In India, there are no specific environmental laws or Guidelines for e-waste. None of the existing environmental laws have any direct reference to electronic waste or refer to its handling as hazardous in nature. However several provisions of these laws may apply to various aspects of electronic wastes. Since e-waste or its constituents fall under the category of 'hazardous" and "non hazardous waste", they shall be covered under the purview of "The Hazardous Waste Management Rules, 2003". Respective definitions, their meaning and interpretation under the rule are given below.

3.1 The Hazardous Wastes (Management and Handling) Rules, 2003

The Hazardous Waste (Management and handling) Rule, 2003, defines "hazardous waste" as any waste which by reason of any of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics causes danger or likely to cause danger to health or environment, whether alone or when on contact with other wastes or substances, and shall include:

- Waste substances that are generated in the 36 processes indicated in column 2 of Schedule I and consist of wholly or partly of the waste substances referred to in column 3 of same schedule.
- Waste substances that consist wholly or partly of substances indicated in five risks class (A,B,C,D,E) mentioned in Schedule 2, unless the concentration of substances is less than the limit indicated in the same Schedule.
- Waste substances that are indicated in Lists A and B of Schedule 3 (Part A) applicable only in cases of import and export of hazardous wastes in accordance with rules 12, 13 and 14 if they possess any of the hazardous characteristics listed in Part B of schedule 3.

"Disposal" means deposit, treatment, recycling and recovery of any hazardous wastes.

Important features of Schedule 1, 2 and 3, which may cover E-waste are given below.

Schedule 1

Although, there is no direct reference of electronic waste in any column of Schedule 1 (which defines hazardous waste generated through different industrial processes), the "disposal process" of e-waste could be characterized as hazardous processes. The indicative list of these processes is given below.

- Secondary production and/ or use of Zinc
- Secondary production of copper
- Secondary production of lead
- Production and/ or use of cadmium and arsenic and their compounds
- Production of primary and secondary aluminum
- Production of iron and steel including other ferrous alloys (electric furnaces, steel rolling and finishing mills, coke oven and by product plan)
- Production or industrial use of materials made with organo silicon compounds
- Electronic industry
- Waste treatment processes, e.g. incineration, distillation, separation and concentration techniques

As per these regulations, once a waste product is classified as hazardous according to industrial process listed in Schedule 1, it is exempted from the concentration limit requirement set by Schedule 2 of Act, and is considered hazardous irrespective of its concentrations.

Schedule 2

The Schedule 2 of the Hazardous Waste Management and Handling Rules 2003, lists waste substances which should be considered hazardous unless their concentration is less than the limit indicated in the said Schedule. The various classes of substances listed in this Schedule relevant to E-waste are covered in Class A, B, C, D and E are given below. E-waste or its fractions coming broadly under Class A and B are given below.

Class A: Concentration Limit: >= 50 mg/kg

The indicative waste list, which could be part of E-waste or its fractions under this class are given below.

- Antimony and antimony compounds
- Beryllium and beryllium compounds
- Cadmium and cadmium compounds
- Chromium (VI) compounds
- Mercury and mercury compounds
- Halogenated compounds of aromatic rings, e.g. polychlorinated biphenyls, polychloroteriphenyls and their derivatives
- Halogenated aromatic compounds

Class B: Concentration Limit: >= 5,000 mg/kg

The indicative waste list, which could be part of E-waste or its fractions under this class are given below.

- Cobalt compounds
- Copper compounds
- Lead and lead compounds
- Nickel compounds
- Inorganic tin compounds
- Vanadium compounds
- Tungsten compounds
- Silver compounds
- Halogenated aliphatic compounds
- Phenol and phenolic compounds
- Chlorine
- Bromine
- Halogen-containing compounds, which produce acidic vapors on contact with humid air or water

Schedule 3

List of Hazardous Waste to be applicable only for imports and exports are mentioned in schedule 3. It define hazardous waste as "Wastes listed in lists 'A ' and 'B ' of part A of schedule 3 applicable only in case(s)of export/import of hazardous wastes in accordance with rule 12, 13, and 14 only if they possess any of the hazardous characteristics in part B of said schedule". This clause defines hazardous waste for the purpose of import and export. It has divided hazardous waste into two parts, A and B. Part A of the schedule deals with two lists of waste to be applicable only for imports and exports purpose. Export and import of items listed in List A and B of part A are permitted only as raw materials for recycling or reuse.

Electronic Waste and Related Items listed in part A, Lists of wastes applicable for Import and Export

Following are the electronic items being mentioned in list A:

A1180 "Electrical and electronic assemblies or scraps containing components such as accumulators and other batteries included on list B, mercury-switches, glass from cathode ray tubes and other activated glass and PCB-capacitors, or contaminated with schedule 2 constituents (e.g. cadmium, mercury, lead, polychlorinated biphenyl)to an extent that they exhibit hazard characteristics indicated in part B of this schedule (see B1110)".

A1090 Ashes from the incineration of insulated copper wire.

A1150 Precious metal ash from incineration of PCBs not included on list 'B'

A2010 Glass waste from cathode ray tubes and other activated glass.

A3180 Wastes, substances and articles containing, consisting of or contaminated with polychlorinated biphenyls (PCB) and including any other poly brominated analogues of these compounds, at a concentration level of 50 mg/kg or more.

Following are electronic items placed on list B B1110:

1. Electronic assemblies consisting only of metals or alloys

2. Waste Electrical and electronic assemblies scrap (including printed circuit board, electronic components and wires) destined for direct reuse and not for recycling or final disposal.

3. Waste electrical and electronic assemblies scrap (including printed circuit boards) not containing components such as accumulators and other batteries included on list A, mercury switches, glass from cathode ray tubes and other activated glass and PCB- capacitors, or not contaminated with constituents such as cadmium, mercury, lead, polychlorinated biphenyl) or from which these have been removed, to an extent that they do not possess any of the constituents mentioned in Schedule 2 to the extent of concentration limits specified therein.

4. Electrical and electronic assemblies (including printed circuit boards, electronic components and wires) destined for direct reuse and not for recycling or final disposal.

3.2 The Municipal Solid Wastes (Management and Handling) Rules, 2000

"**Municipal Solid Waste**" includes commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated bio-medical wastes.

"**Disposal**" means final disposal of municipal solid wastes in terms of the specified measures to prevent contamination of ground-water, surface water and ambient air quality.

"**Processing**" means the process by which solid wastes are transformed into new or recycled products;

"**Recycling**" means the process of transforming segregated solid wastes into raw materials for producing new products, which may or may not be similar to the original products

"**Storage**" means the temporary containment of municipal solid wastes in a manner so as to prevent littering, attraction to vectors, stray animals and excessive foul odour.

3.3 Basel Convention

Basel Convention covers all discarded/disposed materials that possess hazardous characteristics as well as all wastes considered hazardous on a national basis. Annex VIII, refers to E-waste, which is considered hazardous under Art. 1, par. 1(a) of the Convention: A1180 Waste electrical and electronic assemblies or scrap containing components such as accumulators and other batteries included on list A, mercury-switches, glass from cathode-rat tubes and other activated glass and PCB-capacitors, or contaminated with Annex I constituents (e.g., cadmium, mercury, lead, polychlorinated biphenyl) to an extent that they possess any of the characteristics contained in Annex III. Annex IX, contains the mirror entry, B1110 Electrical and Electronic assemblies given below.

- Electronic assemblies consisting only of metals or alloys
- Waste electrical and electronic assemblies or scrap (including printed circuit boards) not containing components such as accumulators and other batteries included on List A, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or not contaminated with Annex 1.

3.4 GUIDELINES FOR ENVIRONMENTALLY SOUND MANAGEMENT FOR E-WASTE

The Environmentally Sound Technologies for e-waste treatment involves complex treatment rationale is driven by “Material Flow”. This is compared with best available technology and e-waste treatment technology currently used in India.

3.4.1 E-waste Composition and Recycle Potential

The consumption of e-waste and its recyclable potential is specific for each appliance. In order to handle this complexity, the parts/materials found in e-waste may be divided broadly into six categories as follows:

- 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.).

Annexure-III provides an overview of the composition of the three appliances selected for the study. The recovery potential (typical values) of items of economic value from PC, TV and Refrigerators has been described in Annexure–IV, Annexure-V, and Annexure-VI respectively.

3.4.2 Assessment of Hazardousness of e-waste

Guidelines for assessment of hazardousness of E-waste have been described in terms of basis, rational and approach and methodology.

3.4.3 Basis

Assessment of hazardousness of E-waste or its component has been carried out based on Indian environmental regulations on hazardous waste, “The hazardous waste (Management and handling) Rules 2003”.

3.4.4 Rationale

A number of global publications have mentioned that the scope of EU’s WEEE Directives and RoHS is narrow with respect to description of hazardous ness of WEEE. Therefore, the Indian regulation has been taken as basis of determining hazardous ness of E-waste, where Schedule 1 lists hazardous waste similar to ‘absolute” entry (irrespective of concentration) in “European Waste Catalogue” and Schedule 2 lists hazardous waste similar to “ mirror” entry Greater than or equal to the threshold limit value in “European Waste Catalogue”.

3.4.5 Approach and Methodology The approach and methodology to determine the hazardousness has been described in following steps as shown in figure 5.1. This approach follows the basis used by “Department for Environment, Food and Natural Affairs”, Government of United Kingdom to classify E-waste. However, it has been customized as per Indian situation.

Step 1: Identify the E-waste category item The identification includes the E-waste items and its tentative year of manufacture. The year of manufacture gives a number of information ex. Technology and likely component present in the Ewaste.

Step 2: Identify the E-waste composition or determine it The identification of E-waste composition or its components can be determined by its year of manufacture. Ideally, industry association should maintain record of "Electrical and Electronic Equipment" composition, which should be regularly updated to facilitate its treatment, once it becomes E-waste. In case of doubt, carry out testing of E-waste to find out the concentration.

Step 3: Identify possible hazardous content in E-waste If the E-waste has hazardous content, then refer schedule 1 and schedule 2 of "The hazardous waste (Management and handling) Rules 2003". A comparison of thresholds of hazardous substances followed in Europe with respect to that mentioned in Indian regulations, which may occur in E-waste, is given at Annexure - VII.

Step 4: Identify, whether the E-waste component is hazardous or the entire E-waste item is hazardous.

The determination of hazardousness of E-waste from washing machine, refrigerator, computer monitor and personal computer is given in appendix 1. The contents of these E-waste items have been taken from the data of globally accepted data of industry associations.

It can be concluded that E-waste generated from televisions, monitors and personal computers is hazardous in nature as per schedule 1 and schedule 2 of "The hazardous waste (Management and handling) Rules 2003". A comparison of the thresholds mentioned in Indian regulations with that of thresholds followed in Europe for E-waste shows that they are stricter. It can also be inferred that Ewaste/ components, which are hazardous in nature need to be covered under the purview of "The hazardous waste (Management and handling) Rules 2003", The Batteries (Management and Handling) Rules, 2001, The Ozone Depleting Substances (Regulation and Control) Rules, 2000.

3.4.6 Recycling, Reuse and Recovery Options

The composition of e-waste consists of diverse items like ferrous and non ferrous metals, glass, plastic, electronic components and other items and it is also revealed that e-waste consists of hazardous elements. Therefore, the major approach to treat e-waste is to reduce the concentration of these hazardous chemicals and elements through recycle and recovery. In the process of recycling or recovery, certain e-waste fractions act as secondary raw material for recovery of valuable items. The recycle and recovery includes the following unit operations.

(i) Dismantling: Removal of parts containing dangerous substances (CFCs, Hg switches, PCB); removal of easily accessible parts containing valuable substances (cable containing copper, steel, iron, precious metal containing parts, e.g. contacts).

(ii) Segregation of ferrous metal, non-ferrous metal and plastic This separation is normally done in a shredder process.

(iii) Refurbishment and reuse: Refurbishment and reuse of e-waste has potential for those used electrical and electronic equipments which can be easily refurbished to put to its original use.

(iv) Recycling/recovery of valuable materials Ferrous metals in electrical are furnaces, non-ferrous metals in smelting plants, precious metals in separating works.

(v) Treatment/disposal of dangerous materials and waste Shredder light fraction is disposed of in landfill sites or sometimes incinerated (expensive), CFCs are treated thermally, PCB is incinerated or disposed of in underground storages, Hg is often recycled or disposed of in underground landfill sites.

The value of recovery from the elements would be much higher if appropriate technologies are used.

3.5 TREATMENT & DISPOSAL OPTIONS

The presence of hazardous elements in e-waste offers the potential of increasing the intensity of their discharge in environment due to landfilling and incineration.

The potential treatment disposal options based on the composition are given below:

- Landfilling
- Incineration

LANDFILLING

The literature review reveals that degradation processes in landfills are very complicated and run over a wide time span. At present it is not possible to quantify environmental impacts from E-waste in landfills for the following reasons:

- Landfills contain mixtures of various waste streams;
- Emission of pollutants from landfills can be delayed for many years;
- According to climatic conditions and technologies applied in landfills (e.g. leachate collection and treatment, impermeable bottom layers, gas collection), data on the concentration of substances in leachate and landfill gas from municipal waste landfill sites differs with a factor 2-3.

One of the studies on landfills reports that the environmental risks from landfilling of e-waste cannot be neglected because the conditions in a landfill site are different from a native soil, particularly concerning the leaching behavior of metals. In addition it is known that cadmium and mercury are emitted in diffuse form or via the landfill gas combustion plant. Although the risks cannot be quantified and traced back to e-waste, landfilling does not appear to be an environmentally sound treatment method for substances, which are volatile and not biologically degradable (Cd, Hg, CFC), persistent (PCB) or with unknown behaviour in a landfill site (brominated flame retardants). As a consequence of the complex material mixture in e-waste, it is not possible to exclude environmental (long-term) risks even in secured landfilling.

INCINERATION

Advantage of incineration of e-waste is the reduction of waste volume and the utilization of the energy content of combustible materials. Some plants remove iron from the slag for recycling. By incineration some environmentally hazardous organic substances are converted into less hazardous compounds.

Disadvantage of incineration are the emission to air of substances escaping flue gas cleaning and the large amount of residues from gas cleaning and combustion.

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 reenter the environment on disposal. Therefore, e-waste incineration will increase these emissions, if no reduction measures like removal of heavy metals from are taken.

3.5.1 E-waste Recycling/Treatment technologies in India

In this context, it is pertinent to assess the e-waste recycling scenario in India, where recycling of e-waste to recover items of economic value is carried out.

The assessment of e-waste recycling sector in India indicates that e-waste trade starts from formal dismantling sector and moves to informal recycling sector. ewaste movement from formal to informal sector is driven by trade and can be tracked by trade value chain. This e-waste trade value chain can be mapped based on material flow from formal sector to informal sector. An example of this chain mapped during “Delhi Study” given in Annexure – VIII.

This chain was identified considering bottom-up approach with three levels of ewaste generation hierarchy. The three levels of e-waste generation hierarchy give rise to three types of stakeholders involved in e-waste trade as described below.

1. 1st Level – Preliminary e-waste Generators.

2. 2nd Level – Secondary e-waste Generators.

3. 3rd Level – Tertiary e-waste Generators.

The input to “Preliminary e-waste Generator” comes from formal organized market like manufacturers, importers, offices and organized markets, where ewaste from domestic consumers comes either in exchange schemes or as a discarded item. Therefore, the major stakeholders are scrap dealers/ dismantlers who purchase e-waste from the first level in bulk quantities. These stakeholders have limited capacity of dismantling and are involved in trading of e-waste with” Secondary e-waste Generators”. The market between first and second level is semi formal i.e. part formal, while the market between second and third level is completely informal. Stakeholders falling under” Secondary e-waste Generators” have limited financial capacity and are involved in item/ component wise dismantling process and segregation ex. Dismantling of CRT, PCB, plastic and glass from e-waste. ‘Tertiary Level Stakeholders” are the major stakeholders between second and third level and are metal extractors, plastic extractors and electronic item extractors. They use extraction process, which are hazardous in nature. The characteristics of emissions from e-waste treatment in semi formal and informal sector in India are as follows:

1. Generation of mixed e-waste fractions along with hazardous waste after dismantling

2. Generation of effluents during metal extraction ex. Acid bath process for copper extraction from printed circuit board

3. Air emissions due to burning of printed circuit board

4. Inefficient secondary raw material generation The entire e-waste treatment is being carried out in an unregulated environment, where there is no control on emissions. There are two e-waste dismantling facilities in formal sector in India. These facilities are M/s. Trishiraya Recycling facilities, Chennai and M/s E-Parisara, Bangalore.

3.5.2 ENVIRONMENTALLY SOUND TREATMENT TECHNOLOGY FOR E-WASTE

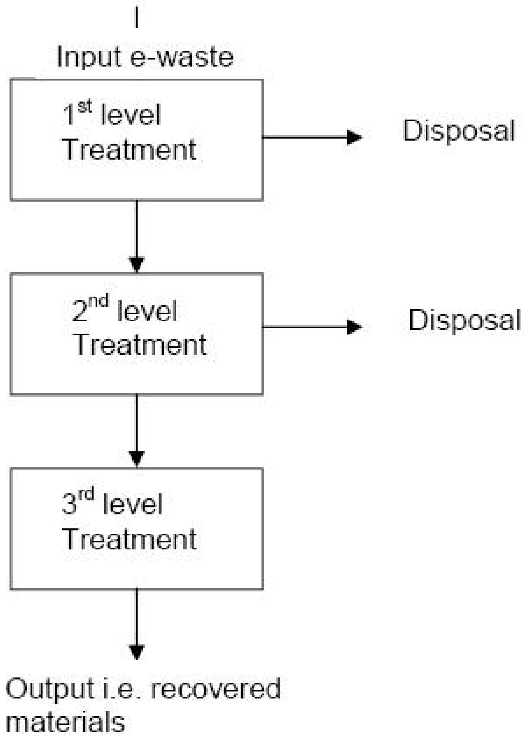
Environmentally sound E-waste treatment technologies Environmentally sound E-waste treatment technologies are used at three levels as described below:

1. 1st level treatment

2. 2nd level treatment

3. 3rd level treatment

ANALYSIS - All the three levels of e-waste treatment are based on material flow. The material flows from 1st level to 3rd level treatment. Each level treatment consists of unit operations, where e-waste is treated and out put of 1st level treatment serves as input to 2nd level treatment. After the third level treatment, the residues are disposed of either in TSDF or incinerated. The efficiency of operations at first and second level determines the quantity of residues going to TSDF or incineration. The simplified version of all the three treatments is shown in figure 3.5.2, while a comprehensive version detailing each stage is given at Annexure –IX. EST at each level of treatment is described in terms of input, unit operations, output and emissions.



Simplified version of EST for e-waste

Figure 3.5.2

3.6 EST for 1st Level Treatment

Input: e-waste items like TV, refrigerator and Personal Computers (PC) Unit Operations: There are three units operations at first level of e-waste treatment

1. Decontamination : Removal of all liquids and Gases
2. Dismantling -manual/mechanized breaking
3. Segregation

All the three unit operations are dry processes, which do not require usage of water.

1. Decontamination - The first treatment step is to decontaminate e-waste and render it nonhazardous. This involves removal of all types of liquids and gases (if any) under negative pressure, their recovery and storage.

2. Dismantling - The decontaminated e-waste or the e-waste requiring no decontamination are dismantled to remove the components from the used equipments. The dismantling process could be manual or mechanized requiring adequate safety measures to be followed in the operations.

3. Segregation - After dismantling the components are segregated into hazardous and nonhazardous components of e-waste fractions to be sent for 3rd level treatment.

Output:
1. Segregated hazardous wastes like CFC, Hg Switches, batteries and capacitors
2. Decontaminated e-waste consisting of segregated non-hazardous Ewaste like plastic, CRT, circuit board and cables Emissions: The emissions coming out of 1st level treatment is given in table 6.1.

Table 6.1: Emissions from 1st level E-waste treatment

Unit Operations/ Emissions	Dismantling	Segregation
Air	√ (fugitive)	X
Water	X	X
Noise	√	√
Land/ Soil Contamination due to spillage	√	√
Generation of hazardous waste	√	√

3.6.1.2 EST for 2nd Level Treatment

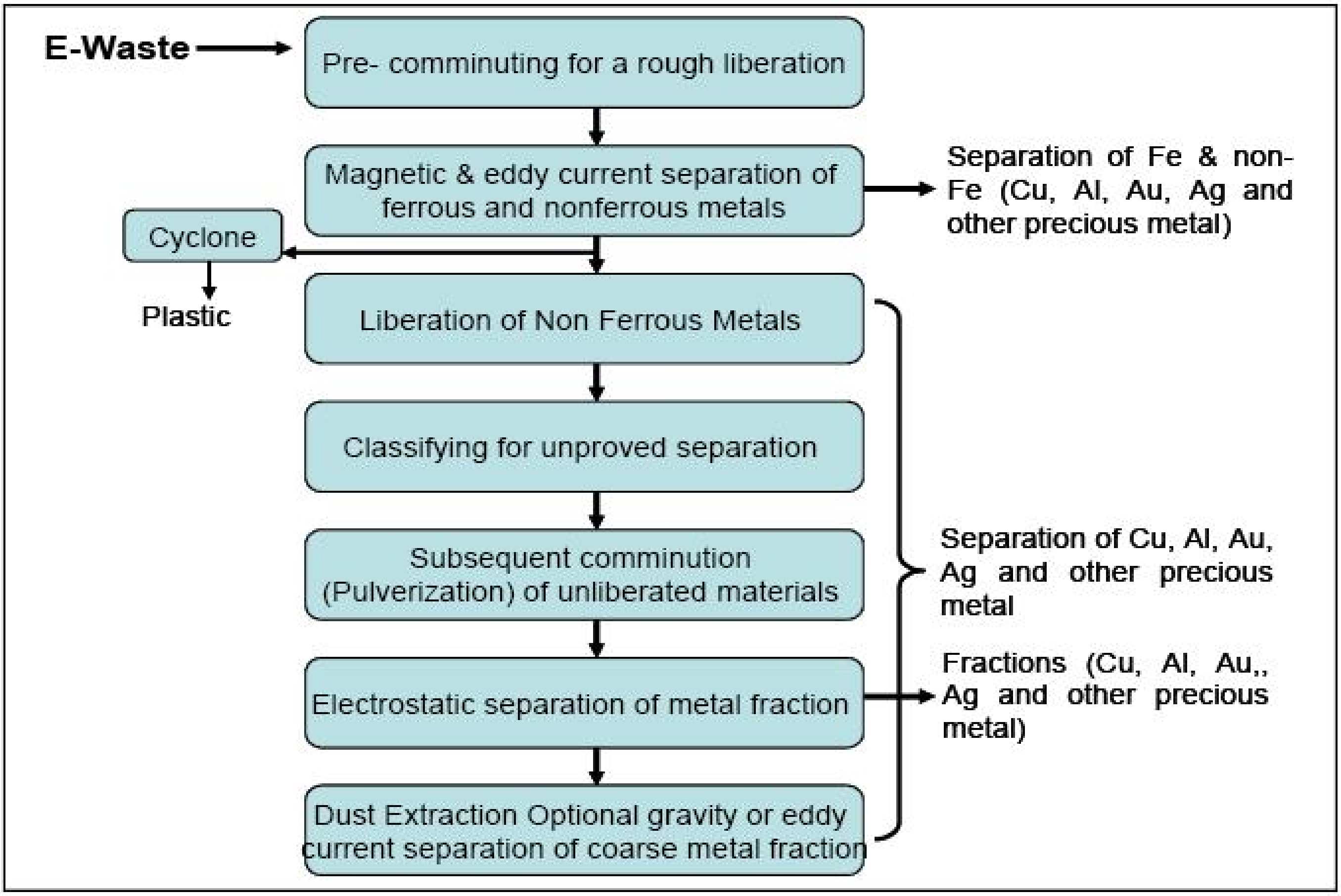
Input: Decontaminated E-waste consisting segregated non hazardous e-waste like plastic, CRT, circuit board and cables.

Unit Operations: There are three unit operations at second level of E-waste treatment

1. Hammering
2. Shredding
3. Special treatment Processes comprising of
    (i) CRT treatment consisting of separation of funnels and screen glass.
    (ii) Electromagnetic separation
    (iii) Eddy current separation
    (iv) Density separation using water

The two major unit operations are hammering and shredding. The major objective of these two unit operations is size reduction. The third unit operation consists of special treatment processes. Electromagnetic and eddy current separation utilizes properties of different elements like electrical conductivity, magnetic properties and density to separate ferrous, non ferrous metal and precious metal fractions. Plastic fractions consisting of sorted plastic after 1st level treatment, plastic mixture and plastic with flame retardants after second level treatment, glass and lead are separated during this treatment. The efficiency of this treatment determines the recovery rate of metal and segregated E-waste fractions for third level treatment. The simplified version of this treatment technology showing combination of all three unit operations is given in Figure 6.2.

Figure 6.2: Process flow of Non CRT based e-waste treatment



1. The proposed technology for sorting, treatment, including recycling and disposal of E-waste is fully based on dry process using mechanical operations.

2. The pre-comminuting stage includes separation of Plastic, CRT and remaining non CRT based E-waste. Equipments like hammer mill and shear shredder will be used at comminuting stage to cut and pulverize Ewaste and prepare it as a feedstock to magnetic and eddy current separation.

3. A heavy-duty hammer mill grinds the material to achieve separation of inert materials and metals.

4. After separation of metals from inert material, metal fraction consisting of Ferrous and Non-Ferrous metals are subjected to magnetic current separation. After separation of Ferrous containing fraction, Non-ferrous fraction is classified into different non-metal fractions, electrostatic separation and pulverization.

5. The ground material is then screened and de dusted subsequently followed by separation of valuable metal fraction using electrostatic, gravimetric separation and eddy current separation technologies to Figure 6.2: Process flow of Non CRT based e-waste treatment Pre- comminuting for a rough liberation Magnetic & eddy current separation of ferrous and nonferrous metals Liberation of Non Ferrous Metals Classifying for unproved separation Subsequent comminution (Pulverization) of unliberated materials Electrostatic separation of metal fraction Dust Extraction Optional gravity or eddy current separation of coarse metal fraction Separation of Cu, Al, Au, Ag and other precious metal Fractions (Cu, Al, Au,, Ag and other precious metal) Separation of Fe & non- Fe (Cu, Al, Au, Ag and other precious metal) Cyclone Plastic E-Waste recover fractions of Copper (Cu), Aluminum (Al), residual fractions containing Gold (Au), Silver (Au) and other precious metals. This results in

recovery of clean metallic concentrates, which are sold for further refining to smelters. Sometimes water may be used for separation at last stage.

6. Electric conductivity-based separation separates materials of different electric conductivity (or resistivity) mainly different fractions of non-ferrous metals from E-waste. Eddy current separation technique has been used based on electrical conductivity for non ferrous metal separation from Ewaste. Its operability is based on the use of rare earth permanent magnets. When a conductive particle is exposed to an alternating magnetic field, eddy currents will be induced in that object, generating a magnetic field to oppose the magnetic field. The interactions between the magnetic field and the induced eddy currents lead to the appearance of electro dynamic actions upon conductive non-ferrous particles and are responsible for the separation process.

7. The efficacy of the recycling system is dependent on the expected yields/ output of the recycling system. The expected yields/ output from the recycling system are dependent on the optimization of separation parameters. These parameters are given below:

- Particle size
- Particle shape
- Feeding rate/ RPM
- Optimum operations

Figure 6.3 shows the non- ferrous metal distribution (which forms the backbone of financial viability of recycling system) as a function of size range for PC scrap. It can be seen that aluminum is mainly distributed in the coarse fractions (+6.7 mm), but other metals are mainly distributed in the fine fractions (−5 mm).

Size properties are essential for choosing an effective separation technique. Therefore, eddy current separator is best for granular nonferrous materials having size greater than 5mm. The eddy current separation will ensure better separation of Al fraction in comparison to fraction containing Cu, Ag and Au.

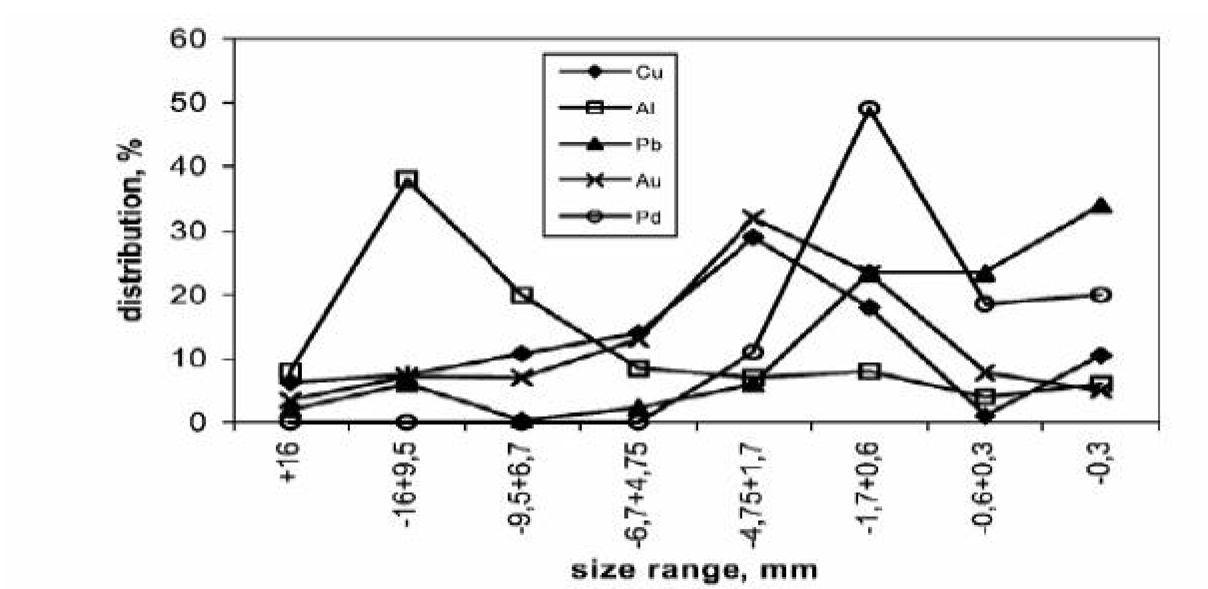


Figure 6.3: Non- Ferrous Metal Distribution Vs Size range for PC scrap

8. Particle shape is dependent on comminuting and separation. Since hammer mills and screens will be used in the proposed technology, the variations are expected to be the same as that of Best Available Technology (BAT).

9. The feeding rate can be optimized based on the speed and width of the conveyor.

3.6.1.2.1 CRT treatment technology

The salient features of CRT treatment technology are given below.

1. CRT is manually removed from plastic/ wooden casing.

2. Picture tube is split and the funnel section is then lifted off the screen section and the internal metal mask can be lifted to facilitate internal phosphor coating.

3. Internal phosphor coating is removed by using an abrasive wire brush and a strong vacuum system to clean the inside and recover the coating. The extracted air is cleaned through an air filter system to collect the phosphor dust.

Different types of splitting technology used are given below.

 NiChrome hot wire cutting

A NiChrome wire or ribbon is wrapped round a CRT and electrically heated for at least 30 seconds to causes a thermal differential across the thickness of the glass. The area is then cooled (e.g. with a water-soaked sponge) to create thermal stress which results in a crack. When this is lightly tapped, the screen separates from the funnel section.

 Thermal shock

The CRT tube is subjected to localized heat followed by cold air. This creates stress at the frit line where the leaded funnel glass is joined to the unleaded panel glass and the tube comes apart.

 Laser cutting

A laser beam is focused inside and this heats up the glass. It is immediately followed by a cold water spray that cools the surface of the glass and causes it to crack along the cut line.

 Diamond wire method

In this method, a wire with a very small diameter, which is embedded with industrial diamond is used to cut the glass as the CRT is passed through the cutting plane.

 Diamond saw separation

Diamond saw separation uses either wet or dry process. Wet saw separation involves rotating the CRT in an enclosure while one or more saw blades cut through the CRT around its entire circumference. Coolant is sprayed on to the surface of the saw blades as they cut. This is to control temperature and prevent warping.

 Water-jet separation

This technology uses a high-pressure spray of water containing abrasive, directed at the surface to be cut. The water is focused through a single or double nozzle-spraying configuration set at a specific distance.

3.6.1.3 3rd Level E-waste Treatment

The 3rd level E-waste treatment is carried out mainly to recover ferrous, nonferrous metals, plastics and other items of economic value. The major recovery operations are focused on ferrous and non ferrous metal recovery, which is either geographically carried out at different places or at one place in an integrated facility. The following sections describe the unit operations, processes, available technology and environmental implications.

3.6.1.3.1 Input/ Output and Unit Operations The input, output and unit operations at 3rd level treatment are described in table 6.2.

Table 6.2: Input/ Output and unit operations for 3rd level treatment of e-waste

Input/ WEEE Residues	Unit Operation/ Disposal/ Recycling Technique	Output
Sorted Plastic	Recycling	Plastic Product
Plastic Mixture	Energy Recovery/ Incineration	Energy Recovery
Plastic Mixture with FR	Incineration	Energy Recovery
CRT	Breaking/ Recycling	Glass Cullet
Lead Smelting	Secondary Lead Smelter	Lead
Ferrous metal scrap	Secondary steel/ iron recycling	Iron
Non Ferrous metal Scrap	Secondary copper and aluminum smelting	Copper/ Aluminum
Precious Metals	Au/ Ag separation (refining)	Gold/ Silver/ Platinum and Palladium
Batteries (Lead Acid/ NiMH and Li ION)	Lead recovery and smelting Remelting and separation	Lead
CFC	Recovery/ Reuse and Incineration	CFC/ Energy recovery
Oil	Recovery/ Reuse and Incineration	Oil recovery/ energy
Capacitors	Incineration	Energy recovery
Mercury	Separation and Distillation	Mercury

The description of some of the 3rd level WEEE/ E-waste processes are described below.

6.1.3.2 Plastic Recycling

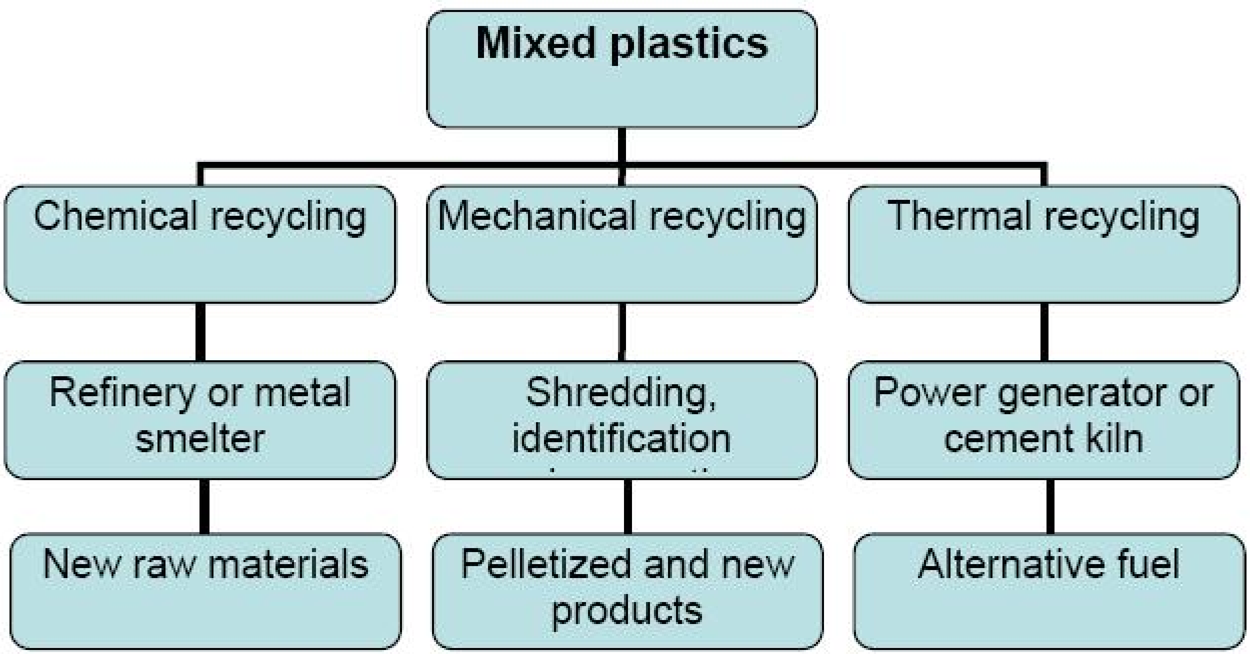
There are three different types of plastic recycling options i.e. chemical recycling, mechanical recycling and thermal recycling. All the three processes are shown in figure 6.3. In chemical recycling process, waste plastics are used as raw materials for petrochemical processes or as reductant in a metal smelter. In mechanical recycling process, shredding and identification process is used to make new plastic product. In thermal recycling process, plastics are used as alternative fuel.

The two major types of plastic resins, which are used in electronics, are “thermosets” and “thermoplastics”. Thermosets are shredded and recycled because they cannot be re-melted and formed into new products, while thermoplastics can be re-melted and formed into new products.

6.1.3.3 Mechanical Recycling Process

Mechanical recycling process is shown in figure 6.4. The first step is sorting process, where contaminated plastics such as laminated and/ or painted plastics are removed. The methods, which may be used for sorting, are grinding, cryogenic method, abrasion/ abrasive technique, solvent stripping method and high temperature aqueous based paint removal method. Any of the method is used for removal of paints and coating from waste plastics.

Figure 6.4: Recycling options for managing plastics from end-of-life electronics



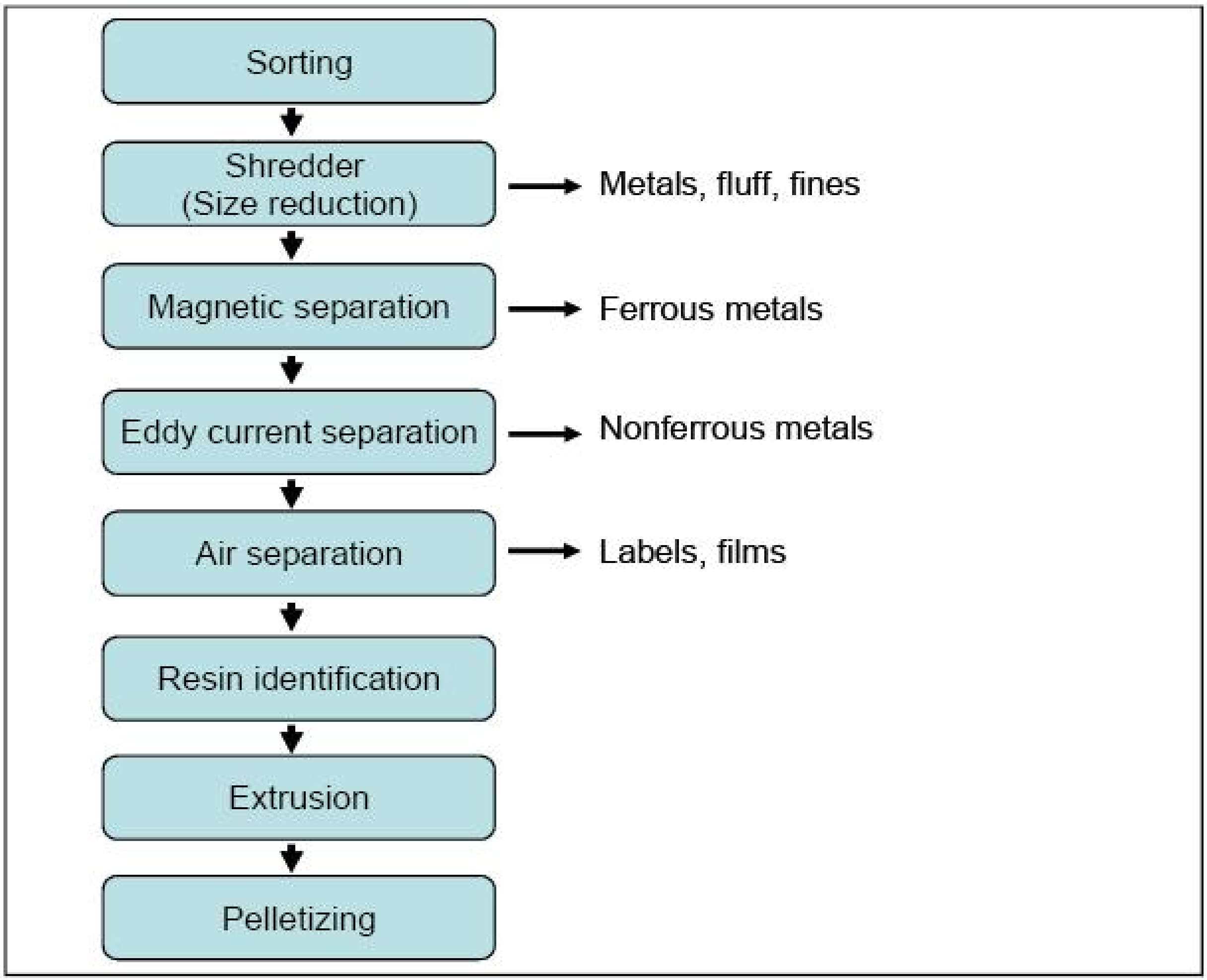
Shear-shredder and hammer mills are generally used for size reduction and liberation of metals (coarse fraction) followed by granulation and milling for further size reduction. Granulators use a fixed screen or grate to control particle size, while hammer mills allow particles between hammers and the walls to exit the mills.

Magnetic separators are used for ferrous metals separation, while eddy current separators are used for non ferrous metals separation. Air separation system is used to separate light fractions such as paper, labels and films. Resin identification can be carried out by using a number of techniques like turboelectric separator, high speed accelerator and X-ray fluorescence spectroscopy.

In hydro cyclones separation technique, plastic fractions are separated using density separation technique, which is made more effective by enhancing material wettability. In turboelectric separation technique, plastic resins are separated on the basis of surface charge transfer phenomena. Different plastic resins are mixed and contact one another in a rotating drum to allow charging. Negatively charged particles are pulled towards the positive electrode and positively charged particles are pulled towards negative electrode. This technique has been found to be most effective for materials with a particle size between 2-4 mm. In high accelerator separation technique, a high speed accelerator is used to de-laminate shredded plastic waste, which is further separated by air classification, sieve and electrostatics. X-ray fluorescence spectroscopy is effective in identifying heavy metals as well as flameretardants.

After identification and sorting of different resins, they are extruded and palletized.

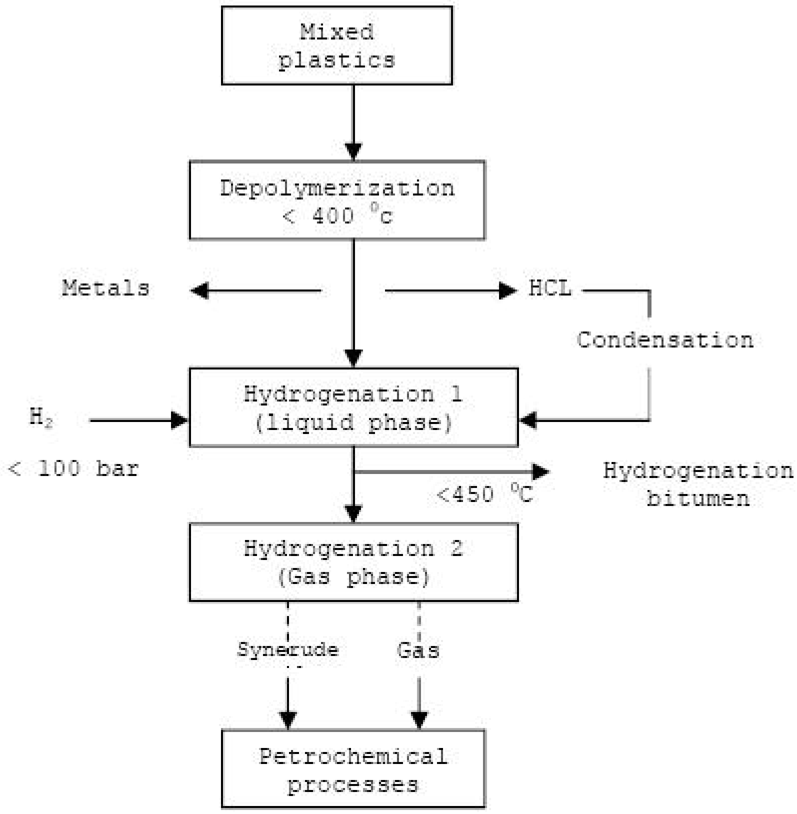
Figure 6.5: Representative process flow diagram for the mechanical recycling of post consumer plastics



3.6.1.3.4 Chemical Recycling Process

Chemical recycling process is shown in figure 6.6. This process was developed by the Association of Plastic Manufacturers in Europe (APME). The different steps in this process are given below.

Figure 6.6: De-polymerization of plastics and conversion processes



1. Mixed plastic waste is first de-polymerized at about 350-400°C and dehalogenated (Br and Cl). This step also includes removal of metals.

2. In hydrogenation unit 1, the remaining polymer chains from depolymerized unit are cracked at temperatures between 350-400° C and hydrogenated at pressure greater than 100 bar. After hydrogenation, the liquid product is subjected to distillation and left over inert material is collected in the bottom of distillation column as residue, hydrogenation bitumen.

3. In hydrogenation unit 2, high quality products like off gas and sync rude are obtained by hydro-treatment, which are sent to petrochemical process.

3.6.1.3.5 Thermal Recycling Process

In thermal recycling process, plastics are used as fuel for energy recovery. Since plastics have high calorific value, which is equivalent to or greater than coal, they can be combusted to produce heat energy in cement kilns. APME has found thermal recycling of plastic as the most environmentally sound option for managing WEEE/ E-waste plastic fraction.

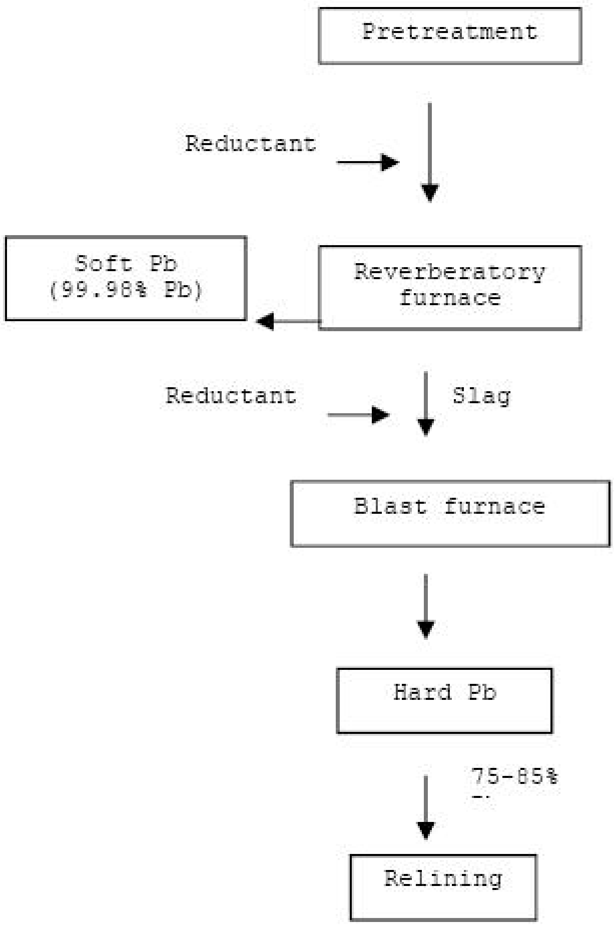
(i) Metals Recycling

Metals recycling have been described below in terms of lead recycling, copper recycling and precious metals recycling. After sorting of metal fractions at 2nd level e-waste treatment, they are sent to metal recovery facilities. These metal recovery facilities use the following processes to recover metals.

(ii) Lead Recovery

Reverberatory furnace and blast furnace are used to recover lead from e-waste fraction. The process is shown in figure 6.7 and involves the following steps.

Figure 6.7: Processes flow for secondary lead recovery



1. A reverberatory furnace is charged with lead containing materials and reductants. In this furnace, the reduction of lead compounds is carried out to produce lead bullion and slag. Lead bullion is 99.9% while slag contains 60-70% wt. % lead and a soft (pure) lead product. The following reactions occur in the reverberatory furnace.

$$PbO + C \longrightarrow Pb + CO$$

$$2\,Sb + 3PbO \longrightarrow 3\,Pb + Sb_2O_3$$

$$2\,As + 3PbO \longrightarrow 3\,Pb + As_2O_3$$

$$Sn + 2PbO \longrightarrow 2Pb + SnO_2$$

2. Slag in reverberatory furnace is continuously tapped onto a slag caster. It consists of a thin, fluid layer on top of the heavier lead layer in the furnace.

3. Lead bullion is tapped from the furnace when the metal level builds up to a height that only small amounts of lead appear in the slag.

4. Lead is recovered from the slag by charging it in blast furnace along with other lead containing materials and fluxing agents like iron and limestone.

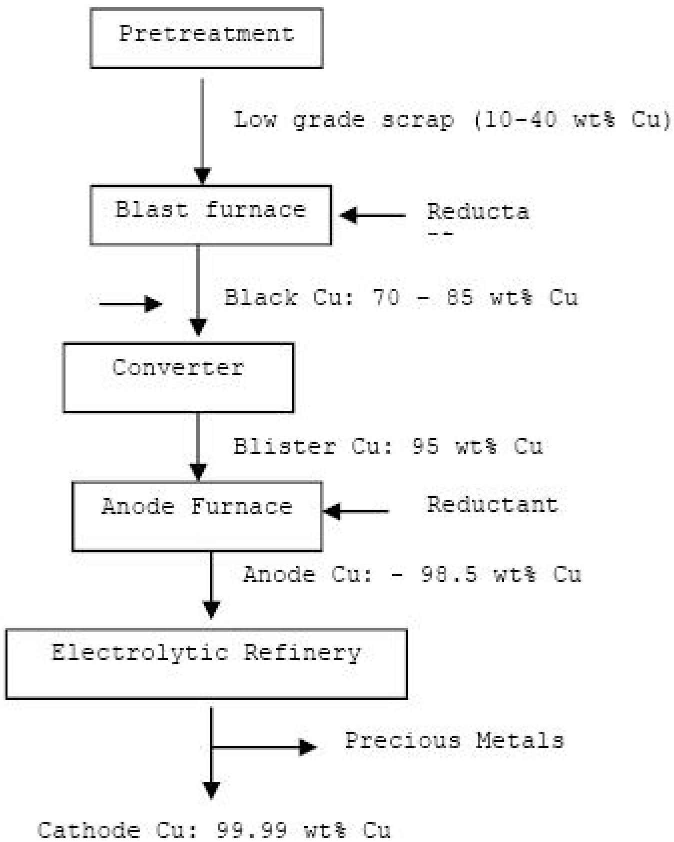
5. Hard lead is recovered from the blast furnace, which contains 75-85 wt. % Pb and 15-25 wt. % Sb. Slag contains 1-3% lead. Slag contains CaO, SiO2 and FeO.

6. Flue gas emissions from reverberatory furnace are collected by bag house and feedback into the furnace to recover lead. Slag from blast furnace is disposed of in hazardous waste landfill sites.

(iii) Copper Recycling

The copper recycling process is shown in figure 6.8. It involves the following steps.

1. E-waste fraction containing Cu is fed into a blast furnace, which are reduced by scrap iron and plastics to produce "black copper". Black copper contains 70-85 wt. % copper. The following reactions occur in blast furnace. Sn, Pb and Zn are also reduced as gas fumes.
   $Fe + Cu_2O \rightarrow FeO + 2Cu$
   $2Zn + C \rightarrow 2\,Zn\,(g) + CO_2$
2. The black copper is fed into converter and oxidized using air or enriched oxygen to produce blister copper having 95 wt. % purity. Sn, Pb and Zn are removed, while Fe is removed as slag.
3. 3. Blister copper and scrap Cu are melted and reduced by coke or wood or waste plastic in anode furnace. Other less noble metal are oxidized and removed from blister copper. Sulfur is also removed from the anode furnace. The following reduction reaction occurs in the anode furnace.
4. 2CuO + C 2 Cu + CO2
5. 4. Recovered anode copper is further purified in electrolytic process where it is dissolved in H2SO4 electrolyte with other elements such as Ni, Zn and Fe. The pure copper 99.99 wt. %) is deposited on the cathodes.
6. 5. The by-products of copper recovery process and slag are reused for roof shingles, sand blasting and ballasts for railroads. The anode slime from electrolytic process is used for precious metal recovery. The entire secondary recovery of Cu uses only one-sixth of the energy that would be required to produce Cu from ore.
7. Figure 6.8: Process flow for secondary copper recovery



(iv) Precious Metals Recovery

The precious metals recovery process is shown in figure 6.9. The anode slime from copper electrolytic process is used for precious metal recovery. The process involves the following steps.

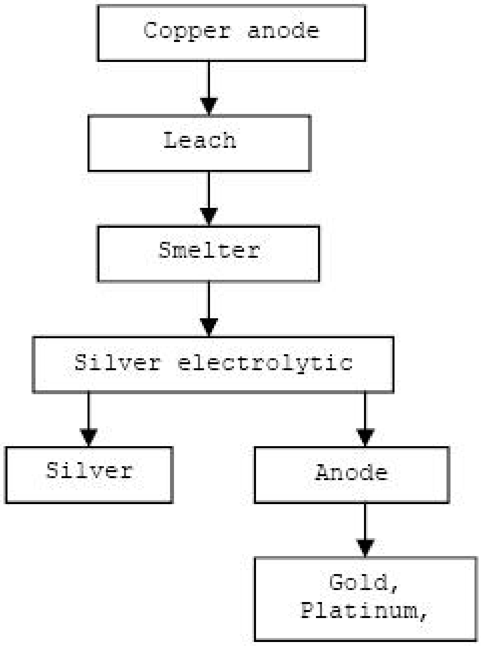
1. Anode slime is leached by pressure.

2. The leached residue is then dried and, after the addition of fluxes, smelted in a precious metals furnace. Selenium is recovered during smelting.

3. The remaining material from smelter is caste into anode and undergoes electrolysis to form high-purity silver cathode and anode gold slime.

4. The anode gold slime is further leached and high purity gold, palladium and platinum sludge are recovered.

Figure 6.9: Precious metals recovery process



6.2 Environmental Impacts of the 1st, 2nd and 3rd level e-waste treatment system In order to assess environmental impacts of e-waste treatment, an example of environmental impacts of entire Swiss take back and recycling system has been described by comparing it with a baseline system. Swiss take back recycling system included take back, collection, sorting, transportation, dismantling and secondary material processing steps. The baseline system included e-waste disposal by incineration in municipal waste incineration plant (MSWI) and primary production of raw material. The impacts have been assessed with respect to environmental attributes like acidification, climate change, eutrophication, photochemical oxidation, ozone and resources depletion. A comparison between the two scenarios has been given at Annexure - X. The environmental impact of the e-waste recycling system is shown with dark bars on the positive side, while the avoided primary production is shown as bright bars on the negative side of the x-axis. In the first row, the value on the negative side represents the incineration of the complete e-waste in an MSWI plant. In the very last row, the bars are on the reverse side since these bars represent the substitute energy generated by the incineration of organic materials in either of the two systems. It can be inferred that the sum of the burden produced (dark bars) is much lower than the burden avoided (bright bars). The various impact categories are dominated by the primary production of steel and precious metals.

6.3 Technology Currently Used in India

For non CRT E-waste, the two E-waste treatment facilities in India use the following technologies.

1. Dismantling

2. Pulverization/ Hammering

3. Shredding

4. Density separation using water

The CRT treatment technology as used by CRT manufacturer in India for discarded CRT's, is shown in Figure 6.10.

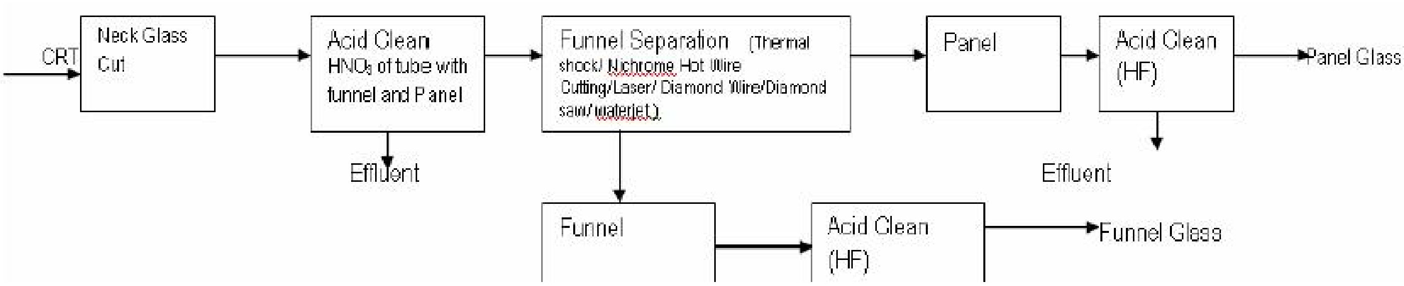


Figure 6.10: CRT Treatment Options used in India

However, both the E-waste treatment facilities at Chennai and Bangalore use thermal shock splitting technology along with abrasive wire brush and vacuum system for CRT treatment. There is no interaction with water or acid for CRT treatment in both the facilities.

Output: The output from the 2nd level treatment technology is given below:

1. Ferrous metal scrap (secondary raw material)

2. Non ferrous metal scrap mainly copper and aluminum

3. Precious metal scrap mainly silver, gold, palladium

4. Plastic consisting of sorted plastic, plastic with flame retardants and plastic mixture

5. Glass fraction (secondary raw material)

6. Lead (Secondary raw material) Emissions: The emissions coming out of 2nd level treatment is given in table 6.3.

Table 6.3: Emissions from 2nd level E-waste treatment

Unit Operations/ Emissions	Dismantling	Shredding	Special Treatment Process			
			CRT	Electromagnetic	Eddy Current	Density
Air	√ (fugitive)	√ (fugitive)	X	√ (fugitive)	√ (fugitive)	X
Water	X	X	√	X	X	
Noise	√	√	√	√	√	X
Land/ Soil Contamination due to spillage	√	√	√	√	√	√
Generation of hazardous waste	√	√	√	X	X	X

The salient features of internationally acceptable for Guidelines for Collection, Refurbishment, Transboundary Movement, Recovery and Recycling of End of Life Mobile Phones are available at web site i.e. http://www.basel.int/industry/mppiwp/guid-info/index.html

3.6.4 Best Available Technology

Best available technologies (BAT) have been described by highlighting the existing e-waste treatment process in Switzerland (Europe) and Japan. The salient features of these technologies are given below.

1. The process combines manual and machine procedures.

2. The e-waste is at first cut, crushed and finally sorted into discreet product streams. These streams consist of scrap iron, non-ferrous metal fractions, PC and TV casing components (consisting of wood and plastics), granulates of mixed plastics, cathode ray tubes, printed circuit boards,

copper cables, components containing organic pollutants such as batteries and condensers, and fine particulates (dust).

3. The machine processes include breaking of / crushing the equipment in a hammer mill. Further, the crushed material is separated according to density, granulate size and magnetic properties, and multiple pulverizations by milling using magnetic and eddy current separation systems.

The analysis of the best available technology shows that the process uses a combination of magnetic and electric conductivity based separation. The research publications sites that magnetic separators, in particular, low-intensity drum separators are widely used for the recovery of ferromagnetic metals from non-ferrous metals and other non-magnetic wastes. Over the past decade, there have been many advances in the design and operation of high-intensity magnetic separators, mainly as a result of the introduction of rare earth alloy permanent magnets capable of providing very high field strengths and gradients. Literature cites that magnetic separation leads to recovery of about 90% to 95% of ferrous metal from E-waste. Currently, eddy current separators are almost exclusively used for waste reclamation where they are particularly suited to handling the relatively coarse sized feeds of size > 5 mm. However, recent developments show that eddy current separation process has been designed to separate small particles. It has been reported that eddy current separation leads to more than 90% recovery of non-ferrous metals from the E-waste.

3.6.5 Available Operating Facilities

Available facilities in the world, which are being used for recovery of ferrous and non-ferrous metals have been described in terms of geographically distributed facilities and integrated facilities.

An example of geographically distributed 3rd level E-waste treatment facility has been described by an environmentally complying operation of such facility in North America. The salient features of this operation are given below.

1. Approximately 50% of the output from recycling plants is shipped copper smelter and the balance (mainly steel and aluminum) is shipped to its approved facilities for smelting and refining.

2. The recycler has two plants; one focused on sampling and preparation of copper and precious metals from E-waste fractions, which is sent for final recovery at the smelter/refinery.

3. At the sampling facility circuit boards and other E-waste residues after second level of treatment are prepared for smelting, sampled and assayed for precious metal content.

4. The assayed material is then sent to copper smelter. Precious metals are recovered at the copper smelter through three stages of refinement; the reactor, the converters, and the anode furnaces, which produce 99.1% pure copper.

5. Precious metals are recovered at other facility, where precious metals and copper alloyed in the anode product are leached, smelted and refined through electrolysis to separate copper from precious metals.

Example of an integrated 3rd level E-waste treatment facility has been described by an environmentally complying operation of such facility in Europe. The specific process followed by the recycler is given at Annexure – XI.