# UNIT-I

# INTRODUCTIN TO e-WASTE MANAGEMENT IN INDIA

## Electronic Waste (e-Waste):

- Electronic waste, or e-waste, is a term for electronic products that have become unwanted, non-working or obsolete, and have essentially reached the end of their useful life.
- Because technology advances at such a high rate, many electronic devices become "trash" after a few short years of use.
- In fact, whole categories of old electronic items contribute to e-waste such as VCRs being replaced by DVD players, and DVD players are being replaced by blu-ray players. E-waste is created from anything electronic: computers, TVs, monitors, cell phones, PDAs, VCRs, CD players, fax machines, printers, etc.

## Growing e-waste is a global concern:

- The growth in global electrical and electronic equipment production and consumption has been exponential in the last two decades, fuelled by rapid changes in equipment features and capabilities, product obsolescence (out-date), decrease in prices and the growth in Internet use.
- This has created a large volume of obsolete electrical and electronic devices, or e-waste.
- E-waste comprises waste from equipments such as, mainly, computers, mobile phones, television sets, photocopiers, DVD players, washing machines, refrigerators and other household consumer durables.
- E-waste is growing at almost three times the rate of municipal waste globally.
- This rapid growth and increased globalised trade of this complex and toxic waste poses a serious challenge for its management and causes serious environmental concerns both in developed and developing countries.

### The main problems related to inadequate management:

- E-waste is highly complex to handle and often contains highly toxic chemicals such as **lead, cadmium, mercury, beryllium, Brominated Flame Retardants (BFRs), PVC and phosphorus compounds**.
- These materials have serious human health concerns and require extreme care in its disposal at the downstream to avoid any adverse impacts.
- This warrants the need for an extensive collection network, recycling infrastructure, sound technology and a supporting regulatory framework for handling and disposal of toxic waste.

- **Though many developed countries have developed stringent norms for recycling these** products to avoid adverse impacts on environment and human health, the absence of facilities and norms in developing countries are posing serious challenges.

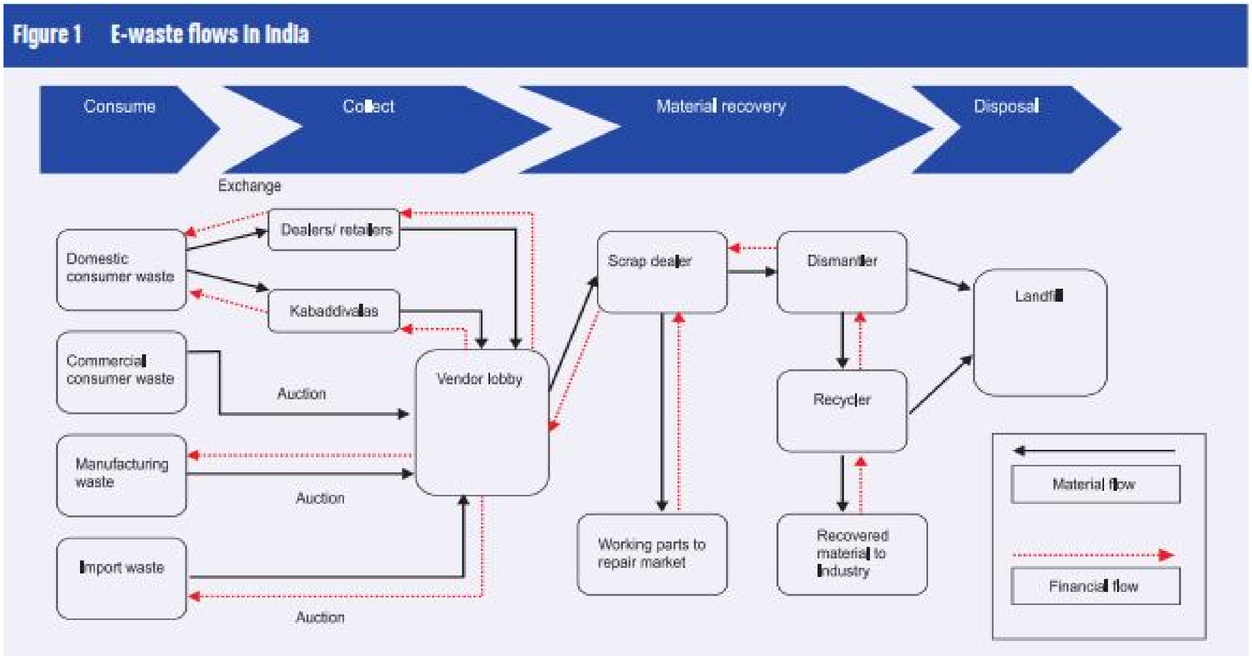
## PRESENT PRACTICE AND SYSTEMS:

### Current volumes and disposal methods:

- The electronics and electrical industry has, in recent years, emerged as one of the fastest growing segments of Indian industry in terms of production, internal consumption and export.

**1) Domestic e-waste disposal mechanisms:**

- The largest generators of e-waste in India are businesses and the government, while individuals and households contribute a smaller percentage of the total waste generated.
- This is mainly because most assessments on e-waste have focused on wastes from computers, mobile phone and television sets and do not take into account household consumer durables which are larger in volume and weight.
- There is no documented study on the waste generation from domestic goods such as washing machines, refrigerators etc.
- The larger electronic appliances also have a relatively longer useful life in India compared to the developed nations, resulting in comparatively lower waste generation from this sector.
- In future, it will be important and useful to take into account waste generation from households and individuals, as this would constitute a significant percentage of total waste generation in the country and necessitate measures to deal with such waste.
- The present data on waste suggests that computers and mobile phones have the highest or fastest obsolescence rates and account for a large segment of the total waste generated.
- These wastes are mainly disposed of to informal waste dealers and traders.




**2) Business disposal mechanisms**

- Ninety four per cent of the organizations do not have any policies on the disposal of IT products. This would effectively mean that they are free to dispose of their waste to unauthorized recyclers or traders.
- Eighty per cent of the replaced computers directly enter the e-waste stream either through scrap dealers or second hand markets and exchange or buy- back schemes.
- A large quantity still continues to be stored within the premises.
- In the government and PSUs, these are mainly auctioned of through tenders to informal scrap traders.
- A small percentage of waste from the government and businesses has started to flow to formal recyclers.

**Promising existing take-back practices in India:**

- Nokia, the largest mobile handset company in India, accepts mobile phones and accessories from consumers free of charge
- Wipro runs a take back-system for the computing system and charges the consumer for the logistics cost
- Dell has introduced a take-back system for consumers, and pay monetary incentive to consumers for returning the waste.
- HCL, an Indian brand, also extends take-back facility to its consumers, online as well as through collection centers in major cities.

**3) Individuals/Households**

- A large number of computers, television sets and mobiles when no longer needed are passed on to family, friends or people in the neighbourhood for further use, thus increasing their total life and reducing waste generation.

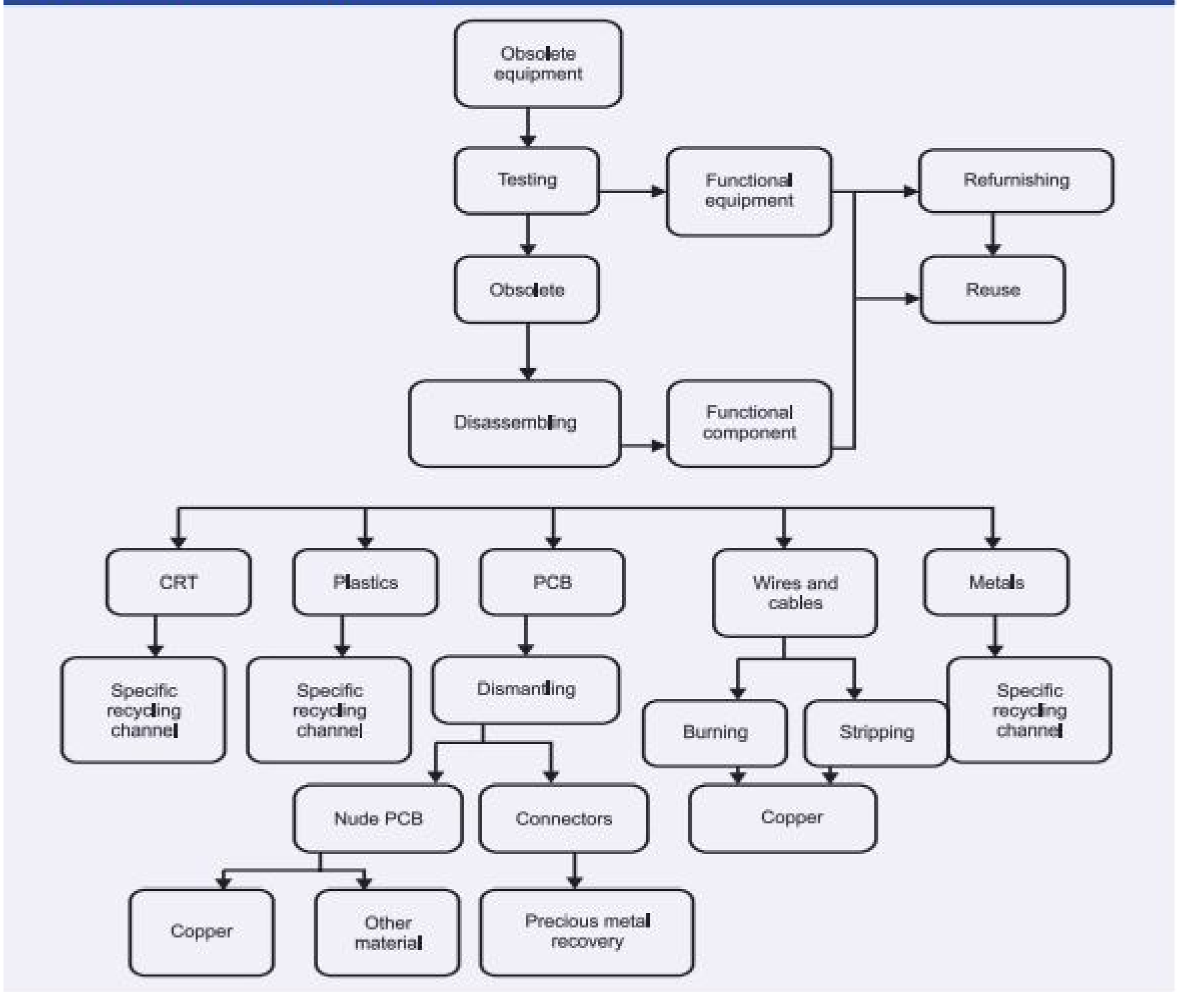
- More than 25 per cent of the total electronic products from households or individuals are estimated to enter the e-waste market directly (through second hand or scrap markets or through exchanges).
- Some of these wastes comprising smaller products is sold or disposed of to 16 local kabadiwalas (waste collectors).

**e-Waste Flows: Informal Sector**

- The informal sector, though unorganized, is part of a very well-oiled machinery and well-defined hierarchy and structure.
- The waste collectors or kabadiwalas are the most important link in this waste flow and are responsible for the collection of waste from all consumers and manufacturers.
- There is another set of operators, waste traders with better financial capacity, who bid for larger volumes of waste being discarded by companies and organization through auctions.
- The waste then flows down to scrap dealers, who at the first stage cannibalise the functional components, re-use them, also engage in refurbishing some of the computers and then shift the waste to the dismantlers.
- It is here that the waste is further separated as monitors, CPU and other parts and then broken down to individual components and materials.
- The waste then finally reaches the recycler by materials as glass, plastics, metal and circuit boards for material recovery.
- The recyclers in a particular cluster are generally engaged in a specific set of activities and operations.
- For other equipment like refrigerators, washing machines or air conditioners, the segregation is more material-based and plastic and metal parts are separated and treated in specific streams.
- Some useful components such as power supplies or motors are taken out for further use if possible.
- Since most electronic and electrical products have a value at the end of their useful life, the informal sector is able to pay the consumer to acquire this waste.

- The formal sector, because of its larger infrastructure and operational costs, finds it hard to compete with the informal sector.

Figure 2 E-waste flows in India (informal sector)




## <u>Financial flows:</u>

### Informal Sector:

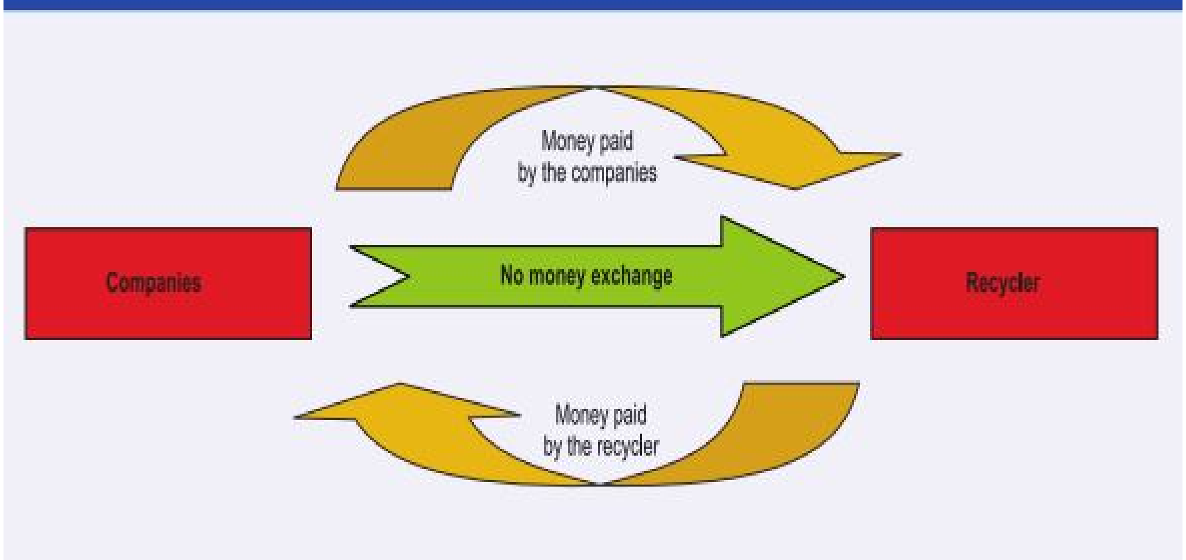
- The financial flow in the informal e-waste sector is very well-organized. The huge network of collectors, traders and recyclers make financial gain through re-use, refurbishment and recycling.
- The low infrastructure set-up and operational costs enable the informal sector to make profit from select end-of-life equipment.
- The economics of e-waste in India is also very different from that of developed countries.

- In contrast to most EU countries, where consumers pay a recycling fee, in India it is the waste collectors who pay consumers a positive price for their obsolete or end-of-life appliances.
- The small collectors in turn sell their collections to traders who aggregate and sort different kinds of waste and then sell it to recyclers, who recover the metals.
- The reusable equipments and components are segregated and attract a higher price in the market.
- In case of large companies and PSUs, the flow is a little different.
  - As the quantity is large and auctioned through tenders to highest bidders, only waste dealers with large financial capacities can participate in this trade.
  - At times the dealers jointly bid for the scrap and share the total waste among them for further processing.

**Formal Sector:**

- Financial Flows in Formal sectors works very differently.

Figure 3 Financial transactions in the formal recycling sector




- The financial arrangements vary for different users as well as for recyclers.
- Most users sell their waste to these authorized e-waste recyclers and hence get paid for the waste;
  - This mainly involves an auction process where recyclers bid for waste.

    - Another mechanism is where the users dispose of their waste without any cost, the recycling cost and the profit from material recovery being the recyclers' responsibility.
- A small segment of users has also emerged recently who are willing to pay for recycling services, including data destruction.

## PRESENT PROCESSING PRACTICES

**Informal Sector:**

- The processing of e-waste in India is largely carried out in an informal backyard setup. But this is unregulated and does not follow the prescribed environmental norms for handling hazardous substances.
- Around 25,000 people work in the informal e-waste sector (people working exclusively on e-waste).
- The processes and activities practiced by the informal sector have serious environment and social impacts (use of toxic chemicals, poor working conditions, child labor, etc.).
- The recycling chain of e-waste consists of two sets of processes:
    - Dismantling and segregation of components
    - Material recovery.
- **Dismantling and segregation of components** involves cannibalization of serviceable parts and renovation of components and products.
    - All unserviceable components and products are then shifted to dismantlers.
    - Individual products such as monitors, keyboards or CPUs are then dismantled and broken down to individual components using bare hands and basic tools such as hammers and screwdrivers.
    - Blowtorches and heaters are used to loosen solders to remove the components attached to the circuit boards.
    - Printed circuit boards are placed directly above the heaters, allowing the solder to melt and drop.
    - The process of dismantling is carried out in unventilated rooms without any semblance of housekeeping or concern for occupational health.

- These segregated components are sorted by their material composition and then shifted for material recovery.
- Most material recovery processes consist of acid bath for recovery of copper from circuit boards.
- Flame retardant-laden plastic is processed through crushers and extruders to create new materials and products.
- Cathode ray tubes are handled by bare hands and broken with hammers in an open environment to separate glass, which is used in small furnaces.
- Copper extraction by burning PVC is also prevalent.

- But, these result in the release of some toxic materials into the environment through emissions or effluents, which poses a serious health concern to workers and communities.
- Some of the processes used in the informal sector to recover material are described in the boxes below:

1. **<u>COPPER EXTRACTION FROM WIRES:</u>**

**Two kinds of processes are followed.**

**(i) Manual drawing of wires for copper:**

- In this process, the edge of a wire is cut with a knife and then the copper is extracted from the PVC with pliers.
- The copper is sold to copper smelters and the PVC is used for plastic graining.

**(ii) Extraction of copper by burning cables**

- The general practice for material recovery from a wire is simply to put it in fire either in closed or open drums.
- At some places, such burning takes place in front of the storehouses, in broad daylight.
- At a few places, the use of drums was observed for recovery of copper from PVC wire. The top of a big-sized drum is cut and a thin layer of iron net fixed in the middle.

- Sometimes the drum is fixed to the ground with mud, and a small opening is made to light the material and to remove the sludge. This layer of iron acts as a filter and allows only ash to go down.

Both processes, open or closed drum burning, are extremely harmful for the environmental and pose a serious occupational health hazard.

2. **PRINTED CIRCUIT BOARD RECYCLING:**

The recycling of circuit boards drawn from monitors, CPUs, printers, etc. involves a number of steps.

- First, gold-plated pins and the integrated circuits (IC) that can be re-used are manually removed.
- The core of each motherboard has a flat, laminated gold plate. These laminated parts are cut down and sold to goldsmiths for recovery of gold. The next step is heating on a stove to remove resalable components like ICs, condensers etc.
- Low heat is maintained to loosen only the chemical bond between solder and plastic. Then, resalable chips, condensers, etc, are plucked out from these plates.
- Then the pre-heated circuit boards are taken by other dealers for recovery of solder (which consists of lead and mercury).
- The method of solder recovery is very rudimentary. A burning kerosene gas kit is placed in a small water tub to store molten lead. The circuit boards are simply put on top of the stove; tongs are used on all sides. The lead extracted through heat application goes into a water tub – it floats due to low density. After de-soldering, the circuit boards are roasted or put in an acid bath and copper is recovered from them.
- The copper retrieval is done through two processes:

**1. Open burning:**

- After separating all remaining components, boards are sent to be burned in open pits to extract the thin layer of copper foils laminated in the circuit board. After charring, it is distilled through a simple froth-floating process.
- The ash content is washed out and copper, with some carbon impurity, goes to another recycling unit.

- Defective IC chips and condensers, which do not have a resale market, are also burned in small enclosures with chimneys, to extract metallic parts.

**2. Acid Bath:**

- In this process, first, the collected motherboards are dipped in the acid for few hours. Then, the acid, along with the motherboards, is heated in a big container to formulate crystal copper sulphate.
- Then, in the rest of the acid, iron chips are added and sludge-containing copper is extracted, which is further put into an ion exchange process so that copper may be recovered from it.

## 3. PLASTIC RECYCLING:

- Plastics scrap from computers is manually fed into the shredder/grinder and is shredded into flakes or grounded or cut to reduce the size of plastic parts.
- After the grinding process, the plastic is segregated into FR plastic and non-FR plastic by use of salt water in sink-float tanks.
- The FR contaminated-plastic pieces settle at the bottom of the container of saline water and are collected separately.
- These grinded plastic pieces are then dried and packed and are bought by pellet-making units.
- At the pellet-making units, situated mainly in the same areas as grinding units, these grinded plastic pieces are first washed to remove dirt.
- The plastic granules are then dried in a dryer or in the open, after which they treated in a mixture machine. The friction and the heat thus generated make the material soft and pliable.
- After preliminary processing, the recycling of plastics involves extrusion to make new products. It is at this stage that virgin plastic is added to these recycled granules.
- Polymer processing extrusion is the most important step. In this, the input material is fed in through a shaft and is melted by passing it through a heated chamber.

## ENVIRONMENTAL AND HEALTH CONCERNS OF INFORMAL SECTOR:

- Open burning of PVC cables releases toxins into the environment
- Burning of PCB releases a cocktail of toxic gases into the environment.
- Use of mercury (a known neurotoxin) for recovery of gold releases mercury into the environment.
- Concentrated acids are thrown on to open land flowing into surface water n Heating of circuit boards for loosening of integrated circuits and other components release lead, mercury, chromium etc into the environment.
- Residues are thrown into open land and dumpsites allowing leaching of toxins into land and surface water.
- The workers do not have any protective clothing and inhale all poisonous gases released during the processes.
- Many workers are women and children who work with bare hands and constantly use caustic soda and acids for washing and cleaning of boards, and stripping causing pain to their hands and other body parts.
- Workers inhale fumes of acids during these processes.
- In the absence of work benches they continue to sit in odd positions for long hours.
- Poor housekeeping of chemicals and reagents cause accidents and physical harm to workers.

## FORMAL SECTOR

- The formal recycling sector in India is in a growing stage.
- All formal recycling facilities, currently 14, are registered with the regulators and have the requisite permission to engage in set of processes for e-waste disposal and management.

- These have been granted permission under the Hazardous Wastes (Management, Handling and Transboundary) Rules 2008.
- The processes of formal recycling include **dismantling and segregation, shredding of PCBs and magnetic separation.**
- These fractions are subsequently transferred to specialized recyclers who are experts in recycling materials such as plastics or glass.
- Most formal recyclers are currently exporting their shredded consignments of PCBs for recovery of precious material to foreign facilities like Umicore, Xtrata and TESSAM.
- The formal recycling companies are faced with one of the biggest challenges of material supply as they are in direct competition with the informal sector who usually outbid the formal operators due to their very low operating costs.
- It is estimated that of the total waste available for processing almost 95 per cent is handled by the informal sector and only 5 per cent by the formal sector.

# Assignment and tutorials Questions:

**Short answer Questions:**

1. Define e-Waste?
2. What do we do with e-waste?
3. Why is e-waste a problem?
4. Write any four problems caused by informal sector processing practices?
5. Draw a neat sketch of financial flow mechanism in Formal Sector?
6. Draw a neat sketch of e-waste flows in the Informal Sector?
7. Differentiate between Domestic e-waste disposal mechanism and Business Disposal mechanism?
8. Discuss the process of plastic recycling in the Informal Sector briefly?

**Long answer Questions:**

1. Explain about processing techniques used in Informal Sector?
2. List out the Environmental and Health Concerns of Informal Sector Processing Techniques?
3. Describe how the financial flows in Informal Sector and Formal Sector?
4. Describe how the e-waste flows in Informal Sector with a neat Sketch diagram?
5. Explain about e-Waste Disposal Mechanisms?
6. Explain about e-Waste flow and financial flows in Informal Sector?
7. List the steps and processes for Recycling Printed Circuit Board in Informal Sector.
8. Describe the process of Copper extraction from wires in Informal Sector?

# UNIT-2

**Unit-2 Syllabus: WEEE (Waste Electrical and Electronic Equipment) - Toxicity and Health**

**Problems and Issues of e-Waste, Initiatives to manage e-Waste, strengths and weaknesses of the current system.**

## Learning material:

### Problems and Issues of e-Waste:

- **Environmental Hazards:**
  - When e-waste is disposed of or recycled without any control, there are negative impacts on the environment and human health.
  - Presently, the informal processing of e-waste in India is not monitored for compliance with environmental regulations, and as a result, the crude methods used to reclaim materials may cause pollution, creating serious problems to environmental ecology and human health.
  - E-waste contains more than 1,000 different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium and BFR.
  - The recovery process being rudimentary has limited efficiency of material recovery, resulting in loss of significant amount of precious metals and disposal of residues of toxic materials into water bodies and soil, which creates serious issues of water and soil pollution.
  - There are also issues of cross-contamination of materials as plastics containing BFR is recycled and mixed with virgin materials and other plastics for manufacture of new plastic products.
  - The other important aspect is the wide dispersal of toxic chemicals and elements into the environment due to the highly dispersed recycling units across the country, resulting in problems such as

- Emissions of dioxins and heavy metals like lead, cadmium, mercury in air;
- release of BFR;
- indiscriminate dumping of spent fluids/chemicals (contaminating soils);
- Groundwater contamination (through leachate) and land filling of non-recyclables.

➢ **Occupational health issues:**

- In the informal sector, there is little regulation in place to safeguard the health of those who handle e-waste.
- Workers are poorly protected in an environment where e-waste from PC monitors, PCBs, CDs, motherboards, cables, toner cartridges are burned in the open and release lead and mercury toxins into the air.
- Many workers are also engaged for long hours, sitting cramped in unventilated rooms with inadequate lighting.
- Most people involved in informal recycling are the urban poor with low literacy levels, and hence with very little awareness regarding the hazards of e-waste and the recycling processes.
- There are considerable number of women and children who are engaged in these activities who might be more vulnerable to the hazards of this waste.
- Many of these workers complain of eye irritation, breathing problems and constant headaches, but in absence of any epidemiological studies, significant data is available.
- The workers also do not have access to any counseling or regular health check-ups.
- Some critical occupational health issues are
  - inadequate working space;

  - poor lighting and ventilation, straining the eyes and breathing polluted air;
  - no work bench hence sitting cramped on the ground for long hours;
  - inhaling toxic fumes;
  - Exposure of body parts to fire, acid and other chemicals; and unavailability of clean drinking water and toilets.

➢ **Shortage of materials and its recovery:**

- The existing formal recycling companies, though, have reflected growth in the last few years, but complaints of non-availability of raw materials and their inability to source adequate materials keep coming.
- They face direct and stiff competition from the informal sector, especially in sourcing raw materials from the market; the informal sector enjoys the distinct advantage of a wide collection network.
- These recycling companies are also in various stages of setting up and consolidating their operations, hence the associated teething issues.
- These are further complicated in the absence of any larger policy and regulatory framework, which provides a level playing field for the operators.
- The informal traders and recyclers are at a further advantage due to their minimal infrastructure and low operational costs.
- The low awareness among the consumers regarding the environmental concerns of improper recycling of discarded equipment means that they give no thought to proper disposal.

**Initiatives to manage e-Waste**

➢ **Current policy framework:**

- Currently e-waste in India is broadly covered under the Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 2008.

- The Ministry of Environment and Forests, Government of India, is the nodal agency at the Central level.
- The Environment (Protection) Act 1986 is an umbrella act that covers hazardous and other wastes and provides broad guidelines to address these.
- The Hazardous Wastes Rules provide for the control of generation, collection, treatment, transport, import, storage and disposal of wastes listed in the schedule annexed to these rules.
- The ones applicable to e-waste are mentioned in the below Table

**Table 2.3 Processes generating hazardous waste relevant to e-waste under the Hazardous Wastes Rules, 2008**

| Processes | Hazardous waste |
|---|---|
| Electronic Industry | Process residues and wastes<br>Spent etching chemicals and solvents |
| Secondary production of copper | Spent electrolytic solutions<br>Sludges and filter cakes<br>Flue gas dust and other particulates |
| Secondary production of lead | Lead bearing residues<br>Lead ash/particulate from flue gas |

- Schedule 2 of the Hazardous Waste Management and Handling Rules lists waste substances which should be considered hazardous unless their concentration is less than the limit indicated in the said Schedule. Some of these may be applicable to appliances.
- E-waste is also covered under Schedule III which governs export/import.
- E-waste is also covered under Schedule IV, listing hazardous wastes that require registration for recycling/ reprocessing.
- Besides the Hazardous Wastes Rules, the following rules cover other kinds of waste.
    - Municipal Solid Wastes (Management and Handling) Rules, 2000
    - Bio Medical Waste (Management & Handling) Rules, 1998
    - The Batteries (Management and Handling) Rules, 2001

- The existing Hazardous Waste Rules were drawn up primarily to address issues of waste generated in industrial processes.
- A consensus has emerged that this is inadequate to cover issues related to specificity of e-waste.
- The government after prolonged deliberation issued a guideline for safe management of e-waste.
- This guideline is a voluntary instrument and is largely attempted to address the technological gap. While the guideline was a step forward, it did not provide the requisite drivers for changing the ground situation.
- The voluntary nature of the guideline was a limiting factor as it failed to provide a level playing field to the brands and trigger significant actions.
- Some of the stakeholders, led mainly by civil society groups and industry associations, suggested that a mandatory regulation specific to e-waste would be the most desirable way forward.
- There is a strong case for separate rules for e-waste due to the distinct features in the flow of e-waste and its hazardous waste requiring mandatory controls.
- The Hazardous Wastes Rules address the needs for hazardous wastes which are in-process wastes originating from a defined source.
- E-waste generation by consumers and businesses is widely dispersed.
- Thus the flow of e-waste needs to be regulated by clearly specified responsibilities and liabilities of each stakeholder: producer, consumer, waste collector, dismantler and recycler.

➢ **The Union Government's new e-waste rules:**

- The Ministry of Environment and Forests took up the e-waste issue in 2004 and has recently engaged with various stakeholders to receive inputs and perspectives on the issue.

- The government, until a few years back, was of the opinion that the current Hazardous Wastes Rules with certain amendments would be adequate to cover aspects of e-waste.
- However, due to pressure from civil society groups and public opinion, the Central Pollution Control Board issued a guideline for safe management of e-waste. Later, the inadequacy of both the Hazardous Waste Rules and the voluntary nature of the guidelines have been acknowledged by all stakeholders, including the MoEF.
- The ministry has drafted the E-waste (Management and Handling) Rules, 2010 that incorporates some of the best practices and experiences from across the globe.

➢ **Initiative from civil society to lobby for e-waste legislation:**

- Civil society organizations in India have been voicing the need for a separate regulation on e-waste, and have lobbied for an appropriate regulation for management of e-waste in India.
- These groups were able to create a unique common platform for all stakeholders to come together and create a common ground on the e-waste issue.
- A core group comprising of members from Greenpeace, MAIT, GTZ and Toxics Link then took up the task of developing a framework for the regulation.
- It was a very transparent and consultative process involving all stakeholders across cities and took almost a year to finalize the text.

## **Strengths and Weaknesses Of The Current System:**

Main strengths of the current system:

- The total amount of historical e-waste in India is still low; hence it will be simpler to deal with this aspect.
- Most computers in use are with the governmental or corporate sector which makes it easier to control generated e-waste.

- Experiences from informal collection systems exist and could partly be applied to e-waste collection.
- There is a recycling industry, which could absorb the plastic and ferrous metals and aluminum fractions.
- Availability of human resource leads to more mechanized processes and reduce cost.
- Ability of informal sector to recycle and extract value from most e-waste prevents and filling of such waste.

**Main weaknesses of the current system:**

Main weakness of the current system:

- There is no specific policy or legislation for e-waste management
- There is no special infrastructure available for the formal collection and recycling of e-waste.
- The problem of imported computer junk seems to be serious.
- The informal activities associated with e-waste might lead to the exposure of individuals to hazardous substances and local pollution of the environment.
- Improper recycling and disposal of e-waste lead to an increase of pollutants in environment.
- There is a general lack of awareness among consumers and collectors of the potential hazards of e-waste to human health and the environment.
- There are weak regulatory and monitoring mechanisms in the country.
- Disproportionate sharing of profits among the informal recycling community.

# E-waste Management

## UNIT-3

## Extended Producer Responsibility (EPR):

- **Fundamentals of EPR as applied in the EU:**
  - EPR is an application of the Polluter Pays principle.
  - A core feature of any EPR-based policy is that it places some responsibility for a product's end-of-life environmental impacts on the original producer and seller of that product.
  - A crucial element of EPR is to make producers and retailers responsible for the take-back of discarded equipment (physical responsibility) and oblige them to cover the costs (financial responsibility).
  - In the application of EPR under sector policy such as e-waste, the government is responsible for enacting legislation to set specific collection targets and recycling rates, define categories, and prescribe data collection and reporting to monitor compliance.
- **Objectives of Extended Producer Responsibility (EPR)**
  - Governments can have several objectives for developing EPR programmes, the principal ones are : **environmental, economic and social.**
  - **Environmental objectives:**
    - Environmental objectives focus on designing for the environment and reducing the consumption of natural resources through high recovery of products and materials.
    - Effective separate collection of discarded products, keeping products and materials out of the general waste stream to facilitate better recovery and disposal of the product and its material.

    - High recovery of products and materials and components incorporated in the products.
    - Environmentally sound disposal of products that cannot be re-used or recovered.
- **Economic objectives:**
    - The objective is to shift all or part of the physical and/or financial burden of the management of post-consumer products from local governments, and thus the general tax payer, to:
        - the producer and other economic operators in the value chain of a product (including importers, distributors and retailers);
        - the consumer, through internalisation by the producer of the waste management costs incurred in the retail price of new products.
- **Social objectives:**
    - An EPR-based system can and should lead to increased recycling, under conditions desirable from the perspectives of the environment, health and society, and as such to the creation of meaningful jobs in the labour-intensive recycling sector.

**<u>Factors for successful e-waste management:</u>**

To achieve successful e-waste management, it is important to meet certain conditions as applicable in India.

- **Extended Producer Responsibility applied:**
    - Legislation and enforcement have to encourage producers to accept responsibilities and help producers to achieve targets.
    - Collection and recycling targets have be stated SMART (specific, measurable, appropriate, realistic, time-bound).

- Producers have to (be able to) provide reliable information on e-waste collected and recycled.
- Monitoring responsibilities must take a minimal effort with regard to administration and enforcement.
- EPR must be affordable; costs have to be proportionate to its purpose.

- **Proportionate contribution to e-waste management:**
  - Government has to monitor fair and proportionate contribution of producers.
  - Monitoring and enforcement must be manageable and require least effort from the government.
  - Producers have to (be able to) provide reliable information on products put on market as well as e-waste collected and recycled.
- **Compliance systems in place**:
  - Due to the need to minimize governmental efforts on monitoring and complexity of the unregulated e-waste market, the number of compliance systems should be limited.
  - The burden on governmental capacity should be minimized.
  - Compliance systems should aim to collect as many appliances as possible and achieve the highest recycling efficiencies as possible.
  - Compliance systems should operate independent of the interests of producers.
- **Collection effective**:
  - Regulated take-back systems must not compete with existing collection channels, but use them as much as possible.
  - Effective and efficient collection must be achieved by using basic economic principles, such as the demand and supply for scrap metals or other raw materials.
  - Regulated take-back system must not lead to loss of employment.
  - Collection must remain affordable.

- There must be an effective monitoring of the receipt of appliances and payment of rewards.

- **Recycling adequate**:
  - New recycling facilities must not lead to loss of employment.
  - Innovating recycling technologies must be affordable.
  - Recyclers must be able to provide reliable data.
- **Monitoring of e-waste management effective**:
  - Register and monitoring agencies must be reliable and act independently of producers.
  - Required information must be available and provided.
  - Means for sanctions must be available for violating regulations.
  - Monitoring should be administratively set up as simple as possible, but still effective enough to be able to observe deviations.
  - Monitoring should include on-site examination.
- **Funding of e-waste management**:
  - Funding must be transparent, information on funding made available to the public.
  - Funds must be sufficient, yet must not abundant, and may only be used to finance e-waste collection and recycling.
  - Producers should not be allowed direct access to funds.
  - Funding must be monitored by government and/or public bodies.
- **Reporting mechanism in place:**
  - There must be resources to weigh and register e-waste at collection points and recyclers.
  - Documentation should be kept at collection points and recyclers.
  - Reliability of documentation at collection points and recyclers must be audited regularly.
- **Creating awareness:**
  - The use of different types of media must ensure that illiterate people also understand the message.

- Government must set SMART targets to be achieved.

**Goals of e-Waste management:**

- Producers collect and recycle discarded appliances as well as provide necessary funding (implementing EPR).
- All producers own up responsibility and contribute to e-waste management.
- Tasks and duties for compliance are distributed effectively and clearly (creating compliance systems).
- E-waste is collected and transported to authorised agencies/recyclers.
- E-waste is processed and recycled adequately.
- Good information to regulator and policy makers about compliance.
- Sufficient funding available for collecting and recycling.
- Awareness among citizens regarding toxicity and hazards of improper e-waste disposal.

**Actions to be considered to achieve goals of e-waste management:**

- **Goal 1:** Producers collect and recycle discarded appliances as well as provide necessary funding (implementing EPR).

| Present Situation | Possible Actions |
|---|---|
| High costs of compliance and lack of regulation does not create favourable conditions for producers to accept EPR. | Imposing responsibilities expressed into targets to be achieved by producers. Ensuring that all producers contribute to e-waste management equally. |
| No reliable information on collection and recycling of e-waste | Generate information on collecting and recycling of e-waste. |

- **Goal 2:** All producers own up responsibility and contribute to e-waste management.

| Present Situation | Possible Actions |
|---|---|
| Little understanding of producers and the numbers of appliances put on the market. | Introducing a system to register new appliances, how producers fulfil their obligations, and to evaluate results. |

- **Goal 3:** Tasks and duties for compliance are distributed effectively and clearly (creating compliance systems).

| Present Situation | Possible Actions |
|---|---|
| An unregulated market of e-waste impedes regulated collection of appliances. | Inviting parties to set up compliance systems.<br>Authorizing parties to set up compliance systems.<br>Creating a regulated take back system. Contracting collection points, transporters and recyclers that can process in the required way. |

- **Goal 4:** E-waste is collected and transported to authorized agencies/recyclers.

| Present Situation | Possible Actions |
|---|---|
| High value leads to an unregulated trade of e-waste and unregulated collection channels. | Creating closed (regulated) take back systems. |

| | |
|---|---|
| Collection is profit-driven and e-waste is brought to the highest bidder. | Create legal collection centres that pay market prices.<br>Raising awareness regarding disposal facilities.<br>Raising awareness about impact on environment |
| Lack of data collected e-waste. | Improve information on collecting and recycling of e-waste. |

- **Goal 5:** E-waste is processed and recycled adequately.

| Present Situation | Possible Actions |
|---|---|
| Processing and recycling of e-waste largely causes environmental issues and affects health of workers. | Introducing recycling standards |
| Capacity and technologies of recyclers are insufficient | Promote creation of large scale recycling plants. |
| Lack of data available on appliances processed and recycled. | Innovating recycling technologies |

- **Goal 6:** Good information to regulator and policy makers about compliance.

| Present Situation | Possible Actions |
|---|---|
| Lack of information on whole cycle of e-waste management | Creating register and monitoring agencies as part of producer's responsibility. |

| | |
|---|---|
| Government’s capacity for monitoring is limited. | Focusing monitoring tasks of government on:<br>- assuring reliability of collection and recycling data and evaluating results;<br>- equal contribution to e-waste management by producers;<br>- mobilisation and use of funds by producers |

- **Goal 7:** Sufficient funding available for collecting and recycling.

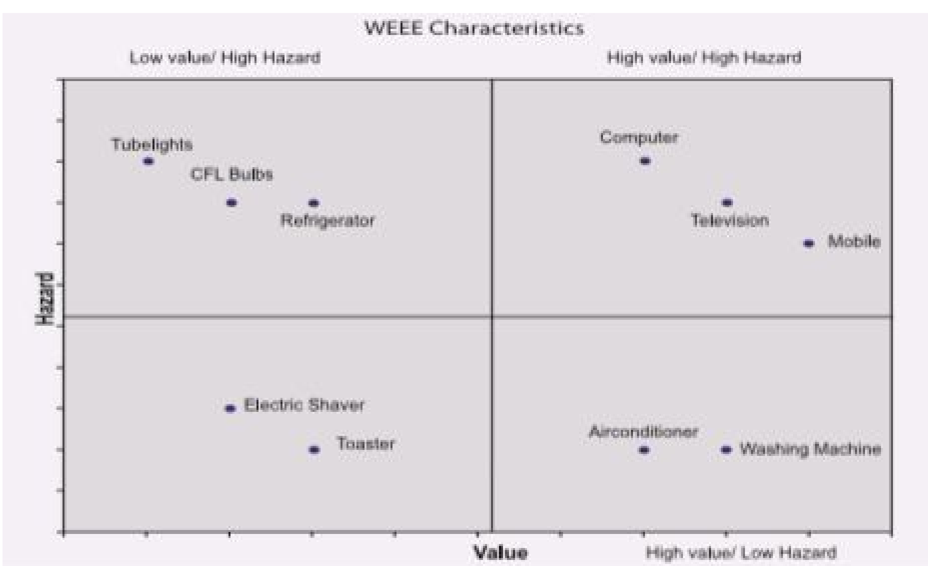
| Present Situation | Possible Actions |
|---|---|
| Only e-waste with sufficient resale value is collected and recycled.<br>Prices do not take environmentally sound processing into account | Fund the collection and recycling of all types of e-waste, particularly kinds with hazardous materials. |

- **Goal 8:** Awareness among citizens regarding toxicity and hazards of improper e-waste disposal.

| Present Situation | Possible Actions |
|---|---|
| Insufficient knowledge of the environmental impact and health risks of handling e-waste.<br>Disposal of appliances is driven by the value of the materials only. | Selecting a party responsible for creating awareness (either government or producer).<br>Setting measurable goals. |

**Product scope and priorities:**

- The scope of products included in the currently operating WEEE management systems varies widely world over.
- For example, the EU WEEE directive covers a broad range of end-of-life equipments, but in other countries like Japan or Korea or some US states, the product scope is more limited.
- One of the key considerations is that discarded equipments vary in terms of hazardous contents and recycling value. For example, recycling of computers and mobile phones is more profitable than recycling electric shavers, but their hazard content is higher.
- Since the e-waste management problem is complex for India for a number of reasons and the capacity of the government is limited, it is important introduce a **policy and legislation that takes a phased approach.**
- Three main considerations are:
    - Hazard of used materials to environment and human health (also when improper processing).
    - The value of materials present in the products and thus economically interesting to recycle.
    - The volumes of products discarded.



- **High hazard content and high recycling** value deserve priority, so that the immediate concern of environmental contamination and resource recovery is addressed.
- The **low value/high hazard category** also deserves priority, and needs application of the EPR principle to generate funding as it may not be profitable enough based on market value.

**Collection/take-back System:**

- Ensuring a closed system with minimum leakages from the collection points will not be easy, considering the number and variety of players (collectors, traders, recyclers, dismantlers, etc.).
- India needs careful evaluation to set up **municipal collection sites**. Collection through a government agency or through municipal bodies might mean a uniform collection network, irrespective of large or small e-waste generation points.
- Smaller cities or villages, which may not be generating huge amounts of e-waste, may not be profitable for private collection agencies, as the infrastructure costs would be high but the collection would be low.
- Assigning more **responsibility to municipalities** would also mean additional burden on local governments, which are already struggling with management of normal municipal solid waste.
- An advantage of **involving local government** is its large number of workers, its command on land for a disposal site, and its infrastructure of collection.
- **Existing institutions** could also play a role, such as **post offices, petrol stations, schools**, etc. that are widely present, particularly to cover smaller cities, towns or villages. Compliance schemes can cooperate with such institutions.
- **Retailers** provide a valuable interface with consumers when new products are being purchased. It is a very convenient option for the

consumers, although retailers have been seen to resist the extra effort involved.

- **Producers or a group of producers** setting up their own take-back system is a practice used in number of countries. Producer Responsibility has the advantage of producers assuming direct physical responsibility of its own product, and it may stimulate making waste minimizing upstream changes in the product.
- **Special collection points** set up by compliance schemes on behalf of producers is an option that should be explored.
- **Door-to-door collection** of bulky waste like refrigerators, air conditioners and washing machines should be considered, and a definite option is the compulsory take-back of old bulky appliance/equipment to be undertaken by the retailer while delivering.
- **Special collection events**, which are used in the US, could also be an option an opportunity. It may also release equipment that users have stored in their houses and offices.

**<u>Funding:</u>**

- Funding options for India are listed below.
    - **Visible fee:** The producers charge a visible fee to the consumers for managing the cost of products they put in the market. (In the EU, it is used for historical products).
    - **Recycling or recovery fee:** Another mechanism for charging consumers at the time of purchase of new products and related to the future cost of recycling of products.
    - **Reimbursed cost:** Consumer deposits the cost of management of e-waste, which is reimbursed after receiving the end-of-life product.

# E-waste Management::UNIT -IV

## Recycling of e-scrap in global environment-opportunities and challenges:

### Introduction

Due to the complex mix of metals, plastics, glass, and other valuable as well as toxic substances, e-waste can cause significant environmental damage if not treated in an environmentally sound way. It also contains a significant amount of valuable secondary resources, which should not be wasted. Hence, more attention should be paid to the overall performance and transparency of the recycling chain dealing with e-scrap. While the first steps in this chain, that is, collection, dismantling, and shredding/preprocessing, are usually taken care of on a local/regional level, the end-processing to recover refined metals or plastics from output streams generated in pre-processing takes place on a global scale in specialized operations, involving an international division of labour and economies of scale. Most of the valuables, as also most of the toxic substances, in e-scrap are contained in the circuit boards. Only a few appropriate 'integrated smelter processes' are available globally for the efficient and environmentally sound recovery of metals from circuit boards. Such a state-of-the-art smelter and refinery process has a major impact on the recycling efficiency, in terms of the elements and valuables that are recovered as well as the overall environmental performance. This article describes the state-of-the-art recovery of metals from e-scrap and also focuses on the opportunities and challenges for India.

## Recovery of metals from e-scrap at Umicore

Umicore is a specialist metals and materials group, striving for growth and leadership in four areas: advanced materials, precious metal products and catalysts, precious metal services, and zinc specialities. The company focuses on technology, innovation, and product differentiation, and is committed to sustainable value creation and closing the loop for its own as well as for external products. It currently employs 17 000 people worldwide, and achieved a turnover of 8.8 billion euros in 2006.

The business unit Umicore Precious Metals Refining operates an integrated metals smelter and refinery at Hoboken, Belgium, which is involved in the recovery of precious metals, special metals, and non-ferrous metals from complex secondary materials. The raw materials include recyclables such as printed circuit boards, mobile phones, and other e-scrap fractions containing precious metals, automotive catalysts, industrial catalysts, and industrial or smelter by-products, namely, anode slimes, slag, flue dusts, and so on. Umicore has adopted a unique innovative technology to process a wide range of complex materials containing precious metals for an international customer base. The company applies world class environmental standards, recovering 17 different metals while generating minimal waste (Figure 1).

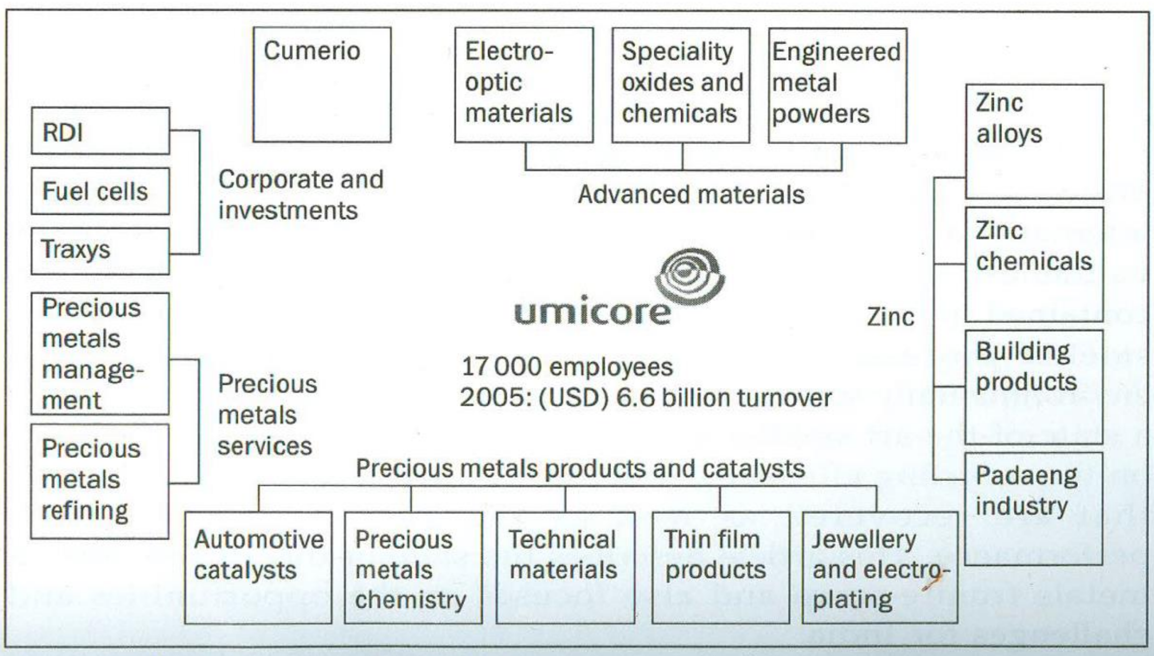



**Figure 1** Business activities of Umicore

**Table 1** Material composition of electronic equipment

| | | *Cell phone (1999)* | *Cordless phone (1999)* | *Portable audio (2000)* | *DVD player (2001)* | *DVD recorder (2002)* | *Calculator* | *TV board* | *PC board* |
|---|---|---|---|---|---|---|---|---|---|
| Weight | g/unit | 125 | 175 | 515 | 3050 | 4350 | | | |
| Cu | % | 13 | 10 | 21 | 5 | 6 | 3 | 10 | 20 |
| Al | % | 1 | 2 | 1 | 2 | 4 | 5 | 10 | 5 |
| Fe | % | 5 | 13 | 23 | 62 | 57 | 3 | 28 | 7 |
| Plastics | % | 57 | 41 | 47 | 24 | 25 | 61 | 28 | 23 |
| Glass | % | 2 | | | | | 13 | 6 | 18 |
| Others | % | 21 | 32 | 8 | 6 | 7 | 14 | 15 | 22 |
| Ni | % | 0.1 | 0.1 | 0.03 | 0.05 | 0.1 | 0.5 | 0.3 | 1 |
| Pb | % | 0.3 | 0.8 | 0.14 | 0.3 | 0.4 | 0.1 | 1.0 | 1.5 |
| Sn | % | 0.5 | 0.9 | 0.1 | 0.2 | 0.2 | 0.2 | 1.4 | 2.9 |
| Ag | PPM | 1340 | 1350 | 150 | 115 | 170 | 260 | 280 | 1000 |
| Au | PPM | 350 | 120 | 10 | 15 | 25 | 50 | 17 | 250 |
| Pd | PPM | 210 | 95 | 4 | 4 | 5 | 5 | 10 | 110 |

PPM – parts per million

Table 1 gives the material composition of some electronic goods such as cell phone, cordless phone, DVD players, DVD recorder, TV/monitor circuit boards, and computer circuit boards. Table 2 gives the percentage of various materials, including plastics and steel, in electronic goods. These figures are only indicative, obtained from specific samples, and they can also vary significantly within one type of equipment, but the order of magnitude is correct.

**Table 2** Weight versus value distribution

| Value share | *Fe (%)* | *Al (%)* | *Cu (%)* | *Total PM (%)* | *Ag (%)* | *Au (%)* | *Pd (%)* |
|---|---|---|---|---|---|---|---|
| TV board | 4 | 11 | 42 | 43 | 8 | 27 | 8 |
| PC board | 0 | 1 | 14 | 85 | 5 | 65 | 15 |
| Mobile phone | 0 | 0 | 7 | 93 | 5 | 67 | 21 |
| Portable audio | 3 | 1 | 77 | 20 | 4 | 13 | 3 |
| DVD player | 13 | 4 | 36 | 48 | 5 | 37 | 5 |
| Calculator | 0 | 5 | 11 | 84 | 7 | 73 | 4 |

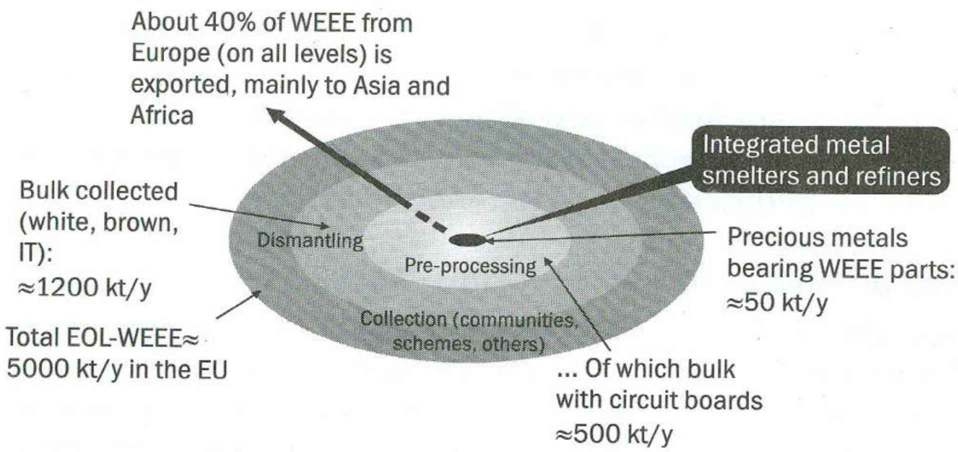
PM – precious metal

As compiled in Table 2, it can be seen that in the grey and brown goods (like TV, DVD player, mobile phone, and so on), plastics and steel dominate the weight of the equipment. In PC boards, cell phones, and calculator, precious metals account for more than 80% of the value; while in TV boards and DVD player, they account for more than 40% of the value. The following can be concluded from the two tables.

- Toxic substances and other harmful substances are usually concentrated in circuit boards.
- Any major loss of precious metals drastically decreases the net recoverable value from electronic goods.
- Material composition can have a significant impact on recycling requirements and technical processes, including emission control.
- Mixing different qualities during collection and pre-processing can negatively influence recycling returns (dilution, technical constraints).
- Legislation impacts the material composition of the electronic goods (and hence the recycling requirements); for example, the ban on lead by the EU (European Union) ROHS (Restriction of Hazardous Substances) directive implies increased use of tin, copper, bismuth, and silver in solders.

## Recycling chain for electronic scrap

Recycling is more complex than it appears due to the interlinking and interdependence of different steps, namely, collection, dismantling, shredding, pre-processing, and end-processing, which involve smelting and refining of various materials and metals. Among the various steps, end-processing is crucial for value generation and control of toxic substances. The overall efficiency of the recycling process depends on the efficiency of each single step. In this regard, making available end-of-life material and ensuring that it is fit for recycling still has the highest priority. Today, probably more than 50% of the IT (information technology) equipment escapes recycling due to several reasons, including incomplete collection, disposal of e-waste along with municipal waste, and export of the material to various developing countries (that lack appropriate recycling infrastructure). Further losses occur due to improper recycling techniques and losses in side streams such as effluents, dust, and slags. Figure 2 illustrates the estimation of today's European e-scrap market. Out of a total collection




EOL – end-of-life; WEE – waste electric and electronic equipment
**Figure 2** Estimation of the European e-scrap market

potential of about 5 million tonnes of e-scrap per annum, only about 1.2 million tonnes of e-scrap per annum is being collected, which includes the white goods (fridges, washing machines, and so on). The portion of e-scrap containing precious metals – brown goods and IT equipment – accounts for about 0.5 million tonnes/annum, and the circuit board fraction itself is estimated at 50 000 tonnes/annum. It is assumed that about 40% of the collected e-scrap leaves Europe as 'reuse' or waste exports, and in this, IT equipment has a relatively large share.

By using appropriate end-processing technologies for e-scrap fractions, it is possible to achieve metal yields of 95% or more in the state-of-the art integrated smelters and refineries. However, due to inefficiencies in collection and pre-processing, the overall yield of the recycling chain is usually well below 50%. Efficient and environmentally sound treatment of complex e-scrap fractions is technologically demanding and capital-intensive. Hence, most of the dismantling and pre-processing can be done locally, while for certain complex fractions derived therefrom, such as circuit boards, economies of scale should be used, which usually requires shipment to specialized integrated smelters and refineries located in developed countries.

Backyard recycling, which usually leads to the release of toxic substances, must be avoided. Recovery yields should be increased. There should be no negative impact on people's health and the environment. Also, treatment should not be carried out in smelters without appropriate off-gas purification installations due to the danger of emission of dioxins and furans. Moreover, adequate infrastructure, trained workers, awareness, and appropriate technology and experience are required for successful recycling. Incineration, landfilling or any other kind of disposal of e-scrap should be avoided as far as possible.

## State-of-the-art metal recovery from e-scrap

As described above, within the recycling chain, a combination of mechanical and metallurgical processes is used for the separation of metals and their recovery. The various stakeholders need to cooperate, bringing in their specific expertise and technology. Usually, the initial steps in the recycling chain comprise manual and mechanical treatment, while for the final metal recovery, sophisticated metallurgical processes are required. Also, in the initial steps of the recycling chain (for example, collection, sorting, dismantling), usually a large number of smaller organizations are active on a more local level, while further downstream (for example, shredding, ferrous smelting, copper smelting), fewer and bigger companies operate within a wider geographical area. For the efficient metallurgical processing of complex metal fractions like circuit boards, globally, only a handful of large-scale, specialized integrated smelters exist. Umicore Precious Metals Refining falls into this latter category, receiving circuit boards and other precious metals from all parts of the world, and closely cooperating with logistics and pre-processing companies that operate on a local and regional level. The separation of metals and their recovery involve mechanical and metallurgical processes (Figure 3).

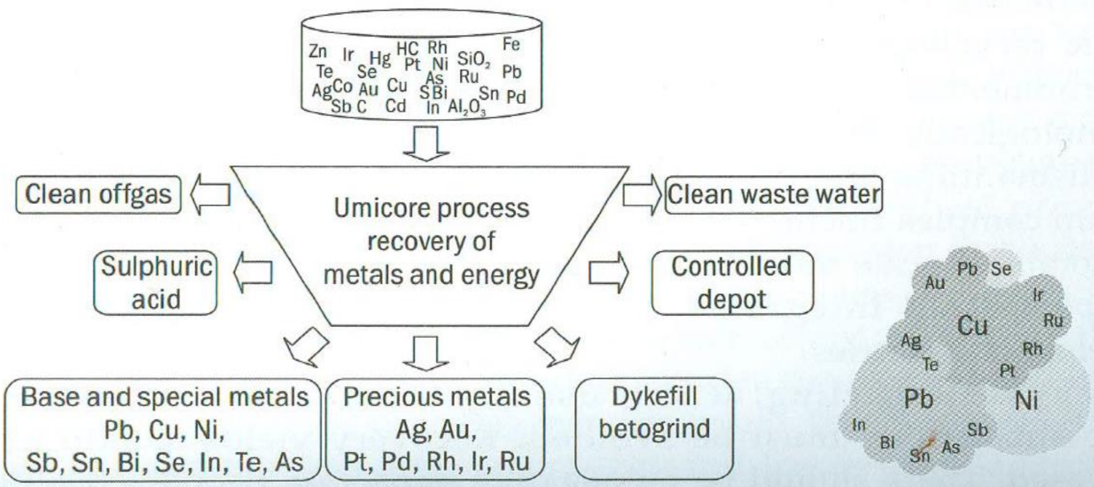



**Figure 3** Principle input-output streams for Umicore's integrated metals smelter and refinery; Cu/Pb/Ni are used to collect precious and special metals

## Mechanical process

To remove components like circuit boards, casings, cables, batteries, and so on, electronic devices are initially treated using manual dismantling or crushing with subsequent manual or mechanical sorting. The remaining device subsequently usually undergoes a (further) mechanical reduction in size (shredding), and then is sorted into defined output fractions due to their specific physical and optical characteristics. The sorting processes used include magnetic separation of ferrous parts, eddy current separation of aluminium, gravity separation, manual and optical sorting along with intermediate screening processes, and further size reduction steps. Final output streams are usually components taken out as a whole—a magnetic fraction (going for further treatment to a steel plant), an aluminium fraction (to aluminium smelters), a copper fraction (to copper smelters), sometimes clean plastic fraction(s), and waste. The waste comprises mixed plastic fractions, glass, wood, rubber, and so on, often in the form of a 'shredder light fraction', which is subjected to further processing, incineration or landfilling.

Mechanical processes have the advantage of being relatively cheap in investments and operating costs as compared to metallurgical processes. However, some of the limitations are inefficient separation due to overlap between the physical properties and the associated problem of dust and other very fine fractions. For the recovery of precious and special metals, mechanical processing is an important pre-processing step, if conducted in the right way. However, these processes are not able to extract and recover these metals in a pure form, and thus metallurgical processing is required for this final step.

## Metallurgical process

A state-of-the-art smelter and refinery process affects recycling efficiency, both in terms of the elements and the values recovered, as well as overall environmental performance. Besides copper and precious metals, modern smelters can recover a large variety of other elements, isolate hazardous elements, and use organics like plastics if these are combined with metals. Umicore recently designed and invested in the optimized treatment of recyclable materials and industrial by-products. The processes are based on complex lead/copper/nickel metallurgy, using these base metals as collectors for precious and special metals. All processes are equipped with state-of-the-art offgas and waste water purification installations. Metallurgical processes involve the initial steps of liberation, separation/concentration, and purification. However, unlike in mechanical processes, smelting is used for liberation. Different materials and metals are sorted from the melt. The main processing steps of the precious metal operations are smelting, copper leaching and electrowinning, and refining of precious metals (Figure 4). The operations are designed in such a way that raw materials can enter at the optimal process stage, based on their physical aspect, analytical fingerprint, and value of precious metals. The IsaSmelt furnace (Figure 5) serves as the main gate for most materials. This involves the injection of oxygen-enriched air and fuel through a submerged lance in a molten bath and the addition of coke as a reducing agent for the metals. Plastics or other organic substances connected to the metals in the feed partially substitute the coke as a reducing agent and fuel. In case of circuit boards, the chemical and energy content from their organic part is high enough to cover all energy needs for the entire recovery process, including metals refining. This means that the energy balance of Umicore's refining process is

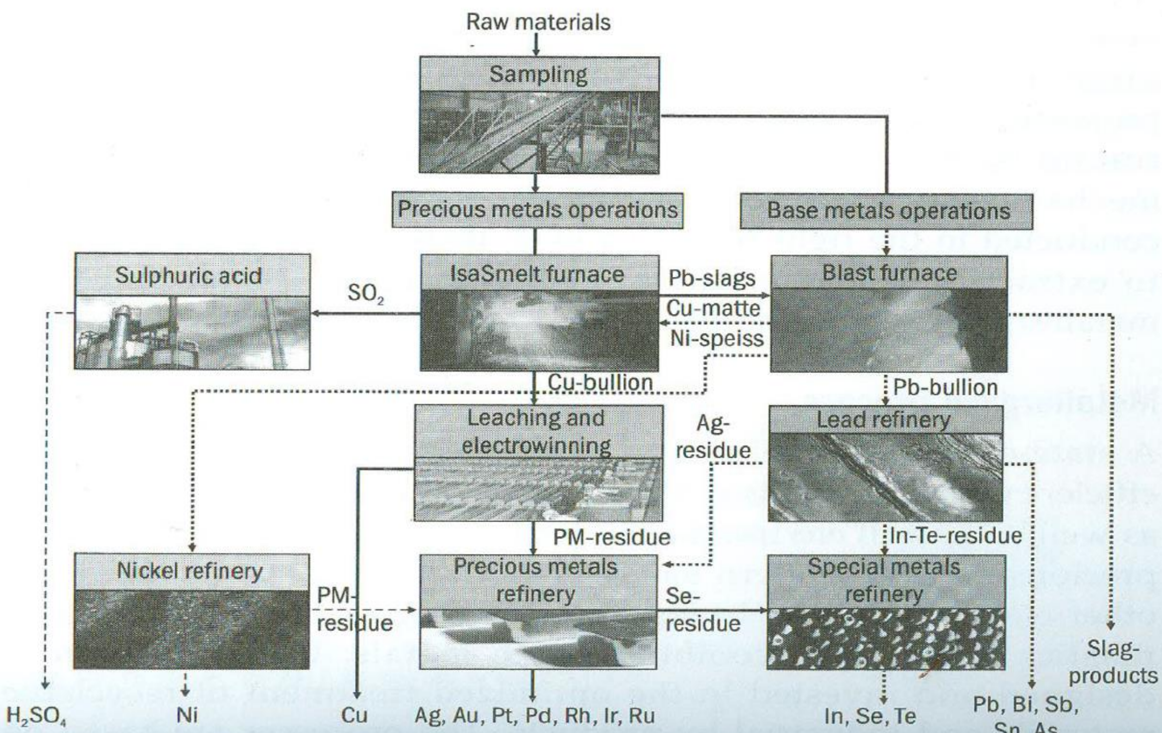



**Figure 4** Umicore's Hoboken plant: state-of-the art technology in a complex flow

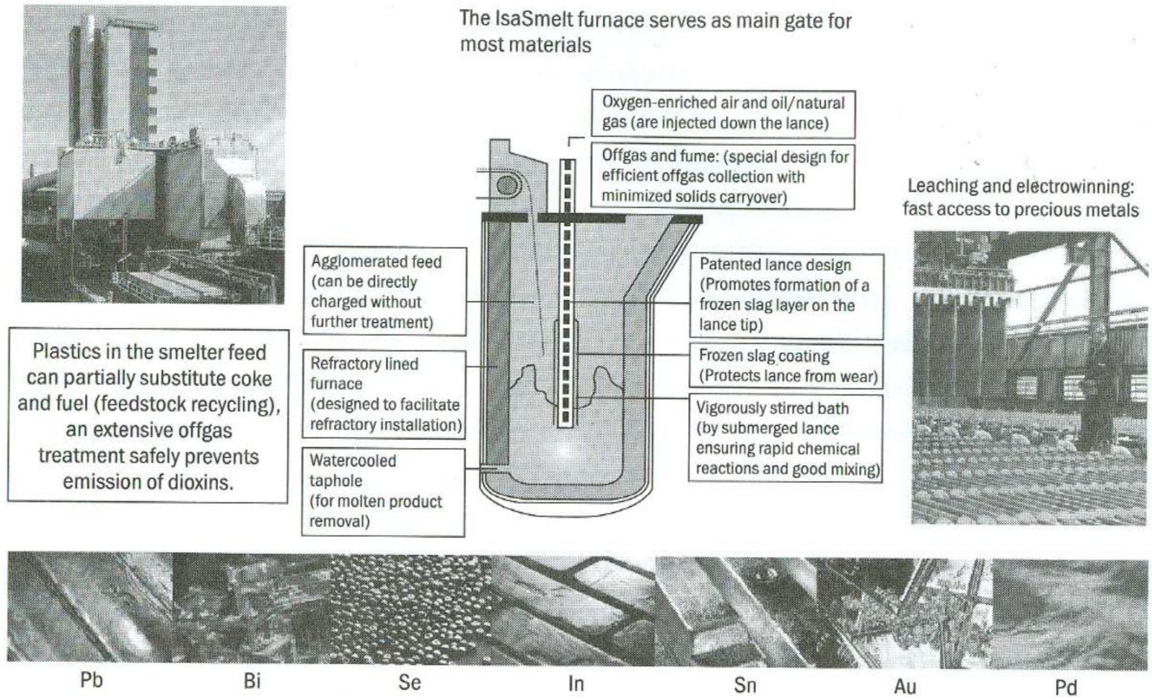



**Figure 5** Impressions from the Hoboken refinery

neutral or even slightly positive; no additional energy is needed in the bottom line and access energy can be utilized to smelt in inert materials like car catalysts. The smelter extracts the precious metals into a copper bullion, which is tapped at regular intervals from the furnace. After subsequent leaching out the copper in the leaching and electrowinning plant, the precious metals are collected in a residue that is further refined at the precious metals refinery. This process combines classical methods (cupellation) with unique in-house developed processes (silver refinery) to enable the in-house recovery of all possible variations and ratios of silver, gold, and the platinum group metals (platinum, palladium, rhodium, iridium, and ruthenium).

Most of the other metals in the IsaSmelt furnace are concentrated in a lead slag, which is then further treated in the base metals operations. The processing steps take place in the lead blast furnace, the lead refinery, and the special metals plant. The lead blast furnace reduces the oxidized lead slag from the IsaSmelter together with high lead-containing third party raw materials and transforms them into impure lead bullion, nickel speiss, copper matte, and depleted slag. The impure lead bullion, containing most of the non-precious metals, is further treated in the lead refinery (Harris process). Besides pure lead and sodium antimonite (used for TV-glass production), the process generates residues of special metals, further refined into pure metals (indium, selenium, and tellurium) in the special metals refinery. Bismuth and tin intermediates are tolled out to dedicated companies to produce pure metals, which are marketed by Umicore. After leaching the nickel out of the nickel speiss and turning it into nickel sulphate at Umicore's Olen plant, the remaining precious metal residue is treated at the precious metals refinery. The copper matte from the lead blast furnace returns to the IsaSmelt furnace. The depleted blast furnace slag is physically calibrated for use in the concrete industry or is used as a dyke fortification substance. Due to this complex flowsheet, which involves several scavenger steps, the Umicore process achieves very high overall recovery yield of precious metals, as well as of base and special metals.

Metallurgical processes, in general, have the following limitations.

- Metallurgical processes do not recover plastics as plastics, but their chemical and energy content is utilized as coke and fuel substitutes.
- No smelter can recover all metals; recovery depends on thermodynamics, technology, and economics. Recovering 17 different metals, Umicore takes a technically leading position and focuses on the most valuable and rare metals. Aluminium and iron, however, are transferred to the slag, which is used as construction material, but cannot be recovered in metallic form. Non-integrated copper smelters recover a far more limited range of metals, and in steel plants or aluminium smelters, all other metals are lost. Thus, it is important to pre-treat materials efficiently so that relevant metal output streams can be individually fed into the most appropriate metallurgical process.
- Thermal treatment of material containing halogenated flame retardants bears the risk of the formation of dioxins unless appropriate measures are taken at the furnace and the offgas side. State-of-the-art integrated metal smelters (as described above) have special installations and measures to safely cope with this and prevent hazardous emissions. However, standard copper smelters (including most of the primary and secondary copper smelters in the world) normally lack the necessary appropriate offgas treatment equipment, and thus are not suitable for the treatment of e-scrap.
- High investment costs and requirement of infrastructure are associated with the setting up and operation of the state-of-the-art integrated smelters. We recently estimated that a replication

of the Umicore Hoboken plant on a 'green field' would require an investment of up to $2 billion.

- Organic dust from the shredder light fraction can lead to problems when fed into the smelter due to instantaneous burning before it reaches the metal baths. Hence, it may require certain pre-processing of dust for agglomeration through pelletization or briquetting. Whenever possible, in pre-processing, the generation of large amounts of dust that contains valuable metals should be avoided.

Both the mechanical and metallurgical steps are important in recycling e-waste. However, the right combination is crucial and the interface between the two steps has to be optimized.

### *Emission control at Umicore's Hoboken plant*

Umicore has implemented an environment management system according to ISO 14001. Further, the environmental performance of the plant is continuously monitored, and installations are adapted to new legislation in compliance with the European and Flemish legal environmental requirements.

### *Air*

Hygienic gases and process gases are cooled with energy recovery and cleaned using BAT (best available techniques) such as bag house filters, electrofilters, and scrubbers. The sulphur present in some feed materials is converted into $SO_2$ (sulphur dioxide), which is transformed into sulphuric acid in the 'contact' plant with the gas treatment and contact processes acting as a 'perfect filter' (Figure 6).

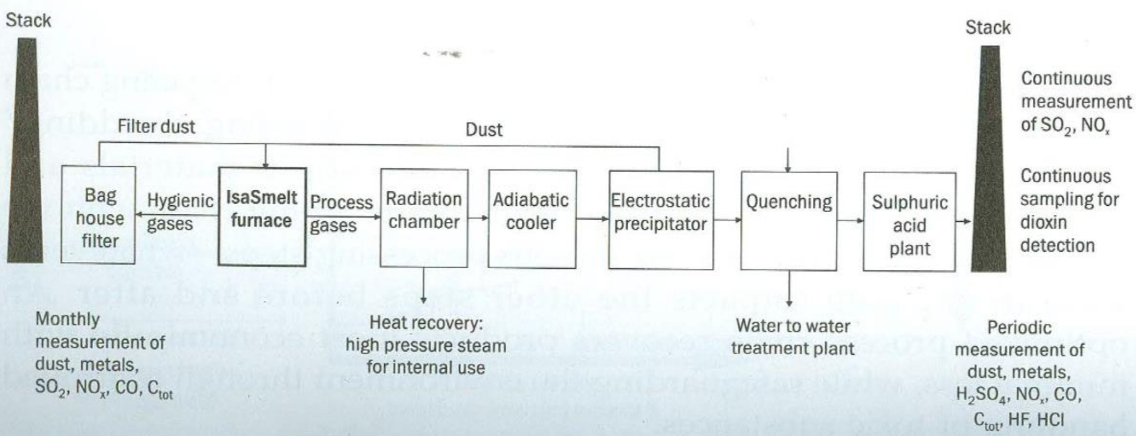



**Figure 6** Emission control installations at Umicore's IsaSmelt process

On the stack, $SO_2$ and $NO_x$ (oxides of nitrogen) are continuously monitored, and diffuse emissions from the stockyards and roads are abated by using either fixed sprinkling systems or watering carts. Measures are also put in place for a dust-free emptying of shipped drums or big bags, the storage of critical materials in containers, and efficient transportation. These steps also prevent the loss of precious metals along with the dust fraction, which further improves metal yields. Thanks to these continuous measures, emissions from the plant are well below the strict European limits.

### *Water*

Process water, cooling water, rainwater, and sprinkling water are treated in an onsite BAT waste water treatment plant. The steps involve neutralization of acids, while metals, sulphates, and fluorine are removed by physical methods. Two-thirds of the cleaned water is reused internally while one-third is discharged into the Schelde river.

### *Waste*

Efforts are made to recover and reuse the waste generated from the process. Sulphuric acid is sold in the market and the depleted slag is further used. Waste that cannot be recycled any further, comprising about 4% of the incoming material, is disposed off in the licensed landfills. Further efforts are on to reduce the amount of waste going to the landfills. The final waste derived from treatment of e-scrap at Hoboken is of very low volume and forms well below 1% of the e-scrap feed.

## Optimization of waste electrical and electronic equipment recycling chain

The WEEE (waste electrical and electronic equipment) recycling chain consists of different steps, namely, collection, dismantling, shredding/ pre-processing, and the end-processing of various materials and metals. It is important to consider the entire recycling chain with the interdependencies between the various processing steps—whatever is done in one step impacts the other steps before and after. An optimized process chain recovers products most economically with minimal loss, while safeguarding the environment through controlled handling of toxic substances.

During optimization, the 'environmental footprint' of a material has to be considered, that is, how much negative environmental impact can be avoided by recycling a metal instead of producing it 'new' from mining operations. Due to the considerable environmental impact of turning precious metals from low-grade primary ores into pure metals, a high overall recycling yield of the precious metals is economical and also has large ecological benefits. Also, recycling 1 kg of gold is ecologically much more beneficial than recycling 1 kg of iron.

Certain technical points have to be considered while optimizing the processing. As described before, integrated smelters recover precious metals, copper, and other base and special metals but not aluminium or iron. On the other hand, aluminium smelters recover aluminium but the precious metals and other metals contained in the feed are lost. Non-ferrous metals are normally lost in fractions that go into landfills, incineration units, steel plants or plastic plants. Hence, large aluminium (and iron) parts as well as clean plastics should be separated from the feed before sending it to an integrated smelter. At the same time, steps must be taken to avoid the entry of precious metals during pre-processing into the output fractions containing ferrous, aluminium or plastics, from where they cannot be recovered.

Improvement can be achieved by mutual optimization of the interfaces between modern integrated metal smelters and dedicated shredding and sorting plants. This includes sorting depth as well as the composition and destination of the various fractions produced (Figure 7).

As in the mineral processing of ores, the concentration–yield function also applies to the mechanical treatment of e-scrap. According to this, the recovery rate for any metal in the input stream during

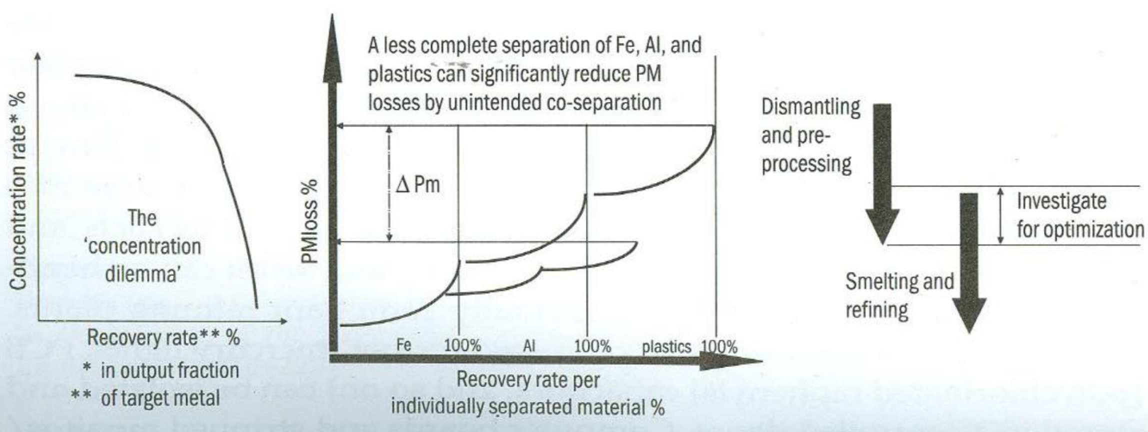



**Figure 7** Interface optimization to improve recycling of precious metals

processing decreases with the increasing concentration rate (purity) of that target metal separated into an output fraction ('concentration dilemma'). Hence, further processing of a clean output fraction becomes easier, but the 'cost' of this translates into a higher loss of the target metal into side fractions.

When separating several major substances like iron, aluminium, and plastics in subsequent mechanical processing steps from a complex material, the unintended co-separation of minor metals or trace elements like precious metals poses a problem. For complex, intensely interlinked high-grade materials such as computer circuit boards, cell phones, hand-held computers, and digital cameras, metallurgical processes offer advantages over mechanical separation, since the unintended co-separation can be avoided, so that precious and special metals as well as toxic substances can be recovered more efficiently. It is thus eco-efficient to feed these materials directly into an integrated smelter after the removal of batteries.

For lower-grade materials, the pre-processing required should involve a coarse size reduction, and not intense shredding, followed by manual or optical removal of circuit board fractions, and subsequent magnetic (ferrous) and eddy-current (aluminium) separation from the remaining stream. Unique opportunities exist here in countries having access to cheap and reliable trained workers, who can partly replace automated processing equipment.

## Opportunities for India

Keeping in mind the availability of cheap labour and artisan skills, it is feasible to utilize manual dismantling as compared to mechanical separation in countries like India. By this, losses and spillage through unintended co-separation of valuables and toxic substances into side streams or wrong fractions can be avoided. The main components like casings, batteries, power units, CRT (cathode ray tube) screens, circuit boards, disk drives, and so on can be manually dismantled. Circuit boards from TVs and monitors should be stripped clean of large iron and aluminum parts. Reusable components can be sold as such, and pure plastics, iron, aluminium, copper cables, and so on can be hand-sorted and sent to local, environmentally compliant refining plants. Toxic substances that cannot be processed further (mercury lights, PCB [polychlorinated biphenyls] capacitors, and so on) can be isolated and stored in a controlled depot. Computer boards and stripped monitor/ TV boards should be shipped to environmentally compliant integrated smelters for the recovery of valuable metals and for the safe handling of toxic substances.

The informal sector can be integrated into the optimized pre-processing and recycling activities, which can generate substantial work and income. However, while integrating the informal sector, it is essential to check the material flows as well as work practices and conditions. Also, it is imperative to ensure appropriate and regular training along with the basic infrastructural facilities. Thus, by turning the informal sector into a professional organization, it is possible to avoid impacting adversely both environment and health while recovering and reusing valuable raw materials.

One of the main recommendations of the existing research (see Keller 2006) is that besides the adverse environmental impacts of backyard recycling operations, there are also considerable economic disadvantages, and this can be used to convince the informal sector to change the system. In a 'best of two worlds' approach (a project under the StEP initiative), local labour can be used to collect, sort, and (deeply) dismantle e-scrap, but then the complex fractions like circuit boards should be shipped to specialized 'high-tech' operation units. Making use of such economies of scale could not only drastically improve the local environment and health conditions, but also generate considerably higher revenue for the local operators.

**Technologies for recovery of resources from e-waste**

## Introduction

Electronic waste or e-waste is a term used to represent any damaged, obsolete or end-of-life electrical and electronic appliances such as computers, televisions, refrigerators, laboratory and medical equipment, scanners, servers, CDs, DVDs, telephones, lighting appliances, and so on.

E-waste contains not only various toxic components, but also several useful materials that can be reused and other constituents that can be processed to obtain precious metals such as gold and platinum. The chemical elements present in e-waste are listed in Table 1.

**Table1** List of chemical elements present in e-waste

| Category of elements | *Examples* |
|---|---|
| Bulk elements | Lead, tin, copper, silicon, carbon, iron, and aluminium |
| Elements in small quantity | Cadmium and mercury |
| Trace elements | Germanium, gallium, barium, nickel, tantalum, indium, vanadium, terbium, beryllium, gold, europium, titanium, ruthenium, cobalt, palladium, manganese, silver, antimony, bismuth, selenium, niobium, yttrium, rhodium, platinum, arsenic, lithium, boron, americium |

Many useful resources are associated with e-waste. However, most of the developing countries are not able to recover these materials more effectively in an environment-friendly manner. This is due to the lack of efficient and advanced technologies for processing various components, namely, glass, metals, and plastics. This chapter focuses on the available technologies for efficient recovery of resources, with minimum impact on the surrounding environment and health of the people.

## Resource recovery potential of e-waste

E-waste consists of materials that can be recovered and reused in the manufacturing process. Figure 1 shows the percentage composition of various useful components present in the computer waste.

The composition of mobile phones also indicates the possibility of recovery of plastics, aluminium, copper, ferrous metals, gold, palladium, and platinum. It is possible to recover 90% of the materials present in mobile phones, which can be used as raw materials for other products (Table 2). Stainless steel can be made from nickel and cobalt, and new batteries can be manufactured from cadmium obtained from old batteries; gold and silver recovered from circuit boards can be used for various applications; and new plastics and metals products can result from plastics and metals

Though the percentage of precious metals and other non-ferrous metals in mobile phone is less than that in computer waste, there is a possibility of recovering the available resources by efficient

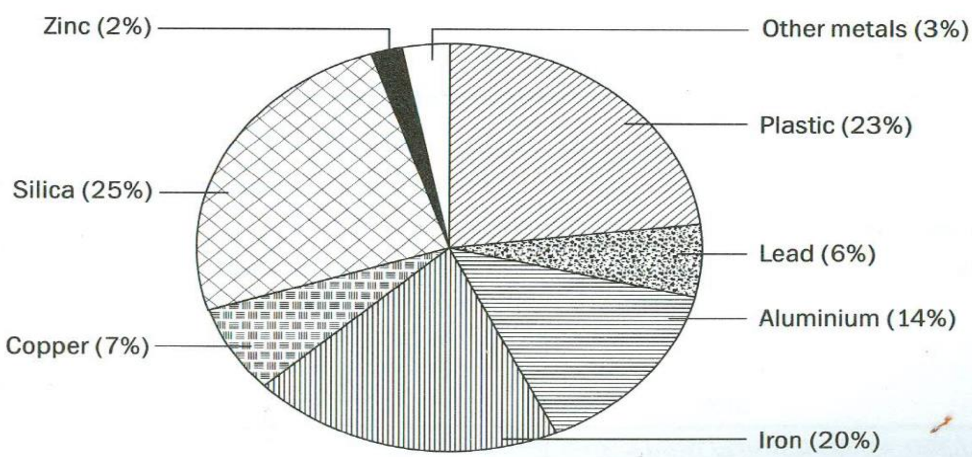



**Figure 1** Resource recovery potential of computer waste

**Table 2** Recovery of resources from mobile phones

| Components | *Percentage composition* |
|---|---|
| ABS (acrylonitrile butadiene styrene)-PC (polycarbonate) | 29 |
| Silicon plastics | 10 |
| Epoxy | 9 |
| Other plastics | 8 |
| Ceramics | 16 |
| Cu and compounds | 15 |
| Iron | 3 |
| Nickel and compounds | 1 |
| Zinc and compounds | 1 |
| Silver and compounds | 1 |
| Al, Sn, Pb, Au, Pd, Mn, and so on | <1 |

**Source** <http://www.envocare.co.uk/mobile_phones.htm>

mechanical processing techniques. Due to the fraction of the non-ferrous and precious metals in TV scraps compared to personal computer, efficient methods of disassembling and recovery process is necessary for cost effective recycling. Table 3 shows resource recovery from TV scrap (Cui and Forssberg 2007).

The resource recovery potential has led to the increase in demand of e-waste in the recycling business in various countries including India. In developed countries, the recycling process is carried out

**Table 3** Recovery of resources from TV scrap

| Parameters | *Value* |
|---|---|
| Al (%) | 1.2 |
| Cu (%) | 3.4 |
| Pb (%) | 0.2 |
| Zn (%) | 0.3 |
| Ni (%) | 0.038 |
| Ag (PPM) | 20 |
| Au (PPM) | <10 |

PPM – parts per million

in an organized sector, while in developing countries like India, this is done primarily in an unorganized sector. It is necessary to have simple, environment-friendly, and economically viable management practices. Efficient collection mechanisms coupled with appropriate equipment and technological interventions would help in improving the profitability of the business and the quality of life of the workers who are part of the recycling chain.

## Steps in recycling and recovery of materials

Collection, dismantling, mechanical processing, and metal extraction are the major steps in recyling (Figure 2).

### *Collection*

In developing countries, the obsolete electronic and electrical items from the individual households, companies, and institutions are collected by the individuals. In developed countries, where the collection system has been streamlined, this step in the recycling chain is taken care of by the municipalities, retailers or the manufacturers. In the city of Dresden, Germany, which has a population of 500 000, e-waste from households and enterprises is collected through five collection points. The waste collected is segregated under five categories, namely, household white goods and automatic dispensing machines, cooling equipment, IT (information technology) and

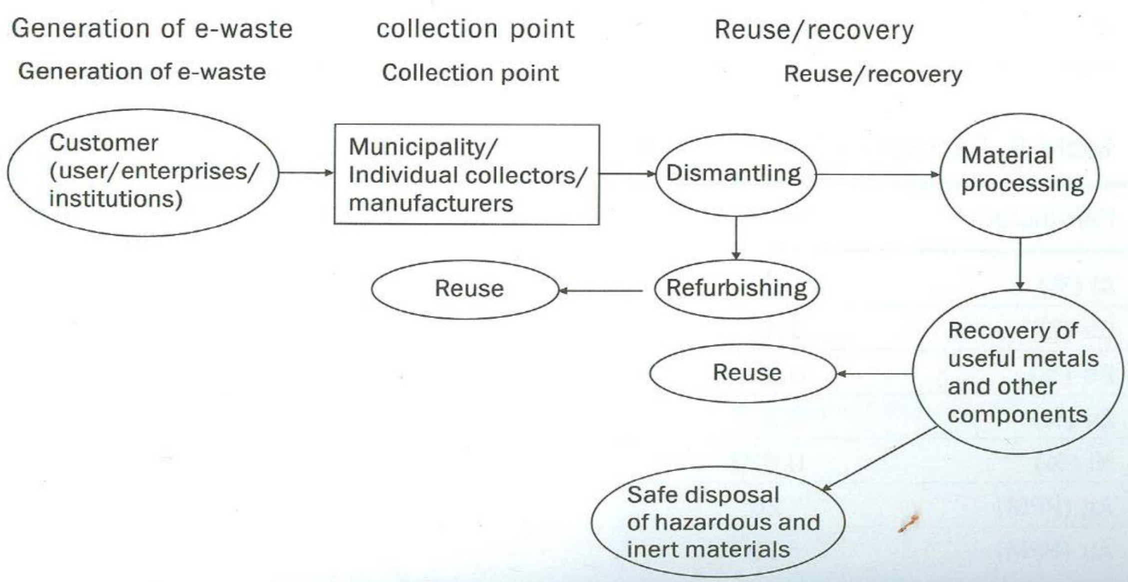



**Figure 2** Steps in efficient recycling of e-waste components

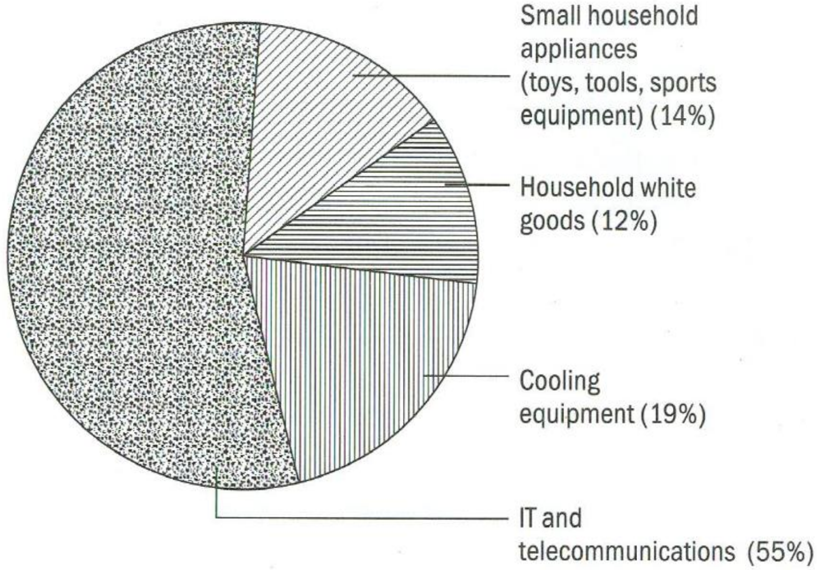



**Figure 3** Percentage fraction of different types of electronic wastes collected

telecommunication equipment, glow discharge lamps, and small household appliances. The quantity of waste collected in a single year from a German city is given in Figure 3.

### *Transportation*

The various categories of waste collected at the different collection points is transported to the recycling centres for further processing.

### *Quantification and storage of waste at the recycling centre*

A proper storage of the waste material, after receiving it at the recycling centre, is important for occupational safety and maintaining the surrounding environment. This would involve proper packaging during its movement within the recycling plant and its transportation to and from the plant. There should be storage and proper labelling of the various components separated from the e-waste along with the dismantled items.

### *Dismantling*

The collected and segregated waste enters the next step of dismantling. Dismantling step is carried out either manually for disassembling and separation of the useful items (Figure 4) or through highly mechanized process (Figure 5) for efficient material separation. The manual dismantling is also a pre-processing step followed by further processing steps like mechanical crushing and separation. One of the methods for disassembly of mobile phones has been tested and patented in Finland. This process involves the use of magnetic induction field to heat the metal fastening screws, resulting in melting of plastics and the separation of the components due to the mechanical impact. However, efficiency of such techniques depends on the type, structure, and material constitution of the device.

After dismantling and refurbishing, components have been reused by Siemens ICN, Germany, as part of the take-back programme for their products that include telephone systems, printers, fax machines, and so on. Components such as assemblies, power supplies, and devices recovered after dismantling are refurbished at the ICN and reused in the service and sales network of Siemens ICN (Renner and Chryssos 2004).

**Figure 4** Manual dismantling process

## *Mechanical* processing

As e-waste is a complex mix of substances, it is characterized by heterogeneity, with the presence of materials with varying physical and chemical characteristics. This property facilitates the easy separation of the materials based on the magnetic properties and particle size. During this stage, adequate care should be taken for achieving high recycling targets, and safe and efficient removal of hazardous substances from the useable materials. The components that should be removed before further processing, because of their hazardous nature, include capacitors containing printed circuit boards, CRTs (cathode ray tubes), toner cartridges, mercury switches, batteries, plastics containing halogenated flame retardants, and fluorescent lamps. Figure 6 shows the various steps in a recycling plant with modern facilities.

After the separation of components containing hazardous materials and reusable parts, the electronic components and the assemblies undergo mechanical processing, which involves shredding and grinding to reduce the particle size. The next stage separates the ferrous materials based on their magnetic properties

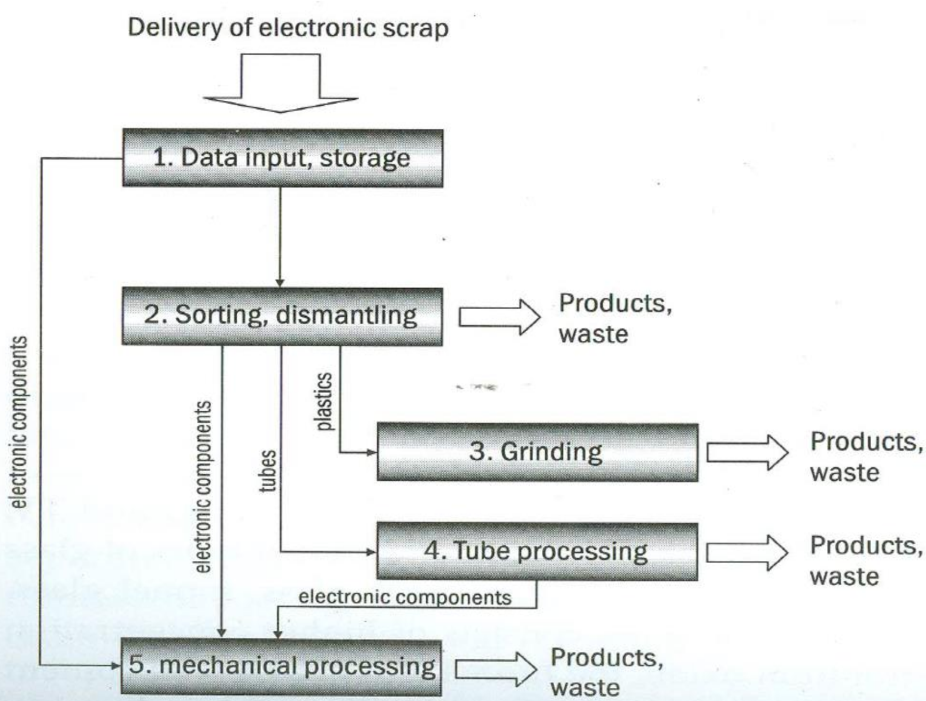



**Figure 6** Various steps in a recycling unit
**Source** Electrocycling GmbH, Germany

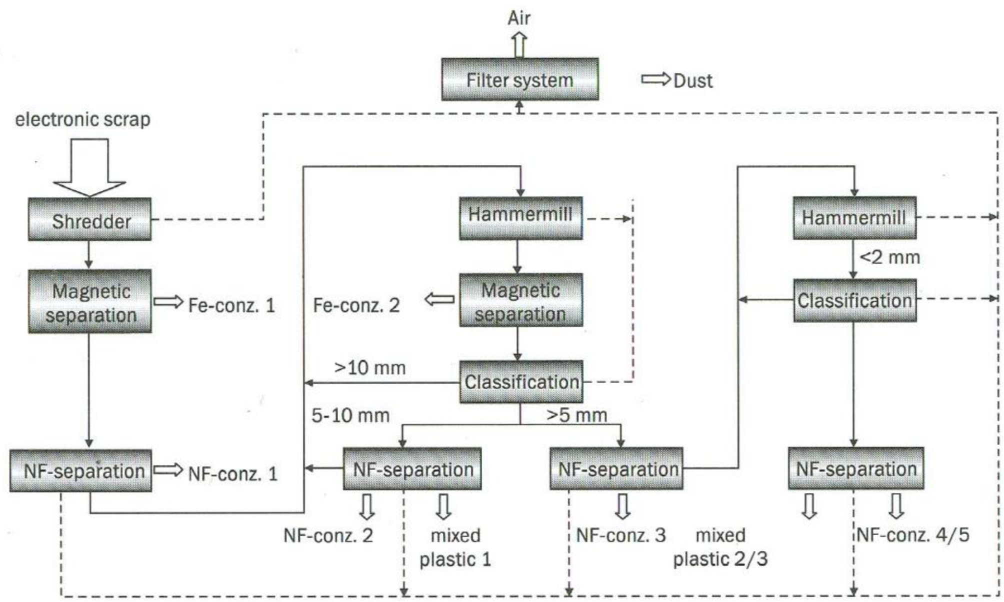



**Figure 7** Mechanical processing steps
**Source** Electrocycling GmbH, Germany

and the non-ferrous materials using eddy current and air table. The processing results in the separation of metals, plastic, and dust. The details of the mechanical processing steps in a modern recycling plant are shown in Figure 7.

## Technologies for recovery of materials

This is the final step in the recovery process wherein major high value materials like glass, plastics, and metals can be recovered from e-waste. The section below gives different types of efficient techniques for recovering the resources.

### Glass recovery from cathode ray tubes

#### *Components of cathode ray tubes*

The CRTs, found in monitors of PC (personal computer) and TV, make up 50% of the e-waste by weight. Four different types of glass are present in CRT, namely, panel glass, neck glass, funnel glass, and solder glass. The panel glass consists of higher concentration of barium and strontium oxide, the funnel glass has a lead content of 25%, and neck glass has 40% lead oxide. The solder glass has very high levels of lead (up to 85%). However, the mixed CRT glass has low level of lead (5%), barium (10%), and strontium oxide (2%)

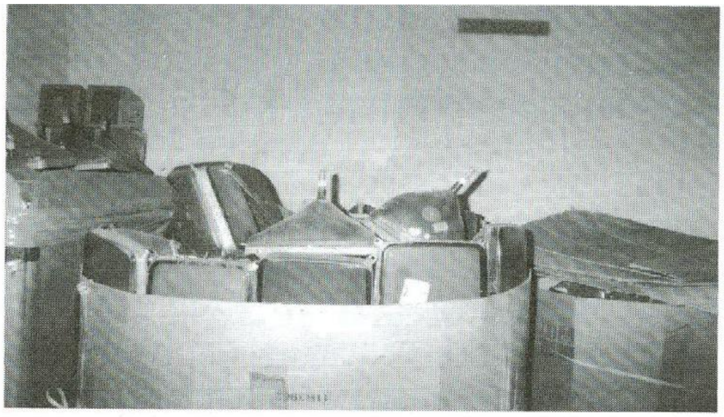


**Figure 8** Components of cathode ray tubes
**Source** Boyce, Lichtenwort, and Johansson (2002)

(Rajeshwari, Basu, and Johri 2007). Further, the composition of glass varies according to the brand of the product. There is a fluorescent layer on the panel glass with aluminium film, and graphite and iron oxide layers on the funnel. In addition to glass, CRT also contains metallic parts such as a steel frame between the panel and funnel section. The other metallic part is the steel electron gun in the neck and nickel–iron shadow mask inside the screen. Figure 8 shows the components of CRTs.

*Recovery of glass from CRT in developing countries*

The functional CRT is dismantled in the informal sector and regunned using cheap manual labour and necessary equipment such as vacuum pumps. The non-functional ones are manually broken to recover glass and metallic frames. The glass is then sold to glass manufacturing units. However, care should be taken that this glass, which contains oxides, is not used as a container for food products. Even while disposing off this glass in the landfill, there is a danger of leaching of heavy metal into the groundwater. This is particularly the case in recycling units where the CRT glass is ground to reduce particle size before disposal. Other major hazardous component that should be separated from the glass components before further use is the fluorescent coating, which contains highly toxic heavy metals and cadmium, zinc, yttrium, and europium.

*Efficient processes for CRT recycling*

The processes of CRT recovery release materials that can be used for the production of CRT components. This is known as closed loop recycling. In an efficient recycling process, glass recovered from CRT is used for the manufacture of panel glass and funnel glass after the removal of non-glassy coatings and other foreign material.

### Steps in CRT closed loop recycling process

*Dismantling* Dismantling is the first step wherein the glassy materials are separated from metallic and other non-glassy materials. These metallic and other non-glassy materials then enter separately the recycling process for the plastics, metal, and so on. This step is a relatively simple process and does not require very sophisticated equipment. It just requires simple tools to disassemble and separate the materials.

*Separation of glass fractions* The separation of the panel and funnel glass is a critical step in the CRT recycling. This can be carried out either manually by separating the plastic casing from the glass or by a fully automated process wherein the monitor and TV are shredded after separating the plastic casing, and different glass fractions are separated. The automatic process has a high capital investment.

The splitting of CRT by heating wire is the most common method for obtaining glass components (Figure 9). In this method, the joint between the panel and the funnel glass is split by wrapping the wire around the CRT and heating it electrically. This gives rise to thermal difference, causing breakage between the panel and funnel

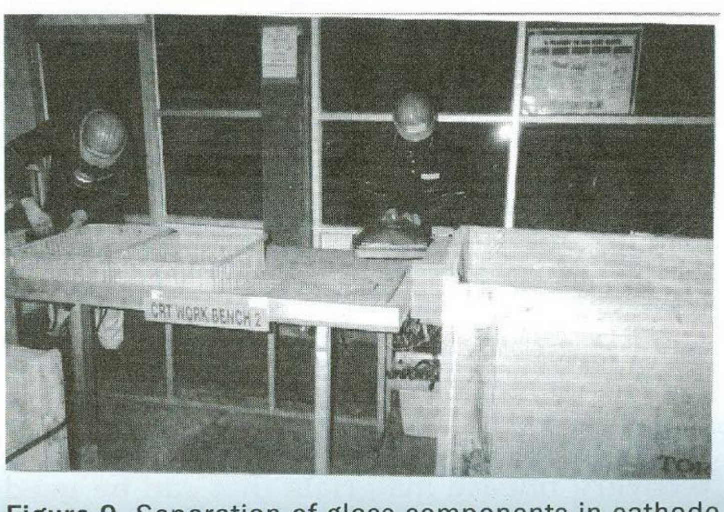



**Figure 9** Separation of glass components in cathode ray tube

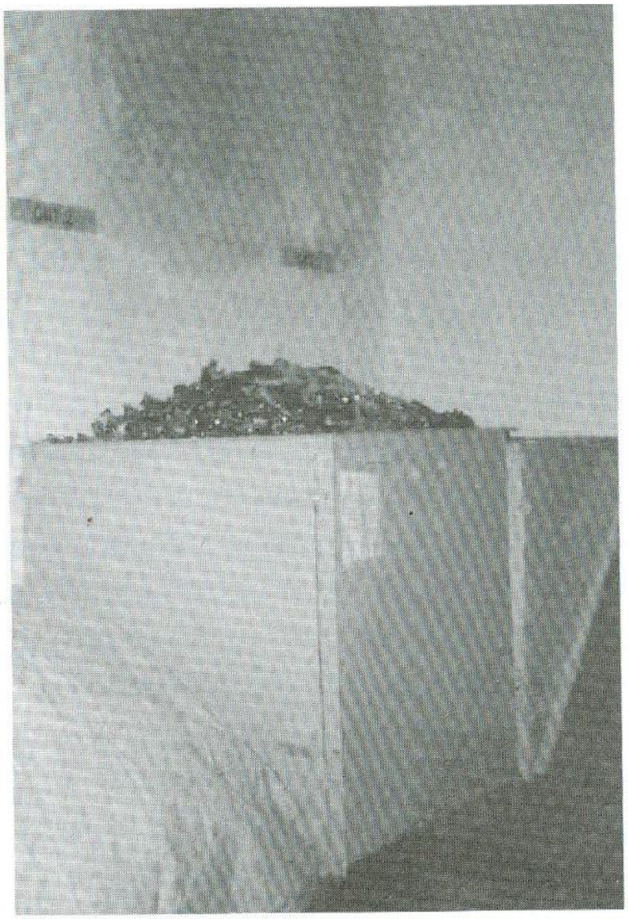


Figure 11 Storage of recycled glass

the reactions between the nickel, cobalt oxide, and glass. To avoid any inhomogeneous mixture in the glass during the manufacture of new glass, it is essential to identify the properties of different types of panels blended together and maintain the quality of the homogenized mix. Meeting the stringent quality standards is not as important in the case of funnel glass as in the case of panel glass, but strict compliance with the standards for strength and radiation shielding should be ensured. The funnel glass should also be free from contaminants and coatings. Further, the use of recycled glass in the manufacture of new glass also depends on the individual's ability and expertise.

## Gold recovery from e-waste

Printed wiring boards dismantled from the electronic wastes are the major source of gold. The recovery process is mainly divided into three steps: (i) leaching, which involves solubilizing the metal glass types. This method is less expensive. However, care has to be taken that the glass breaks along the wire line, and precaution should be taken to prevent any injury due to sharp edges. The cutting of the glass can be achieved by a more expensive laser method, which is also energy intensive. In this technique, laser beam is used to heat up the glass, which is then cooled with water, resulting in the formation of a crack along the edge.

This method has a disadvantage. It cannot be applied to thick glass but can be used for handling large quantities of glass. In the diamond saw separation method, CRT is placed in an enclosure and is cut around the circumference by saw blades. The temperature is controlled by using a coolant. The technique, though expensive, can result in clean separation and can be used if large volume of glass is to be processed. In all these methods of cutting and separation of glass, it should be ensured that there is no lead present, as it will be used for the manufacture of new panel glass.

After the splitting, the funnel glass is separated from the panel and the shadow mask is removed, facilitating the removal of phosphors coating. The coating is removed by a vacuum suction system (Figure 10), and the dust is collected in a filter system. Washing with a caustic solution and water can be used for removing phosphors coating, which is then disposed off as hazardous substance. As the CRT glass require high purity and do not allow any contaminants, the recycled glass (Figure 11) should be devoid of substances like stickers, metal, and other non-glass materials such as graphite and iron oxide layers. While reusing the waste panel glass, it is essential to maintain two properties, namely, the light transmission and colour point, in addition to maintaining purity. The optical properties of the glass depend on

**Figure 10** Removal of phosphors coating

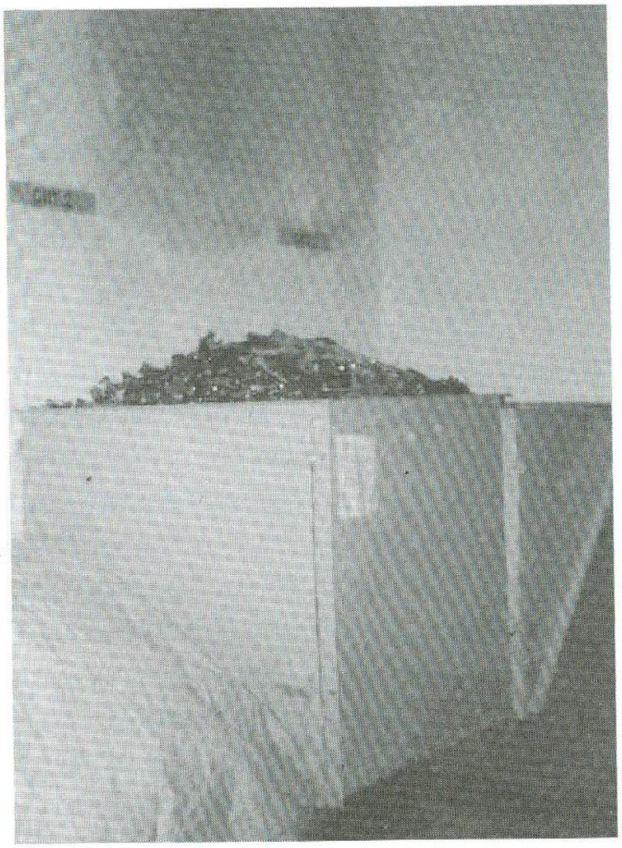


**Figure 11** Storage of recycled glass

the reactions between the nickel, cobalt oxide, and glass. To avoid any inhomogeneous mixture in the glass during the manufacture of new glass, it is essential to identify the properties of different types of panels blended together and maintain the quality of the homogenized mix. Meeting the stringent quality standards is not as important in the case of funnel glass as in the case of panel glass, but strict compliance with the standards for strength and radiation shielding should be ensured. The funnel glass should also be free from contaminants and coatings. Further, the use of recycled glass in the manufacture of new glass also depends on the individual's ability and expertise.

## Gold recovery from e-waste

Printed wiring boards dismantled from the electronic wastes are the major source of gold. The recovery process is mainly divided into three steps: (i) leaching, which involves solubilizing the metal in the solution, (ii) separation, which involves extraction of gold from the mixed liquor, and (iii) purification, which involves the production of pure form of metal from the separated solution.

### *Extraction processes in unorganized recycling sector*

Two techniques are used for the extraction of gold metal. These are mercury amalgamation and cyanide leaching process.

### Cyanide leaching process

This is an age old practice, which has been adopted in the mining industry. This is a low-cost option, and the extraction process occurs at a high pH of 12. The process involves reaction between constituents like gold, oxygen, water, and cyanide (Keller 2006). The cyanide is the complexing agent and the presence of various other constituents affects the efficiency of leaching and extraction process. First, the waste material is immersed in hot water in plastic containers and the leaching of gold is facilitated by the addition of potassium or sodium cyanide in the presence of oxidizing conditions. The first step is the complex formation between cyanide and gold. The reaction is represented by the following equation.

$$4Au\ (s) + 8CN^-\ (aq) + O_2\ (g) + 2H_2O\ (l) \rightarrow 4Au\ (CN)^-_2\ (aq) + 4OH^-\ (aq)$$

The leaching process is followed by sieving and washing, wherein the metal is completely removed from the waste material. Separation of gold is carried out by mixing silver salt (prepared by mixing silver with nitric acid and hot water followed by sodium chloride) and aluminium foil, precipitating the gold and silver. The presence of silver prevents the dissolution of gold again into the mixture. The reaction steps are indicated by the following equations.

$$Ag + 2HNO_3 \rightarrow AgNO_3 + NO_2 + H_2O$$
$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$
$$3[Au(CN)_2]^- + 2\ Al \rightarrow 2\ Al^{3+} + 6\ CN^- + 3\ Au\ (s)$$
$$4Ag\ (s) + 8\ CN^-\ (aq) + O_2\ (g) + 2H_2O\ (l) \rightarrow 4Ag(CN)_2^-\ (aq) + 4OH^-\ (aq)$$

After precipitation, gold is separated from the solution by decanting the liquid and filtering the slag. The purification step consists of melting the precipitate along with calcium carbonate and flux materials, which liberates aluminium. During melting, slag is finely grounded and rest of the melted slag is poured in water. Gold pieces are recovered from the melt and from the ground flux by boiling the excess water and subsequently adding nitric acid to separate silver from gold. The recovered gold material is further melted and the impurity is absorbed through an additive resulting in the formation of liquefied gold, which is further converted into button-shaped structures.

The summarized cyanide leaching process is given in Figure 12.

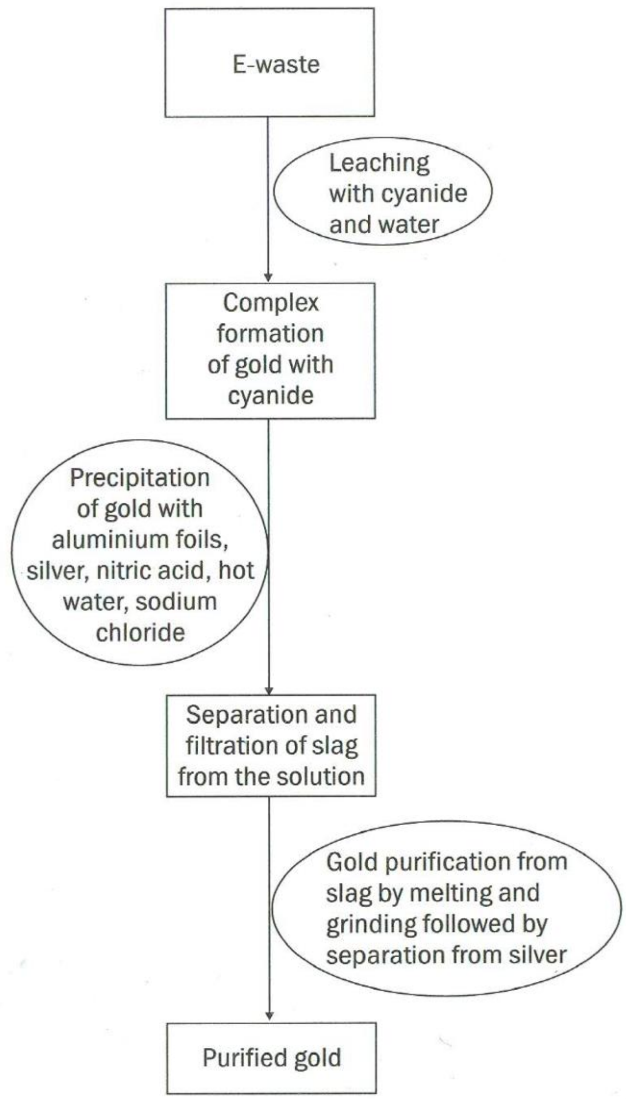



**Figure 12** Cyanide leaching process

### Mercury amalgamation process

This process is based on the principle of formation of amalgam of mercury with gold, which results in the separation of gold from other metals and impurities. This is a less complicated process involving mercury, nitric acid, and sodium carbonate. One of the steps in the amalgamation process includes leaching in the presence of water and nitric acid, which results in the extraction of other metals like copper (Keller 2006). The processing time is three hours and the components such as the joints of gold to the molds are filtered out from the gold pins and flakes. The copper dissolved in the solution is then recovered by adding iron. The filtered gold residues are mixed with mercury and few drops of nitric acid, producing amalgam. The amalgam is filtered through cloth, producing a concentrated gold lump. The purification of the gold lump is achieved by powdering and dissolving it in nitric acid, which removes most of the mercury. Boiling at higher temperature vaporizes mercury and nitric acid, leaving behind the gold. The process is summarized in Figure 13.

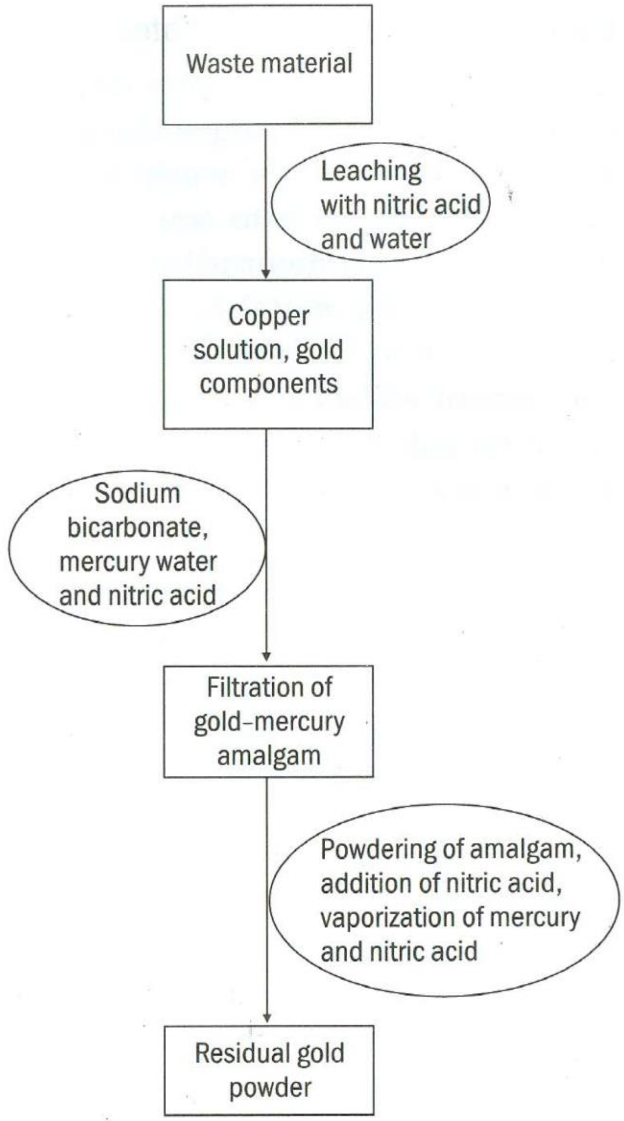



**Figure 13** Mercury amalgamation process

*Gold extraction at formal recycling centre*

A more environment-friendly process involves the use of gold stripping substance for electrolyzing gold from the dissolved gold solution rather than using cyanide or mercury. The overnight soaking of the waste material in the gold stripping solution followed by washing with hot water results in the extraction of gold from the waste material. After leaching, the extract is filtered in a plastic container and electrolysed using a titanium cathode. Electrolysing the solution overnight results in the deposition of gold in the cathode. The gold deposit on the cathode is then removed by drying at a temperature of 178 °C, followed by dissolution in aqua regia. At this stage, precaution should be taken to prevent fume inhalation by the workers, providing them with proper exhaust facilities. The dissolved gold is again filtered and precipitated by the addition of ferrous sulphate. The separated precipitate is then dried to produce the gold powder.

*Environmental impacts associated with metal extraction process*

In the cyanide leaching process, the major hazards are generation of toxic fumes of nitrogen dioxide, which cause eye irritation, as well as generation of waste water from the processes, which is normally drained into sewer, finally ending up in the common waste water treatment plant. The rest of the component of e-waste from which the metal has been extracted enters the solid waste dumping site. It is expected that the leftover metals in this component will slowly leach into the groundwater and surrounding environment. In a research study conducted by Keller (2006), testing of the waste water and waste components has indicated high levels of toxic and heavy metals (Table 4).

Further to the environmental impact, in the informal sector recycling process, workers are constantly exposed to the health hazards such as skin ailments, and they suffer from respiratory disorders due to constant exposure to fumes and acids, as they do not use protection equipment.

The mercury amalgamation process also results in hazards due to the release of fumes from vaporization of mercury and nitrogen dioxide. The waste water or effluent generated during the process is highly acidic, and the presence of leftover metal in the solution affects the environment when the water is discharged. As in the case of cyanide leaching process, the waste components after

**Table 4** Level of metal in the waste water and leftover e-waste components

| Element | *Concentration in waste water* (PPM) | *Concentration in solid waste components* (PPM) |
|---|---|---|
| Aluminium | 1315 | – |
| Arsenic | <0.5 | – |
| Cadmium | <1 | – |
| Copper | 185 | 229 250 |
| Mercury | <0.5 | – |
| Nickel | 9 | 3200 |
| Lead | 4 | 22 650 |
| Zinc | 17 | 23 950 |
| Tin | | 5100 |

PPM – parts per million

removal of the metals are dumped in unmanaged landfill sites, leading to slow leaching.

In the formal recycling centre too, hazardous waste is generated from the process, including the effluent and the solid waste components. The effluent is treated to remove hazardous substances from effluent treatment plant and then disposed off.

### *Process efficiency of the various extraction methods*

Material loss is associated with various steps in cyanide leaching process, particularly during washing and filtering. Due to incomplete washing and decantation, some amount of extracted metal enters the waste solution. Further, in some cases, the extraction is not complete and the waste material still contains the leftover of precious metals. There is also lack of appropriate amount of extracting chemical, which is added during the process, leading to incomplete metal extraction. The process yield is between 36% and 60%. In addition to the loss during chemical extraction, major loss occurs during dismantling and physical processing of the waste components. Even in the formal recycling sector, efforts are made to minimize the loss during the extraction process, and gold is recovered from the waste solution till it reaches a concentration of 0.2 PPM (parts per million) in the solution. However, the major loss occurs during the dismantling process, as the components such as printed wiring boards still contain precious metals, and the complete removal is not feasible with the existing techniques.

## Best available techniques for recovery of metals from e-scrap

Smelters across the developed countries utilize state-of-the-art process (Rajeshwari, Basu, and Johri 2007) for material recovery and safe disposal of the waste materials, with minimal material loss and environmental impact. The processes followed in these units include mechanical and metallurgical processes. In the mechanical process, appropriate techniques for dismantling, shredding, and sorting are adopted. The process is based on the physical and optical characteristics of the materials and fractions that are processed. Some of the commonly employed methods are magnetic separation of ferrous fractions, eddy current separation of aluminium, manual and optical sorting, and gravity separation. The respective metal and non-metal fractions are then sent for further processing. The magnetic fraction is sent to the steel plant for further processing, and the aluminium and copper fractions are sent to the respective smelters. The plastic and glass fractions are either further processed in recycling units or disposed off after treatment in landfills. The metallurgical processes in a modern smelter result in the recovery of base and special metals like lead, copper, nickel, tin, antimony, and bismuth, and precious metals like silver, gold, platinum, palladium, and rhodium. The processes are based on the chemical and metallurgical properties of the materials and consist of three major steps of extraction, separation, and purification. The recovery yield of various metals is high due to several intermediate steps. The processes are accompanied by appropriate waste water and solid waste treatment, and offgas purification processes, and efforts are made to reuse the treated water and waste slag as construction material and recover chemicals and acids.

### Recovery of plastics from the electronic waste components

In addition to glass and various metal fractions, plastics are the major component of the electronic waste (Figure 14). The huge volume and weight of the plastic materials recovered from the waste components have made it necessary for the recyclers to explore economical and environment-friendly solution for regenerating plastic materials without altering their properties. The recovery techniques in this particular area are still emerging. There is a challenge associated with separation of high-value plastic streams from the mixed plastics present in electronic waste. This is due to the presence of different types of brominated flame retardants in the plastic stream. With the development of advanced

**Figure 14** Accumulated plastics recovered from e-waste

technologies, it will be possible to achieve this separation, though the challenge is to arrive at an economical solution.

A methodology, CreaSolv process (Maurer, Schlummer, and Altnau 2004), has been developed for the recovery of polymer fraction from the waste plastics of mobile phones. The process is economical, safe, and environment friendly, and results in high-quality recycled polymer. The process, involves dissolving the main polymers – ABS (acrylonitrile butadiene styrene) or PC (polycarbonate) – in organic solvents. The dissolved components are then separated from the insoluble materials (metals), producing particles of recycled polymer. The polymer can further be extruded in injection moulding processes resulting in pure recycled polymers with properties similar to virgin material. The process is economical as the solvent can also be recovered, which can be further reused for dissolution of plastics. The process is efficient as it does not require any further mechanical processing such as grinding but can be applied directly on plastic materials after dismantling.

## Conclusions

E-waste is a rich source of various valuable materials including precious metals, base metals, glass, and plastics. Several technologies are available for the recovery of the materials from the waste components. The challenge is, however, to adopt efficient process with maximum recovery of materials and minimal loss. Equally important is to study the impact of the processes on the surrounding environment and health of the workers involved in processing of materials. Due to the guidelines and legislations on safe processing and disposal of e-waste, the manufacturers are also forced to take new initiatives to design and develop products that can be easily recycled and are economically viable. Streamlining the collection systems and effective preprocessing techniques are the key to successful recycling and resource recovery programme.