiba Display Devices Inc.).

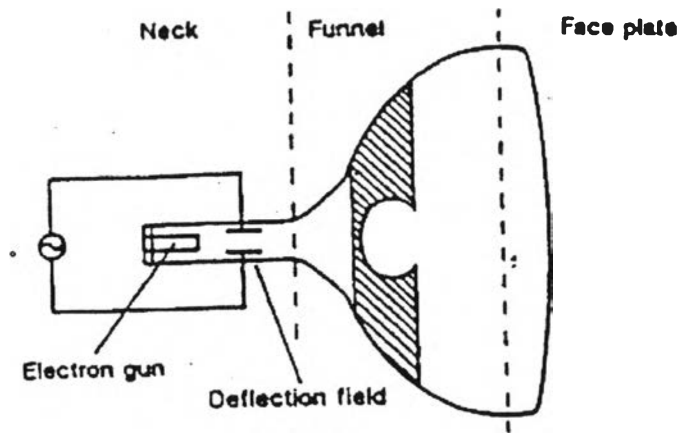


Figure 2.9 Diagram of a typical monochrome CRT (Hedemalm *et al.*).

In all modern CRT monitors and televisions, the beams are bent by magnetic deflection, a varying magnetic field generated by coils and driven by electronic circuits around the neck of the tube, although electrostatic deflection is commonly used in oscilloscopes, a type of diagnostic instrument (Tyson and Carmack, 2009).

a. Electron Gun

In color CRT has many elements as shown in Figure 2.10 and Figure 2.11 shown deflection coils and electron guns. For cutaway rendering of a color CRT consist of:

- Three electron guns (for red, green, and blue phosphordots)
- Electron beams
- Focusing coils
- Deflection coils
- Anode connection
- Mask for separating beams for red, green, and blue part of displayed image
- Phosphor layer with red, green, and blue zones
- Close-up of the phosphor-coated inner side of the screen

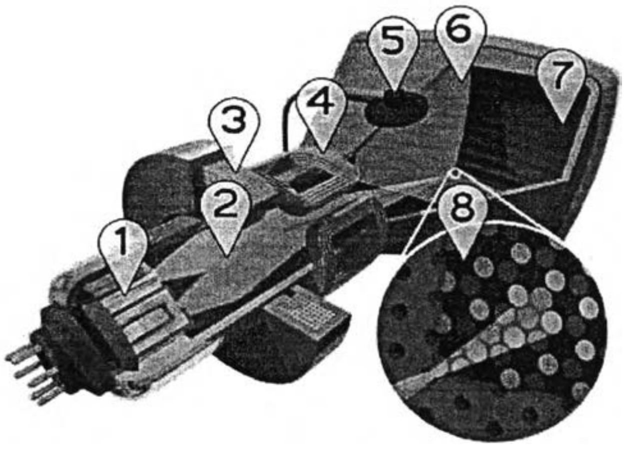


Figure 2.10 Cutaway rendering of a color CRT (Wikipedia, 2006).

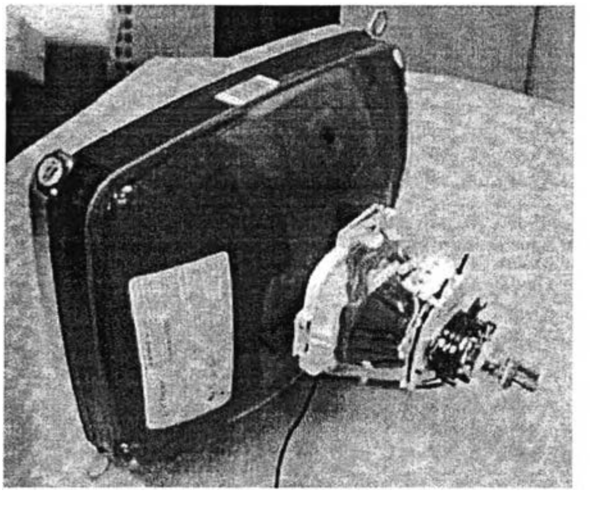


Figure 2.11 Cathode ray tube (Wikipedia, 2006).

b. Shadow Mask

Color tubes use three different phosphors which emit red, green, and blue light respectively as shown in Figure 2.12. They are packed together in stripes (as in aperture grille designs) or clusters called "triads" (as in shadow mask CRTs) (Harris, 2006). Color CRTs have three electron guns, one for each primary color, arranged either in a straight line or in an equilateral triangular configuration (the guns are usually constructed as a single unit). The triangular configuration is often called "delta-gun", based on its relation to the shape of the Greek letter delta. A grille or mask absorbs the electrons that would otherwise hit the wrong phosphor

A shadow mask tube uses a metal plate with tiny holes, placed so that the electron beam only illuminates the correct phosphors on the face of the tube (Harris, 2006). The holes are tapered so that the electrons that strike the inside of any hole will be reflected back, if they are not absorbed (e.g. due to local charge accumulation), instead of bouncing through the hole to strike a random (wrong) spot on the screen. Another type of color CRT uses an aperture grille of tensioned vertical wires to achieve the same result (Kozierok, 2001).

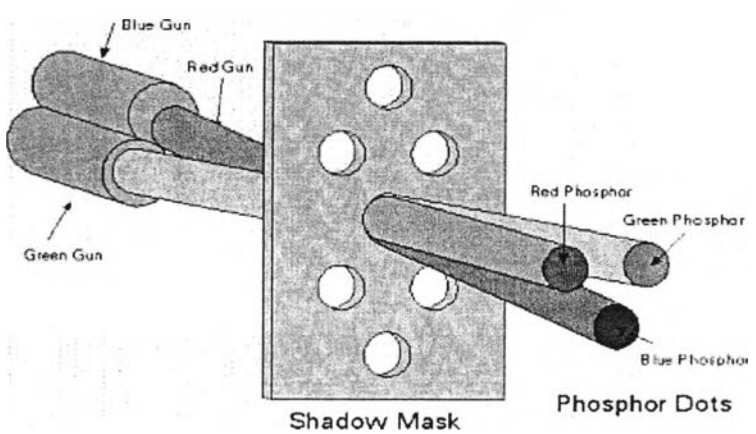


Figure 2.12 Shadow mask of color CRTs (Wikipedia, 2006).

a. Panel Glass and Funnel Glass

The neck (1 wt%) and funnel (33 wt%) glass constitute the back part of the CRT (hidden inside the monitor or TV set) as shown in Figure 2.13. The front part, usually known as the panel (66 wt%), is made of a barium–strontium glass that has been free of lead since 1995 (Mear *et al.*, 2005), and is very homogeneous and thick. These three components are usually joined together with a solder glass called frit, which is 85 % lead (Materials for the Future Foundation, 2001). The neck glass is a lead-rich silicate glass containing more than 25 wt % PbO, which envelopes the electron gun. The lead content of funnel glass is lower than that of neck glass (20 wt % of PbO). The inside of the funnel is coated with iron oxide, and a graphite monolayer is attached to the outside of the funnel. The other components of the CRT include an electron gun, a metal mask, a deflector coil, and metal pins and cables.

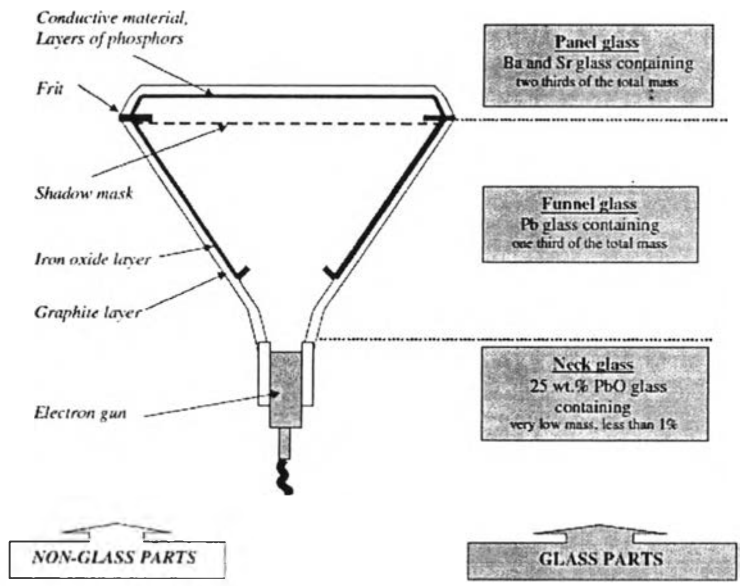


Figure 2.13 Schematic view of the CRT components, showing the non-glass and glass parts (Mear *et al.*, 2005).

2.4 CRT-TV Waste Disposal Technologies

2.4.1 <u>Disposal of CRT-TV Waste Management</u>

2.4.1.1 Recycling Technologies of CRT

a. Europe Technology

In this section, the current best available technologies (BATs) for the pre-processing and the intrinsic recycling process for CRT glass in Europe are presented as well as the results from the assessment of those companies who were asked if they were able to recycle CRT glass in the Cape Metropolitan Area (CMA) and in South Africa.

The pre-processing, which includes the stripping (dismantling) of the CRT, screens. The resulting materials are mainly plastics, printed wiring boards (PWBs), metals and the remaining CRT. The plastics are either disposed of or recycled. Aluminum, copper and ferrous metals are recovered and can be sold to the local scrap dealers to be recycled again. PWBs can be recycled to recover precious metals like gold, silver, palladium, platinum as well as base metals such as copper, lead, nickel and zinc, bismuth, antimony, etc. A state of the art, precious metal smelter in Belgium recovers 17 metals from PWBs (Zumbuehl, 2005).

In South Africa the remaining CRTs currently are disposed of at (hazardous) landfill sites. Alternatively, the CRT can either be separated into funnel and screen glass or they can be crushed depending on the buyer's requirements. When separating the CRTs only the screen coating is removed whereas sophisticated crushing devices are able to remove both the screen and the funnel coating. The crushed culets can then be sorted to derive panel, funnel and mixed glass. Some applications also allow mixed, crushed glass that is not sorted. Ferrous metals are also recovered after crushing or separating CRTs (e.g. the rimband and the shadow mask). Detailed descriptions of the separating and crushing techniques as well as the several applications where the recycled CRT glass can be used are specified in the following section.

The CRT recycling process can principally be divided in the stages as shown in Figure 2.14. Colored boxes indicate products, white represent are process steps in the CRT recycling.

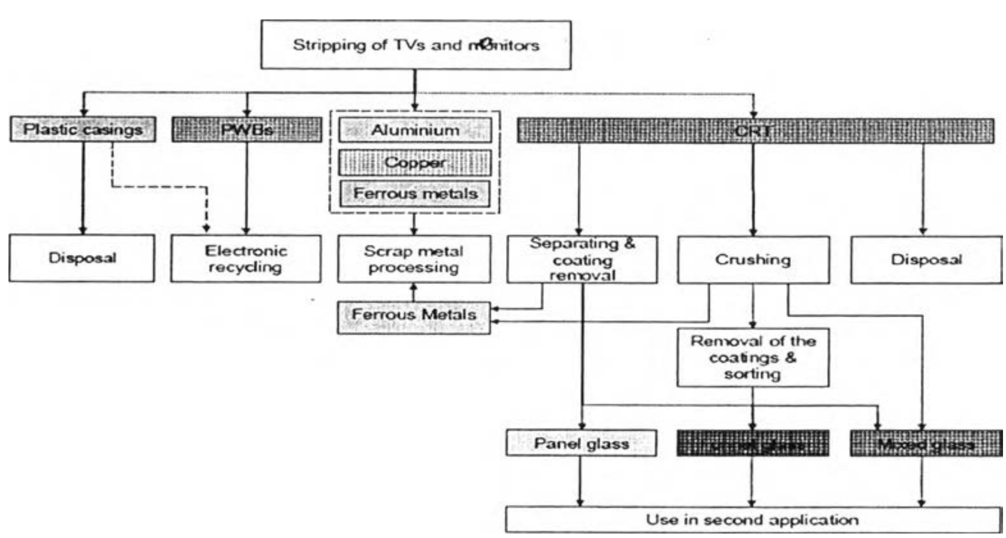


Figure 2.14 Possible pathways for the recycling of CRT appliances. (Zumbuehl, 2005).

- Pre-processing – stripping of CRT monitors and TVs

The stripping of monitors and TV sets was studied at a RUAG Components & Immark AG both Swiss CRT dismantling facilities as well as at Desco Electronic Recyclers in Cape Town. Both the Swiss and the South African facility use low-tech, manual dismantling techniques using electrical screwdrivers, grippers and a hammer for the dismantling of the CRT screens.

First, the plastic casing is removed by unscrewing. To avoid an electric shock, a short circuit of the anode voltage supply terminal of anode cap attached to cathode ray tube (CRT) should be performed using an appropriate tool. Without this tool one can just connect a wire to the outer body of the CRT to then push it under the anode cap and make a good short-circuit (Goldwasser, 2006). After having removed the casing, the main cord, the cables, the printed wiring boards (PWBs) and metals such as the ferrous metals, aluminum and the copper coil on the yoke are manually removed and stored in separate units. The remaining part is the CRT with some stickers on it. The vacuum is being released by breaking the neck glass. The neck glass with the electron gun is stored and disposed of separately.

Ferrous metals, copper, aluminum and the PWBs are then removed and can be easily recycled as it is usually economically feasible to process these materials.

The plastic casings of TVs and monitors containing flame-retardants must be disposed of in incineration plants. Some old types of flame-retardants are carcinogenic. Those halogenated flame retardants form polychlorinated and polybrominated dioxins and furans when burned. Although thermoplastics can be recycled, the recycling of the most of the plastics is difficult because of the many types it occurs and the separation is economically and technically not feasible. Plastics are usually down cycled or thermal recycled to extract at least the energy (Zumbuehl, 2005).

Cables are generally freed by mechanical means of their casings (usually PVC or PE). Only the copper and other metals contained in cables have prospective uses.

Particularly old TV sets contain wooden pressboards as a casing. It is coated with paints and embedded in plastics and can therefore not be recycled.

- Crushing and Sorting Techniques

For some applications the CRT screens have to be either crushed and / or separated leading to different products. The crushing of CRTs is carried out by crushing systems which produce cutlets in different sizes and separate the metals and the coatings of the CRT glass. There are several crushing systems in place and also a mobile solution is available. In this study the sophisticated crushing system of a Swiss CRT recycler was investigated and a mobile crushing solution which is provided by a US company.

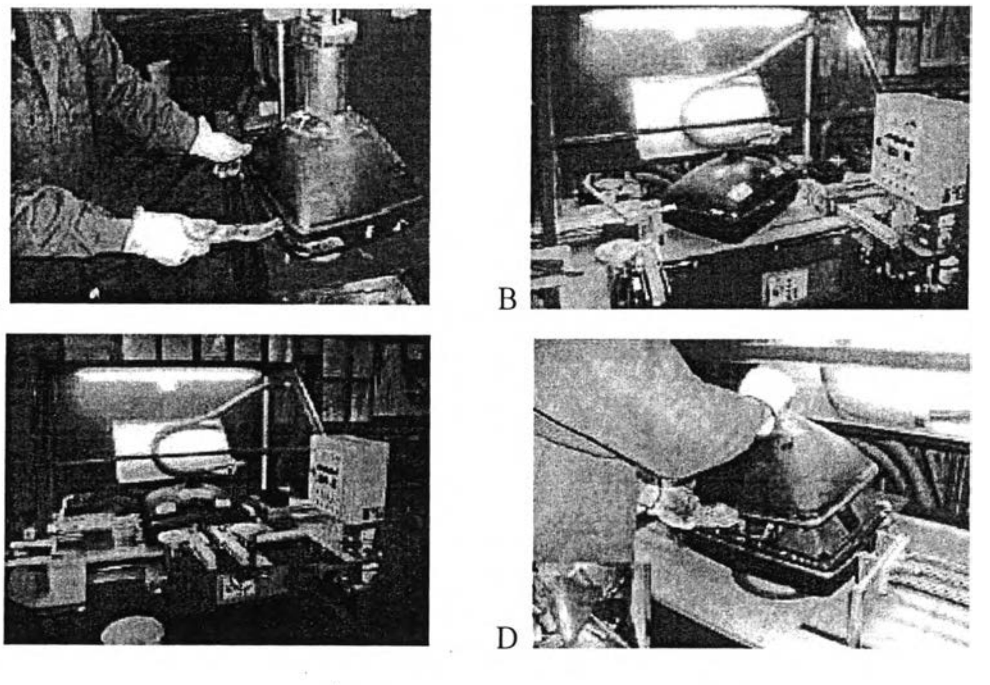
The stripped CRT tubes are first crushed, sieved and partly separated into coarse and fine glass cutlets, then the ferrous metals are separated from the glass fraction. The fluorescent layer on the screen glass as well as the iron oxide coating from the funnel glass have to be removed because of the manufacturers terms to include recycled CRT glass in their smelting process. These coatings are mechanically removed by tumbling the cutlets in a rotating drum. After washing off the dust, containing the removed coatings and some glass dust, the cutlets are dried using electricity. Then the separation step using X-rays to specify the density of each cullet takes place (funnel glass is denser than front glass due to its lead content). On a conveyor belt the cutlets arrive at the X-ray device. After blowing out the denser cutlets with air jets a fraction of funnel glass as well as the remaining front and mixed glass is produced. Then the remaining mixed glass is manually separated into pure front glass and mixed glass. The mixed glass consists of cutlets of front glass frit and funnel glass.

- Separating Techniques

Besides the crushing of CRT glass one can also separate the glass without crushing. The advantage is that one does not have to separate cutlets but the whole front and funnel glass respectively. Depending on the manufacturers requirements sometimes it makes more sense to use separated glass instead of crushed. However when the glass is being prepared for smelting or use in other products like bricks or foam glass, it usually must be crushed. In this section, the current separation techniques are described.

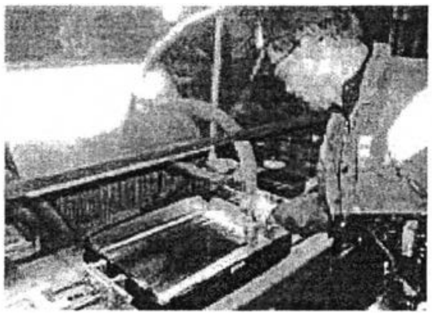
- Hot Wire Technique

This technology has been studied at a Swiss CRT recycling facility (RUAG Components). Since 2001 they run a stripping facility and separate the glass using a semi-automatic hot wire device. After the dismantling of the monitor or TV the stripped CRT is being installed on a workbench manually (Zumbuehl, 2005). The following steps are also illustrated in Figure 2.15. First, the ferrous rim band (implosion protection) is manually removed. A). then the CRT is scored automatically by scratching with a diamond B). In the next step, a NiChrome ribbon is wrapped around the chink and is then electrically heated C). the heating takes about a minute and the resulting thermal stress cracks the glass entirely. Then the cone glass with the frit is manually removed and stored separately D). the remaining front glass is then freed from its coating by suction cleaning it E). Figure 2.15 (F) shows the physical process more schematically.



A B C D

Figure 2.15 Process illustration at RUAG Component Inc., Switzerland (Zumbuehl, 2005).



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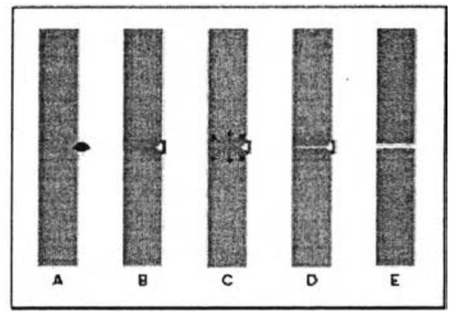

F

Figure 2.15 Process illustration at RUAG Component Inc., Switzerland (Zumbuehl, 2005). (cont.)

❖ Laser Cutting

This method uses a laser cutting device manufactured by Finland as shown in Figure 2.16. This device provides an automatic handling and cutting line for CRTs. A carbon dioxide laser beam cuts the CRT below the frit and separates the CRT into the funnel glass with the frit and the remaining front glass. In addition to the high quality separation and high capacity, the laser technology also has superior health and environmental performance. This device can separate up to 75 CRTs per hour. Additionally a cleaning and crushing device is available. Potential problems with the laser approach include reforming of the glass after the laser beam has passed through, difficulty in cutting thick glass, and sharp edges on the separated fractions. It also uses more power than other cutting techniques and requires significant capital investment (Zumbuehl, 2005).

Advantages: high capacity, high quality, low cost / CRT, dry process

Disadvantages: high investment cost, high energy use (Zumbuehl, 2005).

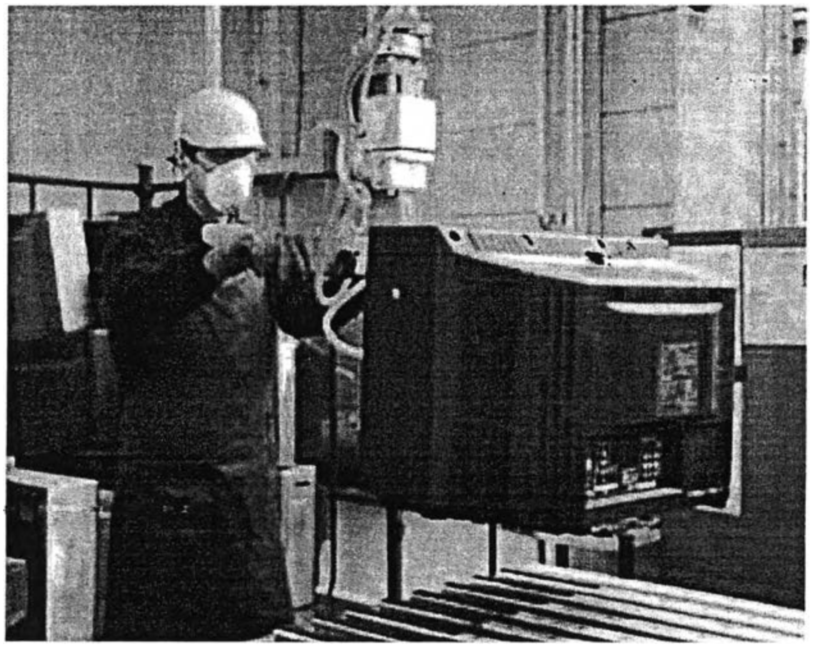

Figure 2.16 Laser cutting process (Panasonic, 2015).

❖ Diamond Cutting Separation

This method uses a wire that is provided with industrial diamonds. The wire diameter is usually very small. A continuous loop of wire cuts into the glass as the CRT is passed through the cutting plane as shown in Figure 2.17. The main problem with this approach is that it is very slow. It also generates dust that needs to be controlled. This technology is marketed and provided for instance in Sweden.

A semi-automatic system provided by Sweden can process up to 45 CRTs per hour. It is capable to handle CRTs from 14 to 32 inches and is equipped with glass dust collection and a cyclone for the rare earth metals. The power consumption is around 10 kW. No economic data are available at this stage.

The CRTs are positioned automatically or manually before cutting depending on the equipment of the machine. After setting the index point for the correct longitudinal position, the screen is placed into the cutting station automatically and front and panel glass are then separated. The station is enclosed to reduce noise and is ventilated to remove dust. The products are automatically transported for further processing. Dust and rare earth powders are collected by a powder cyclone and dust filter.

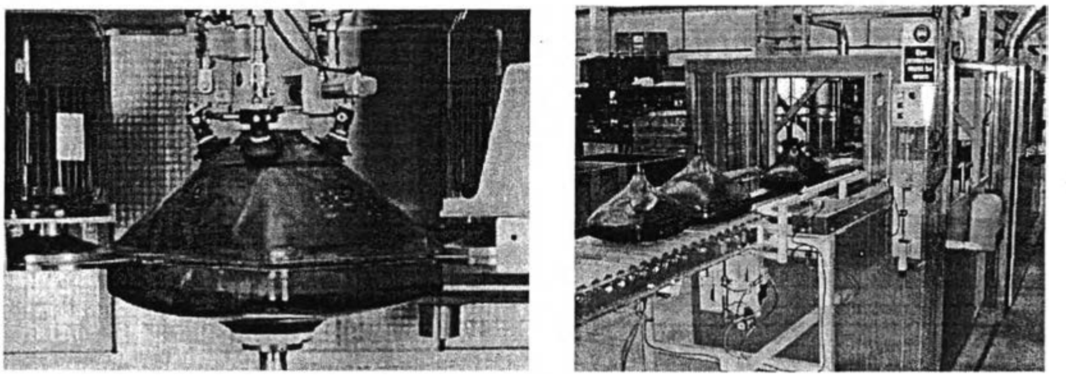

Figure 2.17 CRT is cut by a diamond cutting device (MRT System International, 2015).

- CRT Glass in Smelting Processes

❖ Ferrous Metal Smelting

No sand is used as a flux. Sand is a contaminant in the steel and iron production. Thus ferrous metal smelting is not suitable for the processing of CRT glass (Zumbuehl, 2005).

❖ Primary Lead Smelting

Sweden operates a primary lead smelting facility. Technically, there would be in principle no problem to use the CRT glass in the smelting process. Problems could occur if there is too much of aluminum oxide (Al_2O_3), chromium would increase the smelting point (energy use), quicksilver increases the costs for flue gas treatment, antimony increases the costs for refining and silver, antimony, bismuth and tin require refining capacities. Too much zinc can cause troubles with the slag or the furnace.

Since the lead content in CRT glass (about 5 %) is too low to use economically in their smelting process, they even should be paid for taking CRT glass. The economic feasibility depends on the market price of lead, of the raw materials and the composition of the glass. At this stage, they needed at least 30 % lead in the CRT glass to run the process economically. Including CRT glass would substantially increase the amount of the silica-slag which leads to extra losses (Zumbuehl, 2005).

❖ Precious Metals Smelting

In Belgium, the CRT glass cannot include in precious metal recovery plant economically. Although lead can recovery, the lead content in CRT glass with an overall content of 5 % lead oxide, is not sufficient to run the lead refining economically. The processes are optimized for precious metal refining. Moreover, the supply of materials containing precious metals have concerned than in CRT glass. There is no precious metal smelter which is smelting lead in Europe at this stage (Zumbuehl, 2005).

b. Technology in Asia

- CRT-TVs Recycling in Japan

Japan's Home Appliances Recycling Law makes the collection and recycling of four kinds of appliances mandatory: air conditioners, television sets (CRT, LCD and plasma models), refrigerators/freezers and washing machines / tumble dryers. The Home Appliance Recycling Law requires consumers to pay for collection, transport and recycling fees when disposing of applicable home appliances, retailers to take back such appliances and return them to manufacturers, and manufactures to recycle these appliances (Sony Corporation, 2015).

The CRT-TV recycling process can principally be divided in the section as shown in Figures 2.18 – 2.21.

1. Dismantling and sorting of parts : Printed circuit boards and built-in components containing various metal and plastics are sorted and recovered by hand as shown in Figure 2.18.

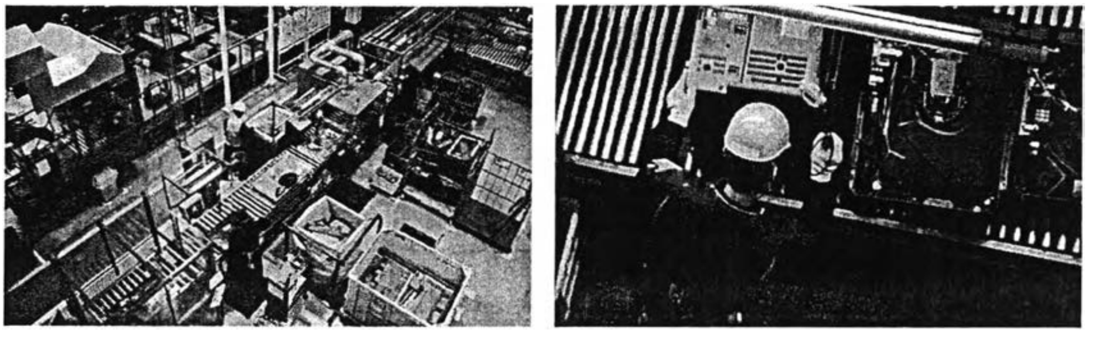

Figure 2.18 Dismantling and sorting of CRT-TV (Panasonic, 2015).

2. Removal and separation of CRTs: Cleaning takes place after removing the reinforcement band from the CRT and the glass is separated into the front panel glass and funnel glass as shown in Figure 2.19.

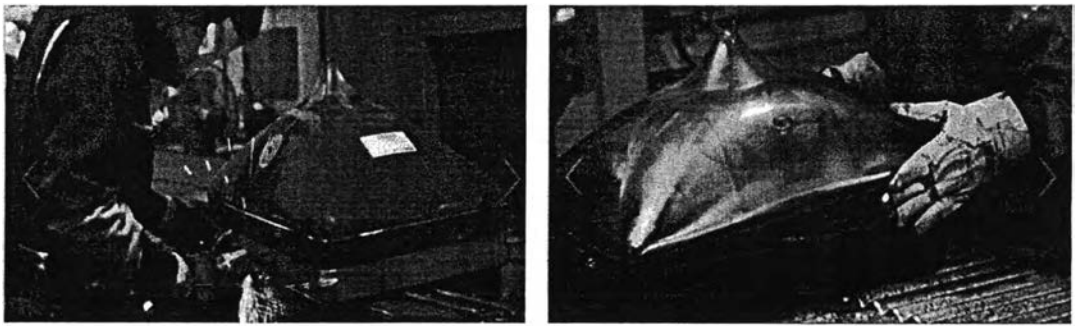

Figure 2.19 Removal and separation of CRTs (Panasonic, 2015).

3. Processing and crushing of two type of glass: Impurities are removed from the two types of glass. Special devices are used to crush each type into 5-cm fragments as shown in Figure 2.20.

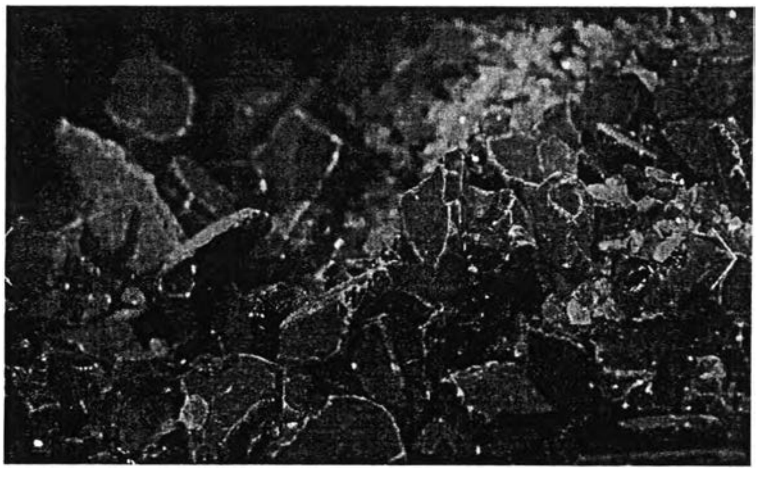

Figure 2.20 Processing and crushing of two type of glass (Panasonic, 2015).

4. Shipping of two types of glass: After being shipping to a CRT manufacturing plant, the glass is reused as a material for new TVs as shown in Figure 2.21.

Figure 2.21 Shipping of two types of glass (Panasonic, 2015).

The Home Appliance Recycling Law obliges manufacturers to maintain recycling rates of at least 55 % for CRT televisions and at least 60% for flat-screen televisions (METI, 2013). Sony has consistently exceeded these rates since fiscal year 2001. Sony corporation reported fiscal year 2013, the recycling rate for Sony-manufactured CRT televisions was 79 % as shown in Figure 2.22, while for Sony-manufactured flat-screen televisions it was 90 %.

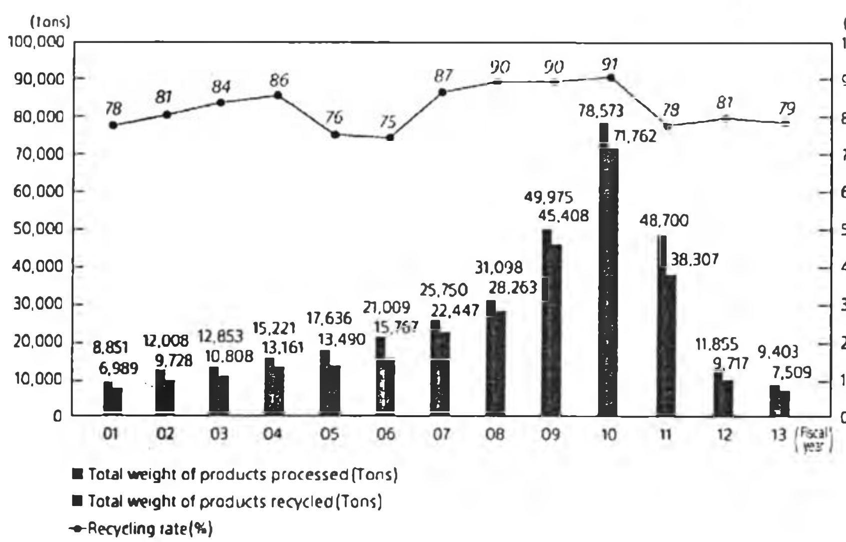

Figure 2.22 CRT-TV recycling rate in Japan between year 2001 and 2013 (Sony Corporation, 2015).

- CRT-TVs recycling in China

The discarded TV sets are treated in the professional dismantling enterprises for e-waste in China, as shown in Figure 2.23. This figure shows that due to the low cost of labor, the manual dismantling of the machines is the most frequent treatment technology used in China (Song *et al.*, 2012). There are three flow directions for the final products of e-waste processing; into reuse, landfills, and incineration.

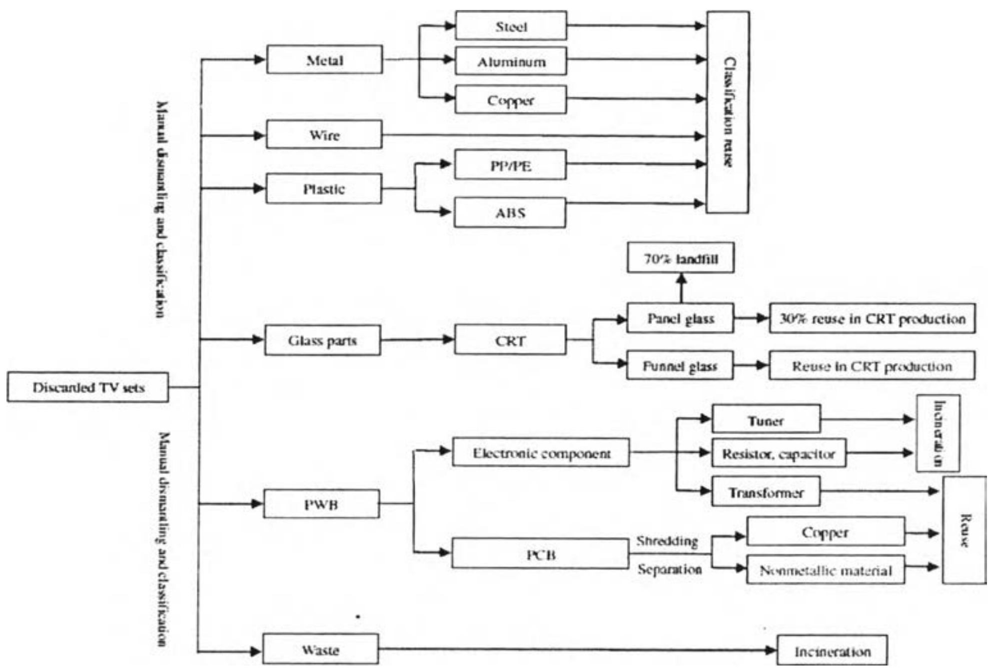

Figure 2.23 The major treatment and disposal procedures for CRT-TV sets in China (Song *et al.*, 2012).

2.4.1.2 Hazardous Technologies

a. Incineration

Incineration is the process of destroying waste through burning as shown Figure 2.24. Because of the variety of substances found in e-waste, incineration is associated with a major risk of generating and dispersing contaminants and toxic substances. The gases released during the burning and the residue ash is often toxic. This is especially true for incineration or co-incineration of e-waste with neither prior treatment nor sophisticated flue gas purification. Studies of municipal solid waste incineration plants have shown that copper, which is presented in printed circuit boards and cables, acts a catalyst for dioxin formation when flame-retardants are incinerated. These brominated flame retardants when exposed to low temperature (600-800 °C) can lead to the generation of extremely toxic polybrominated dioxins (PBDDs) and furans (PBDFs). PVC which can be found in e-waste in significant amounts, is highly corrosive when burnt and also induces the formation of dioxins (SECO and Empa, 2009).

Incineration also leads to the loss valuable of trace elements which could have been recovered and sorted and processed separately.

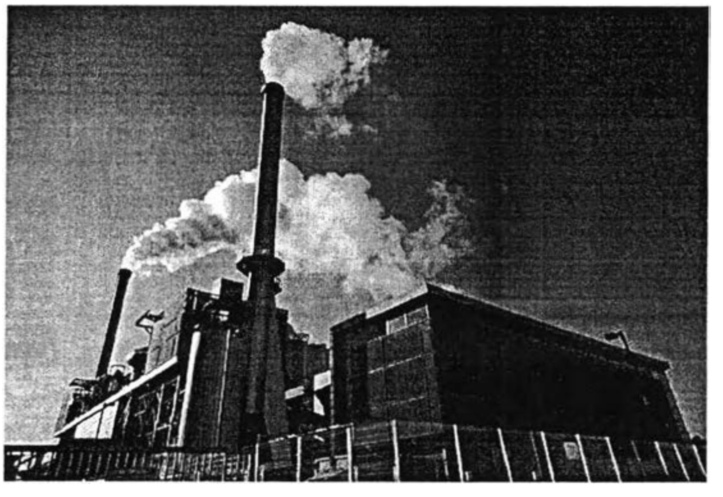

Figure 2.24 Incineration plant (B-Team, 2012).

b. Open Burning

Since open fires is burning at relatively low temperatures as shown in Figure 2.25. They release many more pollutants than in a controlled incineration process at an MSWI-plant. Inhalation of open fire emissions can trigger asthma attacks, respiratory infections, and cause other problems such as coughing, wheezing, chest pain, and eye irritation. Chronic exposure to open fire emissions may lead to diseases such as emphysema and cancer. For example, burning PVC releases hydrogen chloride, which on inhalation mixes with water in the lungs to form hydrochloric acid. This can lead to corrosion of the lung tissues, and several respiratory complications. Often open fires burn with a lack of oxygen, forming carbon monoxide, which poisons the blood when inhaled. The residual particulate matter in the form of ash is prone to fly around in the vicinity and can also be dangerous when inhaled (SECO and Empa, 2009).

Figure 2.25 Open burning (Eco-Waste, 2011).

2.4.2.3 Landfill

Landfill is one of the most widely used methods of waste disposal as shown Figure 2.26. However, it is common knowledge that all landfills leak. The leach often contains heavy metals and other toxic substances which can contaminate ground and water resources. Even state-of-the-art landfills which are sealed to prevent toxins from entering the ground are not completely tight in the long-term. Older landfill sites and uncontrolled dumps pose a much greater danger of releasing hazardous emissions.

Mercury, Cadmium and Lead are among the most toxic leach. Mercury, for example, will leach when certain electronic devices such as circuit breakers are destroyed. Lead has been found to leach from broken lead-containing glass, such as the cone glass of cathode ray tubes from TVs and monitors. When brominated flame retarded plastics or plastics containing cadmium are landfilled, both PBDE and cadmium may leach into soil and groundwater. Similarly, landfill conversers emit hazardous PCB's. Besides leaching, vaporization is also of concern in landfills. For example, volatile compounds such as mercury or a frequent modification of it, dimethylene mercury can be released. In addition, landfills are also prone to uncontrolled fires which can release toxic fumes.

Significant impacts from landfill could be avoided by conditioning hazardous materials from e-waste separately and by landfill only those fractions for which there are no further recycling possibilities and ensure that they are in state-of-the-art landfills that respect environmentally sound technical standards (SECO and Empa, 2009).

Figure 2.26 Landfill (Mcevoy, 2008).

2.5 Life Cycle Assessment (LCA)

2.5.1 Overview of LCA

The history of LCA goes back almost 40 years and started with energy and material budgets to which complementary pollution aspects were progressively added. With the two oil crises in the 1970s, interest in LCA was boosted, but mostly for the energy efficiency part. With the growing solid-waste issues at the end of the 1980s, the development of the methodology accelerated and in 1992 the first formal framework for the impact assessment phase was proposed. The purpose of this phase, based on scientific knowledge and models, is to convert inventory data into potential impacts on ecosystems and human health. The refining of this phase remains one of the key scientific challenges of the methodology for many research teams around the world (Mens and Werf, 2007).

2.5.2 Definition of LCA

Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences (SETAC, 1993).

2.5.3 Methodology

A framework for LCA has been standardized by the International Organization for Standardization (ISO) in the ISO 14040 series. It consists of 4 elements: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation as illustrated in Figure 2.27.

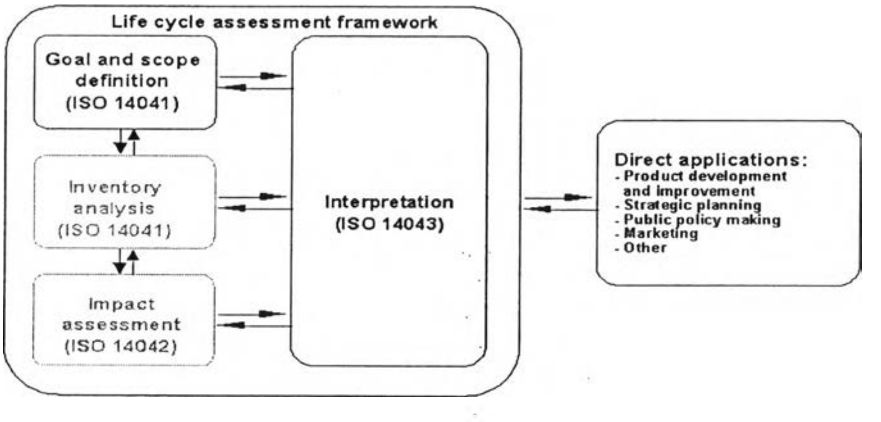

Figure 2.27 Life-cycle assessment framework as laid down in ISO 14040:1997 (Mens and Werf, 2007).

2.5.3.1 Goal and Scope Definition

Goal and scope definition is the first phase in a life cycle assessment containing the following main issues (Jensen *et al.,* 1997):

- Goal

The goal of an LCA study shall unambiguously state the intended application, including the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated.

- Scope

The scope describes the breadth, the depth and the detail of the study. It is important to define a functional unit and the system boundaries. The data quality requirements should be carefully specified.

- Functional Unit

One of the main purposes for a functional unit is to provide a reference to which the input and output data are normalized. A functional unit of the system shall be clearly defined and measurable. The result of the measurement of the performance is the reference flow.

- System Boundaries

The initial system boundary defines the unit processes which will be included in the system to be modeled. Ideally, the product system should be modeled in such a manner that the inputs and outputs at its boundary are elementary flows. However, as a practical matter, there typically will not be sufficient time, data, or resources to conduct such a comprehensive study. Decisions must be made regarding which unit processes will be modeled by the study and the level of detail to which these unit processes will be studied.

Any omission of life cycle stages, processes or data needs should be clearly stated and justified. Ultimately, the sole criterion used in setting the system boundaries is the degree of confidence that the results of the study have not been compromised and that the goal of a given study has been met.

- Data Quality

The quality of the data used in the life cycle inventory is naturally reflected in the quality of the final LCA. The data quality can be described and assessed in different ways. It is important that the data quality is described and assessed in a systematic way that allows others to understand and control for the actual data quality.

2.5.3.2 Inventory Analysis

Life Cycle Inventory (LCI) is the phase of the LCA involving the compilation and quantification of inputs and outputs; it comprises data collection and data calculation. Data collection consists of the identification and quantification of the relevant input and output flows for the whole life cycle of a product.

Basically three types of flows can be differentiated: elementary flows (emissions, resources) that are emitted into the environment or extracted from it, product flows (goods, services), that come from or go to the techno sphere, and waste flows (a sub-type of product flows). The use of resources and the use of land, raw materials, fabricated products, auxiliary materials, energy carriers and electricity are recorded as inputs. Emissions to air, water and land as well as wastes and by-products are outputs in an inventory analysis. In the later stage of the impact assessment, the quantitative information on the product system's elementary flows (and in some methods the waste flows) is used to analyze the product's impacts.

The most important steps of life cycle inventory work are determination of the reference quantity (e.g. functional unit, reference flow), description of system in flow diagrams, identification of unit processes to be modeled separately in LCI model, qualitative determination of inputs and outputs, quantitative determination of inputs and outputs, documentation of the type of data survey, inventory data collection, inventory data collection of transport, and Calculation of the inventory, including allocations and covering the inventories of the background data sets (Jensen *et al.*, 1997).

2.5.3.3 Impact Assessment

The impact assessment is carried out on the basis of the inventory analysis data. It is the third phase in a life cycle assessment containing the following main issues (Bianchi, 2008):

- Category Definition

The impact assessment categories should link the potential impacts and effects on what is referred to as the "areas of protection" of the LCA, i.e. the entities that we want to protect by performing and using the LCA. Today, there is acceptance that the protection areas of life-cycle assessment are:

  - natural resources
  - natural environment
  - human health
  - and often also: man-made environment

- Classification

In the classification step the inventory data are assigned to categories according to their impact. For instance, carbon dioxide emissions contribute to the greenhouse effect and are hence assigned to the impact category climate change. If a substance contributes to several impact categories, it has to be taken into account in all of these categories. Such a case is, for example, nitrogen oxide that causes both eutrophication and acidification.

- Characterization

Classification is followed closely by characterization. Every substance is assigned a potential impact in the impact category under study. The potential impact of a substance is given relative to a dominant factor in the category, e.g. for the Climate change potential this is typically 1 kg of carbon dioxide emissions. These relative impacts (the characterization factors of a substance) are than multiplied with the amount of each emission and the resulting impact values are summed for the respective impact category.

Life Cycle Impact Assessment uses generally the following categories:

- Greenhouse effect (or global warming potential)

Global warming is called the greenhouse effect because the gases that are gathering above the earth make the planet comparable to a greenhouse. By trapping heat near the surface of the earth, the greenhouse effect is warming the planet and threatening the environment. The climate changes that will result from global warming are extremely difficult to predict. If temperatures do indeed rise significantly, the most important result would be that some portion of the polar icecaps would melt, raising global sea levels. The Global Warming Potential (GWP) is the potential contribution of a substance to the greenhouse effect. This value has been calculated for a number of substances over periods of 20, 100 and 500 years because it is clear that certain substance gradually decompose and will become inactive in the long run.

- Acidification

The Acidification Potential (AP) is expressed relative to the acidifying effect of SO_2. Other known acidifying substances are nitrogen oxides (NO_x), sulfuric acid (H_2SO_4), and hydrogen chloride (HCl).

- Eutrophication

Eutrophication is an increase in the concentration of chemical nutrients (nitrogen (N) and phosphorus (P)) in water bodies, often leading to changes in animal and plant populations and degradation of water and habitat quality. The Nutriphication potential (NP) is expressed as kg phosphate (PO_4) equivalents. Other emissions also influence eutrophication, notably nitrogen oxides and ammonium.

2.5.3.4 Interpretation

Within the framework of an evaluation, the results from the impact assessment and the inventory analysis are analyzed and conclusions and recommendations are established. A further aspect is the transparent presentation of the LCA results. The ISO standards comprise three interpretation elements (Bianchi, 2008):

- Significant Issues

In order to determine the significant issues the main contributions of each impact category have to be identified (which emissions and/or which processes are dominant within each category). The relevant inventory data which cannot be recorded through impact categories must also be integrated into the study. Following the scope definition, the main contributions can be grouped by the individual process step, individual life phases and the entire life cycle. Together with these results, the significant issues can now be established, since it is now also clear which processes or life phases are dominant.

- Results Evaluation

To evaluate the results according to the ISO standard, a completeness check, a sensitivity check, and a consistency check of the identified processes or life phases must be carried out. Completeness is checked by e.g. a mass and energy data analysis and considering experts' know-how of the modeled processes. Sensitivity is determined by calculating scenarios for different processes or different parameters (e.g. varying yield of processes and emission factors). The effects of the different assumptions on the total result show the sensitivity. It must be ensured that all necessary information and data relevant to the interpretation are available and complete; for confidentially needs or process operators the ISO standards foresee to establish respective agreements. It is also important to check to what extent uncertainties, for example through the estimation of data due to data gaps, may influence the result. The consistency check should ensure that the procedure is consistent with the goal and scope definition and that the methodology and other rules have been accurately and consistently applied for the whole product system.

- Conclusions and Recommendations

The aim of this third step of the interpretation is to reach conclusions and recommendations for the report of the LCA study or life cycle inventory study. This step is important to improve the reporting and the transparency of the study. Both are essential for the readers of the LCA report. The results of the critical review of the study shall also be included when presenting the conclusions and recommendations.

2.5.4 Applications of LCA

The applications of LCA can be included into decision making in various fields, examples are (Bianchi, 2008):

- product development and improvement
- process and service operation
- strategic planning
- technological impact assessment
- public policy making
- marketing

2.6 LCA and Related Studies on Television

Oguchi *et al.* (2011) examined the characteristics of end-of-life electrical and electronic equipment (EEE) as a secondary metal resource. They categorized various types of end-of-life EEE into several groups by the metal content and the total annual amount of metals contained in end-of-life products for 21 types of EEE and discussed the potential of each group as a secondary source of metals.

Tables 2.4 and 2.5 show the median values of the material composition of products and the content of selected common metals, precious metals, and less common metals in printed circuit boards for 21 types of EEE. The median values of contents for Ba and Sr in CRT panel glass and Pb in funnel glass were 79,000, 74,000, and 215,000 mg/kg, respectively, and that for Co in Li-ion battery was 167,000 mg/kg.

Rocchetti and Beolchini (2014) presented a comparison of the environmental impacts of two different frameworks for the management of end-of-life CRTs. In particular, the impacts of conventional recycling (when CRTs were produced on a large scale) and more recent recycling (when CRTs are considered obsolete and are being replaced by the flat screen technology) of CRTs were considered. These scenarios are also compared to the disposal in landfill sites of end-of-life CRT.

Table 2.4 Material composition for 21 types end-of-life of EEE (Oguchi *et al.*, 2011)

Equipment type	Number of data	Weight fraction of materials[a]							
		Ferrous material (%)	Aluminum material (%)	Copper cable and material (%)	Plastic (%)	Printed circuit board (%)	CRT glass (%)		Battery(%)
							Panel glass	Funnel glass	
Refrigerator	2	47.6	1.3	3.4	43.7	0.5	-	-	-
Washing machine	3	51.7	2.0	3.1	35.3	1.7	-	-	-
Air conditioner	2	45.9	9.3	17.8	17.7	2.7	-	-	-
CRT TV	15	12.7	0.1	3.9	17.9	8.7	22.9	12.9	-
PDP TV	3	33.6	15.1	1.2	10.1	7.8	-	-	-
LCD TV	5	43.0	3.8	0.8	31.8	11.6	-	-	-
Desktop PC	6	47.2	-	0.9	2.8	9.4	-	-	-
Notebook PC	10	19.5	2.4	1.0	25.8	13.7	-	-	14.4
VCR	21	52.6	4.5	2.0	24.1	15.8	-	-	-
DVD player/recorder	4	62.5	-	3.6	15.3	14.0	-	-	-
Stereo system	4	41.4	1.7	1.7	18.9	11.1	-	-	
Radio cassette recorder	18	35.1	0.5	3.2	46.9	10.4	-	-	-
Facsimile	5	33.3	1.7	6.1	49.1	12.2	-	-	-
Telephone	2	-	-	10.3	53.2	12.6	-	-	-
Printer	6	35.5	0.2	3.2	45.8	7.4	-	-	-
Mobile phone	16	0.8	-	0.3	37.6	30.3	-	-	20.4
Digital camera	2	5.2	4.3	0.3	31.8	20.2	-	-	-
Camcorder	2	5.0	-	2.9	29.0	17.7	-	-	-
Portable CD player	2	0.8	-	0.4	72.3	10.1	-	-	-
Portable MD player	2	16.1	6.5	3.0	26.3	15.7	-	-	-
Video game	2	19.9	2.3	1.6	47.8	20.6	-	-	-

[a] Median values of obtained data.

Table 2.5 Metal content of printed circuit boards for 21 types end-of-life of EEE (Oguchi *et al.*, 2011)

Equipment type	Number of data	Metal content of printed circuit board[a] (mg/kg)														
		Common metal						Precious metal			Less common metal					
		Al	Cu	Fe	Pb	Sn	Zn	Ag	Au	Pd	Ba	Bi	Co	Ga	Sr	Ta
Refrigerator	1	16,000	170,000	21,000	21,000	83,000	17,000	42	44	-	82	480	120	-	51	-
Washing machine	1	1000	70,000	95,000	2200	9100	2400	51	17	-	65	51	16	-	9	-
Air conditioner	1	6900	75,000	20,000	5800	19,000	4900	58	15	-	320	-	29		26	-
CRT TV	5	62,000	72,000	34,000	14,000	18,000	5300	120	5	20	2400	280	36	-	550	-
PDP TV	2	38,000	210,000	20,000	7100	15,000	12,000	400	300	-	3900	100	-	-	650	100
LCD TV	1	63,000	180,000	49,000	17,000	29,000	20,000	600	200	-	3000	-	-	-	300	-
Desktop PC	8	18,000	200,000	13,000	23,000	18,000	2700	570	240	150	1900	50	48	11	380	7
Notebook PC	2	18,000	190,000	37,000	9800	16,000	16,000	1100	630	200	5600	120	80	10	380	5800
VCR	2	35,000	160,000	38,000	20,000	18,000	16,000	210	23	50	1200	-	47	9	27	23
DVD player/recorder	3	54,000	220,000	11,000	12,000	22,000	26,000	710	150	20	4300	85	110	9	400	77
Stereo system	1	29,000	150,000	12,000	19,000	22,000	14,000	57	6	-	1400	-	3	-	14	-
Radio cassette recorder	2	61,000	140,000	58,000	17,000	24,000	11,000	170	26	34	1400	230	8	12	120	9
Facsimile	1	37,000	120,000	11,000	19,000	7400	7700	69	35	110	4300	-	420	-	95	-
Telephone	1	67,000	96,000	150,000	19,000	34,000	8600	2400	-	-	4700	400	100	-	300	-
Printer	2	180,000	140,000	17,000	10,000	16,000	4200	70	38	21	3000	9	39	3	170	-
Mobile phone	19	15,000	330,000	18,000	13,000	35,000	5000	3800	1500	300	19,000	440	280	140	430	2600
Digital camera	10	24,000	270,000	30,000	17,000	39,000	8800	3200	780	200	16,000	230	140	15	440	7900
Camcorder	8	29,000	210,000	45,000	30,000	38,000	13,000	5000	530	970	18,000	240	180	52	610	8000
Portable CD player	2	68,000	200,000	46,000	12,000	50,000	20,000	3700	370	10	8600	1100	80	-	230	670
Portable MD player	2	27,000	330,000	45,000	9300	48,000	11,000	3400	940	550	19,000	660	150	-	340	9600
Video game	6	40,000	190,000	77,000	13,000	26,000	12,000	740	230	43	5100	260	100	16	400	83

[a] Median values of obtained data.

In the recycling scenarios, they compared the impacts of the recycling options, the disposal in a landfill site of the whole end-of-life CRT was considered inside the system boundary. Scenario 1 included the recycling of the panel and funnel glass and steel for the manufacturing of new CRT screens. Scenario 2 referred to the recycling of the panel glass and steel, while scenario 3 included also the funnel glass recycling, in the ''flat screen technology'' framework. Scenario 0 represented the disposal in a landfill site for hazardous waste of the whole end-of-life CRT as shown in Figure 2.28.

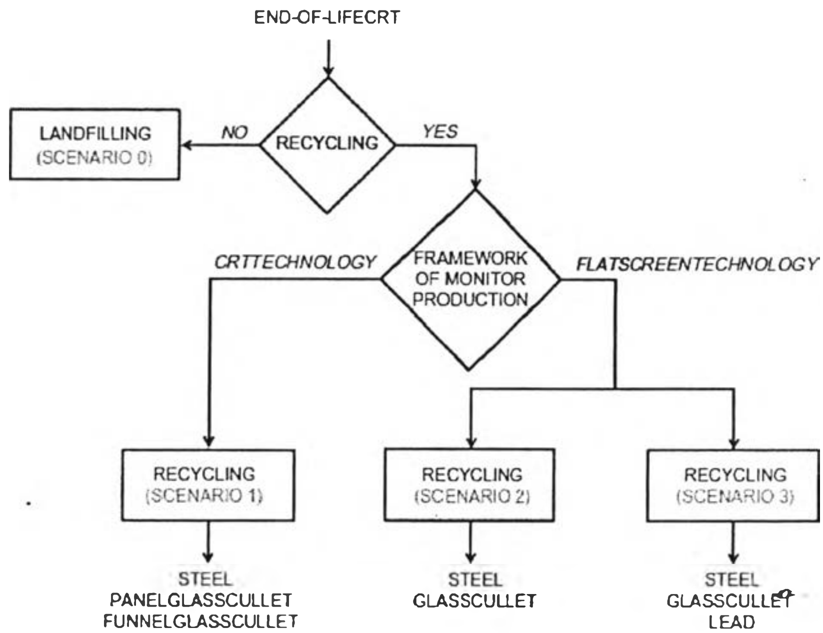

Figure 2.28 Flow diagram of the management options for an end-of-life CRT (Rocchetti and Beolchini, 2014).

The results of the study showed that CO_2 emissions in the scenarios considered within the two frameworks with the different technologies of monitor production: either CRT or flat screen displays as shown in Figure 2.29. In scenario 0, the impact was due to the disposal to landfill sites of some parts of the end-of-life CRTs. Scenario 1 showed the reduction of global warming from steel and glass. In scenario 2, the credit was derived from the recycling of the steel and panel glass in the form of cullet, while the debit was from the electricity required and the impact due to the disposal in landfill. In scenario 3, it is higher a net credit, mainly due to the recovery of lead and steel.

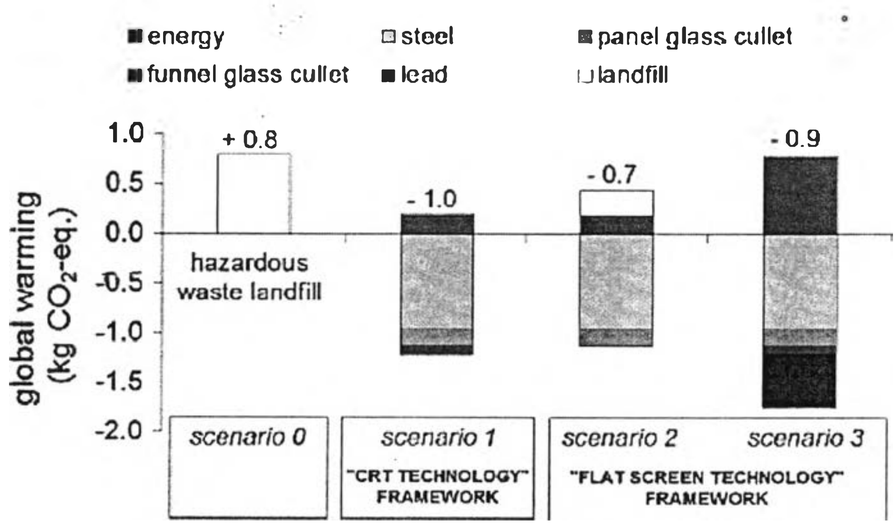

Figure 2.29 Carbon dioxide emissions for the different options in the management of an end-of-life CRT (Rocchetti and Beolchini, 2014).

Song *et al.* (2012) studied the entire life cycle assessment of a Chinese TV set was analyzed from environmental impact assessment, using the LCA method. Although LCD TV had become the main technological trend, but in China the production of CRT TV still accounts for a large ratio of television market, and compared with LCD TV, CRT television is more important in the use stage and end of life stage, for example, obsolete CRT TV sets accounted for 81.53 % of the e-waste collected by formal e-waste dismantling companies in China in 2010.

The results of the impact assessment of the complete life cycle of a CRT TV-set monitor, as shown in Figure 2.30, were that the use stage generated significantly more environmental impacts than the other three life stages, followed by the manufacturing stage. The distribution step contributed very little impact, because the energy consumption of transportation was the only input. The EoL stage even generated substantial environmental benefits, because of the recovery of valuable materials.

The result showed the effects of the four scenarios on the environmental impacts of Eol treatment are shown in Figure 2.31. The comparison of the four treatment methods, it can be concluded that the incineration of TV sets should be avoided. In addition, although dumping e-waste into landfills will cause relatively small environmental impacts, this method should be used as little as possible, because it wasted a large volume of valuable materials. In China, the recycling treatment by the formal dismantling enterprises was more efficient than other three treatment method.

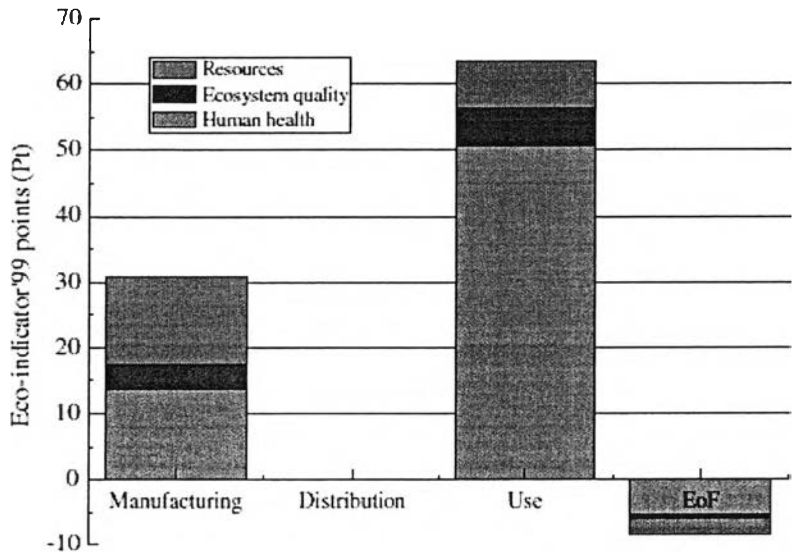

Figure 2.30 Environmental impacts of the TV sets expressed by Eco-indicator'99 method (Song *et al.*, 2012).

Feng and Ma (2009) studied analyses the different processes followed during color TV set production along with the energy consumption and the environment emissions in each stage. The system investigated includes the production of manufacturing materials (defined process 1), transport of manufacturing materials (defined process 2), color TV set manufacturing (defined process 3), transport of color TV sets (defined process 4), use of color TV sets (defined process 5), discarding color TV sets (defined process 6) and partial plastic waste energy utilization (defined process 7).

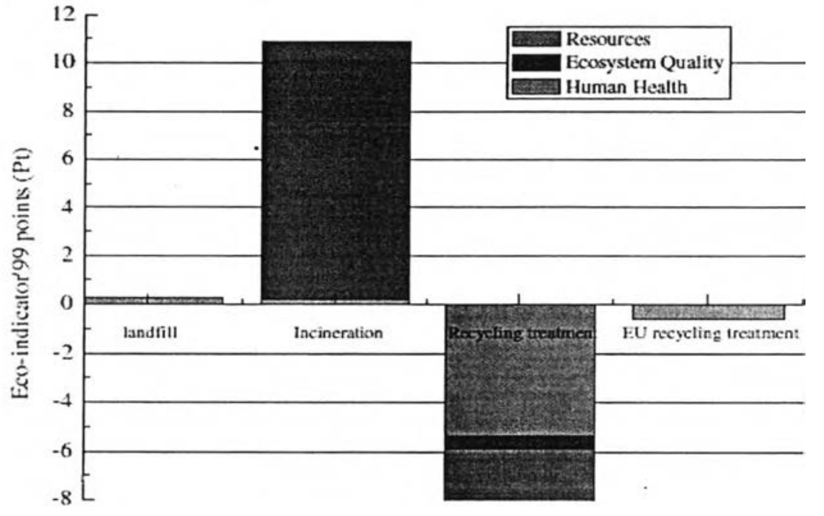

Figure 2.31 Environmental impacts of the various EoL scenarios (Song *et al.*, 2012).

From their study, the global warming emissions of different processes in color TV set life cycle are presented in Figure 2.32, which shows that process 5 emitted highest amount of emissions, followed by process 1, process 3, process 7, process 2 and process 4. Process 6 doesn't emit any global warming emissions.

From their study, the acidification emissions of different processes in color TV set life cycle is presented in Figure 2.33, which showed that process 5 emits most amount of atmospheric emissions, followed by process 1, process 3, process 7, process 2 and process 4 . Process 6 doesn't emit acidification emissions.

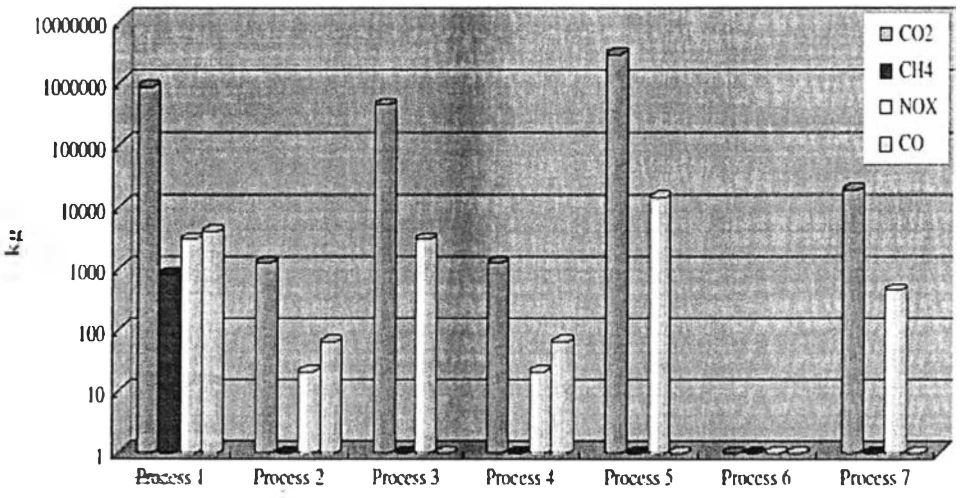

Figure 2.32 The global warming emissions of different processes in color TV set life cycle (Feng and Ma, 2009).

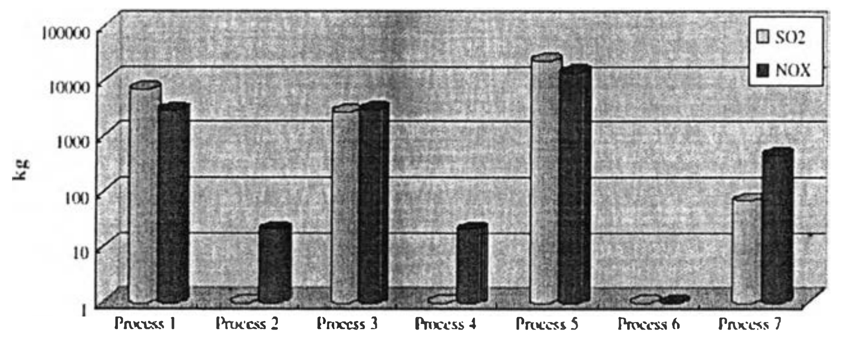

Figure 2.33 The acidification emissions of different processes in color TV set life cycle (Feng and Ma, 2009).

Niu *et al.* (2012) studied the life cycle environmental impacts of scrap CRT display in three scenarios. The environmental assessment of the dismantling and incineration are important to the human health, ecological quality and the resource. The life cycle impact assessment used the Eco-indicator 99 method. The results of the research showed the scrap CRT display in the three scenarios of treatment technology which are incineration, manual dismantling and mechanical dismantling. The each assessment steps all indicated that the incineration treatment technology had the highest environmental impacts in the three scenarios. Because in the incineration phase, there are many toxic material are produced. In the dismantling of the two type, the mechanical dismantling consumed more electricity energy, so it had a high environmental impact in the resources as shown in Figure 2.34.

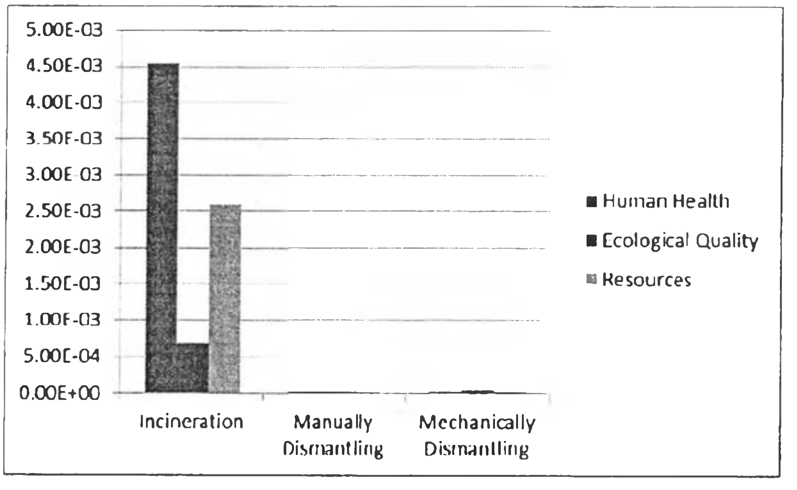

Figure 2.34 Standardization of life cycle impacts assessment (Niu *et al.*, 2012).