PROCESSING OF ELECTRONIC WASTE (E-WASTE)

K. K. SAHU AND A. AGRAWAL
kksahu@nmlindia.org, archana@nmlindia.org

INTRODUCTION

Rapid growth of information and telecommunication technology has penetrated nearly every aspect of modern life even in the most remote area of the developing countries. The advancement of the technology has led to rapid decrease in the product lifetime and generating large quantity of waste electronic equipment (e-waste). The rapid technological progress forced manufacturer for production of new units, which ultimately adds to the number of old electronic equipment destined for land fills/recycling. The typical life span of a computer in the advanced countries is about 2 years. As the old PC, mobile, laptop and other electronic equipments become obsolete, they are replaced by the new one and added to the quantity of e-waste. The consumer electronics is now the fastest growing sector of municipal solid waste in both developed and developing countries. The e-waste is a global concern today and it will have a far reaching adverse impact on the environment if not dealt with immediately.

WHAT IS E-WASTE?

Electronic waste or e-waste is the term used to describe old, end of life electronic appliances such as computers, laptops, DVD player, mobile phones which are usually disposed of by original users. In most cases e-waste comprises of relatively expensive as essentially durable products used for data processing, telecommunications or entertainment in private house hold and businesses. Electronic waste is a subset of waste electrical & electronic equipment (WEEE). Three categories of WEEE account for almost 90% of the total generation are: -

- Large house hold appliances- 42%
- Information & Communication technology equipment- 34%
- Consumer electronic- 14%

Various categories of e-waste defined by the EU WEEE directive are as follows:

1. Large household appliances
2. Small household appliances
3. IT and telecommunications equipment
4. Consumer equipment
5. Lighting equipment

6. Electrical and electronic tools (excluding large-scale stationary industrial tools)

7. Toys, leisure and sports equipment

8. Medical devices (with the exception of all implanted and infected products)

9. Monitoring and control instruments

10. Automatic dispensers

E-WASTE COMPOSITION

The recyclable potential of e-waste is specific for each appliance. Various parts/materials usually found in electronic waste have been divided into following categories.

- Iron and steel, used for casings and frames
- Non-ferrous metals, especially copper used in cables, and aluminum
- Glass used for screens, windows
- Plastic used as casing, in cables and for circuit boards
- Electronic components
- Others (rubber, wood, ceramic etc.).

Different components present in the e-waste specific to refrigerators & freezers, personal computer and TV sets are presented in Table-1 & 2.

Table-1 : Average weight and composition of selected appliances

Appliances	Refrigerators and freezers	Personal computer	TV sets
Average weight	48	29.6	36.2
Iron, %	64.4	53.3	5.3
Non Ferrous metal, %	6	8.4	5.4
Glass, %	1.4	15	62
Plastic, %	13	23.3	22.9
Electronic components, %	-	17.3	0.9
Others, %	15.1	0.7	3.5

Major concern

Electronic waste is the most rapidly growing waste problem in the world today. According to a survey by IRG system, South Asia, the total waste generation of obsolete or broken down electronic equipment in India has been estimated to be 1,46,180 MT. The dumping of e-waste, particularly computer waste into India for developed countries has further aggravated the problems associated with waste management. India has emerged as the largest dumping ground for end of life computers and electronic equipments for the developed nations. Close to 50,000 tons of used electronic equipment dumped in India every month. If remains unaddressed the unauthorized dumping (Fig.-1) will end-up contaminating the countries environment with toxic compounds and components. The major problem of e-waste dumping is that the absence of appropriate recycling facilities. The major part of the e-waste is usually recycled by the local recyclers where recycling is undertaken in an unscientific manner which affect both health & environment. According to Toxic link, India annually generates about 1.5 billion worth of e-waste.

It has been estimated that about 20 million computers entered the market every year in the USA and 12 million are disposed every year and only about 80% of the e-waste received by e-waste recycling industry was exported into Asia. Environmental organization says the Delhi's e-waste yards alone employ about 20,000 labors to handle about 20,000 tons of e-scrap every year.

Table-2 : Typical metal values present in a PC

Elements	percent of total weight	Content (g)	Elements	Percent of total weight	Content (g)
Plastics	23	6250	Zinc	2	55
Lead	6	1710	Beryllium	0.0157	4.26
Aluminum	14	3850	Gold	0.0016	0.434
Germanium	0.0016	0.4345	Cobalt	0.0157	4.2
Gallium	0.0013	0.3531	Palladium	0.0003	0.081
Iron	20	5570	Manganese	0.0315	8.55
Tin	1	271	Silver	0.0189	5.13
Copper	7	1880	Mercury	0.0022	0.597
Barium	0.0315	8.55	Arsenic	0.0013	0.35
Nickel	0.8503	231	Silica	24.8803	6770

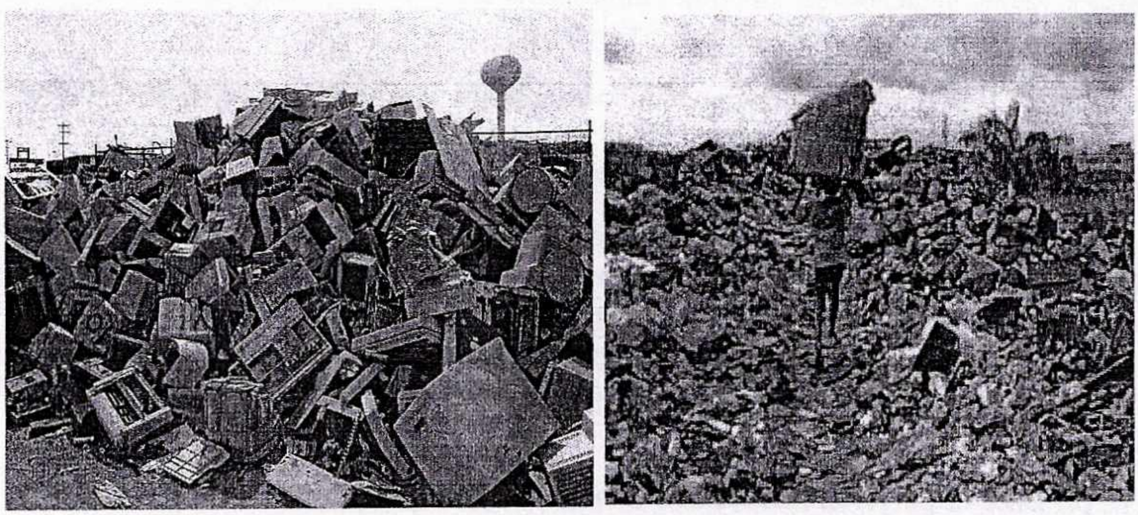

Fig.1 : Unauthorized dumping of electronic waste

Deleterious Effect

The material of most concern in e-waste is lead. It constitute up to 6.3% of a typical PC. Average content of lead is about 2 kg in every computer including monitor. About 20% of the weight of the monitor is lead. It is used as a radiation shield in the monitor glass. Tin-lead solder that connects computer chips and the printed wiring boards contains appreciable amount of lead. Other substances of environmental health concern in e-waste include cadmium, chromium, mercury, antimony and brominated flame retardants. In most of the developing countries e-waste is mostly treated using backyard recycles. These crude methods result in loss of resources, energy and also create environmental pollution. They do not use personal health protection equipment and also don't have waste water treatment facilities as well as proper exhaust of waste gases.

E-waste contains more than 1000 different substance and many of which are highly toxic. About 70% of heavy metals including Hg and Cd found in soil are of electronic origin. Some of the toxic effects of heavy metals are given below.

Lead : It causes damage to the central and peripherial nervous systems, blood, kidney and reproductive system in humams. Lead in computers are found in glass, panels, gasket, solders and in monitors

Cadmium : Cadmium is found in infrared detectors, semiconductors chips, chip resistors etc. It is highly toxic metal and pose a risk of irreversible effect on human health and are bioaccumulative.

Chromium : Hexavallent chromium used for corrosion protection of untreated and galvanized steel plates and as a decorative or hardener for steel housings. It easily passes through cell membranes and damage DNA and also causes asthmatic bronchitis.

Mercury : Mercury can cause damage to various organs including the brain and kidneys. It is bioaccumulative causes damage to skin and respiratory organ. Mercury is used in thermostats, sensors, relays, switches viz. on printed circuit boards and in measuring equipment, medical equipment, lamps, mobile phones and in batteries.

Beryllium : Beryllium is mainly found in mother board. It is highly carcinogenic and mainly causes lung cancer due to inhalation of fumes and dust. It also causes chronic beryllium disease or beryllicosis and skin diseases such as warts.

Several other harmful substances in e-waste are arsenic, polychlorinated biphenyls (PCBs), chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), nickel, and asbestos. Some of these chemicals very often contribute to toxic landfill leachate and vapours, such as the vaporization of metallic and dimethylene mercury. Furthermore, uncontrolled fires may arise in landfills, releasing extremely toxic dioxins and furans (dioxin-like compounds) into the atmosphere.

The presence of polybrominated flame-retardants in plastic makes recycling dangerous and difficult. It has been shown that Polybrominated Diphenylethers (PBDEs) form the toxic polybrominated dibenzo furans (PBDF) and polybrominated dibenzo dioxins (PBDD) during the extruding process, which is part of the plastic recycling process. As a consequence, the German chemical industry stopped the production of these chemicals in 1986.

In addition, high concentrations of PBDEs have been found in the blood of workers in recycling plants. A recent Swedish study found that when computers, fax machines or other electronic equipment are recycled, dust containing toxic flame-retardants is spread in the air. Workers at dismantling facilities had 70 times the level of one form of flame retardant than are found in hospital cleaners. Because of their common presence in air, clerks working full-time at computer screens also had levels of flame-retardants in their blood - slightly higher than for cleaners. Humans may directly absorb PBDEs when they are emitted from electronic circuit boards and plastic computer and TV cabinets.

For the time being a lot of the e-waste ends up in uncontrolled pathways leading to backyard recyclers. On one hand, the informal scrap industry provides for semi-skilled and unskilled jobs and thus an opportunity to earn money for many (uneducated) people. On the other hand, these jobs are neither secure nor safe. For instance, people working in the informal sector do not usually enjoy social securities such as insurance benefits or legal securities. Another problem is that the methods used for retrieval and recycling of valuable components are mostly very hazardous and can cause serious long-term damage to human health and the environment.

Recycling and Recovery

The search for new processing methods which could segregate and process highly diverse obsolete electronic scrap without losing much of precious metals in eco-friendly manner would continue. Several processes proposed for recovery of metal values include pyrometallurgy, hydrometallurgy and electrochemistry. However, mechanical processing and physical separation plays most crucial role in deciding the actual processing route.

The most common initial step for processing of e-waste is mechanical processing to reduce bulk and to separate the material fractions. Several unit operation include hand disassemble, crushing in a hammer mill, air classification, magnetic separation, vibrating screening, eddy current separation, high tension separation before mechanical processing. Recyclers are much interested in recycling of PC and mobile phones as they contain most of the valuable metals including precious metals such as gold, silver palladium etc. PCs are separated into three parts namely body, key board and monitor. The main components of the body and key board are plastics, iron, aluminum, printed circuit boards etc. After a series of crushing, cuttings, melting extrusion the plastic components, iron and aluminum are sold as scrap. The key to success of recycling the PCs and mobile phones depends on the economical and efficient technologies for recovering valuable metals from PCBs. Various techniques adopted for processing of valuable metals usually present in printed circuit board are described below.

RECYCLING PRINTED CIRCUIT BOARDS

Printed circuit board mounted with various integrated circuits and other electronic parts are the key components of a computer. Around 60 million PCBs are produced each year. Each circuit board has a metal content of up to 30% by weight. The integrated circuit and other parts usually contains resins, fibreglass and the metals such as copper, silver, gold, nickel iron and aluminium besides tin and lead in the solder material (Table-3). Metal content in PCB makes it a potentially recyclable material. However lead in the solder and the bromine in the resin must be treated carefully during the recovery process. Many of the processes used to recover non-precious metals are based on mechanical, pyrometallurgical process typically practiced in copper smelters (Fig.-2) and combined process of mechanical pre-treatment and hydrometallurgical techniques. The processes adopted widely are described below.

Table 3 : Typical composition of a scrap IC board

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

Smelting Method

Since the IC board contains high concentration of copper, it can be treated as high grade copper ore and processed along with the ordinary ore. During smelting the resin is incinerated and the fibreglass melted into slag. The precious metal is recovered following the standard method during the refining process. The process finds difficulty for the material containing low metal value besides having air pollution and loss of noble metals. The process also fails to recover aluminium, tin and lead.

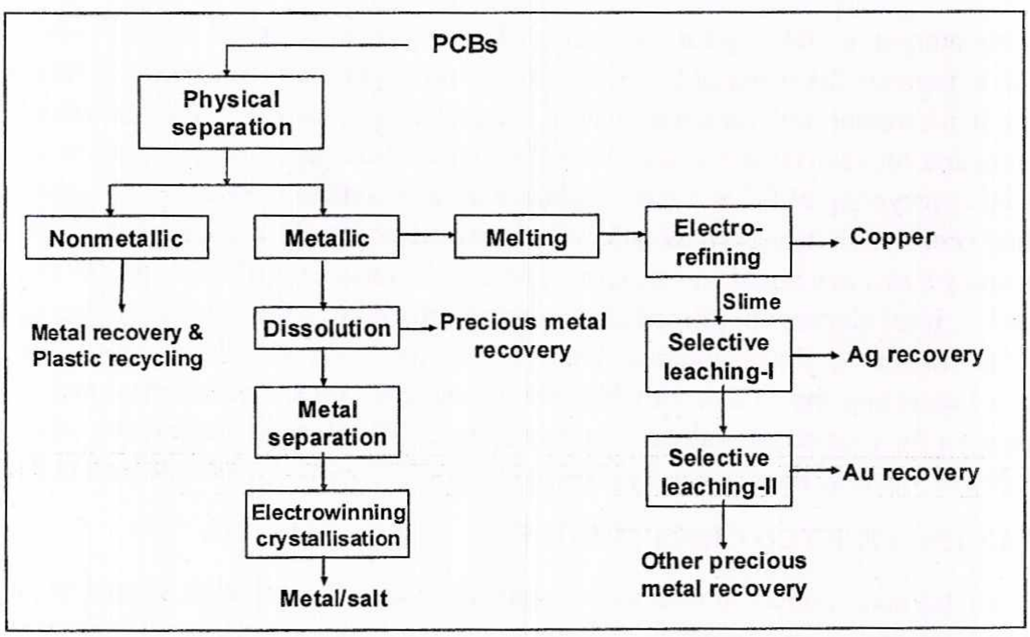

Fig. 2 : Flow-sheet for the recycling of metal values from the printed circuit board mounted with various integrated circuits and other electronic parts

Hydrometallurgical Method

This process involves efficient liberation and separation of metallic components from non-metallic components for effective surface contact and dissolution metallic fraction by the lixiviant during dissolution. The mechanical pre-treatment for separation of metallic components makes the extraction and purification processes easier. As the precious metal present in the form of thin layer on the surface of other metals, they are concentrated as fine particles the non-metallic fraction during air separation. They are usually dissolved in aqua regia and recovered by conventional method. A series of hydrometallurgical techniques including dissolution, metal separation/purification and recovery are employed for the recovery of valuable metals from metallic fractions. There are several other processes which are very specific to dissolution step are reported and are under development stage.

Physical Separation Method

This method removes the non-recyclable material from the IC board to increase the value of the recyclable with higher metal concentration (Fig.-3). Generally this type of separation plants consist of a series of physical treatment facilities such as crushing, grinding, screen, magnetic separation, air classification, eddy current and electrical conductivity separation etc. Such method gives several metal fragments of various size and composition. Except for iron different fragments usually contains more than one kind of metals which need appropriate recycling market to process mixed metal fragments.

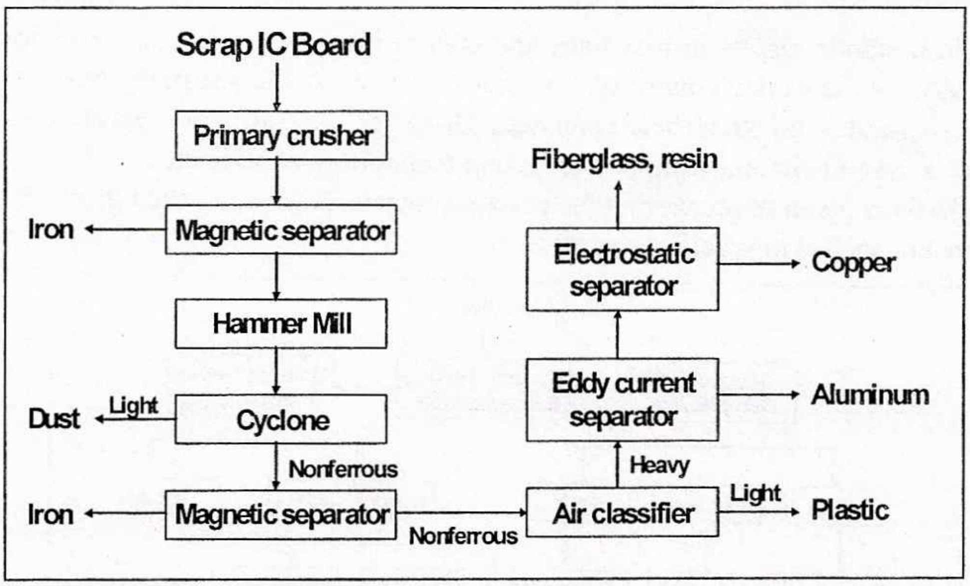

Fig.-3 : HueiChia-Dien Company's physical separation flow-sheet for recycling of scrap IC boards.

Scraping method

By this method the solder is melted and the mounted electronic parts are mechanically scraped off so that the clean board and the scraped off material can be treated separately. The recycling efficiency is better due to separate processing of metallic part and resin.

It is also pertinent to assess the e-waste recycling scenario in India, where recycling of e-waste to recover items of economic value is carried out in environmentally dangerous manner as described below.

E-WASTE RECYCLING/ TREATMENT TECHNOLOGIES IN INDIA

India is one of the fastest growing economies of the world and there is an increasing domestic demand for consumer durables. The growth in PC ownership per capita in India between 1993 and 2000 was 604%, compared to a world average of 181%. India, the second most populous country with over 1 billion people is gradually becoming the major e-waste producing countries in the world. Also the illegal import and the unauthorized recycling of e-waste in India as other developing countries are emerging as a new environmental challenge at the present moment. The increase of the potential environmental disaster in developing countries not only due to the generation of the huge amount of the e-waste, but also for the wide spread home grown recycling activity to recover metal values. Most of the e-waste recycling and dumping operations by backyard recycler are manual disassembling, open burning of plastics, exposure to toxic solders, river dumping of acids which are highly polluting and very damaging to the environment. Very crude recycling activities are adopted by backyard recycles which is mainly aimed at material recovery. In this program e-scrap undergo open sky incineration, cyanide leaching and smelting operation to recover mainly copper, gold and silver with comparatively low yields. Wires are collected and burned in open piles to recover re-saleable copper. Circuit boards are treated in open acid bath to recover copper and precious metals.

These crude methods results in resources and energy wastages and cause environmental pollution. Most of the workers involved in such activities are not aware of the environmental and health risks and do not know better practices. However, there are few organisations trying to establish a systematic and complete recycling technology as indicated in Fig.-4, where major emphasis is given in recovering the precious metals. Almost all the other component obtained are channelise to specific recyclers.

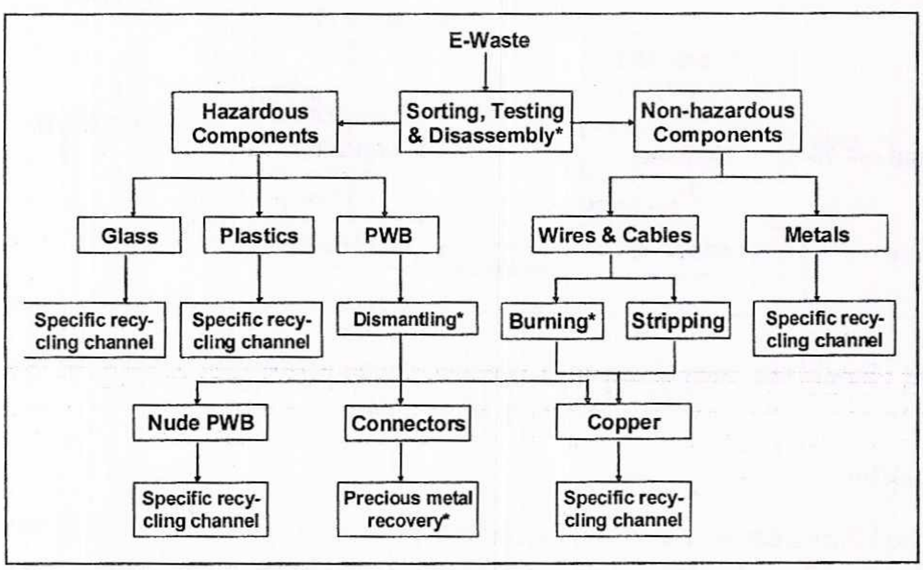

Fig.-4 : Simplified process flow-sheet of the present Bangalore e-waste management system.

There is no available research study or comparable data, which indicates the impact of e-waste emissions into the overall performance of municipal waste incineration plants. Waste incineration plants contribute significantly to the annual emissions of cadmium and mercury. In addition, heavy metals not emitted into the atmosphere are transferred to slag and exhaust gas residues and can re-enter the environment on disposal. Therefore, e-waste incineration will increase these emissions, if no reduction measures like removal of heavy metals from e-waste are taken care off.

The retrieval of copper or aluminium is done by open burning of wires in narrow lanes without any protective gear. This process is hazardous as burning of PVC results in the emission of carcinogenic dioxins and furans. Dismantling and breaking of monitors and hard disks is done with screw drivers and hammers. The recovery of gold from gold-coated plug-ins is done through the hazardous process of acid treatment. The most worrying factor is that the plug-ins containing the gold is treated along with the plastic casings which might emit toxic fumes endangering the lives of the workers.

THE GOVERNMENT RESPONSIBILITIES

Though India signed the Basel Convention, there is no specific legislation regulating the export or the collection and treatment of e-waste. There are however several existing environmental legislations which are of importance and useful in the context of e-waste. India is one of the countries that have to deal with the arising load of e-waste. The PC growth per capita in India had been over 1000% between 1993 and 2000. From 2002 to 2004 the sales of computers in India almost doubled as a market study shows, which had been performed in 22 Indian cities (Fig.-5). Since the growth of PC sales correlates with the generation of e-waste these sales implicate a massive increase of e-waste.

On the other hand, the Central Pollution Control Board (CPCB), Government of India's regulatory and monitory body, continues to deny that e-waste is coming into India. It is high time that the Government and Port Authorities in India implement the Hazardous Waste Rules and check the illegal imports of hazardous e-waste at the entry points itself. E-waste is included in the List A and B of Schedule 3 of the Hazardous Waste Rules, 2002, where its import is restricted.

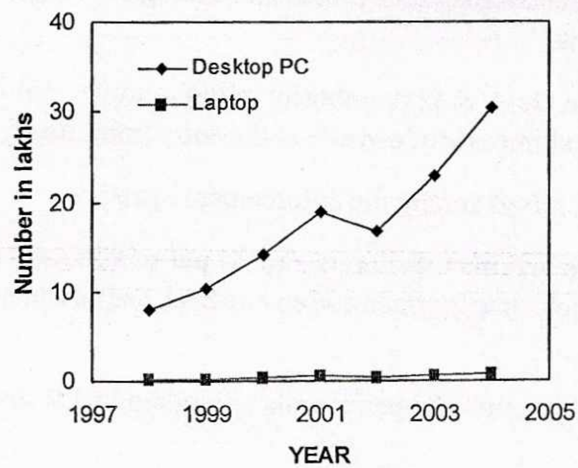

Fig.-5 : PC market trends in India from 1997 to 2004.

No regulatory norm is applicable with out the help of Governmental agencies. Considering the severity of the problem, Government must take serious effort to enforce proper law for the kind of management option be adopted to handle the bulk of e-waste generated in India. The Government stand should be as per the following :

- Government should be responsible for providing adequate system of law, controls and administrative procedures for hazardous waste management.
- Such law should empower the agency to control, supervise and regulate the relevant activities of the Government department.
- Identify the potentially harmful substances and test them for adverse health environmental effects.
- Collecting from manufacturers/consumers for the disposal of toxic materials
- Should subsidies recycling & disposal industries
- Incentive schemes for garbage collectors and general public and collection & handling over the e-waste
- Encourage manufacturer for gradual elimination of toxic chemicals from electronic goods to ensure lead, cadmium, mercury and chromium free components.
- Awareness program on e-waste for school children and general public

RECOMMENDATIONS/CONCLUSIONS

The main environmental impacts of e-waste mainly arise due to inappropriate processing rather than inherent toxic contents. However processing appropriately to recover valuable metals is the best alternative from the environmental and economic point of view. Therefore there is a need to evolve strategy as per the following to achieve the target.

- Considering e-waste as an alternative resource of several metals, serious efforts must be put towards development of a suitable process technology in collaboration with premier technology institutions.
- It is high time that the Govt. & port authority in India implement the hazardous waste rule & check the illegal imports of e-waste at the entry point itself.
- Awareness should be raised among the enforcement agencies
- Electronic companies and manufacturers should put continuous effort in eliminating toxic chemicals from electronic goods and ensure lead, cadmium, mercury & chromium free components.
- Create computer components and peripherals of biodegradable materials.