An overview of recycling of electronic waste PART 1

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Summary

In the report, the authors discuss the present status of recycling of electronic waste (e-waste) in both developed and developing countries. It was found that there are advances in e-waste management systems in both developed and developing countries.

In addition, major techniques that are being used or potentially could be utilized for recovery of metals from e-waste were summarized in the report. Comparison between these technologies provides valuable knowledge on the topic for both educational work and research.

E-waste characterization

E-waste encompasses discarded electronic appliances. Many computers and mobile phones become obsolete due to their short lifespan. The average lifespan of a new computer has decreased from about 4,5 years in 1992 to approximately 2 years in 2005 and this figure is still on a decline. Moreover, e-waste contains a variety of substances, many of which are toxic, and result in pollution upon disposal. Due to the hazardous nature of e-waste and the fact that it is mass produced due to obsolescence, makes e-waste a potential problem. However, e-waste also contains considerable quantities of valuable materials such as precious metals, aluminium and copper. Early generation computers used to contain up to 4 g of gold each; nowadays the figure is in the region of 1g. Recycling of e-waste has potential to be a profitable business.

E-waste or waste electrical and electronic equipment (WEEE) is composed of the ten categories listed in Table 1.

Table 1: E-waste classification according to the EU directive on WEEE

Number	classification
1	Large household appliances
2	Small household appliances
3	IT and telecommunications equipment
4	Consumer equipment
5	Lighting equipment
6	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7	Toys, leisure and sport equipment
8	Medical devices (with the exception of all implants and infected products)
9	Monitoring and control instruments
10	Automatic dispensers

As shown in Table 1, e-waste encompasses a broad range of electronic appliances ranging from large household appliances such as refrigerators, microwaves, to mobile phones, iPods and computers. Given the diverse range of materials found in e-waste, it is a challenge to give a general material composition for the e-waste stream; however, most studies examine the following categories of materials: metals, glass, plastics and 'other'.

The metals stream can further be divided into ferrous and non-ferrous metals. Ferrous metals dominate the metal stream; the non-ferrous metals include copper, aluminium and precious metals etc. Figure 1 shows typical composition of e-waste to be recycled.

Figure 1 shows a composition of e-waste recycled by the SWICO and SENS recyclers in Switzerland. As can be seen from Table 1 and Figure 1, the e-waste stream is characterized by a wide range of materials. Of particular importance as mentioned *a priori* are the highly toxic, ie, potential environmental contaminants and valuable elements, as these are among the main drivers of e-waste recycling.

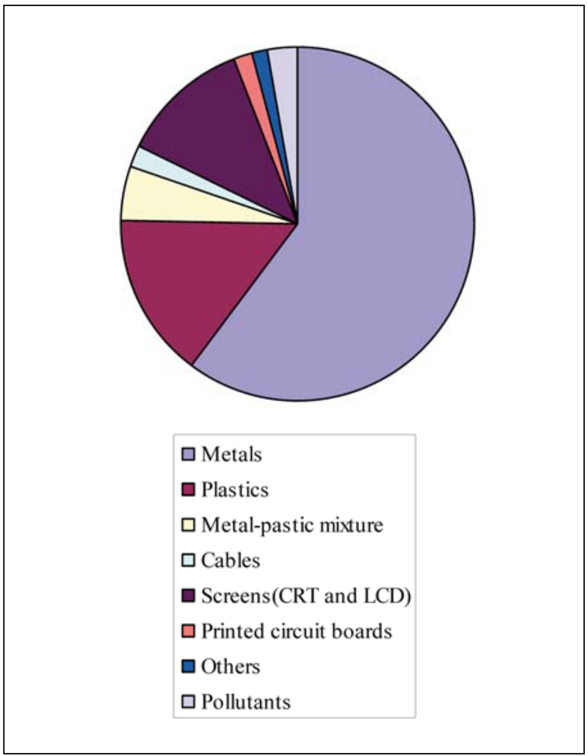

Figure 1: Composition of e-waste sample

Table 2 lists a combination of elements and compounds that are of particular interest in e-waste recycling.

All the elements listed in that table and more, are of interest in e-waste recycling as they are either of high value and warrant recovery, such as gold and copper, or extremely toxic, such as mercury and lead and require recovery for environmental and health concerns.

E-waste recycling has a relatively short history in many countries; consequently there is no established e-waste management system in place in many countries. Managing of e-waste is essential and a priority; countries are therefore forced to develop strategies for managing of e-waste. Switzerland is one of the few countries with an established e-waste management system, and was the first country in the world to implement an organized system for e-waste collection and recycling. The factors of interest with regards to e-waste recycling systems include appliance collection, reuse, recycling, disposal, monitoring, financing of recycling systems, as well as social and environmental impacts associated with the e-waste recycling practices.

E-waste collection and transportation

Collection and transportation are vital in e-waste recycling. Moreover, this step can be very costly; it has been shown from estimates that collection and transportation costs can be as high as 80% of the total costs of recycling. An efficient collection system largely depends on accessible and efficient collection facilities and adequate as well as consistent information to users. For risk minimization of harm to people and the environment, the collection and transport system should ensure minimal movements of e-waste and minimal handling. Moreover, hazardous components should be removed as early as possible in the process.

Common collection methods of e-waste are as follows: Curbside collection, special drop-off events, permanent drop-off, take-back and point-of-purchase.

Table 3 (page 10) gives a summary of the merits and disadvantages associated with each of the collection methods as well as the transport responsibilities associated with each method.

Table 3 shows a matrix to be considered for collection methods and transport responsibilities for e-waste. Curbside collection is the most convenient collection method to residents as there is no transportation required from residents for transportation of e-waste to collection sites as is the case with the other collection methods. An apposite collection site can be selected on the basis of the geographical location, friendliness to consumers, and the population distribution.

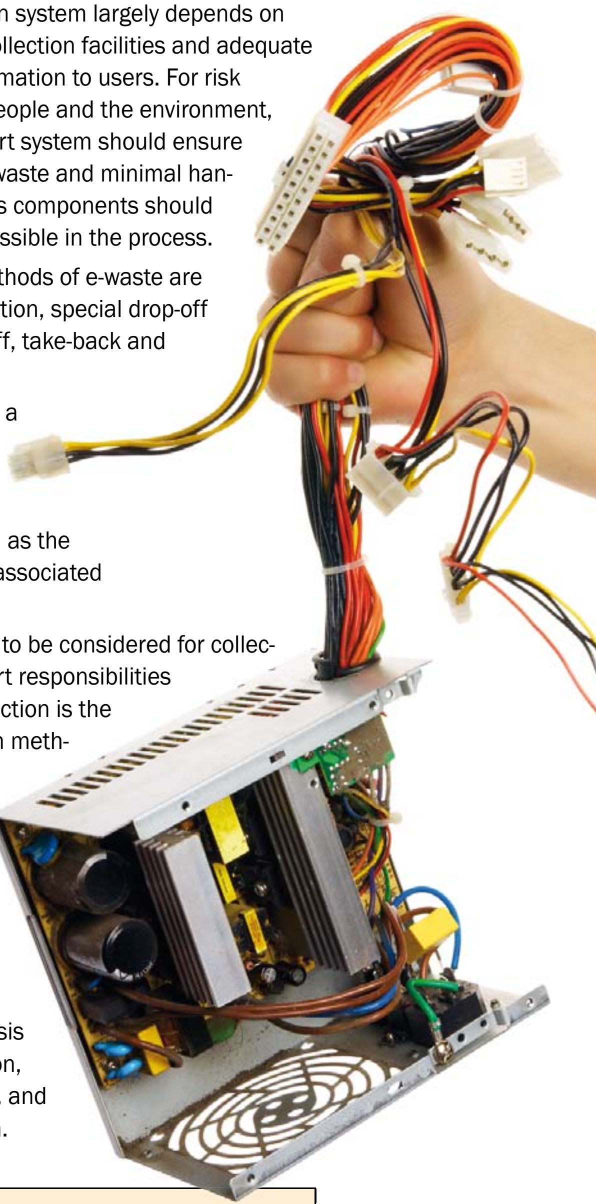

Table 2: E-waste valuable and hazardous elements and compound

Acrylonitrile butadienestyrene	Chlorofluorocarbon	Nickel
Americium	Chromium (CrVI)	Polybrominated biphenylys
Aluminium	Copper	Polyethylene, polypropylene
Asbestos	Gallium	Polystyrene
Antimony	Gold (precious metals)	Poly vinyl chloride
Arsenic	Indium	Rare earth elements
Barium	Iron	Selenium
Beryllium	Lead	Silver
Brominated flame retardants	Lithium	Tin
Cadmium	Mercury	Zinc

Table 3: E-waste collection methods and transportation responsibilities

Collection method	Transport to recycling site	Advantages	Disadvantages
Curbside	Recycler or local government	Residence participation, due to convenience	High transportation costs, potential theft
Special drop-off event	Recycler or local government	Recycling awareness, Ideal for rural areas	Sporadic collection, storage needed
Permanent drop-off	Recycler or local government	Low transportation cost, Most cost effective	Regular inspections needed, not effective for all communities
Take-back	Original manufacturer, contractor	No collection site	High shipment costs, special packaging needed
Point of Purchase	Retailer	Low cost, high visibility if marketed properly	Retailer commitment, need storage space

Reuse entails direct second-hand use or use after minor modifications are made to the original appliance. Reuse is desirable as it lengthens the life of a product. The reality is that a majority of reusable electronic equipment ends up as waste; only about 3% of computers were reused in 1998.

Markets in developing countries are characterized by a cheap labour force which buys working and non-working old electronic equipment, repairs them at significantly low cost, and resells them for a profit. Plug and play is generally used to separate working and non-working electronic equipment; non-working equipment is dismantled for repair or recycling, while working equipment is prepared reuse.

Albeit that any reuse is good, very old electronic appliances with a limited lifespan and non-repairable electronic appliances, end up as waste sooner or later. E-waste generally ends up in countries with no proper expertise to deal with e-waste treatment. Therefore, re-use must be encouraged, particularly when the appliance of interest has been discarded because it could no longer meet the user's needs or is still useable.

Recycling techniques and practice

Technical solutions exist to recover valuables from e-waste as secondary resources with minimal environmental impact. There are four broad techniques employed for recycling of e-waste and they are as follows:

- Equipment dismantling – the manual separation of reusable and recyclable components; critical components, ie, hazardous components, are also separated from e-waste at this stage in order to avoid contamination with toxic substances in downstream processing. Critical components include CRT screens, batteries, CFC gases from refrigerators, etc.
- Mechanical recycling – Further separation occurs at this processing step. E-waste is generally granulated and shredded in order to remove recyclable materials such as metals and plastics. Typical components of a mechanical processing facility are crushing units, shredders, magnetic eddy current and air separators. The gas emissions are filtered and the effluent is treated to minimize environmental impact.
- Incineration and refining or pyrolysis, smelting and refining – a majority of volatiles are removed during pyrolysis or incineration, and the valuable volatile materials can be recovered; subsequently, metals can be recovered from refining.
- Chemical recycling – these recycling techniques are commonly used for recovering precious metals such as gold.

The techniques mentioned above are in many instances used in different combinations, depending on the nature of the e-waste of interest. Refining or conditioning is a necessary step for most fractions in order to be sold as secondary raw materials or to be disposed of respectively. The materials of interest for refining are metals, plastics and glass.

It is important to note that even though the four techniques of interest are used globally for e-waste recycling, the practices are generally different between developing and developed countries. In developed countries, e-waste recycling is carried out in purpose-built recycling facilities under controlled conditions. EU states for example do not generally recycle plastics from e-waste to avoid brominated furans and dioxins being released into the atmosphere.

The situation is different in developing countries: there are no such controls; recycling is done by hand, in back yards, and scrap yards, often by children. Figures 2 to 5 show the techniques of recycling of e-waste as practised in the developed and the developing countries.

Figures 2 to 5 clearly show differences in e-waste recycling practices between developing and developed countries. E-waste recycling practice in developed countries is controlled and safety is not compromised, while unsafe and hazardous e-waste recycling is practised in developing countries.

Disposal

Unfortunately, a majority of e-waste ends up in landfills and incinerators. It is known that toxic components in e-waste can leach from landfills over time, with adverse effects to nearby communities and the environment. In Europe, regulations are in place to prevent e-waste from being dumped in landfills due to its toxic nature. However, this practice is carried out in many countries including the EU. It is estimated that more than 4,6 million tonnes of e-waste ended up in US landfills in the year 2000, and in Hong Kong for example, it is estimated that approximately 15% of discarded computers report to landfills.

Social and environmental impact

A majority of e-waste is not recycled, because e-waste has a propensity to go out with household waste and receive no special treatment. It is estimated that about 50-80% of the collected e-waste in the US for recycling is being legally exported to developing countries. This practice is legal because the US does not endorse the Basel Convention which is an international initiative on the control of transboundary movements of hazardous wastes and their disposal and has been enforced since 1992.

Later, the Basel Convention Ban Amendment came into play; in essence it protects the developing countries from exploitation by the developed countries with regard to exporting of hazardous wastes from OECD to non-OECD countries. Developed countries in Europe and some Asian countries have extended producer responsibility (EPR) programs in place as a policy instrument, and product stewardship in the US to assure sound management of e-waste. A definition of EPR as defined by one of the pioneers of EPR is: "an environmental protection strategy to reach environmental objective of decreased total impact from the product by making the manufacturer of the product responsible for the entire lifecycle of the product and especially for the take back, recycling and final disposal of the product".

Both approaches have their merits and limitations but have had positive contributions to e-waste management. For these programs to be effective they must be implemented effectively and controlled. Such programs are much needed in developing countries.

The factors affecting e-waste recycling in developed and developing countries have been studied. It is reported that globalization plays a role; high salaries coupled with strict environmental regulations and pronounced environmental awareness result in promotion of e-waste recycling in developed countries with emphasis on safety and environmental friendly practices. Developing countries on the other hand are characterized by low per capita income, environmental and occupational regulations are not well forced and environmental

Figure 2: CTR removal in the dismantling step: safe practice in Switzerland (left), hazardous practice in China (right)

Figure 3: Shredding of e-waste in a developed country (left), handling of e-waste in a developing country (right)

Figure 4: Refining practice: in a developed countries (left), developing countries (right)

awareness in the general public is still very low. Moreover, demand for inexpensive secondary products is high in poor countries. These factors contribute largely to the hazardous e-waste recycling techniques practised in developing countries.

In developed countries, government and municipalities play a pivotal role in e-waste management, including take-back and providing the needed infrastructure. In some countries subsidies for recycling materials are provided to promote recycling. The situation is different in developing countries: financial resources are limited, and there are other more pressing issues such as basic developmental requirements. Therefore, the informal sector plays an important role in e-waste management in developing countries.

Switzerland is of particular interest in e-waste recycling, as mentioned *a priori*. It is the first country in the world to have established a formal system to manage e-waste. SWICO and SENS of Switzerland are pivotal in the e-waste success story of the country. Both companies have more than a decade of experience in e-waste management; they started their e-waste programs based on the principle of EPR, well before it became legally instituted.

Switzerland only introduced legislation on e-waste management in 1998. The Switzerland e-waste system is supplemented by secured financing in the form of an Advanced Recycling Fee (ARF) in Switzerland charged for all new appliances. The ARF covers the costs for collection, the transport and the recycling of the disposed items. Due to environmental awareness coupled with high income in Switzerland, consumers are willing to pay for recycling without a problem, and the system has been functioning smoothly for the past decade. Since Switzerland is a signatory of the Basel Convention, it does not permit the export of e-waste to non-Organisation for Economic Cooperation and Development (OECD) countries.

Figure 6: E-waste in a landfill

China is the destination of a fair share of e-waste from developed countries, for example about 90% of the e-waste exported to Asia from the developed world ends up destined for China. In response to the high influx of e-waste imports, the Chinese government instituted a ban on e-waste import to China in 2000. However, e-waste is still imported illegally to China. E-waste recycling practice in China is potentially hazardous, and child labour is common. Moreover, large amounts of materials and residues are dumped at random.

The Chinese government has an interest in e-waste as it is a source of secondary resources; new e-waste recycling and treatment facilities are planned and financed by both government and private companies. Similar to the situation in India, consumers are paid for their e-waste in the informal sector. The big challenge for implementing a formal e-waste recycling system in China is that informal collectors and second hand appliance dealers remove e-waste from the waste stream before formal recycling companies can obtain it, and divert the e-waste stream to the informal sector where e-waste is processed in poor regions of China.

E-waste recycling in India is also of interest and represents typical recycling in developing countries. Indians endorse reuse; electronic products often find second-hand or even third-hand users. Moreover, e-waste recycling in India is a market-driven and a growing industry, but the environmental concerns are not considered amid more pressing problems. The government has passed several environmental protection laws, but their implementation is rather questionable. Illegal imports of e-waste are common in India.

The already established scrap metal industry in India absorbed the e-waste stream to recover metals, ie, feed stocks to mini-mills and non-ferrous smelters and refiners. In India the waste collectors pay consumers for obsolete appliances. The entire e-waste industry in India is based on a network existing among collectors, traders and recyclers each adding value, and creating jobs, at every point of the chain. This is socially friendly as far as employment opportunities are concerned for the poor. The major drawback of the e-waste system in India is its hazardous nature.

Africa is not immune to the e-waste problems. It has been reported that Nigeria handles large quantities of illegally imported e-waste and is managed using various hazardous practices that are potential environment polluters. West African countries such as Ghana and Ivory Coast handle e-waste imported from developed countries. It is reported that South Africa is the only African country with an established formal e-waste recycling system.

References for this article are available from the editor, Glynnis Koch, at chemtech@crown.co.za. Part 2 of the article will be published in the July 2012 issue and will include the list of references for the entire article.