University of Southern Queensland

Faculty of Engineering and Surveying

Recycling Consumer Electrical and Electronic Equipment

A dissertation submitted by

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Abstract

This project is aimed at analyzing the amount of electrical and electronic products that were previously and are currently in circulation in Australia and how this is recycled and disposed of when they reach their end of useful live. It was not possible to find the exact figures of these volumes since the data found from the Australian Bureau of Statistics contained only some of the consumer electrical and electronic equipment imported into the country in 2004 and that data was used to make possible assumptions regarding the numbers in circulation and being disposed of this equipment in Australia. It was also observed that there were no active proper recycling activities in place specifically for the electrical and electronic equipment in Australia. And this has eventually led to a lot of Waste Electrical and Electronic Equipment (WEEE) being disposed of into the landfills. The negative and positive impacts of these disposals on the environment were also analyzed. The small recycling activities and disposals of WEEE have also been found to have been performed without measures ensuring that these are done in a manner not endangering the public health and the environment.

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ENG4111 & ENG4112 *Research Project*

Limitations of Use

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

TSHEPO PILANE

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Signature

Date

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Appendix A

Project specification – In this appendix, the specification of my project has been attached. This is the specification that I followed until I achieved the final task of this project.

Chapter 1

Introduction

The purpose of this project is to investigate the consumer electrical and electronic products recycling and disposals in Australia and around the world. The main reason behind this is to find out if the processes involved in recycling and disposing this equipment are being carried out properly in a manner that avoids health and environmental risks. These effects result when the toxic materials making this equipment leaks into the environment after their disposals polluting the water and air. The health and environmental risks will be further discussed as a general awareness to the community. Recycling techniques that are up to standards and that can reduce these disposals will be suggested. And recommendations based on the re-design of the electrical and electronic products will be made. These can in the near future resolve the problems associated with recycling making it much more feasible.

Chapter 2

Volumes of consumer electronics in Australia

2.1 General Description of Consumer Electrical and Electronic Equipment (EEE)

In this chapter, a research was done in order to find out the number of consumer electronic products being sold and disposed of when they are obsolete in Australia.

Consumer electronic products include equipment such as brown goods like televisions, audio/stereo equipment, VCR's, radios, video cameras and speakers, office equipment such as printers and copiers, data processing equipment including personal computers, monitors, mainframe computers and keyboards and telecommunication equipment such as telephones, facsimiles, answering machines, public telephones, mobile phones, pagers and transmission equipment.

2.2 EEE in Circulation in Australia

It was not possible to get the exact figures based on the individual customer purchase of these electronics from time to time from the Australian Bureau of Statistics. This shows that there are no proper records that are maintained by the electronics dealers that monitor the outgoing electronics from their shops to the consumers, which can then be sent to or rather be used by the Australian Bureau of Statistics so as to monitor the volumes of these products in Australia. It is not yet certain as to whether even the largest non-residential consumers who keep large quantities of these used electronics keep a good record of this.

Industry practices of collecting such data could be helpful because with such data at hand, the electronics being disposed can be easily monitored and tracks of the remaining equipment still in use can be recorded and the federal government could easily enforce its disposable regulations on these large consumers. It could be also helpful in the sense that it would not be difficult to know the estimated figures of this equipment that would be obsolete in the near future and has to wait to be recycled, something that can be very useful to the Australian recyclers.

The only information that was collected from the Australian Bureau of Statistics was on the imports of these electronic products from the other international countries into Australia in the year 2004. This can then be used to estimate how much of this equipment will have reached its end of life and will have to be disposed or recycled, based on the assumption that a similar quantity of goods is being disposed of in the same year. A graphical representation showing some of the consumer electronics imported into Australia is as shown in figure 1.
In this representation, not all the consumer electronics mentioned at the beginning of this chapter are represented; this was a handful of the products that were collected from the Australian Bureau of Statistics for analysis.

From the data received indicated in figure 1, in order to make a reasonable approximation on the disposals that will be in place at a certain period of time looking into the lifespan of the different equipment, an analysis will be carried out on the data containing computers, laptops, video games, music amplifiers, television receivers, mobile phones and video cameras since the data on these products is not combined with any other equipment. It will not be reasonable to in fact try to analyze the data on the monitors since it is combined with the keyboards and if used will not give a reasonable assumption because it is not clearly specifying the quantity of each separately and each equipment has to have its own different lifespan.

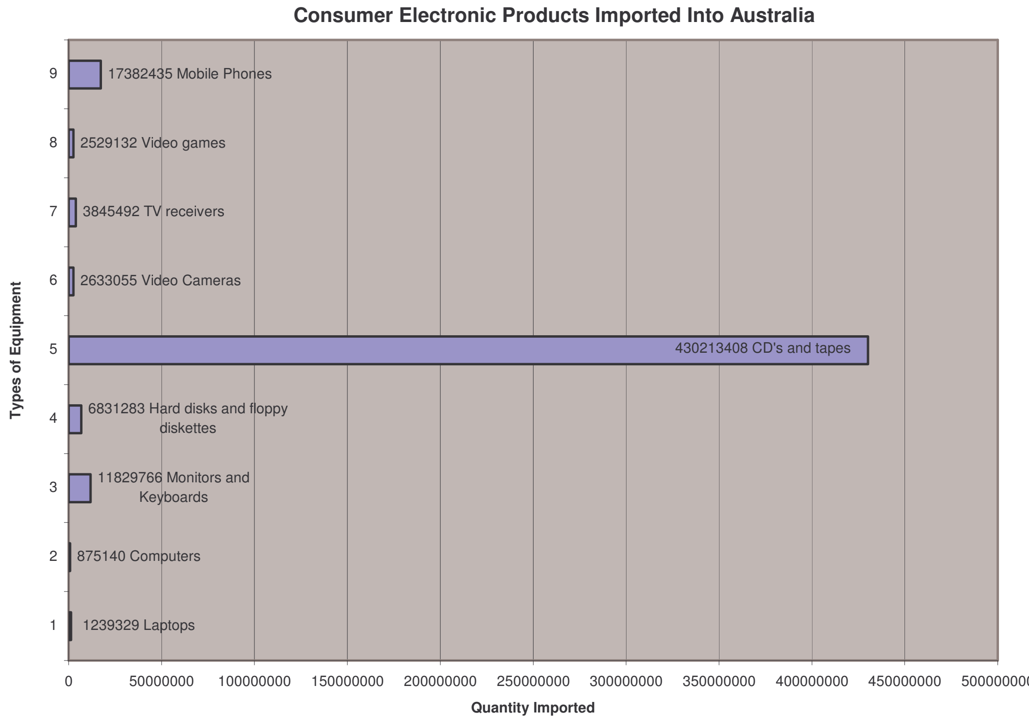

Figure 1: Quantity of electronic equipment imported into Australia in 2004

Source: Australian Bureau of Statistics (2004)

The information first reveals a total of 1,239,329 and 875,140 of laptops and computers respectfully, which were imported by the year 2004. On average, the lifespan of useful computers is from three and half to six years. This tells us that between mid 2006 and 2009 we will have at least more than fifty percent of each of these two products being obsolete. This can be even before 2007 since it has been observed by **(Macauley, Molly et al. 2003)** that the more rapid advances in the technology of computing continually reduces the lifespan of computers with every successive generation of newer ones. It is almost clearly visible however, that by the end of 2009 we will have a total of 2,114,469 computers and laptops that will have reached the end of their useful life. The average useful lives of the other equipment, estimated from personal experience are as listed below:-

- Magnetic tapes - 10 years
- Magnetic discs - 1 year
- Hard disk drives - 3 years

- Monitors - 3 years
- Alkaline batteries - 1 year
- TV receivers - 5 years
- Mobile phones - 3 years
- Music amplifiers - 4 years
- Audio speakers - 3 years
- Video games - 4.5 years

For example, the lifespan of television receivers is estimated to be at least five years. This means that at the end of 2009, from the 3,845,492 imported into Australia we will have at least eighty percent (3,076,394) of these television receivers, which will be obsolete. The other equipment is listed below with its estimated date of obsolesce and at least the figure that would not be functional at an estimated certain period of time.

Table 1: Consumer electronic equipment's estimated date of obsolesce.

Equipment	**Lifespan**	**Estimated date of obsolesce**	**Quantity estimated to be obsolete**
Mobile phones	3 years	2006	15,644,192
Music amplifiers	4 years	2007	146,636
Audio speakers	3 years	2006	6,665,544
Video games	4.5 years	2008	2,276,219
Video cameras	6 years	2009	2,369,750

After considering the lifespan of the equipment from the data above, a reasonable judgement was made and in this case it was estimated that at least ninety percent of each of the equipment above will be obsolete since some of the equipment will still be operational even at the end of their estimated lifespan. This shows that by the end of 2006 there will be at least an estimated 15,644,192 mobile phones and 6,665,544 audio speakers, making a total of 22,309,736 electronic products that will be in the waste stream waiting to be recycled or disposed off into the landfill, 146,636 music amplifiers in 2007, 2,276,219 video games in 2008, and 7,560,613 by the end of 2009. In figure 2 below, this equipment has been represented graphically for clarity.

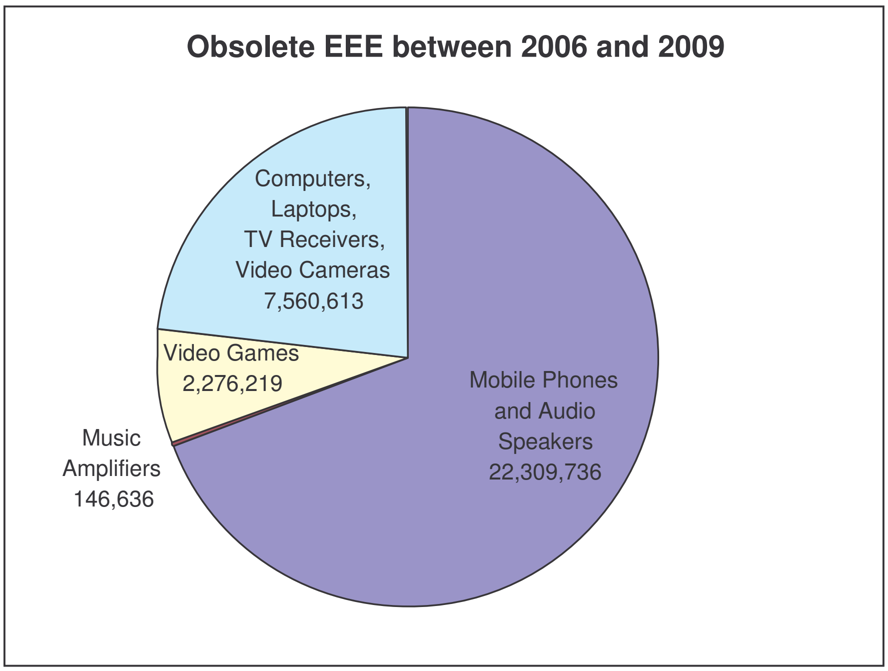

Figure 2: Obsolete EEE between 2006 and 2009

If this equipment will be kept in the electronic waste stream without being recycled or disposed then there will be 22,309,736 in 2006, 22,456,372 in 2007, 24,732,591 in 2008 and finally 32,293,204 at the end 2009. It must be noted however, that these figures are not very precise because not all the entire consumer electronics list of equipment was obtained and also there was some data that combined two or more equipment which made it impossible to separate that data before making analysis because different equipment will each have a different lifespan. This is actually a reasonable assumption that was reached based on what was available from the Australian Bureau of Statistics.

The graph in Figure 3 below shows the amount of WEEE that will be accumulated if recycling is not performed actively.

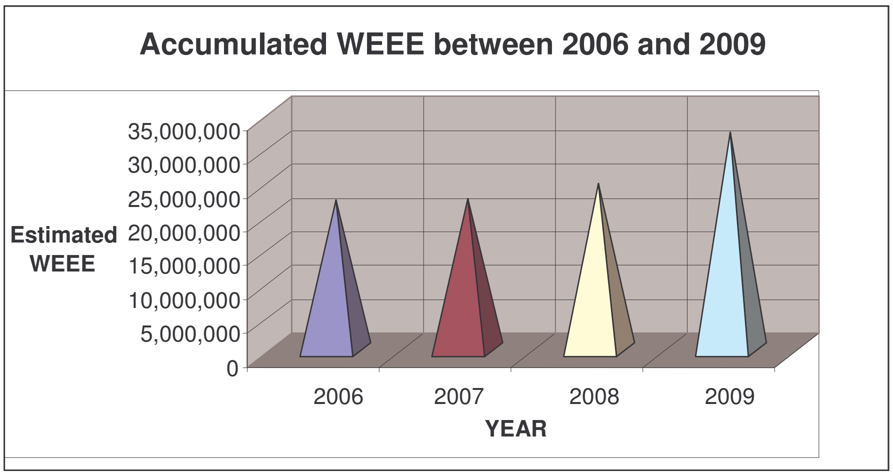

Figure 3: Accumulated WEEE between 2006 and 2009

The figures indicated in figure 2 suggest that there is a likelihood of significant health and environmental negative impacts from WEEE disposals between 2006 and 2007. If active recycling of WEEE is not made a priority in Australia by then, then these disposals will have significant impacts on the environment. These impacts will be discussed in further details in the next chapter.

It is not clear so far as to what exactly happened to the other equipment that was purchased in the previous years before 2004, how much of that equipment was recycled and disposed in the landfill.

The analysis above was based entirely on the imports made in the year 2004. Clearly, the volumes may be much higher because similar volumes probably imported in the other previous years have not been included in this analysis.

Chapter 3

Positive and Negative Impacts of WEEE Disposals

In this chapter, the needs for reducing the impacts of WEEE disposals into the land fills will be discussed and this will include both negative and positive impacts on the environment.

Consumer electronic products are made of such valuable components like metals, glass, plastics and other materials which can be profitably refurbished and which can also be sometimes reused with little effort. However, if these materials are not properly managed when they are disposed, it will be throwing away resources, which will cause consequences of environmental pollution as well as waste of resources. For example, cathode ray tubes, which are found in television receivers and in monitors, contain some hazardous materials such as lead, chromium and other toxic materials, which if this equipment is not properly disposed can end up being washed away by rains into rivers and dams polluting drinking water.

3.1 Environmental, economical and social benefits when reducing the disposals of consumer electronic products.

1. The reuse and recycling of consumer electronic products diverts the electronic products from disposals and this also diverts the materials from landfills and incinerators and this will minimize the negative impacts on the environment.

2. If the equipment is reused then that equipment can be donated to some charitable organizations or schools that cannot afford to buy such equipment and this also extends the useful life of the consumer electronic products.

3. a). Recycling and reuse conserve the natural resources and minimizes the possibilities of pollution. This will also reduce greenhouse gas emissions.

b). Even though cellular phones, television receivers, laptops and desktop computers have relatively low value components recovered and recycled but this also has a positive effect in keeping the air clean and the water we drink from being polluted.

c). Recycled and recovered materials from consumer electronic products conserve the energy used for manufacturing and reduces the environmental and health negative impacts and also keeps the rate of extraction of new raw materials low.

4. The material recovered from obsolete consumer electronic products can be used to refurbish the older electronic products and on the other hand reproduce other new useful materials.

5. a). Disposals can be reduced through recycling practices, which can create industrial jobs for workers.

b). A system where materials are collected, recovered and recycled into newer products creates another new chain of economic activity which results in businesses being extended and ultimately leading to more jobs and other economic growth.

6. Recycling can encourage major capital investments and will also support the federal government through tax revenues and fees.

7. The recovery of materials that can still be used to service other equipment or be used in the production of other new materials sometimes result in a positive net value.

3.2 Negative health and environmental impacts resulting from improper disposals of consumer electronic products.

Some of the known negative impacts of WEEE disposals are given below. Computer equipment has been constructed with well over 1000 materials which are highly toxic, having chlorinated brominated substances, toxic gases, toxic metals, biologically active materials, acids, plastics and plastic additives as mentioned by **JUST SAY NO TO E-WASTE (2005).**

Even at the production stage of consumer electronic products, it has been found that materials such as hard disk drives, monitors and printed circuit boards, hazardous materials and chemicals are used and workers involved at the production stage have reported some cases of cancer clusters. Computer recyclers have also been found to have chemicals that are highly dangerous. Some of the materials used in computers and found to be highly toxic are given below from **JUST SAY NO TO E-WASTE (2005):**

1). **Lead -** this is used in the construction of computers mainly for metal joining and radiation shielding. This element is highly hazardous if not properly disposed of or if its disposal in the landfill is not reduced because
it is capable of causing damage to the central nervous system, blood system and kidneys in human beings.
Its effects have also been found to have a serious negative impact on the children's brain development. If it is left to accumulate on the environment it will have highly toxic effects on plants, animals and microorganisms.

2). **Cadmium –** this is used in small amounts in batteries and cathode ray tubes and also as a stabilizer but poses as a risk on human health that may be irreversible. Humans can take it from polluted drinking water and its substances will accumulate in the kidneys. It can be inhaled too and be taken in up with food. This in the end causes the effects of poisoning.

3). **Mercury** – it is mostly used in batteries and printed circuit boards. If inorganic mercury is allowed to leak into drinking water, it changes into methylated mercury, which easily accumulates in living organisms and concentrates through the food chain and this has the effects of chronic damage to the brain.

4). **Chromium** – this can penetrate through the cell membranes of a human being producing highly toxic effects in those cell membranes. The effects of these lead to allergic reactions such as asthmatic bronchitis and chromium is also capable of causing DNA damages.

5). **Plastics** - it has been observed that of the plastics that are largely used in computers, the largest volume causing more health hazards and environmental negative effects is polyvinyl chloride. Production and burning of PVC generates dioxins and furans. This plastic which is commonly used in household products is a major cause of dioxin formation in open burning and garbage incinerators.

6). **Brominated flame retardants** – these are products that are used in consumer electrical and electronic products in order to reduce flammability in these products. Substances of these retardants can cause neurotoxic effects in humans just like the toxic substances in printed circuit boards. It has also been found that these substances reduce the levels of thyroxin if exposed to animals and even enters the blood brain barrier in the developing fetus. Thyroid is a mostly important hormone to both humans and animals of all species since it regulates normal development of all these species. The substances can also cause the risks of cancer of digestive and lymph systems, stomach, pancreas and liver cancers.

7). **Arsenic** – some of the electronic components such as relays, switches and circuit boards contain arsenic substances. Arsenic is also used as a doping agent in transistors. If these materials are not properly disposed of they lead to the effects of arsenic causing minor skin damage to the skin and lung and lymphatic cancer.

3.3 Possible ways of reducing negative impacts

Some of the materials effects from WEEE when released into the environment have been discussed above. It must be noted however that these materials can weigh differently from one product to the other and the effects on health and the environment will also vary depending on the quantities used. The high rate of accumulation on the environment can also lead to highly significant negative impacts, posing a serious health risk on the community and the environment.

It is possible however to convert these materials from the disposals into the landfills by either reuse or recycling. The recycling of WEEE is not yet fully economical but the few recycling activities that already exist have generated capital investments and created employment for the community.

There is need for both Australia and international federal governments to implement regulations guiding the recycling and disposals of this equipment. If these regulations are not implemented then recyclers can only use the cheapest ineffective methods that may have serious consequences in the near future. There is also need for environmental protection agencies to help federal governments by implementing tough measures regarding these disposals. The next chapter will cover recycling activities in Australia and around the world and the measures that have been implemented so far to control recycling with the aim of reducing the WEEE disposals which can further minimize their consequential effects on the environment.

Chapter 4

Recycling Practices In Australia and Around the World

4.1 Chapter Overview

Under this chapter recycling activities in Australia and internationally will be discussed and analyzed. These activities will include the collection schemes in place for consumer WEEE for treatment and recycling, the legislations for guiding and monitoring such activities. The disposals of WEEE into the landfills in Australia will also be discussed since these are widely spread in Australia. After making analysis of this, recommendations of what could be implemented as a major step in minimizing these disposals through recycling and reuse will be made. And lastly, a few international practices from a few countries will be discussed and compared with the Australian practices to find out how best these may benefit the Australian present situation. Some of the weaknesses in the international practices will also be identified and discussed.

4.2 Recycling Practices in Australia

In Australia recycling, including the take-back schemes of Waste Electrical and Electronic Equipment (WEEE), where and how this equipment is being collected for recycling and disposal is very limited. Even the refurbishment and remanufacturing of consumer Electrical and Electronic Equipment (EEE) is also done on a very limited scale according to **Meinhardt Infrastructure and Environment Group for Environment Australia (2001).**

This is mainly due to the fact that most of the EEE is manufactured and also assembled outside Australia and then imported into Australia. Basically re-manufacturing is made ineffective by lack of EEE manufacturing industries.
This has to be seriously considered because there is a lot of consumer EEE in circulation which also indicates that there might be a lot of WEEE in storage.

Due to the limitations of active WEEE recycling and take-back programs activities in Australia, most of the WEEE ends up being disposed of into the landfills. Apart from the fact that most of the EEE is not manufactured and assembled in Australia, some of the companies including government departments find disposals into the landfill as the best secure alternative of disposing their EEE especially computers containing classified and confidential information. Such organizations are made insecure by the lack of enough awareness by small scale commercial recycling companies to remove the highly confidential stored information.

According to **Meinhardt Infrastructure and Environment Group for Environment Australia (2001, p 17**);

> 'The eventual fate of used PC's is that 72.5% are stockpiled or sent to the landfill and 27.5% are reused or recycled. Therefore, currently three out of four used computers in Australia are potentially destined for landfill, while one in four is reused or recycled.'

Figure 4 below shows the disposal pathways for used computers within Australia. This figure was obtained from the report by Environment Victoria on its Environmental Report Card on computers 2005. The figure gives an overview of how reuse, recycling and disposals are being carried out.

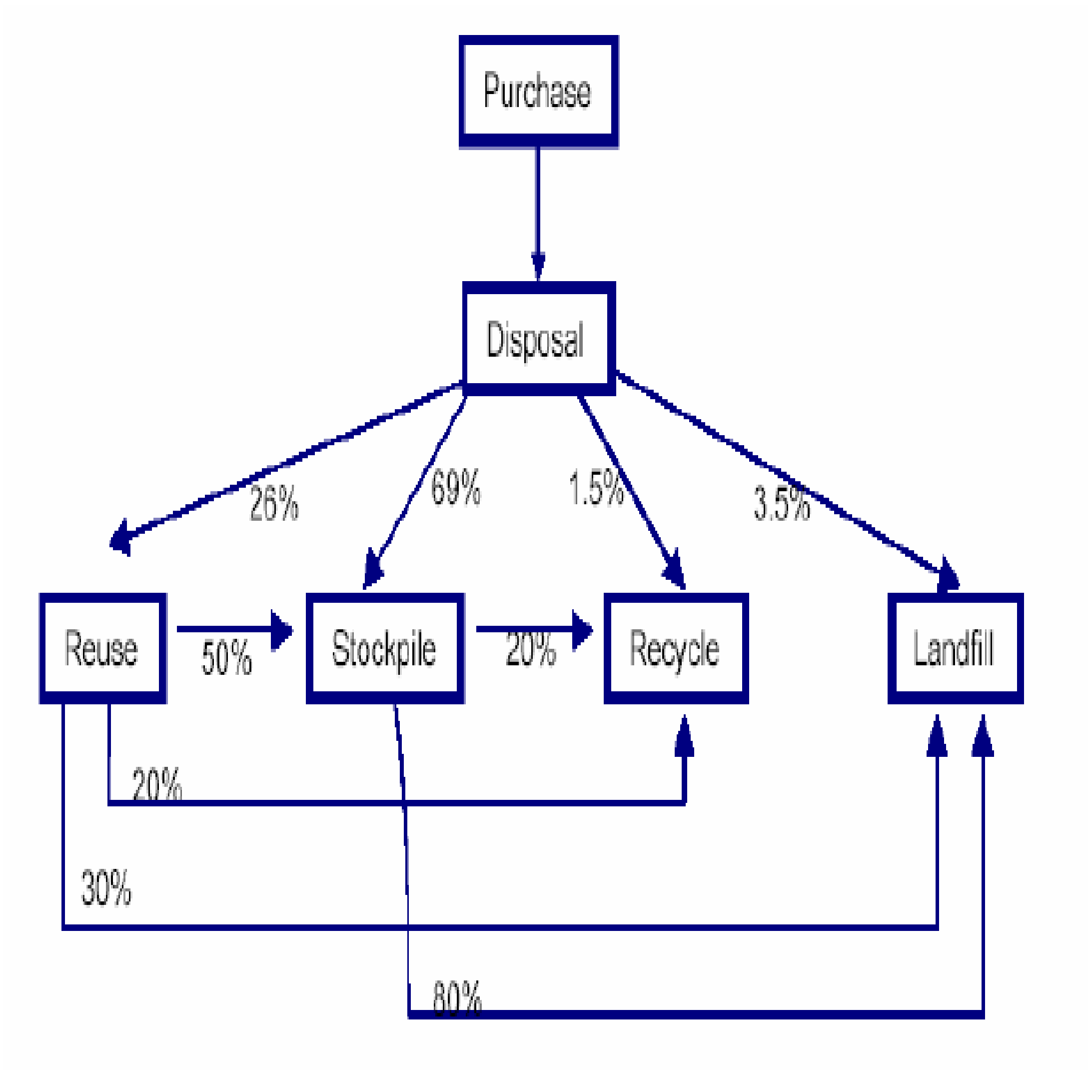

Figure 4: Disposal pathways in Australia

Source: Computer Waste in Australia and the Case for Producer Responsibility (2005)

According to the figure above it is obvious that most of recycling that is taking place is indeed very minimal. The Australian Capital Territory is the only jurisdiction in Australia which bans computer waste into the landfill, the other states do not classify obsolete computers as hazardous waste, and therefore these states simply allow computers from domestic and commercial waste streams into the landfills. There are no further details of what happens at the landfills, and no proper regulations are in place from various states that ensure the safety of the landfills, whether these landfills are not posing any threat to the environment. But a lot of landfill areas are not managed to maximize the reusability of EEE and the equipment may not even be tested before disposal. There are no monitoring schemes that ensure these landfills are being properly used to ensure safety. And finally under this section, the disposals into the landfills in Australia are mostly widespread due to lack of alternatives and cost implications despite the landfill fees.

4.2.1 Recycling Schemes Available in Australia

There is one collection scheme in New South Wales, Computer Asset Recovery Scheme funded by the New South Wales government **(Meinhardt Infrastructure and Environment Group for Environment Australia, 2001)**. Under this scheme only the end-of-life computers are collected and taken to the waste stream but much not is known about what happens to this WEEE. The scheme is not entirely effective since it only accepts collection from large-scale companies and does not accept obsolete computers from domestic users. And it covers a very small limited geographical area in Australia. It has also been observed that most of the recycling activities in Australia by companies such as Hewlett-Packard, Fuji Xerox and Ricoh Australia are on printers and cartridges as mentioned in the report by **Meinhardt Infrastructure and Environment Group for Environment Australia (2001)**. Recovery of toner cartridges is mostly practiced in Australia by Australian recyclers but their manufacturers are not actively involved in recycling them.

The recycling program introduced by Hewlett-Packard is on exchange basis for a few dollars off on old HP printers when customers are purchasing new laser printers. These old printers are then recycled, refurbished and resold. This scheme is not quite successful mainly because it restricts the model of old printers that can be taken back on purchasing the newer ones and the program activities are not entirely known to customers This is discussed briefly by **Meinhardt Infrastructure and Environment Group for Environment Australia (2001).**

Hewlett-Packard is not completely doing enough to improve its recycling program activities in Australia which can be simply achieved by publications of this program, attaching the general take-back procedure onto the newly purchased HP printers to make users aware of the possible ways of disposal of this particular EEE at its end-of-life.

4.2.2 Discussing Weaknesses in Recycling Practices in Australia

For so many years, the Australian Federal Government has been relying on the Basel Convention conditions of placing the responsibility on countries exporting any equipment that may contain hazardous elements to ensure that any hazardous waste exported has to be treated in an environmentally sound manner in the importing countries and that these countries have been made aware of the toxic materials involved. This convention is too general and does not specifically deal in broad terms with WEEE, it only deals with certain metals and chemicals and mainly with their transportation from one country to the other. Since the Department of Environment and Heritage is mainly responsible for the implementation and administration of the hazardous waste, it should take a step further and directly implement regulations that will specifically guide the recycling and disposals of EEE in Australia.

4.3 Recycling Practices around the World

4.3.1 Japan

In 1991 the Japanese government introduced the law of the Promotion of Utilization of Recycled resources aimed at setting up proper standards for use of recycled materials by local producers and ensures ease of recycling in their designs. By 2000 the Basic Law for Establishing a Recycling based Society was approved by the cabinet. This was much more specific about WEEE recycling and Extended Producer Responsibility. Ever since then the consumer EEE producers, especially the computer manufacturers in Japan have been required by the law to collect and recycle their own products.

The law in Japan also forces manufacturers and producers of computers, computer accessories and copy machines to make their drafts of take-back national programs of WEEE for recycling. Under this law manufacturers have to transport their own products from retailers and local governments to their take back sites. This came to be effective in 2001. And for the manufacturers to be able to manage these collections and recycling expenses customers are required by the law to pay collection and recycling fees of $25 to $37 for computers as indicated in a report on **Computer Waste in Australia and the Case for Producer Responsibility (2005)**. Even though the Japanese government formed this legislation to try and reduce WEEE deposals and to manage the recycling of EEE, this is only emphasized on computers and their accessories. It is not entirely regulating the other entire consumer WEEE.

4.3.2 Taiwan

Taiwan came to be one of the countries in July 1998 to create a national legislation aimed at the recycling of used computers **(Electrical and Electronic Products Infrastructure, 2004)**. This makes it compulsory for the manufacturers, importers and retailers to be financially responsible for the collection, transportation and disposal of their end-of-life computer products. This legislation was further expanded in 2000 to include other computer accessories such as printers and fax machines and other EEE such as televisions, air conditioners and other household appliances.

The local government is responsible for the collection and arranging recycling but the manufacturers are still responsible for paying recycling and collection fees. These fees are not fixed and they depend on the sales made by the manufacturers and producers (**Computer Waste in Australia and the Case for Producer Responsibility, 2005**).

This legislation is also limited mostly to the management of obsolete computers and just a few other consumer EEE which only make a small portion of the total consumer WEEE.

4.3.3 Netherlands

The Netherlands government enacted a legislation which specifically deals with WEEE. The legislation directly makes manufacturers, producers and importers to be responsible for the take back and recycling of their obsolete EEE products **(Electrical and Electronic Products Infrastructure, 2004)**. To make collection and recycling to be effective, consumers of EEE are required by the law to pay a certain fixed fee when purchasing electrical/electronic equipment. The fee covers collection schemes and recycling systems.

Disposal fees have to be paid by the manufacturers of the products. And to ensure that manufacturers and producers of these products are collecting and recycling their WEEE, the Netherlands government has specifically chosen the Ministry of Housing, Regional and development and Environment to be the overall supervisor of this program. The government also sets targets to be achieved by these recycling companies as indicated from **Computer Waste in Australia and the Case for Producer Responsibility (2005)**.

4.3.4 United States of America

According to **Electronics Recycling and Landfills (2005)**, in the United States of America every state is responsible for making up its own legislations in order to control the WEEE disposals. For instance, California created its own recycling legislation which placed a fee on every electrical and electronic equipment being purchased. This fee is only applied to the EEE that contains cathode ray tubes and is varied from US$6 to US$10 and this also depends on the size of the equipment being purchased. According to this bill, the Department of Toxic substances is required to create regulations that prohibits the sale of electrical and electronic equipment that is not meeting the requirements of the Restriction on Hazardous Substances directive. Manufacturers are also required to report to the state of California the number of units sold, estimated amount of toxic elements making up every electrical and electronic device and also to produce a report on how they intend to reduce these hazardous elements in the near future.

Apart from such legislations, manufacturing companies such as Dell and Hewlett Packard have come up with their own individual recycling practices in order to try to reduce WEEE disposals. These are broadly discussed by **Dell (2005)** and **Hewlett-Packard (2005)** respectively. These practices include informing customers on the procedures that they need to follow in order to recycle their equipment and this effectively makes the public community to be fully part of the recycling process. This is normally carried out on extended recycling tours. Other than these recycling tours these companies also have websites where enquiries can be made regarding the recycling of WEEE. Dell has provided asset recovery and recycling services to the business customers. It is also willing to meet the requirements of the European Union's directive and has currently developed specific implementations so as to comply with national laws on WEEE.

4.3.5 Europe

In Europe, the **The European Parliament and the Council of the European Union (2003)** issued a new directive on the 13th of February 2003 to facilitate the ease of management of WEEE.

The main objectives of this directive are mainly for the member states to protect health of the community, preserve and improve the quality of the environment and also to ensure that natural renewable and non-renewable resources are used sensibly and very cautiously. A summary detailing the regulations under this directive for the European member states are listed below:-

- In a case where it is not possible to avoid the generation of waste, it should at least be reused or recovered for its material energy or energy.

- The EU encourages the design and production of EEE which ensure ease of dismantling and recovery and mainly encourages reuse and recycling.

- Producers are not in any way allowed to discourage WEEE from being reused by implementing specific design processes unless such designs provide some significant advantages with regard to the protection of the environment and safety of human health.

- Member States shall find appropriate processes to reduce WEEE disposal and implement separate collection.

- Member States were given a time limit of up to 13^{th} August 2005 to make sure that systems facilitating the return of WEEE from households free of charge were set up.

- On the purchase of a new product, distributors shall allow that such a product when it reaches its end-of-life can be returned to the distributor free of charge on a one to one basis.

- All the WEEE collected should be taken for treatment unless the whole equipment is to be reused.

- Producers of EEE to set up systems of treating WEEE with the best of treatment available and implement acceptable recovery and they should also provide manuals for recycling, treatment and reuse to facilitate recycling.

- Recycling techniques should be improved. To ensure that this happens, Member States are allowed to set up minimum quality standards for the treatment of WEEE.

- Competent authorities shall be appointed by the Member States to carry out random inspections on the types and quantities of WEEE collected, to check if the general requirements of treating such equipment are satisfied and finally to ensure that the correct safety measures were followed properly.

- The directive has set up a target to ensure that by the end of 31 December 2006, producers and manufacturers should have increased the recovery of consumer electronics to at least eighty percent by an average weight per appliance and the component, material and substance reuse and recycling should have increased to a minimum of seventy five percent by an average weight per appliance.

- For Member States to be able to monitor the success of the above process accordingly, producers, manufacturers and any other party acting on their behalf should keep a clear record of WEEE mass, materials and substances when entering and leaving treatment, recovery and recycling facilities.

- Producers are asked to make a guarantee for their newer products in the market clearly stating that such products will be financed as part of the process of managing those products when they become part of the WEEE.

- The management of WEEE that was on the market before the 13th of August 2005 shall be fully financed for by the producers of such products.

- Users of EEE in private households have to be given enough information requiring them not to dispose of WEEE, where the take back and collection systems are available and how these systems operate so that they can also play a vital role in reuse, recovery and recycling of WEEE.

4.3.6 Comparison of the EU and other international recycling practices

The European Union directive is clearly stating its objectives in its attempt to reduce the disposals of WEEE by making all the stakeholders of EEE to be responsible for the management of WEEE. The producer extended responsibility that it has established will make the producers to be fully responsible for their products effects on both the human health and the environment. To make its objective to be successful it has set some targets to be achieved within certain time limits. In order to monitor its process member states are required conduct random inspections on WEEE collected and to check if the necessary safety procedures are being performed when recycling this equipment and also to report their progress to the council.

It has been observed in this chapter that the existing recycling practices in Australia and other international countries are very limited. Most of these recycling practices as discussed in this chapter are mainly focused on computers and their peripherals but this only forms a small amount of the total consumer EEE in circulation around the entire world. It is therefore important for other countries to follow the same steps as the EU directive in order to make the world a safe living place. The European directive objectives has however received a lot of criticism by the US trade associations with regard to the permanent ban of toxic materials on EEE manufacturing and the re-design requirements but favor the principle of minimizing the use of hazardous materials. This may be true in the sense that these restrictions may create barriers to trade more so that these objectives may not be easily achievable. But on the other hand for example, the United States alone was estimated to have over 315 million obsolete computers by the year 2004 mostly destined for the landfills **(JUST SAY NO TO E-WASTE (2005))** which could be making it one of the major countries to follow the example by the European directive.

4.4 Personal Computer recycling

In this section a brief description of the difficulties associated with recycling a personal computer will be outlined. This section briefly illustrates the problems associated with recycling consumer electrical and electronic product with regard to the complex materials making up this product some of which are hazardous. A personal computer is made up of a lot of metals and materials some of which are highly toxic. Table 2 below shows the materials used in manufacturing a personal computer and the percentage at which each material is recycled. This table shows that a lot of materials that are being recycled at a higher rate are precious metals such as iron, tin, copper, nickel, zinc, cobalt, gold, platinum and silver which are of economical value. It is also evident that plastic, which contributes more to the manufacturing of electrical and electronic equipment, is recycled at a low rate. This is mainly because plastic is not easy to recycle and it is also very expensive to recycle. The other materials which are very hazardous cannot be recycled at all and most of this is either disposed into the landfill or incinerated. This material is mostly not profitable to recycle. The other reason for disposing these materials is that there are no effective current recycling techniques that can handle them.

Table 2 Materials making up a desktop Computer

Composition of a Desktop Personal Computer Based on a typical desktop computer, weighing ~60 lbs.				
Name	**Content (% of total weight)**	Weight of material in computer (lbs.)	**Recycling Efficiency (current recyclability)**	**Use**
Plastics	22.9907	13.8	20%	includes organics, oxides other than silica
Lead	6.2988	3.8	5%	metal joining, radiation shield/CRT, PWB
Aluminum	14.1723	8.5	80%	structural, conductivity/housing, CRT, PWB, connectors
Germanium	0.0016	< 0.1	0%	Semiconductor/PWB
Gallium	0.0013	< 0.1	0%	Semiconductor/PWB
Iron	20.4712	12.3	80%	structural, magnetivity/(steel) housing, CRT, PWB
Tin	1.0078	0.6	70%	metal joining/PWB, CRT
Copper	6.9287	4.2	90%	Conductivity/CRT, PWB, connectors
Barium	0.0315	< 0.1	0%	in vacuum tube/CRT
Nickel	0.8503	0.51	80%	structural, magnetivity/(steel) housing, CRT, PWB
Zinc	2.2046	1.32	60%	battery, phosphor emitter/PWB, CRT
Tantalum	0.0157	< 0.1	0%	Capacitors/PWB, power
Indium	0.0016	< 0.1	60%	transistor, rectifiers/PWB
Vanadium	0.0002	< 0.1	0%	red phosphor emitter/CRT
Terbium	0	0	0%	green phosphor activator, dopant/CRT, PWB
Beryllium	0.0157	< 0.1	0%	thermal conductivity/PWB, connectors
Gold	0.0016	< 0.1	99%	Connectivity, conductivity/PWB, connectors

Europium	0.0002	< 0.1	0%	phosphor activator/PWB
Titanium	0.0157	< 0.1	0%	pigment, alloying agent/(aluminum) housing
Ruthenium	0.0016	< 0.1	80%	resistive circuit/PWB
Cobalt	0.0157	< 0.1	85%	structural, magnetivity/(steel) housing, CRT, PWB
Palladium	0.0003	< 0.1	95%	Connectivity, conductivity/PWB, connectors
Manganese	0.0315	< 0.1	0%	structural, magnetivity/(steel) housing
Silver	0.0189	< 0.1	98%	Conductivity/PWB, connectors
Antinomy	0.0094	< 0.1	0%	diodes/housing, PWB, CRT
Bismuth	0.0063	< 0.1	0%	wetting agent in thick film/PWB
Chromium	0.0063	< 0.1	0%	Decorative, hardener/(steel) housing
Cadmium	0.0094	< 0.1	0%	battery, glu-green phosphor emitter/housing, PWB, CRT
Selenium	0.0016	0.00096	70%	rectifiers/PWB
Niobium	0.0002	< 0.1	0%	welding allow/housing
Yttrium	0.0002	< 0.1	0%	red phosphor emitter/CRT
Rhodium	0		50%	thick film conductor/PWB
Platinum	0		95%	thick film conductor/PWB
Mercury	0.0022	< 0.1	0%	batteries, switches/housing, PWB
Arsenic	0.0013	< 0.1	0%	doping agents in transistors/PWB
Silica	24.8803	15	0%	glass, solid state devices/CRT,PWB

Source: JUST SAY NO TO E-WASTE (2005)

Chapter 5

Recommended Practices in Australia

After a careful analysis on the recycling practices that are currently in place in Australia today and comparing that with the other international recycling practices some of the following recommendations were reached.

The Department of the Environment and Heritage with the help and support of the Australian State departments should come under one umbrella and implement regulations that can make manufacturers, distributors and retailers to be both physically and financially responsible for their electrical/electronic products waste to be manageable. After implementing such regulations that guide the recycling and disposals of WEEE, the Federal Government should introduce possible effective monitoring schemes to ensure that recycling and disposal policies are being properly carried out.

It may be possible for the government to support the already existing small scale recycling companies by subsidizing their recycling activities so that these organizations can extend their geographical coverage in Australia. It is important here to note that this can be possible only if these companies can draw their own take-back programs, present them to the government and convince the government that their recycling activities will not endanger the environment and the health of the public. In addition to this, EEE users can be charged a certain amount of fee when purchasing new EEE so that this can be used for recycling, making it affordable for these companies to manage WEEE.
Before these charging these small fees these bodies will have to educate consumers about the importance of recycling and reuse so that they can also play a vital role in WEEE recycling.

Since three out of four end-of-life computers are taken into the landfills as mentioned in **Computer Waste in Australia and the Case for Producer Responsibility (2005)**, the Australian State Government may impose a temporary ban of landfill disposals and incinerations for a while until the process of recycling is permanently solved. If a sound alternative can be found it might even be possible to ban landfill and incinerations for ever. On the other hand governmental organizations and the small scale recycling companies of WEEE in Australia have to encourage refurbishment and reuse of WEEE since there are no common widespread techniques at the moment to effectively recover materials from these products.

If it can be made feasible by setting up a legislation forcing manufacturers to take back their end-of-life EEE products for recycling, then these manufacturers and producers can be made to attach labels to their manufactured products making users to be aware of the hazardous elements contained in the products and the take back program activities for recycling by those producers **(The European Parliament and the Council, 2003)**. This will reduce the WEEE stored in the households. A lot of people purchase this EEE annually but at the end of this equipment's useful life they do not know where or how they are supposed to get rid of it other than just keeping it in their households. This is mainly because a lot has not been done in the past and even at the present stage to make the community aware of the EEE recycling.

Computer dealers such Dell, Apple and Hewlett-Packard have implemented some recycling programs in the United States and other international countries such as Japan, Italy, Canada, Belgium, Netherlands and Sweden. For example, Apple Computer, Inc has long developed a recycling collection scheme in Canada where the residents can return their WEEE or unwanted ones free of charge instead of having to pay a fee for this equipment to be recycled in order to reduce the impact of WEEE as indicated by **Apple Company, Inc (2005)**. These companies also attend extended tours in the USA educating customers about their recycling activities. Regulations forcing such companies to do the same in Australia can be implemented.

And lastly, the EEE manufacturers and the EEE dealers in Australia and Australian Bureau of Statistics dealers should keep records of all the manufactured and imported consumer electrical/electronic equipment into Australia and be able to track the distribution of such equipment around the Australian states. These records can help with better estimates of the obsolete EEE in Australia, the equipment recycled and disposed into the landfill. They can also help in the near future if used to set some targets for to be achieved by the recycling companies and this will further help to monitor the progress of recovery and recycling. The proper management of these records can improve the waste management of WEEE.

Chapter 6

Recycling Techniques

Under this topic, the recycling techniques used by the Australian and international recyclers to recover materials and components from Waste Electrical and Electronic Equipment will be studied. After this study an analysis of these techniques will be carried out to find out if more urgent and effective measures are being considered and all exhausted before the disposals into the landfills are performed as a last resort.

At the beginning of this chapter a general simplified recycling diagram is shown below in figure 5 and explained in order to try and give the reader a clear general overview of some of the processes that take place when recycling WEEE. All these recycling stages are connected to each other by the means of transportation.

WEEE

At the top of the flow chart below in figure 5, there is WEEE which is the input to the whole process of recycling. This is the electrical and electronic equipment which has reached its end of useful life and has become Waste Electrical and Electronic equipment. This equipment will be kept in some storage where it waits for collection to the recycling industry.

Collection

The next step is for this WEEE equipment to be collected and transported to the recycling industry where it is sorted before being recycled or some of it being land filled or disposed. Immediately after the EEE becomes WEEE, it is then transported to the collection sites.

Sorting

At this stage the WEEE from the collection sites at the recycling industry is sorted into categories, for example, brown goods are sorted as one category where video cameras, television receivers, radios and audio/stereo equipment are sorted out as one type of equipment falling under one category. Printers and copiers are sorted out as office equipment, personal computers, monitors and mainframe computers are put aside as data processing equipment and finally a category of telecommunications equipment is sorted out which includes public telephones, mobile phones, pagers and telephone equipment.

Dismantling/Disassembling

After the WEEE has been sorted out into its respective categories, this is then disassembled or dismantled. Here the materials and components are dismantled from equipment. This process allows the removal of a component or a part or group of parts from a product or separating a product into all of its parts for a given purpose. Sometimes this becomes a tedious process because the removals of such components depend upon the connections attaching the components together and in most cases these connections are not standardized. And this may require a lot of labor and specialized tools to perform this task. The components are then tested and if they are still active and functioning properly they are used in upgrading and maintaining other

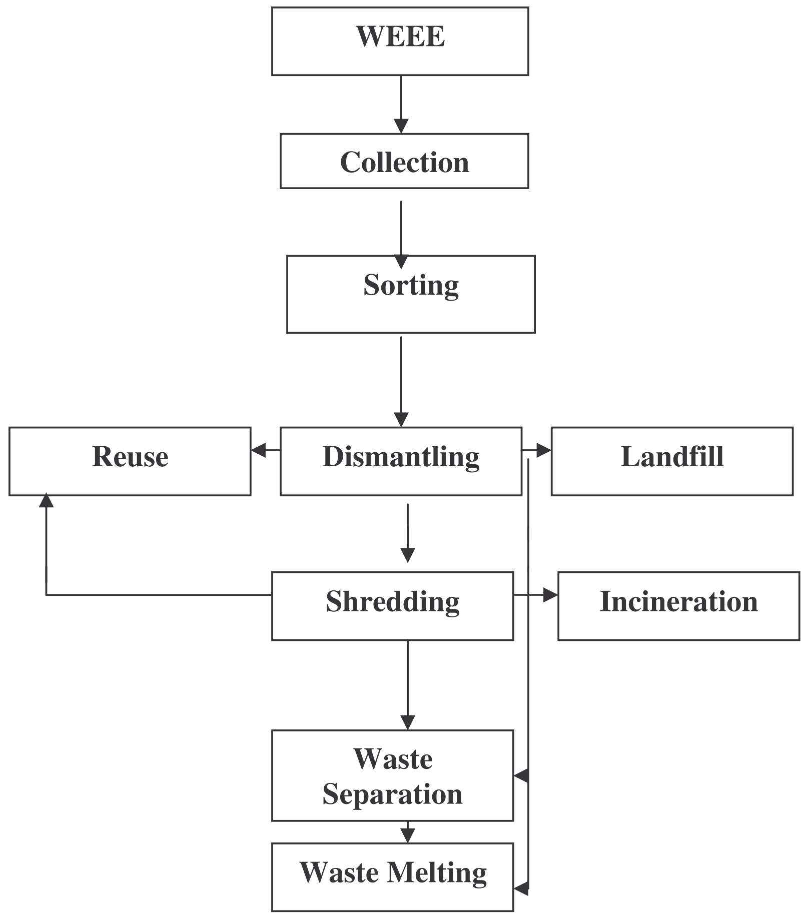

Figure 5: Simplified recycling diagram

components in the other equipment and this equipment is then resold or contributed to non-profitable charitable organizations where it is reused. The components and materials that cannot be reused to refurbish the other equipment have to be treated and will later on be disposed into the landfill or incinerated.

Shredding

WEEE that cannot be separated into individual elements is further passed into the next stage where it is all placed into huge shredding machines. At this level

WEEE, together with other equipment such as old vehicles are all put in these shredding machines. These machines use electromagnets to draw out larger ferromagnetic steel fragments for re-melting in electric arc furnaces. And again in this process, there is also another separation which is carried out performing further removal of other large fragments of non-ferromagnetic metals such as brass and aluminium.

Waste Separation

This process accepts mixed residual waste as the input. It is actually the output obtained after ferromagnetic and non-ferromagnetic metals that have been drawn out from the shredding machines. This is in the form of large volumes of sludge which contains other little particles of steel, copper, aluminium, brass, solder and wires mixed with different types of plastics and glass. All this mixture is then separated at this stage. The remaining waste is taken to another different process for further separation.

Also at this stage, some of the material will be just a reduced volume that is destined for the landfill and some output residuals will have to be treated and incinerated **(Institute for Sustainable Futures, UTS, 2005)**. The reason for treating these residuals before being incinerated is that this mixture will probably consist of highly toxic substances from various equipment constructed with different chemical components. The treatment of such mixture is only intended to reduce the air pollution effects of such toxic chemicals when incinerated.

Waste Melting

From figure 5 of the simplified recycling diagram above, the waste melting stage is the last recycling process before incineration and landfill disposals are considered. The input material to this process is a limited variety of wastes which cannot be separated in the waste separation process but could be used for energy production. The output products here are mainly green energy and metal residue as shown by the **Institute for Sustainable Futures, UTS, (2005)**.

Reuse

This level of recycling is where some components disassembled and materials recovered from WEEE and some obtained after shredding are reused to refurbish the other WEEE. After the refurbishment and upgrade of this equipment, it is either resold by the recyclers as second hand electrical and electronic equipment, contributed to charitable organizations and schools or given to families that cannot afford to purchase this equipment. In some cases it will only be components that can still be reused for other repairs that are tested and if in a good condition are resold individually provided they can still be useful in the current electrical and electronic equipment. And if these components cannot be reused in the current equipment in the market they will either be stored to be used in the other WEEE or be incinerated or disposed.

Landfill

The landfills are used by recycling industries as the last resort to dispose of the WEEE that cannot be further recycled. Although it is said to be the last resort to recycling, in practice as earlier said some commercial companies including other governmental organizations prefer to dispose their WEEE into the landfills without taking it to the whole recycling stages as a measure of security to the classified and confidential information that may be recovered by second hand parties. The WEEE here is either the whole WEEE that does not have any reusable components that cannot be used to refurbish and upgrade other WEEE and other individual components after dismantling that cannot be maintained. The other material is from shredding, waste separation and waste smelting processes which is in the form of a residual waste and sludge. All this material is buried together under the earth. The output products at the landfills is mostly green energy and methane which is used for energy production **(Institute for Sustainable Futures, UTS, 2005)**.

Incineration

This is also another option that is normally practiced by WEEE recyclers. In this process the mixed waste residual from the other recycling processes including toxic and other hazardous elements are burned in high-temperature incineration plants. This requires considerable air emission control equipment and it is also important for the input waste to be chemically treated before being burned to reduce air pollution. Most of the output products include heat, steam and waste destruction.

6.1 Practical Recycling

6.1.1 Disassembly In Practice

In practice, the recycling of WEEE involves a lot of selective dismantling which is a very tedious process since reuse of EEE components has a first priority and the removal of toxic elements from this equipment is also essential. It is also very common according to **(Cui, Jirang et al. 2003)** to dismantle highly valuable components and high grade materials such as printed circuit boards from which only copper in small quantities is sometimes extracted, cables and engineering plastics so as to simplify the subsequent recovery of materials. In most of the cases the recycling plants use manual dismantling which further makes this process to be indispensable.

It is also important to indicate here that before practically disassembling the WEEE there is a disassembly planning process **(Cui, Jirang et al. 2003)** which is carried out. This is undertaken in order to develop procedures and software tools for implementing and configuring disassembly strategies. This planning process involves the input and output analysis where an identification of reusable, hazardous and valuable materials is made before optimal dismantling is identified. Then there is assembly analysis in which joining elements and assembly sequences are analyzed. In the third phase an analysis regarding the uncertainty of disassembly from defective parts and joints and also on the upgrading and downgrading of equipment during consumer use and disassembly damage. The last phase of this process is to determine a strategy in dismantling a product. This is where it is decided whether to use destructive or non-destructive disassembly.

6.2 Physical Recycling Process

6.2.1 Screening

This process is used in the preparation of uniformly sized feed which goes into a mechanical process. It is also useful when metals contents are being upgraded. This is essential since the particle and shape properties of metals are different from those properties found in plastics and ceramics. Screening uses **(Cui, Jirang et al. 2003)** a trommel mainly used in both car scrap and municipal solid waste processing.

6.2.2 Shape separation

The shape separation process developed specifically to control the properties of particles in the powder industry as highlighted by **(Cui, Jirang et al. 2003)**. The separation methods make use of particle velocity on a tilted solid wall, the time that is taken by a particle to pass through a mesh aperture, the particle's cohesive force to a solid wall and the settling velocity of a particle in a liquid. The most common method that has been used in the recycling industry has been shape separation by a tilted plate. And in Japan copper is being recovered from electric cable waste, printed circuit board scrap and waste television and personal computers using inclined conveyor and inclined vibrating plate.

6.3 Magnetic separation

Magnetic separation is also used in mechanical recycling to recover ferromagnetic metals from non-ferrous metals and other non-magnetic materials. This process in metal recycling mainly uses low-intensity drum separators.

6.4 Electric conductivity-based separation

This process separates materials according to their different electric conductivities. Three different methods used here are eddy current separation, corona separation and triboelectric separation.

6.4.1 Eddy current separation

The operation of this technique is based on permanent non-electric rare earth magnetics **(Cui, Jirang et al. 2003)**. In operation, a piece of non-ferrous metal will pass over a rotating separator at high speed creating eddy currents in the non-ferrous metal and generating a magnetic field around it. In a case where the polarity of the magnetic field is similar to that of a rotating magnetic then the non-ferrous metal will be repelled from the magnet. The repelling force will then separate the metal from the non-ferrous metal this gives an output of a cleaner product for further processing. The separators recover non-ferrous metals from shredded car scrap and also from electronic scrap. At the present moment the eddy current separators are used almost exclusively for waste recovery. This process cost effective has high separation efficiency.

6.4.2 Corona electrostatic separation

Corona electrostatic separation uses the rotor-type electrostatic separators to separate raw materials into either conductive or non-conductive fractions. This technique discussed by **(Cui, Jirang et al. 2003)** is suitable for separating fine particles with a size range of 0.1 to 5mm. This method effectively uses the electrode system, rotor speed, moisture content and the particle size to determine the separation of results.

6.4.3 Triboelectric separation

This is another method **(Cui, Jirang et al. 2003)** used to sort plastics based on the differences between their electric properties. Intensive rubbing of plastics against each other is performed in order to give them opposite charges. The charge accumulated by each plastic depends on the type of plastic being charged. And ultimately the plastics with the same density are separated.

6.5 Jigging

Jigging separation helps to sort smaller pieces of metals through density separation. In this process **(Cui, Jirang et al. 2003)** jigs with high capacity per unit surface are used and these are suitable and efficient in processing large amounts of fine particles. This method of separation is applied in the separation of both light and heavy metals in a recycling demolition ruble.

6.6 Other Recycling Technologies

Over the past years it has been easy to extract and recycle ferrous and no-ferrous metals such as steel, aluminium, copper and brass, but it has not been that much practicable and easy to handle other material components from consumer electrical and electronic equipment and establish markets for such materials. The materials some which are Cathode Ray Tube (CRT) glass and plastic are hard and sometimes not economically viable to recycle. Recently there have been some new processes and technological trends developed to handle glass and plastic materials as discussed by **Porter, J.D (2000).**
Some of these technologies are discussed below.

Cathode Ray Tubes Technology

In the United States of America, Andela Products, Ltd based in New York has already installed its first Cathode Ray Tube glass processing unit in San Francisco. This process consists of its own individual air filtration system which is meant to control glass dust coming out during processing. CRT's are placed in this unit and are then separated into streams of ferrous and no-ferrous metals. There will be an output of residual materials as well some of which will be leaded glass which will be further taken for another processing in the smelters.

Plastic Recycling Technologies

Another prototype technology by Argone National Laboratories in the United States in Illinois which may be helpful in the near future has been developed and successfully tested. This process is called froth floatation also mentioned briefly by **Porter, J.D (2000)** and is mainly developed to separate some plastics specifically from Waste Electrical and Electronics. This technology will handle large volumes of plastics from WEEE and can in the near future help to reshape the plastic recycling industry into a much more profitable operation.

Still in the United States of America, a company called MBA Polymers has started new markets for plastics from WEEE. Its technology will be based on sorting out plastic from WEEE which is not normally so easy to separate and usually expensive to recycle. This will in another stage be processed and sold as pellets.

6.7 Australia Recycling Techniques

A study was conducted to find out the most common recycling techniques in practice in Australia and around the world. It was found out that in Australia alone a recycling company called CSIRO uses shredding machines to recycle a small amount of WEEE. This recycling company has some shredding plants in Australia's capital cities. The company collects old car scraps and some of waste consumer electrical and electronics like washing machines and refrigerators and all this is put into one shredding machine. This process according to this company is mainly aimed at extracting metals from this waste equipment.

But from the previous chapter, it was noted that out of four used computers in Australia, three is being disposed of into the landfills alone. This indicates that most of the consumer electrical and electronic equipment is not fully recycled in Australia at its end of useful life. It can therefore be assumed that most of the recycling processes used to recover WEEE involve mostly dismantling of this equipment, refurbishing and upgrading the other WEEE and the rest is land filled or incinerated.

6.8 International Recycling Techniques

International recyclers around the world especially in the United States of America and the United Kingdom also use large recycling shredding machines to recycle WEEE. The companies using this technique around the world apply it almost the same way as it is being applied by CSIRO company in Australia. They are not using one shredding machine for only one purpose at a time i.e using one shredder specifically to reclaim metals from old car scraps and the other for recovering materials from end-of-life electrical and electronic equipment. In Canada Printed Circuit Boards are smelted and after this process copper is extracted but this only comes in smaller quantities.

Other recycling techniques in North America involve de-manufacturing of obsolete electrical and electronic equipment. These operations engage in labor intensive approaches where WEEE is being taken apart to harvest for valuable components such as chips and hard disk drives. And other precious metals such as copper, steel and aluminium are taken out of the WEEE and resold to scrap consumers.

After carefully analyzing these recycling techniques, it is obvious that most practices in place are mainly dismantling, shredding and some limited reuse of WEEE which exist in Australia and some international countries around the world some of which are UK, USA, Canada and North America. In almost all the cases most of the material of interest being extracted is ferrous and non-ferrous metals. And the simple reason for this is that these are the only materials that are economically profitable. There has not been enough details showing how the other material from WEEE is being handled some of which is assumed to be toxic even if it is not economically viable to recycle.

This hazardous material may not be economically sound to recycle which indicates that almost all of it goes into either the landfill as mixed residual waste or is being incinerated. It must be noted that this material has adverse impacts on the environment of which the prize to pay in the future will be much higher than the economic gain of the present period by recyclers.

Chapter 7

Recycling Problems

In the previous chapter a general overview of recycling as a whole was carried out followed by more precise practical recycling techniques employed today. It must be noted however that recycling of WEEE has its own difficulties and some of these problems that have been observed in recycling industry of WEEE range from economical, technical, and political to social problems. All these are described in little more details in this chapter.

7.1 Economic Problems

In the recycling process that was previously explained from the simple recycling diagram in figure 5 reuse is one of the most important activities that can divert the WEEE disposals from the landfill and incinerations. But then the economic aspects of producing raw materials from WEEE have to be considered. It is of vital importance to realize that it becomes important to recycle the material from WEEE which will benefit the recycling industry as well.

According to an extraction from **Henstock (1996)** discussed by **Norgate, T.E (2004)** recycling can be considered in the following ways:-

1. Purity of recovered materials

2). Markets for recovered products

3). Unit value of each component

4). Residual disposals

5). Costs for the entire recycling operation

7.1.1 Purity of recovered materials

Most of the WEEE recycled becomes economically viable when its recovered material can be used to upgrade and maintain the electrical and electronic equipment that is currently on the market or if that material can be recycled to manufacture other components of the EEE. In some cases it is impossible to recover useful material because the equipment that has reached its end-of-life period has the components that cannot meet the current operation of the modern electrical and electronic equipment in use. This is mainly because most of electrical and electronic equipment manufactured has a very smaller lifespan and at the same time the rate of manufacturing and production is just too high.

A television receiver can be used as an example to prove that the fact above is true. A television receiver has on average an estimated lifespan of approximately 5 years. On the other hand this television receiver can practically reach its end of useful period between 5 and ten years. In a lot of households' television receivers of more than five years are still in use and working properly. In a case where this equipment stops being functional at ten years there will be at least an estimated two newly developed models in the current market making it impossible for most of the material and components in an obsolete equipment to be used in the newly developed models. And this will make the recycling of such equipment to be uneconomical since the best choice will be to dispose most of it into the landfill. The other reason is that the purity and the financial value of materials in the electrical and electronic equipment decline as the operation of the equipment prolongs beyond its estimated lifespan. Immediately after the production of this equipment, the materials used in its construction will start getting contaminated with impurities. There is a low quantity of the purest materials in a lot of WEEE which is of sound economical value. This ends up making this equipment to have a negative value when being recycled as observed by **Ohio Dept of Natural Resources, August 2002 Recycling electronics and computers, Ohio Dept of Natural Resources (2002).**

7.1.2 Markets

The costs of recycling Waste Electrical and Electronics are also affected by a lot of factors which include collection and transportation of this equipment to the recycling industries. Apart from these costs, there are also processing costs at the recycling industries involving sorting, dismantling, shredding, waste separation, incineration, landfill and also the maintenance costs incurred on the equipment used at various processes. This even becomes more increasingly expensive by the products that are continuously being manufactured with more complexity. All these factors contribute to overall market initiation of the recycled products. And this makes a lot of recycled material from these products to be very narrow.

Extracted from **Norgate, T.E (2004)**, the graph in figure 6 shows the relationship between recycling costs and the product factor.
This is described by the product complexity which is divided by the product size. The complex of the product indicates the number of materials applied to the product and its size for a given component. The graph shows how the recycling costs increase with the components complexity making up the whole product. For example, if there are more complex materials making up one particular product then that product will be more expensive to recycle. The products that have their recycling costs increased by more than US$100/t become more uneconomic to recycle. It therefore indicates that the recycling costs of household appliances of which some are electrical and electronic equipment and the electronic chips have increased by more than US$100/t becoming more uneconomic to recycle. This suggests that a lot of WEEE at the time of recycling is uneconomical due to the complex materials making up this equipment. And with this, there will relatively be a low market generated for WEEE recycled products due to the uncertainty of this industry.

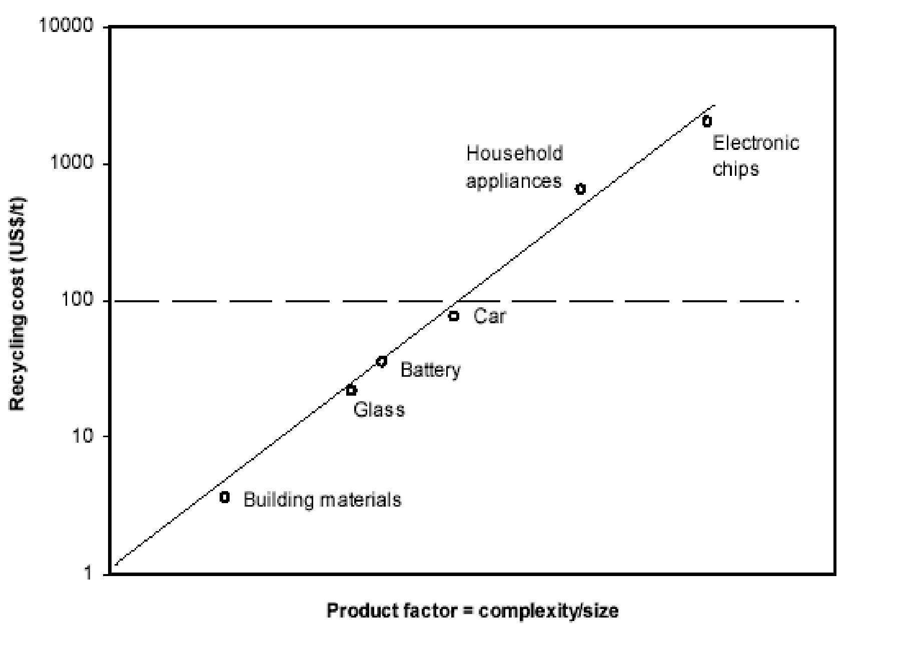

Figure 6: Metal Recycling

Source: Norgate, T.E (2004)

7.1.3 Residual Disposals

Most of the residual products from WEEE include crushed metals and chemicals of no value which can only be disposed of into the landfills.

For a recycling company to dispose of this residual waste there is a certain amount of money charged by the Federal governments so as to maintain these landfills and the landfills are charged at a higher cost as said earlier in order to discourage disposals and encourage reuse and recycling.

7.2 Technical and practical problems

There are also technical problems that are associated with recycling WEEE. Some of these problems which will be discussed below focus on the processes that take place in shredder machines, recovery of sensitive information and recycling of plastics.

7.2.1 Shredding machines

As mentioned in the previous chapter, the current shredder machines are not devised for only one purpose. In a lot of cases the input to the shredder machines does not only include WEEE but also include other scrap materials such as old cars. The materials that are mostly extracted are precious metals of economic value and most of the other waste will either be land filled or incinerated. This indicates that the existing recycling techniques are not yet efficient in isolating the complex mixture of materials from the shredder machines so as to recover some of the recyclable materials. These techniques cannot also currently handle the toxic materials from WEEE that end up being disposed.

7.2.2 Recovery of sensitive information

It is also very hard for the current recycling companies to prove that they can recover confidential and sensitive information from the WEEE before recycling it. This makes some of the companies to be insecure about recycling their WEEE fearing that some of this information may end up be recovered by second hand parties and they end up preferring the disposals of their WEEE as a safety measure.

7.2.3 Recovery of plastics from WEEE

In most of the cases the output of metals from the recycling processes are much easier to handle as compared to plastics. The current recycling techniques cannot recover plastic to its original specification, making it hard for recyclers to create markets for recycled plastics since most consumers prefer to purchase new plastic.

7.3 Political problems

There is a lot of pressure by the governments and other non-governmental organizations on the Federal governments all over the world to find the best means of reducing the disposals of WEEE and encourage reuse and recycling at all costs. This then forces the governments to implement tougher regulations on manufacturing companies to recycle their WEEE. The governments also end up charging a lot of money for the landfills due to lack of land and to discourage disposals into the landfills. This is an attempt carried out to discourage disposals but irregardless of these charges a lot of WEEE is still being land filled mainly because a lot of the recycling companies find a lot of WEEE not economically viable to recycle.

7.4 Social problems

The recycling of WEEE has just recently become a newly developed industry which has just evolved. This is driven by the society which decides what is valuable from this equipment, what is measured and what material components from WEEE is acceptable for recovery and this will ultimately influence the costs of recycling.

It has been discussed before at the end of section 7.3 that recycling of WEEE in most cases is not a viable economic industry. It is therefore assumed that only a few people are employed at the collection, sorting and dismantling processes of recycling. This can also lead to this industry to engage in cheap labor which will also be not reliable looking into the trend in which this equipment is being recycled. Even though there are some minimal jobs created by this industry they are not benefiting the entire population of the community at large. May be in the near future the industry will grow to benefit the entire population as expected.

The WEEE is made up of hazardous materials which must be handled with care during recycling. Some of the negative health impacts have been discussed in the third chapter of this project and if safety is not practiced during the recycling of this equipment then it possible for these impacts to easily affect the people handling the materials and components from WEEE. It has recently been discovered that some people who have been engaged in the production of semiconductors, printed circuit boards and monitors have reported some cases of cancer clusters. And it has also emerged as new evidence that the people involved in recycling computers have already accumulated poisonous chemicals in their blood **(JUST SAY NO TO E-WASTE, 2205).**

In some other countries like Japan and the US, resident users of electrical and electronic equipment are charged a minimal fee which is used in subsidizing the recycling industry so as to effectively manage this industry. It may be impossible in near future for this community to pay these costs if they are increased. This may be possible looking at the rate at which WEEE is accumulating.

Chapter 8

Redesign of Electrical/Electronic Equipment

In the third chapter of this project possible health and environmental negative impacts of improper disposals into the landfills were discussed. The high rate at which this electrical and electronic equipment is being manufactured and produced combined with its shorter lifespan has also become an increasing concern. These two factors above contribute to a lot of WEEE being in waste storage areas waiting to be recycled or disposed, but the rate which this is being recycled is low. According to Silicon Valley Toxics Coalition, there was an estimated 315 million obsolete computers in the United States of America alone in 2004 and most of which will be disposed into the landfills or incinerated.
JUST SAY NO TO E-WASTE (2005).

There is still a lot to be devised technologically in order to reduce the disposals and increase reuse and recycling. And for this to be achieved, the design of the electrical and electronic equipment has to be implemented from the early stages before manufacturing with recycling and reuse in mind. From the previous chapter the economical, technical, political and social aspects of recycling were outlined most of which still need to be reviewed in the near future in order to make recycling both economically and socially viable. All these factors have led to the Federal governments around the world to put pressure on the manufacturers and producers of electrical and electrical products to reconsider redesigning these products.

In this chapter the recommendations regarding the redesign considerations of this equipment will be outlined. These have been brought up with the hope that they can reduce the disposals and that they can make the product changes to gain the greatest savings by making reuse and recycling much more effective and efficient. This can also ultimately create wider markets for recycled products.

8.1 Replacing hazardous substances in EEE

Consumer electrical and electronic equipment has been constructed and assembled with a lot of complicated assemblies which include highly toxic materials such as brominated substances, toxic gases, biologically active materials, plastic additives and acids. It is in fact possible and advisable to avoid using such material and in cases where these materials are used, they can be clearly marked and made easier to be separated. Some considerations for replacing such materials with less toxic materials are discussed below.

8.1.1 Lead

Lead has been used in the construction of electrical and electronic equipment in glass for cathode ray tubes, light bulbs and in soldering to attach components to the printed circuit boards (**Sustainable design of electrical and electronic products to control costs and comply with the legislation, 2005**).
Lead-free solders with the present existing components and coatings can be considered.

8.1.2 Chromium

Chromium is used in electrical and electronic equipment for corrosion resistant surface treatments and to provide hard wearing surfaces (**Sustainable design of electrical and electronic products to control costs and comply with the legislation, 2005**). It is also used in paint pigments and stabilizers to achieve bright yellows, oranges and reds. In case where chromium coatings are needed to be used, silver and copper coatings including nickel-based coatings such as electroless nickel, boron nickel and zinc-based coatings and compounds like zincate can be used as alternatives.

8.1.3 Brominated flame retardants

The brominated flame retardants have been used for so many years by adding them to polymers which are used in the manufacturing of EEE. Below is a table showing some of the applications and polymers used in the EEE production:

Table 3 Application and polymers used

Application	Polymers used
Laminated PCBs	Epoxy,phenolic,polyamides
Encapsulants for electronic components	Epoxy
Housings for electrical and electronic equipment	ABS, HIPS, PC, nylons
Switches, sockets and connectors	PET, PBT, polymers
Wire and cable insulation	PVC, EVA, XLPE

Source: Sustainable design of electrical and electronic products to control costs and comply with the legislation (2005)

There are some recommended halogen-free flame retardants which can be used as replacements for the brominated-flame retardants and these already commercially available on the market. A table showing some of these halogen-free retardants is provided below.

Table 4 Halogen free retardants with applicable polymer types used.

Halogen-free retardant	Applicable polymers types
Aluminium trioxide	Epoxy, ABS, HIPS, PC, EVA, XLPE
Magnesium hydroxide	Epoxy, ABS, HIPS, PC, nylons, PVC, EVA, XLPE
Magnesium carbonate	Epoxy, ABS, PC, PVC, EVA, XLPE
Zinc borate	Epoxy, nylons, PVC, EVA
Zinc hydroxystannate	PVC, EVA
Zinc stannate	Epoxy, nylons, PVC
Red phosphorous	Epoxy, phenolic, nylons
Ammonium polyphosphate	Epoxy
Phosphate esters	Phenolic, ABS, HIPS, PC, PVC, EVA
Melamine derivatives	ABS, HIPS, PC, nylons
Reactive-P-N	Epoxy

Source: Sustainable design of electrical and electronic products to control costs and comply with legislation (2005)

8.1.4 Mercury

It is estimated that 22% of mercury is used annually in EEE assembling mainly in themostats, sensors and printed circuit boards and in measuring equipment according to **JUST SAY NO TO E-WASTE (2005).** As discussed earlier in the third chapter, mercury can spread in drinking water after leaking from the landfills causing chronic damage to the brain.

Some manufacturers have begun to phase out mercury by using drop-in replacements for components which do not use mercury. This is an essential step by these manufacturers and the others can follow this example.

8.1.5 Cadmium

Cadmium is soft poisonous bluish-white metal used in the electrical and electronic industry by manufacturers to solder components and to stabilize paints and plastics **Sustainable design of electrical and electronic products to control costs and comply with the legislation (2005).** Cadmium-plated parts produce good lubricity when used as anti-binding agents and these parts can protect connectors from corrosion when used as anti-corrosion agents. Cadmium has negative impacts in its disposal as explained in the third chapter.

Design changes can be implemented to replace cadmium coatings where its coatings are essential and the alternatives that can be used are listed below:-

- Nickel
- Tin and its alloys
- Aluminium coatings
- Zinc and its alloys

8.2 Re-design for material recycling

This section will cover some materials that may be re-designed and used in the construction of EEE which can be effectively and efficiently recycled. This will be on metals and plastics.

8.2.1 Metals

Consumer electrical and electronic equipment has been constructed with less metal components. This is mainly the case by the manufacturers to reduce the manufacturing costs of this equipment and they end up using an increased amount of plastic as highlighted from the **Sustainable design of electrical and electronic products to control costs and comply with the legislation (2005).** As mentioned earlier, on average it is not possible at present for the recycling technology to return used plastic to its original performance specification and it is also more expensive to recycle plastic than it is to purchase a new one.

Even though manufacturers have reduced the use of metals in the production of this equipment by using a lot of plastic that is cheaper in value, metals are mostly recyclable and need to be used more than plastic. Metal recycling is economically viable as compared to plastic components which are hardly recycled profitably. To reduce the manufacturing costs using metals, manufacturers can re-design their products of electrical and electronics by making the components and sub-assemblies thinner, smaller or lighter and also maximize the reuse of these components. And there are currently new metal alloys being developed in the electrical and electronic industry which can offer profitable additional recycling advantages over plastics.

8.2.2 Plastics

It is of vital importance when manufacturing EEE to select the best choice of plastic for a particular product involved. This choice to be made, consideration of upstream material flows with materials suppliers and downstream end-of-life issues need to be made **(Sustainable design of electrical and electronic products to control costs and comply with the legislation , 2005)**. These issues concern discussions with polymer materials manufacturers and suppliers on whether it is necessary to use the specialist polymer or commodity polymer materials for the product. Specialist polymer includes engineering plastics or higher performance plastics while commodity plastics examples are polypropylene, polycarbonate and polyurethane. The latter is cheaper and may provide greater security for supply as compared to specialist plastic.

The downstream considerations can be carried out by the electronic and electrical recyclers to find out whether the recycled product polymers will make a significant demand on the market or whether it will be possible for them to separate the polymers used in electrical and electronic product manufacturing and recycle them individually. Another fact to be considered here is to evaluate if it is possible to recycle polymers together and produce an output which is a mixed polymer.

8.3 Design for assembly and disassembly

In electrical and electronic equipment manufacturing and assembly, a lot of various attachment techniques apply which are used in joining the components together to make the whole product operational. This will depend on the costs for assembling and the required performance parameters during the products useful life stage. The attachments for joining these components can either be made permanent or temporary in which case they may have to be serviced, repaired or upgraded during the period when this equipment is fully operational **(Sustainable design of electrical and electronic products to control costs and comply with the legislation, 2005).**

The choice for the attachments will therefore contribute to the purity of recycled materials used including their value. For the attachments that will need service, repair and upgrade, these will need to be designed to be accessible, easy to remove and durable and can result in purer materials after disassembly.

The following guidelines can be used where fasteners apply which is discussed in the **Sustainable design of electrical and electronic products to control costs and comply with the legislation (2005) report**:

- Screws to be used to replace rivets for easier disassembly when the electrical and electronic equipment reaches its obsolete stage.
- Use of simple component should be applied.
- Assemblies that require power tools to be taken apart should be avoided
- The fastening material of the same type as the components joined should be considered in order to maximize the recycling of materials at the end-of-life period.
- Screw heads can be standardized to make assembling and disassembling easier with as few tools as possible.

- Fastening points have to be made accessible, visible and should be clearly marked. Colour coding of attachments can be considered in order to aid assembly and disassembly for upgrades and repairs.

And lastly, joining of different materials by adhesives or welding should be practiced and staking techniques which are used for joining thermoplastic parts to other component materials should be considered.

8.4 Components

Component specification for electrical and electronic equipment design must be considered as a starting point before the production stage of this equipment. Components have impacts on the design and production of the electrical equipment and their ease of assembling and disassembling should be initiated from the beginning of this equipment's design.

Reprogrammable components need to be designed so that they can make newly developed products design to be quite flexible with design upgrades that do not need hardware change requirements**(Sustainable design of electrical and electronic products to control costs and comply with the legislation, 2005)**. These components also offer a lot of opportunities for WEEE reuse.

8.5 Component connections

Once the components specifications have been agreed on, it becomes important now to look into how to make their connections easier. Some of the connections considerations have been given below for ease of assembly and disassembly **(Sustainable design of electrical and electronic products to control costs and comply with the legislation, 2005)**.

- In order to aid assembly, it is important to consider standardizing connector types.

- Design plug-in boards that aid assembly and disassembly.

- ❖ Hazardous materials making up this electrical and electronic equipment should be grouped together on this equipment and incorporate snap lines so that they are ease to break off when separated at their end useful life.

After careful evaluations by both manufacturers and suppliers of polymers and EEE recyclers it will become possible to choose plastics that are much more robust to the recycling process. In this process some design features and process steps such as heating profiles have to be carefully applied so as not to degrade the polymers and the quality of plastic of plastic for recycling. It may also be possible for manufacturing companies and suppliers to use only one type of plastic polymers which is proven by both manufacturers and recyclers to be effectively recyclable without loosing its original form in all electrical and electronic products. This can in the end benefit the plastic manufacturers since large-scale quantities can be purchased and can also increase the end-of-life plastic recycling. The increased end-of-life plastic recycling will on the other hand contribute to making the plastic recycling industry to be economically profitable.

In a case where all these alternatives fail to be implemented then polymers which are easily separated when they are obsolete for individual recycling may be selected for use. This will heavily depend on the recycling techniques available. This indicates that polymer manufacturers need to work together with recyclers to develop a viable solution to the best choice of plastics to be used in assembling the electrical and electronic equipment.

Other alternatives include using both virgin polymer and the same type of recycled polymer for different parts of the product which may not affect the recycling value of obsolete polymer leading to cast savings **(Sustainable design of electrical and electronic products to control costs and comply with the legislation, 2005).**Various combinations of polymers may also be selected and recycled together to form alloys that can be useful.

Chapter 9

Conclusion

During the course of this project, it was realized that there is a lot of electrical and electronic waste in Australia and that most of this waste ends up in the disposals. This suggests that in the near future there may be some reported cases of the environmental and health impacts in Australia resulting from the WEEE improper disposals. This is very possible since there has not been any programs found so far that monitor the safety of these disposals into the landfills. And since recycling of WEEE is not yet a profitable industry, recyclers may not follow the correct appropriate procedures that ensure safety on the environment but can use cheaper methods at the landfills in disposing this equipment resulting in possible leaks of toxic substances from the landfills.

The European Union directive consists of some very good examples of managing the WEEE. Some other countries can also follow this example in managing and controlling WEEE waste.

It must be realized that it is not always a simple task to manage the electrical and electronic disposals anywhere in the world, even where recycling has become one of the biggest industries in the world in the United States of America. What this project is trying to emphasize is that a serious effort need to be made to make the living environment a safe place from the hazard effects of these disposals by undertaking the correct processes in disposing, incinerating and recycling these products. Where an effort is made there shall always be progress. At the end of this project, the public will also be aware be aware of the consequential effects of electrical and electronic disposals on the environment and how recycling can be a major can be a major solution to these effects. The design modifications which have been recommended in the last chapter of this project are very critical since they are a first major step in eliminating the toxic substances at the early stages before these products are actually assembled. These will also make the difficulties involved in recycling in recycling to be much more manageable at the time the time these products become obsolete. On the other hand design by manufacturers will make them to be responsible for their products and enhance safety on the environment. It must noted however that these recommendations may not probably be the best as some other good ones can always be suggested by other authors who may be interested in the near future to take a project of the same nature.

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Appendix A

University of Southern Queensland

Faculty of Engineering and Surveying

ENG411/4112 Research Project
PROJECT SPECIFICATION

FOR: **TSHEPO PILANE**

TOPIC: RECYCLING CONSUMER ELECTRONICS

ENROLLMENT: ENG4111 –S1, D, 2005;
ENG4112 –S2, D, 2005;

PRROJECT AIM: The main aim of this project is to investigate the impact of consumer electronic products on the physical environment, find out about the legislations in place in some countries requiring recycling, look into ways of improving designs and the manufacturing in order to make recycling much more easier.

SPONSORSHIP: Faculty of Engineering and Surveying

PROGRAMME: Issue A, 07, May 2005

1. Research about the volumes of electronics currently being sold and subsequently disposed in Australia
2. Identify the needs to reduce the impact of these disposals on the environment
3. Research information on recycling practices in Australia and around the world and outline how a particular equipment is being recycled and the problems associated with recycling that equipment.
4. Discuss and analyze the techniques employed by Australia and international recyclers to recover materials
5. Describe the problems associated with recycling, including technical, practical, social and economical.
6. Make recommendations about the possible design of electronic equipment in order to make recycling easier and much more efficient.

AGREED :-----------(Student)-----------------(Supervisor/s)

DATE: 17-03-05