Waste electrical and electronic equipment in India: diversity, flows, and resource recovery approaches

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The electrical and electronic waste (E-waste) is one of the fastest growing waste streams in the world. The increasing "market penetration" in developing countries, "replacement market" in developed countries, and "high obsolescence rate" make E-waste as one of the fastest growing waste streams. Sustainable development goals of UNESCO address the National Environmental Policy (NEP). Thus, there is a need to facilitate the recovery and/or reuse of useful materials from waste generated from a process and/or from the use of any material thereby, reducing the wastes destined for final disposal and to ensure the environmentally sound management of all materials. The NEP also encourages giving legal recognition and strengthening the informal sectors for collection and recycling of various materials. In particular considering the high recyclable potential of E-waste, such wastes should be subject to recycling following state of the art technologies for resource recovery. Environmental issues and trade associated with E-waste and resource recovery approaches are covered in this chapter

10.1 Resource recovery approaches

1. Pyrometallurgy
2. Extraction technology (mild or non-invasive)
3. Biometallurgy
4. Electrochemistry
5. Super critical technology

E-waste offers an economic opportunity as well as toxicity. The gold in the world's E-waste thrash contain more than a 10% of the gold mined globally each year. However, much of this precious metal is simply buried in landfills. The Hazardous Substances Management Division (HSMD) is the nodal point within the Ministry for management of chemical emergencies and hazardous substances. The

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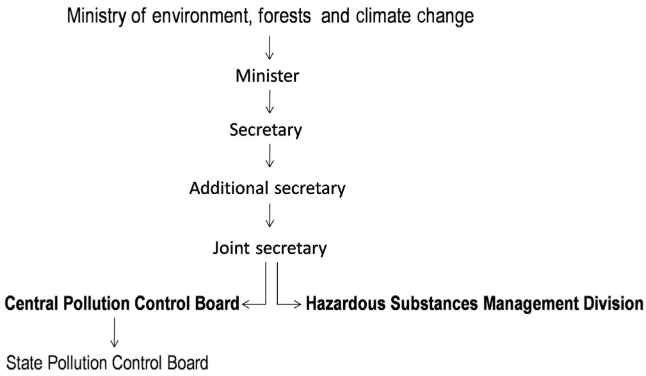

Figure 10.1 Hierarchy in the MoEF&CC for E-waste and hazardous susbstances management.

main objective of the Division is to promote safe management and use of hazardous substances including hazardous chemicals and hazardous wastes, in order to avoid damage to health and environment. The Division is also the nodal point for the following four International Conventions, viz. Basel Convention on Control of transboundary movement of Hazardous waste and their disposal; Rotterdam Convention on Prior Informed Consent Procedure for certain Chemicals and Pesticides in International trade; Stockholm Convention on Persistent Organic Pollutants; and the Minamata Convention on Mercury and Strategic Approach to International Chemicals Management (Fig. 10.1) (Table 10.1).

10.2 Current Indian scenario

According to ASSOCHAM (Associated Chambers of Commerce & Industry of India)-KPMG (Klynveld Peat Marwick Goerdeler) by 2020 Indias E-waste from old mobiles and computers will rise by about 1800% and 500% respectively by 2020 as compared to the levels in the year 2007.

India discarded approximately 1,800,000 [lakh] metric tonnes of E-waste in 2016 which is about 12% to the global E-waste production. India is the fifth largest producer of E-waste in the world and recycles less than 2% of the total E-waste it produces annually, the Ministry of Environment, Forest and Climate Change rolled out the E-waste (Management) Rules in 2016 with the aim of reducing E-waste production and increasing recycling in the most efficient manner. Under these rules, the government introduced Extended Producers Responsibility (EPR) which makes producers liable to collect 30% to 70% (over 7 years) of the E-waste they produce, reveals the ASSOCHAM-KPMG joint study.

The industry is unable to cope up with these targets as majority of the E-waste collected in India is managed by an unorganized sector. Also, informal channels of recycling/reuse of electronics such as repair shops, used product dealers, and

Table 10.1 E-waste recycling, resource recovery, and best management practices.

2018	Awasthi and Li	Assessing resident awareness on E-waste management in Bangalore, India: a preliminary case study
2018	Bakhiyi et al.	Question of E-waste opened a Pandora's box
2018	Cai et al.	Polybrominated diphenyl ethers [PBDE] emission from E-wastes during the pyrolysis
2018	Cao et al.	Increased memory T cell populations in Pb-exposed children from an E-waste recycling area
2018	Chakraborty et al.	PCBs and polychlorinated dibenzo-p-dioxins (PCDDs) dibenzo-p-furans [PCDD/Fs] in soil from informal E-waste recycling sites and open dumpsites in India
2018	Dias et al.	Waste electrical and electronic equipment (WEEE) management: an analysis on the australian E-waste recycling scheme
2018	Islam and Huda	Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/ E-waste
2018	Jeon et al.	Gold recovery from shredder light fraction of E-waste recycling plant by flotation-ammonium thiosulfate leaching
2018	Li et al.	Proteomic evaluation of human umbilical cord tissue exposed to polybrominated diphenyl ethers in an E-waste recycling area
2018a,b	Liu et al.	Microbial community structure and function in sediments from E-waste contaminated rivers at Guiyu area of China
2018a,b	Liu et al.	Halogenated organic pollutants in aquatic, amphibious, and terrestrial organisms from an E-waste site
2018	Roslan et al.	The use of an electrogenerative process as a greener method for recovery of gold(III) from the E-waste
2018	Sahajwalla and Gaikwad	The present and future of E-waste plastics recycling
2018	Shen et al.	Chemical pyrolysis of E-waste plastics: char characterization
2018	Singh et al.	Health risk assessment of the workers exposed to the heavy metals in E-waste recycling sites of Chandigarh and Ludhiana, Punjab, India
2018	Tong et al.	Towards an inclusive circular economy: quantifying the spatial flows of E-waste through the informal sector in China
2018	Torres et al.	Effect of temperature on copper, iron and lead leaching from E-waste using citrate solutions
2018	Wang et al.	Factors influencing the diurnal atmospheric concentrations and soil-air exchange of PBDEs at an E-waste recycling site in China
2018	Wu et al.	Regional risk assessment of trace elements in farmland soils associated with improper E-waste recycling activities in Southern China

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Table 10.1 (Continued)

2018	Yan et al.	Urinary metabolites of phosphate flame retardants in workers occupied with E-waste recycling and incineration
2018	Yu et al.	Associations between PBDEs exposure from house dust and human semen quality at an E-waste areas in South China: a pilot study
2018	Zhang	Maternal urinary cadmium levels during pregnancy associated with risk of sex-dependent birth outcomes from an E-waste pollution site in China
2018	Radulovic Verena	Portrayals in print: media depictions of the informal sector's involvement in managing E-waste in India
2017	Alvarez-de-los-Mozos and Renteria	Robots in E-waste management
2017	Bindschedler et al.	Fungal biorecovery of gold from E-waste
2017	Borthakur and Govind	Emerging trends in consumers' E-waste disposal behavior and awareness
2017	Cui et al.	Speciation and leaching of trace metal contaminants from E-waste contaminated soils
2017a,b	Fowler	Magnitude of the global E-waste problem
2017a,b	Fowler	Risk assessment/risk communication approaches for E-waste sites
2017	Golev and Glen	Corder quantifying metal values in E-waste in Australia: the value chain perspective
2017	He et al.	Organic contaminants and heavy metals in indoor dust from E-waste recycling, rural, and urban areas in South China
2017a,b	Jiang et al.	The influence of E-waste recycling on the molecular ecological network of soil microbial communities in Pakistan and China
2017a,b	Kumar et al.	E-waste: an overview on generation, collection, legislation and recycling practices
2017a,b	Li et al.	Accumulation of polybrominated diphenyl ethers in breast milk of women from an E-waste recycling center in China
2017	Patel et al.	Study on mechanical properties of environment friendly aluminium E-waste composite with fly ash and e-glass fiber
2017	Petridis et al.	Investigating the factors that affect the time of maximum rejection rate of E-waste using survival analysis
2017	Shirodkar and Terkar	Stepped recycling: the solution for E-waste management and sustainable manufacturing in India
2017	Tansel	From electronic consumer products to E-wastes: global outlook, waste quantities, recycling challenges
2017	Tesfaye et al.	Improving urban mining practices for optimal recovery of resources from E-waste

2017a,b,c	Wang et al.	Barriers for household E-waste collection in China: perspectives from formal collecting enterprises in Liaoning Province
2017a,b,c	Wang et al.	Factors influencing the atmospheric concentrations of PCBs at an abandoned E-waste recycling site in South China
2017a,b	Zeng et al.	A simplified method to evaluate the recycling potential of E-waste
2017a,b	Zeng et al.	Decreased lung function with mediation of blood parameters linked to E-waste lead and cadmium exposure in preschool children
2017a,b, c,d,e,f	Zhang et al.	Elevated lead levels from E-waste exposure are linked to decreased olfactory memory in children
2017a,b, c,d,e,f	Zhang et al.	Airborne PCDD/Fs in two E-waste recycling regions after stricter environmental regulations
2017e	Zhang	Alteration of the number and percentage of innate immune cells in preschool children from an E-waste recycling area
2017f	Zhang	An environmentally friendly ball milling process for recovery of valuable metals from E-waste scraps
2016	Amankwah-Amoah	Global business and emerging economies
2016	Cao et al.	Extended producer responsibility system in China improves E-waste recycling: government policies, enterprise, and public awareness
2016	Debnath et al.	E-waste management: a potential route to green computing
2016	Garlapati	E-waste in India and developed countries: management, recycling, business and biotechnological initiatives
2016	Lu et al.	Associations between polycyclic aromatic hydrocarbon (PAH) exposure and oxidative stress in people living near E-waste recycling facilities in China
2016	Manjunath	Partial replacement of E-plastic waste as coarse-aggregate in concrete
2016	Mary and Meenambal	Inventorization of E-waste and developing a Policy: bulk consumer perspective
2016	Pascale et al.	E-waste informal recycling: an emerging source of lead exposure in South America
2016	Rhee et al.	Beneficial use practice of E-wastes in Republic of Korea
2016	Suzuki et al.	Comprehensive evaluation of dioxins and dioxin-like compounds in surface soils and river sediments from E-waste-processing sites in a village in northern Vietnam: heading towards the environmentally sound management of E-waste
2016	Wang et al.	Enhanced bioleaching efficiency of metals from E-wastes driven by biochar
2016	Wang et al.	Determinants of residents' E-waste recycling behavior intentions: evidence from China

(*Continued*)

Table 10.1 (Continued)

2016	Zeng and Li	Measuring the recyclability of E-waste: an innovative method and its implications
2016	Zhong and Huang	The empirical research on the consumers' willingness to participate in E-waste recycling with a points reward system
2015	Abdollahi et al.	Enhancement of electronic protection to reduce E-waste
2015	Baldé et al.	The global E-waste
2015	Cucchiella et al.	Recycling of WEEEs: an economic assessment of present and future E-waste streams
2015	Dwivedy et al.	Modeling and assessment of E-waste take-back strategies in India
2015	Kasper et al.	Electronic waste recycling
2015	Kasapo et al.	E-waste flow among selected institutions of higher learning using material flow analysis model
2015	Reddy et al.	Producing abjection: E-waste improvement schemes and informal recyclers of Bangalore
2015	Song and Li	A review on human health consequences of metals exposure to E-waste in China
2015	Veit et al.	Electronic waste recycling techniques, *In Topics in Mining, Metallurgy and Materials Engineering*
2015	Zeng et al.	Solving E-waste problem using an integrated mobile recycling plant
2014	Bhat et al.	E-waste consciousness and disposal in Pune City
2014	Chi et al.	E-waste collection channels and household recycling behaviors in Taizhou of China
2014	Estrada-Ayub J et al.	Decision factors for E-waste in Northern Mexico: to waste or trade
2014	Jibiri et al.	Assessment of radiation exposure levels at Alaba E-waste dumpsite in comparison with municipal waste dumpsites in southwest Nigeria
2014	Perkins et al.	E-waste: a global hazard
2014	Yue et al.	Chen Polybrominated diphenyl ethers in e-waste: level and transfer in a typical E-waste recycling site in Shanghai, Eastern ChinaWaste
2013	Jinhui et al.	Regional or global WEEE recycling: where to go?
2013	Kiddee et al.	Electronic waste management approaches: an overview
2013	Masahiro et al.	Metals in WEEE: characterization and sub- stance flow analysis in waste treatment processes
2013	Milovantseva et al.	E-waste bans and U.S. households' preferences for disposing of their E-waste
2013	Qu et al.	A review of developing an E-wastes collection system in Dalian, China
2013	Rafia et al.	Survey and analysis of public knowl- edge, awareness and willingness to pay in Kuala Lumpur, Malaysia e a case study on house- hold WEEE management

2012	Oliveira et al.	Collection and recycling of electronic scrap: a worldwide overview and comparison with the Brazilian situation
2012	Tuncuk et al.	Aqueous metal recovery techniques from e-scrap: hydrometallurgy in recycling
2011	Tsydenova and Bengtsson	Chemical hazards associated with treatment of waste electrical and electronic equipment
2010	Sepúlveda	A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: examples from China and India
2009	Robinson	E-waste: an assessment of global production and environmental impacts
2008	Cui and Zhang	Metallurgical recovery of metals from electronic waste: a review
2008	Spalvins	Impact of electronic waste disposal on lead concentrations in landfill leachate
2007	Hageluken	Recycling of e-scrap in a global environment: opportunities and challenges
2007	Wong	Export of toxic chemicals—a review of the case of uncontrolled electronic waste recycling
2006	Hageluken	Recycling of electronic scrap at umicore's integrated metals smelter and refinery
2004	IRGSSA	Management, handling and practices of E-waste recycling in Delhi. IRGSSA, India
2002	Nakazawa et al.	Bioleaching of waste printed wiring board using *Thiobacillus ferrooxidans*
2002a,b	Veit et al.	Using mechanical processing in recycling printed wiring boards
2002a,b	Veit et al.	Recycling of metals from PCB by dense medium separation processes
2001	Brandl	Computer-munching microbes: metal leaching from electronic scrap by bacteria and fungi

e-commerce portal vendors collect a significant proportion of the discarded electronics for reuse and cannibalization of parts and components, adds the study.

Accompanied by the huge size of the population and rising electronics users in the country, managing an unorganized sector to achieve such high targets may not be feasible. Thus, the ASSOCHAM suggests that the government may look at collaborating with the industry to draw out formal/standard operating procedures and a phased approach toward the agenda of reducing E-wastes to the lowest.

Alternatively, the government may also refer methods adopted by other countries for efficient collection and recycling of E-wastes. For example, South Korea, one of the largest producer of electronics managed to recycle 21% of the total 0.8 million tonnes of E-waste that it produced in 2015, noted the joint study.

Seoul recycles all the E-waste that it produces. It has set up the Seoul Resource Center which receives 20% of the Seoul's E-waste for extraction of valuable metals such as gold and copper. The remaining 80% of Seoul's E-waste is used entirely for landfilling. The government may also evaluate privatization of recycling like in the United Kingdom wherein a private company, Concept governed by the public body, Electrical and Electronic Equipment (WEEE) Directive has been handed over the responsibility of collecting and recycling E-wastes in the UK, mentioned the study.

The industry is of the view that the government may increase the Merchandise Exports from India Scheme (MEIS) incentive and introduce new incentives to attract more players in the market and to encourage the existing players to ramp up manufacturing implementation targets of E-waste collection need to be reviewed, as against the current requirement, to ensure compliance across the industry.

The electronics industry has emerged as the fastest growing segment of Indian industry both in terms of production and exports. The share of software services in electronics and IT sector has gone up from 38.7% in 1998–99 to 61.8% in 2003–04. A review of the industry statistics shows that in 1990–91, hardware accounted for nearly 50% of total IT revenues while software's share was 22%. The scenario changed by 1994–95, with hardware share falling to 38% and software's share rising to 41%. This shift in the IT industry began with liberalization, and the opening up of Indian markets together with which there was a change in India's import policies vis-à-vis hardware leading to substitution of domestically produced hardware by imports. Since the early 1990s, the software industry has been growing at a compound annual growth rate of over 46% (supply chain management, 1999). Output of computers in value terms, for example, increased by 36.0%, 19.7%, and 57.6% in 2000–01, 2002–03, and 2003–04, respectively. Within this segment, the IT industry is prime mover with an annual growth rate of 42.4% between 1995 and 2000. By the end of financial year 2005–06, India had an installed base of 4.64 million desktops, about 431 thousand notebooks and 89 thousand servers. According to the estimates made by the Manufacturers Association of Information Technology (MAIT), the Indian PC industry is growing at a 25% compounded annual growth rate.

The E-waste inventory based on this obsolescence rate and installed base in India for the year 2005 has been estimated to be 146,180 tonnes. This is expected

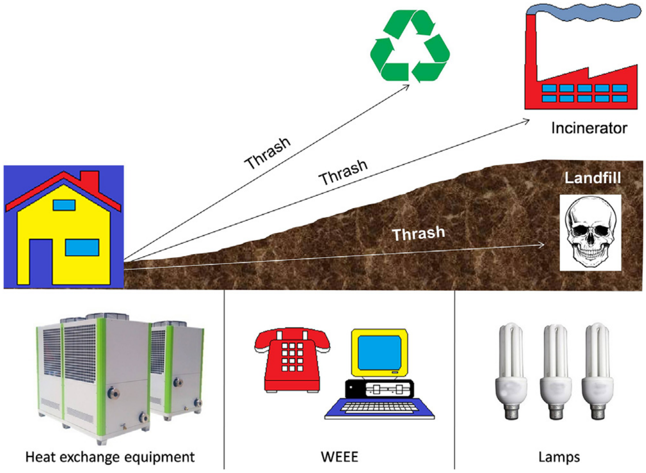


Figure 10.2 Disposal (landfill and incineration) of E-waste.

to exceed 800,000 tonnes by 2012. *There is a lack of authentic and comprehensive data on E-waste availability for domestic generation of E-waste and the various State Pollution Control Boards have initiated the exercise to collect data on E-waste generation.*

Sixty-five cities in India generate more than 60% of the total E-waste generated in India. Ten states generate 70% of the total E-waste generated in India. Maharashtra ranks first followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh, and Punjab in the list of E-waste generating states in India. Among top ten cities generating E-waste, Mumbai ranks first followed by Delhi, Bangalore, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat, and Nagpur. There are two small E-waste dismantling facilities are functioning in Chennai and Bangalore. There is no large scale organized E-waste recycling facility in India and the entire recycling exists in unorganized sector (Fig. 10.2).

10.3 E-waste management in India

The Ministry of Environment and Forest has notified E-waste Rules in May 2011, which has come into force with effect from 1st May 2012. The concept of EPR has been enshrined in these rules. As per these Rules the producers are required to collect E-waste generated from the end of life of their products by setting up collections centers or take back systems either individually or collectively. E-waste recycling can be undertaken only in facilities authorized and registered with State Pollution Control Boards/Pollution Control Committee (PCCs). Wastes generated are required to be sold to a registered or authorized recycler or reprocessor having

Table 10.2 Global E-waste generation - population versus weight.

Year	E-waste generated (Mt)	Population (billion)	E-waste generated (kg/inh.)
2010	33.8	6.8	5.0
2011	35.8	6.9	5.2
2012	37.8	6.9	5.4
2013	39.8	7.0	5.7
2014	41.8	7.1	5.9
2015	*43.8*	*7.2*	*6.1*
2016	*45.7*	*7.3*	*6.3*
2017	*47.8*	*7.4*	*6.5*
2018	*49.8*	*7.4*	*6.7*

Source: Data 2015 onwards are forecasts. Baldé, C.P., Wang, F., Kuehr, R., Huisman, J. (2015), The global E-waste monitor – 2014, United Nations University, IAS – SCYCLE, Bonn, Germany.

environmentally sound facilities. The rule has provision for setting up of Collection Center individually or jointly; or by a registered society or a designated agency; or by an association to collect E-waste.

These rules are the main instrument to ensure environmentally sound management of E-waste. Under these rules EPR authorizations have been granted to 128 Producers which are spread in 11 states. 134 collection centers are set-up in 19 States.

10.3.1 Batteries management

The Batteries (Management & Handling) Rules, 2001 was notified in May, 2001 to regulated the collection, characterization, and recycling as well as import of used lead acid batteries in the country. These rules inter-alia make it mandatory for consumers to return used batteries. All manufacture/assemblers/reconditioners/importers of lead acid batteries are responsible for collecting used batteries against new ones sold as per a schedule defined in the rules. Such used lead acid batteries can be auctioned/sold only to recyclers registered with the Ministry on the basis of their possessing environmentally sound facilities for recycling/recovery (Table 10.2).

E-waste in India grew by about 30%
India contributes about 12% to the global E-waste production
India recycles less than 2% of the E-waste it produces

10.4 Environmental regulations for E-waste in India

E-waste comprises of wastes generated from used electronic devices and household appliances which are not fit for their original intended use and are destined for recovery, recycling, or disposal. Such wastes encompasses wide range of electrical

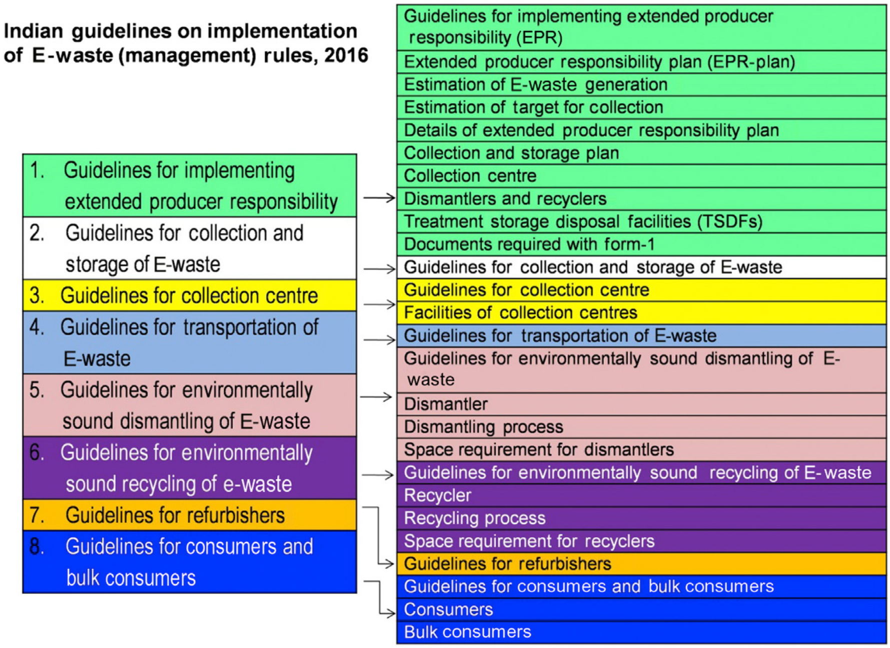


Figure 10.3 Indian guidelines on implementation of E-waste management.

and electronic devises such as computers, hand held cellular phones, personal stereos, including large household appliances such as refrigerators and air conditioners. E-wastes contain over 1000 different substances many of which are toxic and potentially hazardous to environment and human health, if these are not handled in an environmentally sound manner.

The growth of E-waste has significant economic and social impacts. There is no large scale organized E-waste recycling facility in India and there are two small E-waste dismantling facilities are functioning in Chennai and Bangalore, while most of the E-waste recycling units are operating in unorganized sector.

Schedules 1, 2, and 3 cover E-waste are given below (Figs. 10.3 and 10.4).

10.5 Schedule 1

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

- Secondary production and/or use of Zinc
- Secondary production of copper
- Secondary production of lead

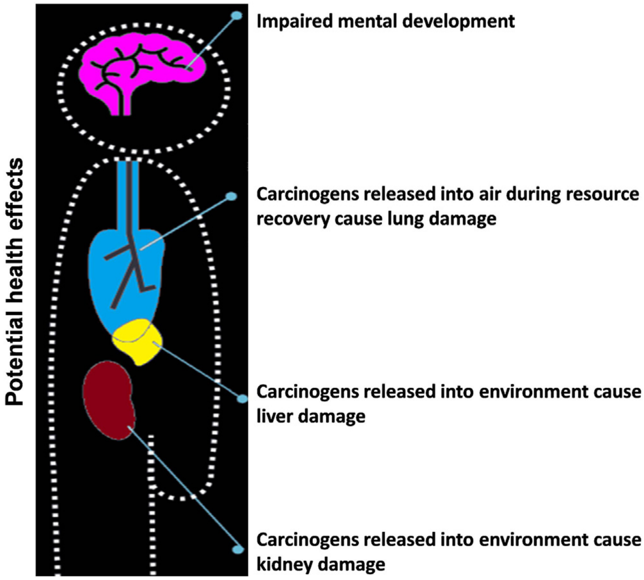


Figure 10.4 Potential health effects of E-waste.
Data source: Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The Global E-waste Monitor – 2014, United Nations University, IAS – SCYCLE, Bonn, Germany. ISBN Print: 978-92-808-4555-6. Thanks are du to United Nations University under a Creative Commons Attribution-Noncommercial-Share Alike 3.

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

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

10.6 Schedule 2

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

10.7 Class A: concentration limit: ≥50 mg/kg

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

- Antimony and antimony compounds
- Beryllium and beryllium compounds
- Cadmium and cadmium compounds
- Chromium (VI) compounds
- Mercury and mercury compounds
- Halogenated compounds of aromatic rings, for example, polychlorinated biphenyls
- Polychloroteriphenyls and their derivatives
- Halogenated aromatic compounds

On March 22, 2018, the Ministry of Environment, Forest and Climate Change, Government of India, New Delhi notified that the collection, storage, transportation, segregation, refurbishment, dismantling, recycling and disposal of E-waste shall be in accordance with the guidelines published by the "Central Pollution Control Board" issued notification for rule 23 and Schedule 3 (Table 10.3).

List of Hazardous Waste to be applicable only for imports and exports are mentioned in schedule 3. It define hazardous waste as "Wastes listed in lists 'A' and 'B' of part A of schedule 3 applicable only in case(s)of export/import of hazardous wastes in accordance with rule 12, 13, and 14 only if they possess any of the hazardous characteristics in part B of said schedule." This clause defines hazardous waste

Table 10.3 MoEF&CC Govt. of India notification of Schedule 3 sated March 22, 2018.

Year	E-waste collection target (weight)
2017−18	10% of the quantity of waste generation as indicated in Extended Producer Responsibility Plan
2018−19	20% of the quantity of waste generation as indicated in Extended Producer Responsibility Plan
2019−20	30% of the quantity of waste generation as indicated in Extended Producer Responsibility Plan
2020−21	40%of the quantity of waste generation as indicated in Extended Producer Responsibility Plan
2021−22	50% of the quantity of waste generation as indicated in Extended Producer Responsibility Plan
2022−23	60% of the quantity of waste generation as indicated in Extended Producer Responsibility Plan
2023 onwards	70% of the quantity of waste generation as indicated in Extended Producer Responsibility Plan

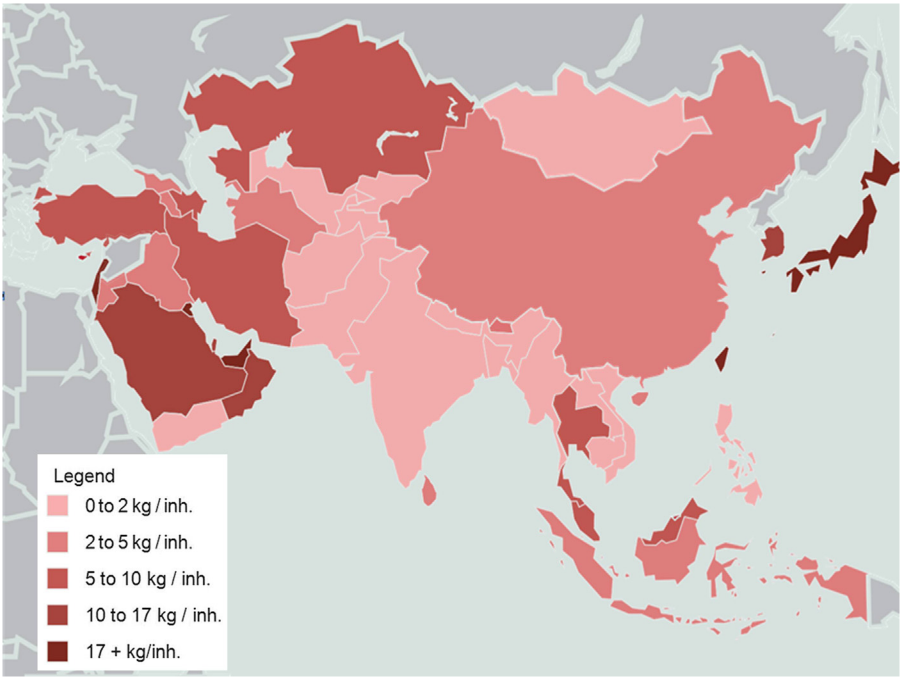


Figure 10.5 Asia has 49 countries with 4.4 billion inhabitants producing 4.2 kg of E-waste per inhabitant (inh.) 40.7% of world's E-waste is generated in Asia. It is estimated that 2.7 Mt documented to be collected and recycled.
Data source from: Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The Global E-waste Monitor—2014, United Nations University, IAS—SCYCLE, Bonn, Germany. ISBN Print: 978-92-808-4555-6.

for the purpose of import and export. It has divided hazardous waste into two parts, A and B. Part A of the schedule deals with two lists of waste to be applicable only for imports and exports purpose. Export and import of items listed in List A and B of part A are permitted only as raw materials for recycling or reuse (Fig. 10.5).

Based on the outcome of the studies carried out and the consensus arrived at the National Workshop on electronic waste management held in March 2004 and June 2005 organized by CPCB and Ministry of Environment & Forests, an assessment was made of the existing practice in the E-waste management.

10.8 Classification of E-waste

10.8.1 Composition of E-waste

It contains more than 1000 different substances, which fall under "hazardous" and "nonhazardous" categories. Broadly, it consists of ferrous and nonferrous metals,

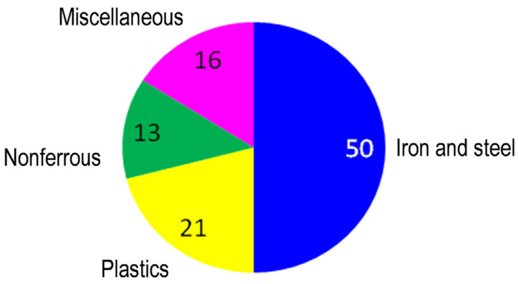


Figure 10.6 Composition of E-waste.

plastics, glass, printed circuit boards, concrete and ceramics, rubber and other items (Fig. 10.6).

Nonferrous metals consist of metals like copper, aluminum and precious metals consist of metals like silver, gold, platinum, and palladium. The presence of elements like lead, mercury, arsenic, cadmium, selenium, and hexavalent chromium and flame retardants beyond threshold quantities in E-waste classifies them as hazardous waste.

10.9 Components of E-waste

E-waste has been categorized into three main categories, viz. large household appliances, IT and telecom, and consumer equipment. Refrigerator and washing machine represent large household appliances; personal computer, monitor, and laptop represent IT and telecom, while television represents consumer equipment (Fig. 10.7).

1. Radioactive substances, refractory ceramic fibers, electrolyte capacitors (over L/D 25 mm), textile, and magnetron are not present in any item.
2. Plastic, circuit board, and external electric cables are present in majority of items (BFR).
3. Containing plastic is present in refrigerator, laptop, and television.
4. Refrigerators are unique items because of presence of CFC/HCFC/HFC/HC, cooling, insulation, incandescent lamp, and compressor.
5. Heating element is found in washing machine, while thermostat is found in both refrigerator and washing machine.
6. Fluorescent lamp is found only in laptop.
7. Metal and motor are found in majority of items except refrigerator.
8. Transformer is not found in washing machine and refrigerator.
9. CRT is found in personal computer and TV, while LCD is found in PC and TV.
10. Batteries are found in PC and laptop.
11. Concrete is found in washing machine.
12. Rubber is found in refrigerator and washing machine.
13. Wiring/electrical is found in all the items.

Large household appliance (refrigerator) may consist of electric motor, a circuit board, a transformer, capacitor, thermal insulation, switches, wiring, and plastic casing that contain flame retardants. A typical washing machine may consist of the metal

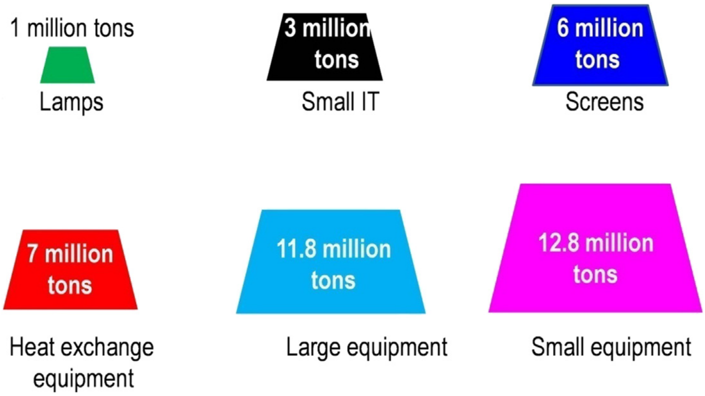


Figure 10.7 Total E-waste categories. Redrawn from Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The Global E-waste Monitor –2014, United Nations University, IAS – SCYCLE, Bonn, Germany. ISBN Print: 978-92-808-4555-6.

casing, concrete ballast, inner and outer drums, a motor, a pump, washing cycle controller unit, switches, and other components. The latest trend in these appliances is the phase out of the use of ODS and improvement of energy efficiency. Old washing machines are likely to contain large capacitors, while in relatively new machines, variable speed motors are controlled from the circuit board. IT and telecom equipments sector is observing a trend of "micro miniaturization," while CRTs are being replaced by LCD screens (Table 10.4) indicates that the range of different items found in E-waste is diverse classifying it a waste of complex nature. However, it shows that E-waste from these items can be dismantled into relatively small number of common components for further treatments. The composition and the overall hazardousness of each item of E-waste is shown in Figure 10.8.

The possible substance of concern, which may be found in selected E-waste item is given in Figure 10.8.

The substances within the above mentioned components, which cause most concern are the heavy metals such as lead, mercury, cadmium and chromium (VI), halogenated substances (e.g., CFCs), polychlorinated biphenyls, plastics, and circuit boards that contain brominated flame retardants (BFRs). BFR can give rise to dioxins and furans during incineration. Other materials and substances that can be present are arsenic, asbestos, nickel, and copper. These substances may act as a catalyst to increase the formation of dioxins during incineration (Figs. 10.9 and 10.10).

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

First level treatment
Second level treatment
Third level treatment

All the three levels of E-waste treatment are based on material flow. The material flows from first level to third level treatment. Each level treatment consists of

Table 10.4 Components in WEEE (by category).

	Large household appliances		*IT and Telecom (personal computer)*			**Consumer equipment**
	Refrigerator	**Washing machine**	**Base and keyboard**	**Monitor**	**Laptop**	**Television**
Metal	■	■	■	–	–	■
Motor/compressor	■	■	■		■	–
Cooling	■	–	–	–	–	–
Plastic	■	■	■	■	■	■
Insulation	■	–	–	–	–	–
Glass	■	■	–	–	–	–
CRT	–	–	–	■	–	■
LCD	–	–	–	■	■	–
Rubber	■	■	–	–	–	–
Wiring/electrical	■	■	■	–	■	■
Concrete		■				
Transformer	–	–	■	■	■	■
Circuit board	–	■	■	■	■	■
Fluorescent lamp (ineballast)	–	–	–	–	■	–
Incandescent lamp	■	–	–	–	–	–
Heating element		■	–	–	–	–
Thermostat	■	■	–	–	–	–
BFR—containing plastic	■				■	■
Batteries	–	–	■	–	■	–
CFC, HCFC, HFC, HC	■	–	–	–	–	–
External electric cables (over L/D 25 mm)	–	○	–	–	–	–

■Present as a component; Refractory ceramic fibers; Radioactive substances; Electrolyte CapacitorsPossible hazardous substances present in E-waste; possible presence as a component.
Source: Anonymous, 2008. Guidelines for Environmentally Sound Management of E-Waste (as Approved Vide MoEF Letter No. 23-23/2007-HSMD dt. March 12, 2008). Ministry of Environment, Forests and Climate Change, Central Pollution Control Board, Delhi. Adapted from Guidelines for environmentally sound management of E-Waste (As approved vide MoEF letter No. 23-23/2007-HSMD dt. March 12, 2008) Ministry of Environment, Forests and Climate Change. Central Pollution Control Board. Delhi, 2008.

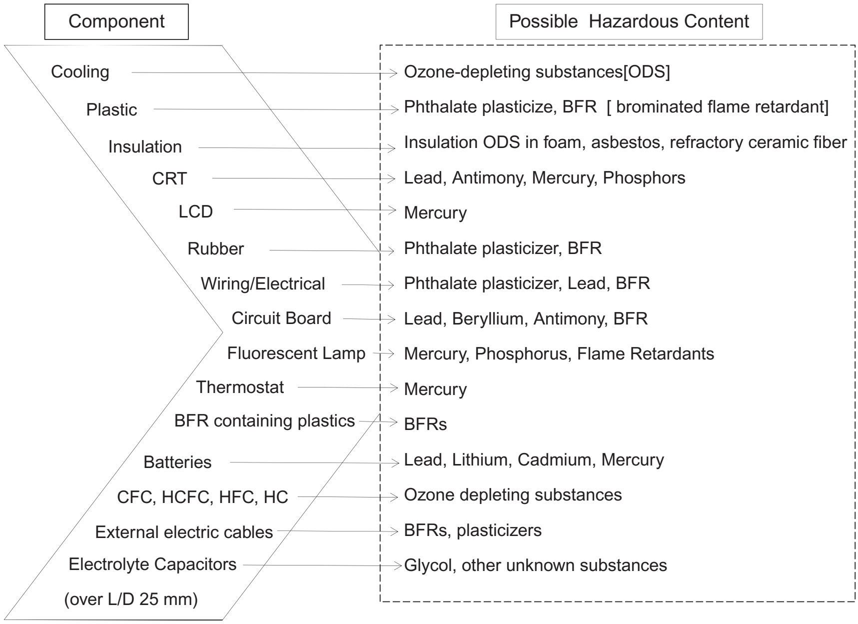


Figure 10.8 Possible hazardous substances in components. Adapted from Guidelines for environmentally sound management of E-waste (As approved vide MoEF letter No. 23-23/2007-HSMD dt. March 12, 2008) Ministry of Environment, Forests and Climate Change. Central Pollution Control Board. Delhi, 2008.

unit operations, where E-waste is treated and output of first level treatment serves as input to second level treatment. After the third level treatment, the residues are disposed of either in TSDF or incinerated. The efficiency of operations at first and second level determines the quantity of residues going to TSDF or incineration. The simplified version of all the three treatments is shown in Figs. 10.11 and 10.12.

EST at each level of treatment is described in terms of input, unit operations, output and emissions (Fig. 10.13).

Unit operations: There are three units operations at first level of E-waste treatment:

1. Decontamination: removal of all liquids and gases
2. Dismantling: manual/mechanized breaking
3. Segregation

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

1. Decontamination

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

Figure 10.9 (A–H) E-waste, collection, dismantling, shredding for resource recovery in E-waste.

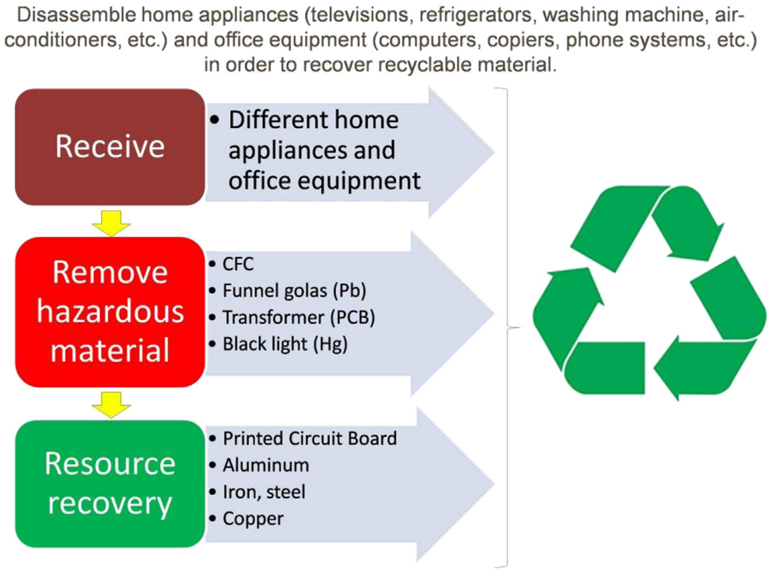


Figure 10.10 Environmentally sound treatment technologies for E-waste.

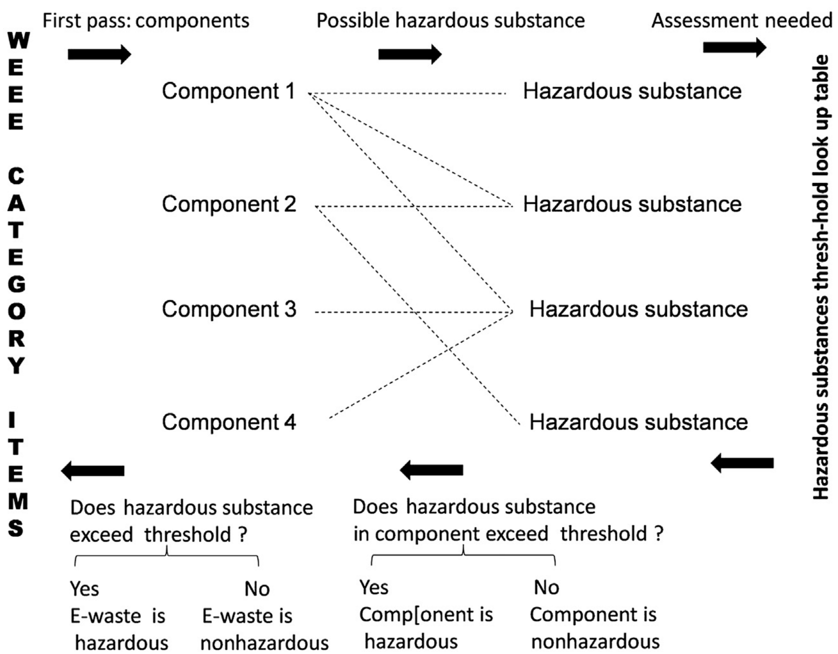


Figure 10.11 Approach and methodology for assessment of hazardousness of E-waste.

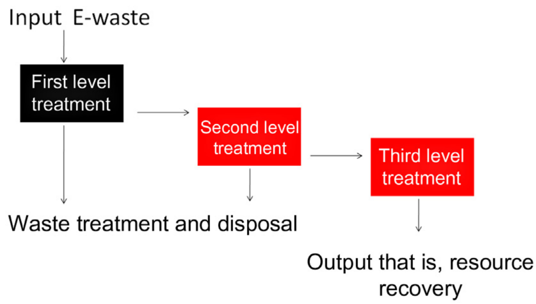


Figure 10.12 Simplified version of EST for E-waste.

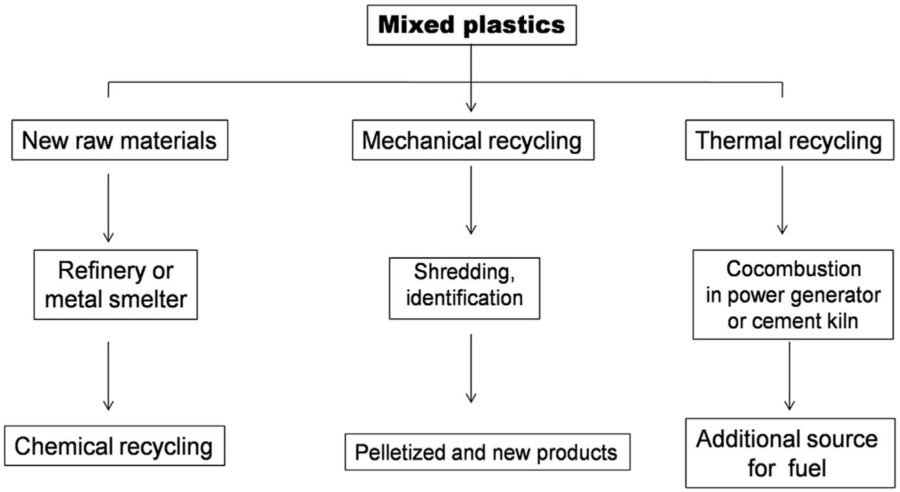


Figure 10.13 Recycling of mixed plastics in E-waste.

2. Dismantling
   The decontaminated E-waste or the E-waste requiring no decontamination are dismantled to remove the components from the used equipments. The dismantling process could be manual or mechanized requiring adequate safety measures to be followed in the operations.
3. Segregation
   After dismantling the components are segregated into hazardous and nonhazardous components of E-waste fractions to be sent for third level treatment.

10.10 EST for second level treatment

Input: Decontaminated E-waste consisting segregated nonhazardous E-waste like plastic, CRT, circuit board, and cables (Figure 10.14).

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

Figure 10.14 Input/output and unit operations for third level treatment of E-waste. Adapted from Guidelines for environmentally sound management of E-waste (As approved vide MoEF letter No. 23-23/2007-HSMD dt. March 12, 2008) Ministry of Environment, Forests and Climate Change. Central Pollution Control Board. Delhi, 2008.

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

1. Hammering
2. Shredding
3. Special treatment processes comprising of
   a. CRT treatment consisting of separation of funnels and screen glass.
   b. Electromagnetic separation.
   c. Eddy current separation.
   d. Density separation using water.

10.11 Technology currently used in India

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

1. Dismantling
2. Pulverization/hammering
3. Shredding
4. Density separation using water

The CRT treatment technology as used by CRT manufacturer in India for discarded CRTs, is shown in Fig. 10.15.

CPCB established guidelines for establishment of integrated E-waste recycling and treatment facility in different locations of India and total units are 178 (Fig. 10.16).

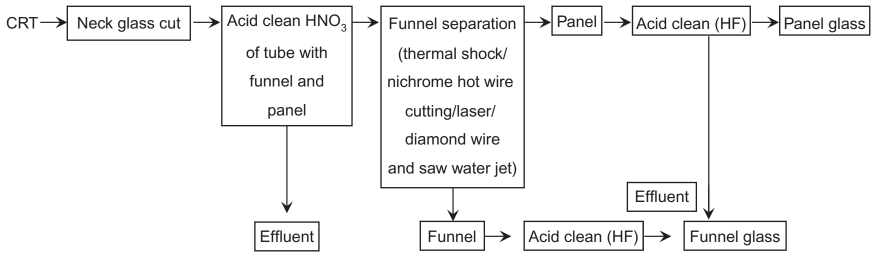


Figure 10.15 The CRT treatment technology as used in India for discarded CRTs.

Average weight and composition of selected appliances (typical)
Recoverable quantity of elements in a PC (typical)
Recoverable quantity of elements in a TV (typical)
Recoverable materials from refrigerators (typical) (Figs. 10.17–10.20).

Mechanical processing, hydrometallurgy, supercritical fluids: supercritical fluids are substances that are submitted to pressures and temperature that exceed their critical points.

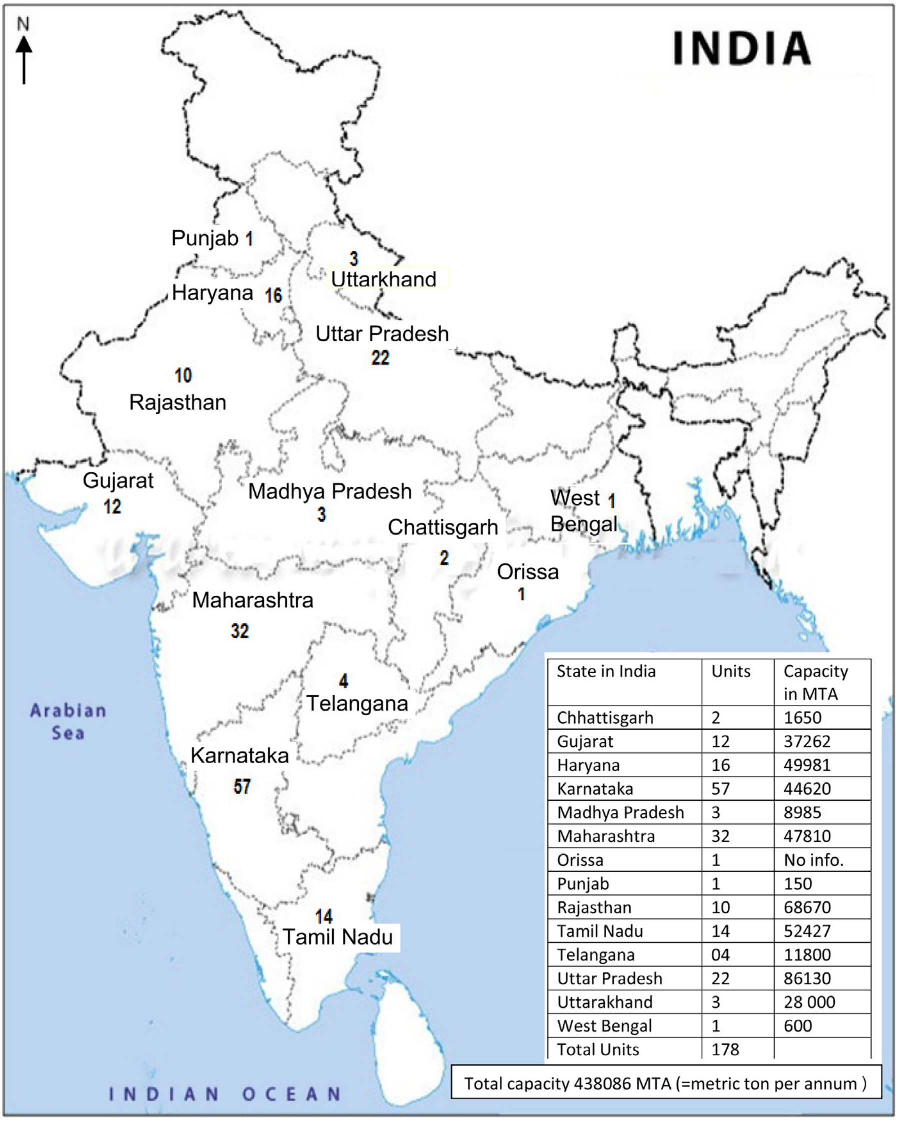
Electrometallurgy and Pyrometallurgy
Biotechnology, or a combination of various techniques.
Electronic waste: generation, management and waste recycling
Processing techniques
Mechanical processing
Leaching processes
Electrometallurgical processing
Pyrometallurgical processing
Bioleaching of electrical and electronic waste microorganisms (MOOS)
Batteries
Material selection and separation methods based on mineral processing techniques.

Electronic waste processing is very complex due to the great heterogeneity of its composition and its poor compatibility with the environment. The first step is usually manual disassembly, where certain components (casings, external cables, CRTs, PCBs, and batteries.) are separated. Following disassembly, the technologies used for the treatment and recycling of electronic waste include mechanical, chemical and thermal processes. For metals recovery there are four main routes: mechanical processing, hydrometallurgy, electrometallurgy, and pyrometallurgy. There are also references in the literature on biotechnology, or a combination of techniques.

10.12 Mechanical processing

10.12.1 Biotechnology

Bacteria such as (*Thiobacillus thiooxidans, ferroxidans*) and fungus (*Aspergillus niger*, *Penicillium simplicissimum*) grow in the presence of this type of residue. In this study, high quantities of metals, such as Cu, Ni, Zn, and Al, were leached. The



State in India	Units	Capacity in MTA
Chhattisgarh	2	1650
Gujarat	12	37262
Haryana	16	49981
Karnataka	57	44620
Madhya Pradesh	3	8985
Maharashtra	32	47810
Orissa	1	No info.
Punjab	1	150
Rajasthan	10	68670
Tamil Nadu	14	52427
Telangana	04	11800
Uttar Pradesh	22	86130
Uttarakhand	3	28 000
West Bengal	1	600
Total Units	178	

Total capacity 438086 MTA (=metric ton per annum)

Figure 10.16 Registered E-waste dismantlers/recyclers in different provinces of India.

main limitations of biohydrometallurgical processes are the long periods necessary for the leaching and the need of the metal to be exposed, that is, the metals content must be mainly located on the surface layer (Fig. 10.21).

The advantages of electrometallurgical processes are:

- Few steps
- Higher selectivity for desired metals

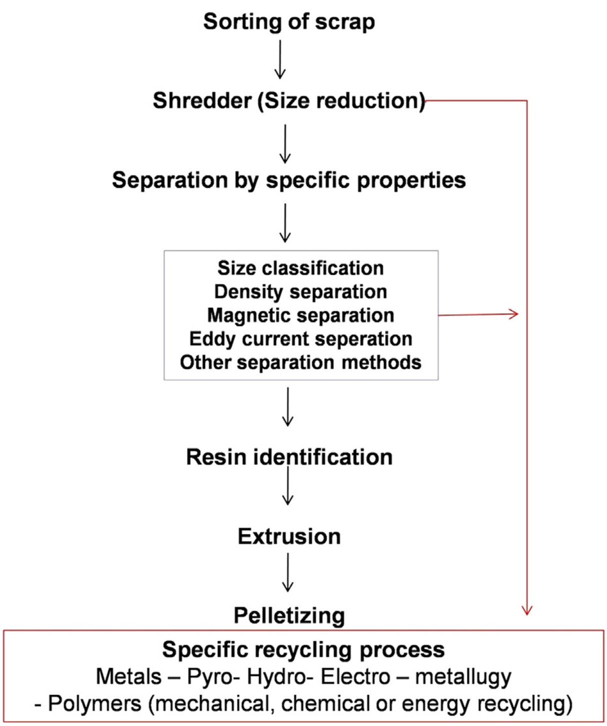


Figure 10.17 Various unit processes for resource recovery from E-waste.

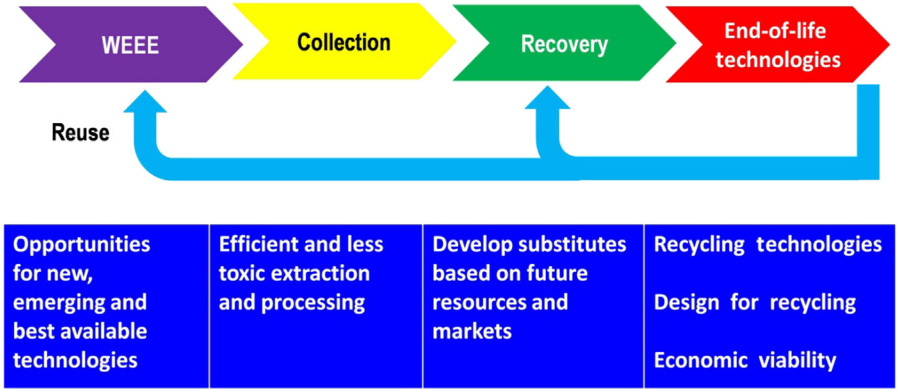


Figure 10.18 Recycling from end-of-life technologies alone cannot meet the demand. Opportunities for new, emerging, and best available technologies, efficient and less toxic extraction and processing substitutes based on future resources and markets, design for recycling and economic viability.

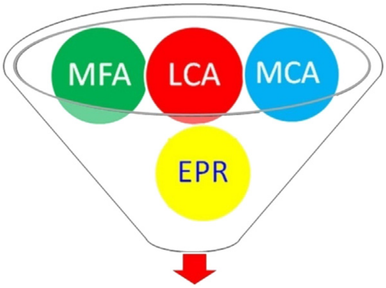


Figure 10.19 Multiple strategies for optimized management of WEEE. *EPR*, Extended produce responsibility; *LCA*, life cycle assessmet; *MCA*, multi criteria analysis; *MFA*, material flow alaysis.

- The electrolyte can be reused
- Pure metals can be obtained.

The main limitation is the need of a pretreatment (usually based on mechanical and hydrometallurgical processes).

10.13 Pyrometallurgy

Pyrometallurgical processing has some advantages, such as applicability to any type of electronic waste, no need for pretreatment and few steps in the process. Some of the methods involving thermal processing of electronic waste, may cause the following problems:

Polymers and other insulating materials become a source of air pollution through the formation of dioxins and furans.

Some metals can be lost through volatilization of their chlorides.

Ceramic and glass components present in the scrap increase the amount of slag in the furnace, increasing the losses of precious and base metals.

Recovery of some metals is low (e.g., Sn and Pb) or almost impossible (e.g., Al and Zn).

www.usepa.gov/epaoswer/hazwaste/recycle/ecycling/index.htm
www.defra.gov.uk/environment/waste/index.htm
www.ec.gc.ca
www.environment.gov.au
http://ec.europa.eu/environment/waste/weee/index_en.htm
www.ewasteguide.info
www.basel.int
www.unep.org
http://www.unep.ch/ozone/index.shtml
www.cpcb.nic.in/Hazardous%20Waste/default_Hazardous_Waste.html

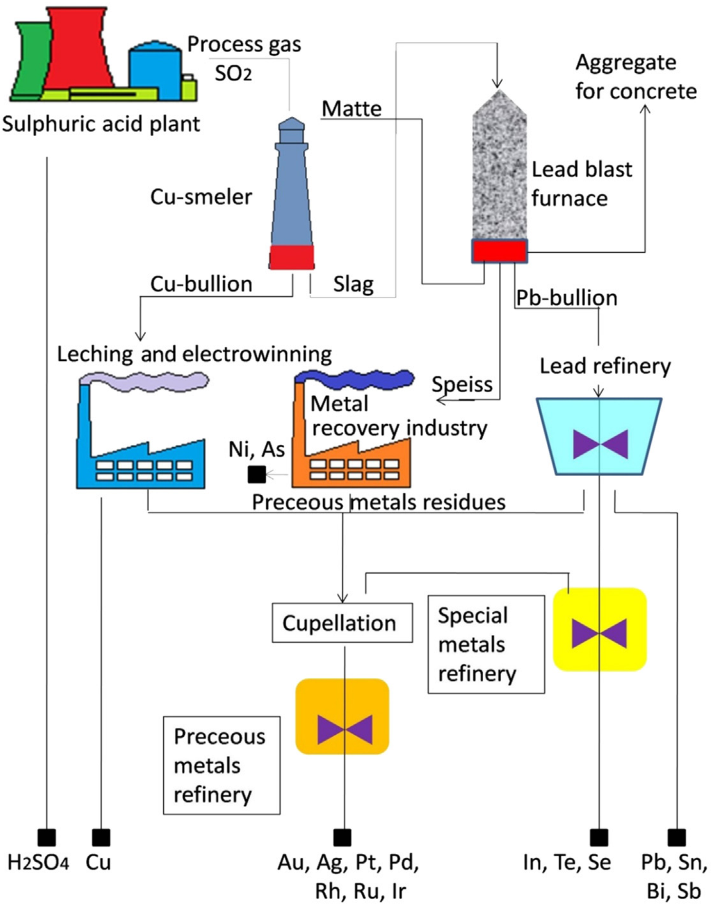


Figure 10.20 The first step is usually manual disassembly, where certain components (casings, external cables, CRTs, PCBs, and batteries) are separated. Following disassembly, the technologies used for the treatment and recycling of electronic waste include mechanical, chemical, and thermal processes. For metals recovery the main routes are as follows: mechanical processing, hydrometallurgy, supercritical fluids, electrometallurgy, pyrometallurgy, biotechnology, or a combination of various techniques including bioleaching using microorganisms.

http://www.basel.int/industry/mppiwp/guid-info/index.html
http://www.saicm.org
http://www.basel.int/about.html
http://www.mercuryconvention.org/
http://www.pic.int/en/ViewPage.asp?id = 104
http://www.pops.int

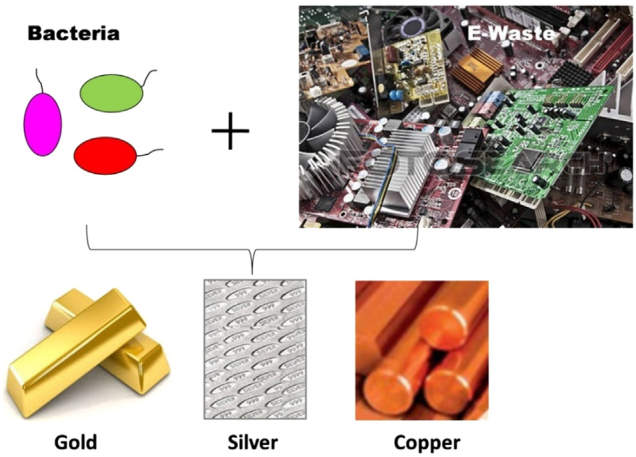


Figure 10.21 Metal bioleaching from E-waste using microorganisms, for example, *Acidiphilium acidophilum*.

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