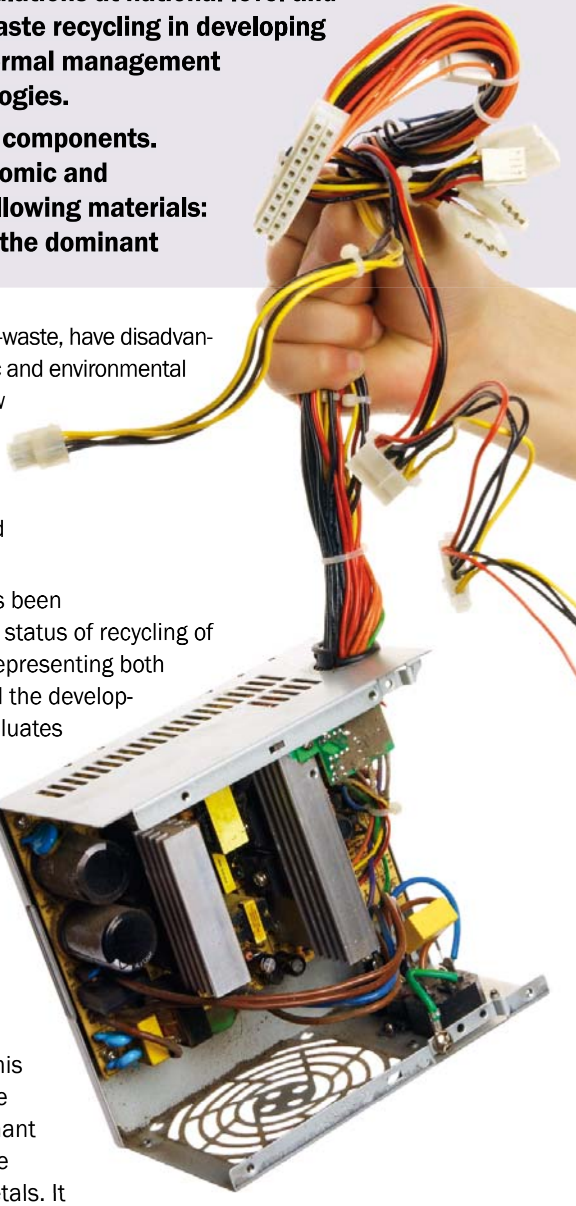
An overview of recycling of electronic waste PART 2

by Buhle S Xakalashe, Mintek, Randburg, South Africa and NTNU (Norwegian University of Science and Technology), Trondheim, Norway; K Seongjun, NTNU, Trondheim, Norway and J Cui, NTNU, Trondheim, Norway

E-waste is a potential global problem as well as a business opportunity of growing significance, due to large volumes of e-waste being generated coupled with the content of both toxic and valuable materials in them. The study, of which Part 1 was featured in the June 2012 issue of this magazine, reviewed the present status of recycling of e-waste in some countries representing both developed and developing countries.

A majority of e-waste is disposed of in landfills; the best practice being to reuse or recycle, and dispose as a last resort. It was found that logistics can be a very costly in e-waste management and also that, although illegal under the Basel convention, developed countries export e-waste to poor countries, where primitive, unsafe e-waste recycling techniques are employed. Moreover, the lack of regulations at national level and negligent enforcement of existing laws lead to the expanding of informal e-waste recycling in developing countries. However, developing countries are working towards establishing formal management systems which can substitute the informal processing with advanced technologies.

E-waste is intrinsically heterogeneous and complex in terms of materials and components. Characterization of the e-waste stream is pivotal for the development of economic and environmentally friendly recycling systems. E-waste generally contains the following materials: ferrous-metals, non-ferrous metals glass, plastics and 'other'. The metals are the dominant



Electronic waste (e-waste) refers to discarded electronic devices such as mobile phones, PCs and entertainment electronics destined for reuse, resale, recovery, recycling or disposal. Due to market expansion and technological advancements, the use and replacement of electronic devices has gained enormous momentum in the in recent times worldwide. By the same token, the generation of e-waste is growing significantly. The current global production of e-waste is estimated at 20-50 million tonnes per year. Moreover, the global generation of e-waste is predicted to increase by about 16-28% annually.

The e-waste stream together with waste electrical appliances such as refrigerators and air conditioners collectively called waste electric and electronic equipment (WEEE) accounts for up to about 8% of municipal solid waste stream and is one of the fastest growing waste fractions. The e-waste stream is characterized by hazardous substances which are dangerous to human health and the environment, and is simultaneously of value due to wealth of valuable metals such as platinum group metals (PGMs), silver, copper and aluminium as well as other materials which can be recovered.

Managing the high volumes of e-waste effectively and in a cost-effective manner, as well as in an environmentally sound fashion, is complex. The factors of interest with regard to e-waste recycling systems include: special logistic requirements for collection of the e-waste, reuse, recycling, disposal, monitoring, financing of recycling systems, as well as social and environmental impacts associated with the e-waste recycling practices. Conventional disposal methods, including incineration and landfills for e-waste, have disadvantages from both the economic and environmental points-of-view. As a result, new e-waste management options need to be considered, for example, recycling to conserve the resources and protect the environment.

In this study, a review has been made relating to the current status of recycling of e-waste in some countries representing both the developed countries and the developing countries. This study evaluates the entire value chain in the management system of e-waste; with emphasis on recovery processes for metals as they constitute a fair share of e-waste.

Recovery of metals from e-waste

As mentioned in Part 1 of this article published in the June 2012 issue, both the dominant materials and most valuable materials in e-waste are metals. It was therefore deemed necessary to have a section dedicated to recovery of metals from e-waste. As discussed in the previous part, there are four broad techniques for recycling of e-waste, ie, equipment dismantling, mechanical recycling, refining and chemical recycling. The latter three techniques, namely, mechanical recycling, pyrometallurgical and hydrometallurgical recycling, are discussed below as they are pivotal for the recovery of metals from e-waste.

Mechanical recycling processes

In metallurgy, ores and other raw materials are generally prepared or upgraded in the minerals processing step for downstream processing such as smelting. Particle size of materials is of particular interest in minerals processing in order to achieve the desired products. E-waste follows a similar scheme, due to its complex and heterogeneous nature. As mentioned previously, it is necessary to prepare or upgrade e-waste for downstream processing. In some instances the final product is obtained directly from mechanical separation, similar to minerals processing. The mechanical step is therefore key for downstream processing.

Mechanical separation of materials is based on the differences in the physical characteristics/properties of the materials. Therefore, for effective separation of the materials, the differences in their physical properties/characteristics are pivotal for developing a mechanical recycling system. Characterization of this e-waste stream is of importance. A number of mechanical recycling techniques exist which have both merits and disadvantages. The basic mechanical recycling techniques are discussed in the following sections.

Screening

Shredded materials from the dismantling step are screened; this yields uniformly sized particles effective for downstream separation. Screening is one of the mechanical processes employed to separate metals from non-metals due to differences to size and shape distributions, ie, upgrading of the metals content is achieved during screening. The commonly used method of metals recovery employs the rotating screen. Vibratory screening is also commonly used, especially for non-ferrous recycling. A common problem is wire blinding: trammel are robust and are highly resistant to blinding.

Magnetic separation

Magnetic separation is based on the principle of magnetic attraction between a permanent or electric magnet and ferrous components in e-waste. Magnetic separators are generally used to recover ferromagnetic metals from non-ferrous metals and other non-magnetic components. An overhead belt magnet is the most widely used magnetic separation system. Iron recovered from this step can be taken directly to steel mills or mini mills for smelting and refining respectively for the production of steel and stainless steel.

Electric conductivity and charge separation

The three separation methods are evaluated in this section as follows:

- Eddy current separation – based on a combination of density and electrical conductivity, for separating non-ferrous metals such as aluminium copper and silver from non-metals. A combination of high electrical conductivity and low density favours Eddy current separation. For this separation method to work, the non- ferrous metal must be liberated from non-metallic materials.
- Corona electrostatic separation – the principle of this separation method is the difference in the electric conductivity between metals and non metals. The Corona charge and discharge of particles are essential for the resulting forces. This separation method is used for the recovery of copper, aluminium, and precious metals.
- Triboelectric separation – surface charge phenomenon is the basis for separation; when materials are rubbed against each other, one would be negatively charged and the other would either be positively charged or would remain neutral. This method is effective for separation of plastics from one another.

Density-based separation

In principle, density-based separation separates heavier materials from lighter ones, eg, metals from non-metals. The basis of density separation is specific gravity (SG). It is however pivotal that both size and shape of materials to be separated are uniform for the relative motion of the particles to be highly SG-dependant.

Pyrometallurgical recycling processes

A variety of ores are processed pyrometallurgically to recover valuable components of interest. Each product stream from different pyrometallurgical processing unit has the potential to be a valuable product, from high-grade titania slags, microsilica, to ferromanganese. Pyrometallurgical processing offers a range of processing equipment; examples include rotary kilns, blast furnaces and electric arc furnaces, to name a few.

Pyrometallurgy is the traditional method for recovering non-ferrous metals as well as precious metals from e-waste. In the process, the pre-processed e-waste is smelted or melted in a furnace and volatiles could be recovered, for example, plastics can be used as reducing agents, or removed. Depending on the process under investigation, components such as iron can be lost to the slag or recovered to the metal, or slag-forming oxides such as aluminium, report to the slag.

Copper recovery

E-waste containing 5-40% Cu are fed into a blast furnace; this composition range is similar to that of a typical copper sulphide concentrate. The smelting process is therefore similar to that of smelting of copper sulphide concentrate in a blast furnace. Copper compounds are reduced by reductants such as scrap iron and plastics, both of which can be sourced from e-waste. Impurities such as lead and zinc report to the slag and the off-gas due to high volatility. The tapped copper matte, containing precious metals is transferred to the converters, where, after blowing with air, blister copper is produced, refined in an anode furnace and cast into anodes with a purity of 99,1%.

The balance of 0,9% is rich in precious metals, along with nickel and other minor impurities. The marketable metals are recovered on the anode. Slag from the blast furnace is either cooled, milled and taken through flotation or melted in a furnace with a reducing agent to recover the copper. The slag from the converter is recycled to the primary furnace. It is reported that the Noranda smelter in Canada employing a similar process to above mentioned one recycles about 100 000 tons of e-waste per year. According to studies undertaken by the Association of Plastics Manufactures in Europe, the energy required to reclaim copper from e-waste is only about one-sixth of the energy requirements for copper production form ore.

Precious metals recovery

The metals of interest for recovery in a precious metals refinery are platinum, palladium, gold and silver. The anode slime from the copper electrolysis is pressure -eached. The leach residue is then dried and smelted with fluxes in a precious metals furnace. Selenium is recovered during smelting. Silver is cast into a silver anode. A high intensity electrolytic refining process follows where a high-purity silver cathode and anode gold slime are formed. The anode gold slime is then leached, and high-purity gold, as well as palladium and platinum sludge, are precipitated. It is reported that recovering precious metals from e-waste contributes significantly to the recycling industry. Moreover, about 30% of the precious metals recovered from e-waste is gold.

Limitations of pyrometallurgical recycling processes

1. Aluminium is lost to the slag due to its nature, ie, being highly stable as an oxide. Moreover, aluminium is generally not wanted in the slag.
2. Conventional smelters designed for processing of ores and concentrates constitute a challenge for e-waste recycling. State of the art smelters are expensive.
3. Flame retardants in smelter feed from e-waste can lead to formation of dioxins.
4. Due to partial separation of metals achieved using pyrometallurgy, subsequent processing steps such as hydrometallurgy, for example, are required.
5. A bulk of the precious metals is only recovered from a pyrometallurgical process at the end of a process.

Hydrometallurgical recycling processes

Hydrometallurgical processes present an alternative to recovery of metals from e-waste. With regards to e-waste these processes are normally focused on recovery of precious metals. They are easier to control, predictable and the precision level is high compared to pyrometallurgical processes. Hydrometallurgical processes do not require major capital costs as is the case with smelters. In the last decade, focus has shifted to hydrometallurgical processes for metals recovery from e-waste.

The first step of this process is leaching. Leaching means converting metals into soluble salts in aqueous media. Leaching agents which are normally used include cyanide, halides, thiourea, and thiosulfate. Both economic efficiency and environmental impact such as leaching rate, reagent cost, and toxicity should be taken into consideration when selecting a method. The solutions are subsequently moved to converter for further processing. Different types of electrochemical treatments including precipitation, cementation, solvent extraction, ion exchange and supported liquid membranes are possible depending on the type of solutions. The final step is refining and is carried out by filtration or combustion in order to attain high purity product.

In addition to both pyrometallugical and hydrometallurgical processes, biometallurgical processes are gaining momentum on the research front; those characterized by bacterially-assisted reactions are among the most interesting technologies. Compared with other methods, biometallurgical processes have many advantages for various applications, such as low costs, and environmental sustainability.

Discussion and conclusions

Due to the ever increasing generation of e-waste and the hazardous nature of this waste stream, e-waste is a potential problem of unprecedented proportion, affecting the entire globe. In the future, collaborations between countries that have advanced in e-waste and new players in the industry are essential, as this would fast track advances in e-waste management. It was found that there are advances in e-waste management systems in both developed and developing countries. Proactive approaches are particularly needed in developing countries as their markets are far from saturated with electronic goods.

It is also critical that international legalities or initiatives such as the Basel Convention Ban be enforced, and countries not endorsing such initiatives, such as the US, be penalised. It was found that although illegal under the Basel convention, developed countries export e-waste to poor countries, where primitive and unsafe e-waste recycling techniques are employed. The lack of regulations at national level and negligent enforcement of existing laws lead to the expanding of informal e-waste recycling in developing countries, where environmental awareness is minimal.

However, developing countries are working towards establishing formal management systems which can substitute informal processing with advanced technologies. A majority of e-waste is disposed of in landfills; the best practice would be to reuse or recycle, and dispose of as a last resort. It was found that collection and transportation costs can be very high in e-waste management.

E-waste is intrinsically heterogeneous and complex in terms of materials and components. Characterization of the e-waste stream is pivotal for the development of economic and environmentally friendly recycling systems. E-waste generally contains the following materials: ferrous-metals, non-ferrous metals glass, plastics and ‘other’. The metals are the dominant materials in e-waste both in quantity and value. Mechanical, pyrometallurgy and hydrometallurgy techniques are the primary means employed in industry for recovery of metals from e-waste.

The already established metallurgical industry has played a significant role in the processing of e-waste streams; methods originally applied to processing of metallurgical feed, such as ores and concentrates, have been integrated and applied to e-waste treatment. It is important to note that there are intrinsic differences between e-waste and conventional metallurgical feeds such as ores and concentrates, thus conventional metallurgical processes need to be modified. In some instances e-waste has been absorbed by conventional metallurgical processes. Such an example is the processing of copper-rich e-waste at Noranda smelter in Canada. Due to the limitations of pyrometallurgical processes, focus has now shifted to hydrometallurgical processes for metals recovery from e-waste. Other processing techniques are also investigated which include biometallurgical processing.

Both pyrometallurgical and hydrometallurgical processing emphasise recovery of precious metals from e-waste; this is no surprise due to both the monetary value associated with precious metals and their noble nature. In terms of volumes, ferrous metals and non-ferrous metals such as iron and aluminium, contribute significantly to the e-waste stream, but these are generally lost in refining processes such as pyrometallurgical processes. It is therefore important to advance developments in refining of these metals. Materials such as plastics are generally lost in high temperature processes. As plastics contain energy that could be recovered, they could be used as reducing agents in smelters. This way, the use of these resources would have been optimized.

References

1. S. Schwarser, A.D. Bono, P.Peduzzi, G.Giuliani,S.Klusner, E-waste, the hidden side of IT equipment’s manufacturing and use, UNEP Early Warning on Emerging Environmental Threats No.5 2005
2. J. Ylä-Mella, E. Pongrácz, R. Keiski, Recovery of waste electric and electronic equipment (WEEE) in Finland, Proceedings of the waste minimization and resources use optimization conference. 2004, Oulu, 83-92.
3. R.Widmer, H. Oswald-Krapf, D. Sinha-Khetriwal, M Schnellmann, H. Boni, Global perspective on e-waste, Environ. Impact Assess. Rev. 2005, 25, 436-458.
4. D. Sinha-Khetriwal, P. Kraeuchi, M. Schwaninger, A comparison of electronic waste recycling in Switzerland and in India, Environmental Impact Assessment Review. 2005, 25, 492–504.
5. H. Kang, J. Schoenung, Electronic waste recycling: A review of U.S. infrastructure and technology options, Resources Conservation & recycling. 2005, 45, 368-400
6. J. Puckett, L. Byster, S. Westervelt, R. Gutierrez, S. Davis, A. Hussain, M. Dutta, Exporting harm: The-high-tech trashing of Asia, BAN. 2002
7. http://www.greenpeace.org/usa/campaigns/toxics/hi-tech-highly-toxic/e-waste-goes
8. http://www.rreuse.org/t3/fileadmin/documents/00029_Brochure_ACRR_Part_II.pdf
9. J. Puckett, T. Smith, Exporting harm: the high-tech trashing of Asia, The Basel Action Network, Silicon Valley toxic coalition, 2002
10. B. Robinson, E waste: An assessment of global production and environmental impacts, Science of the total environment. 2009
11. I. Nnorom, J. Ohakwe, O. Osibanjo, Survey of willingness of residents to participate in electronic waste recycling in Nigeria- A case study of mobile phone recycling, Journal of cleaner production, 2009, 17, 1629-1637 12
12. P. Van den Bergh, J. Van den Beukering. Modilling and analysis of international recycling between developed and developing countries, Resources conservation and recycling, 2006, 46, 1-26
13. T. Lindhqvist, Extended producer responsibility in cleaner production. Lund, Sweden: The international institute for industrial environmental economics, Lund University, 2000.
14. C. Hicks, R. Dietmar, M. Eugster, The recycling and disposal of electrical and electronic waste in China – legislative and market responses, Environmental Impact Assessment Review, 2005, 25, 459-471.
15. J. Cui, E. Forssberg, Mechanical recycling of waste electric and electronic equipment: a review, J. Hazard. Mater. 2003, 99, 243-263.
16. W. Dalmijn, Practical application of eddy current separators in the scrap recycling industry, Second international symposium-recycling of metals and engineering materials, 1990.
17. J. Cui, L. Zhang, Metallurgical recovery of metals from electronic waste: A review, J. Hazard. Mater. 2008, 158, 228-256.
18. United States Geological Survey(USGS), Obsolete computers “gold mine”, or high tech trash? Resources recovery from recycling, USGS fact sheet, 2001.