Chapter 12
Electronic Waste (E-Waste) Generation and Management

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1 Introduction

With the beginning of this millennium, the world has been struggling to deal with increasing quantities of solid waste. Rapid advancement in technology, especially the production of electrical and electronic goods has resulted in a new stream of waste known as electrical and electronic waste making it the fastest growing waste stream in the world. Equipment at the end-of-life (EOL) leads to e-waste generation in huge amounts. Increasing obsolescence rates of electrical and electronic equipment result in higher e-waste generation rates leading to disposal problems. E-waste, if managed improperly or inadequately, can cause enormous impact on the global environment as well as on human health.

Discarded electronic devices like televisions, PCs, floppies, CDs, batteries, switches, telephones, air conditioners, cell phones, electronic toys, refrigerators, washing machines, kitchen ware and even parts of aircraft are included in the list of electrical and electronic wastes and the substances present in them are listed in Table 12.1. Typical weights and life-spans of some of the most common electronic waste items are summarised in Table 12.2. E-waste covers more than 1000 materials which can be categorized as 'hazardous' or 'non-hazardous'. Mostly, it consists of ferrous and non-ferrous metals, plastics, glass, plywood, printed circuit

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Table 12.1 Substances present in e-waste

Component	Possible substances present
Plastic	Phthalate plasticizer, Brominated flame retardant (BFR)
Insulation	Asbestos, refractory ceramic fibre
Cathode ray tube (CRT)	Lead, antimony, mercury, phosphorus
Liquid-crystal display	Mercury
Rubber	Phthalate plasticizer, BFR
Wiring/Electrical	Phthalate plasticizer, lead, BFR
Circuit board	Lead, beryllium, antimony, BFR
Thermostat	Mercury
BFR – containing plastic BFRs	BFR
Batteries	Lead, lithium, cadmium, mercury
External electric cables	BFRs, plasticizers
Electrolyte capacitors	Glycol, other unknown substances

Source: Jadhav (2013)

Table 12.2 Typical weights and life spans of e-wastes

Item	Mass (kg)	Typical life span (years)
Computer	25	3
Television	30	5
Mobile telephone	0.1	2
Video recorder and DVD player	5	5
Radio	2	10
Photocopier	60	8
Telephone	1	5
Refrigerator	35	10
Air conditioning unit	55	12
Electric heaters	5	20
Washing machine	65	8
Electric cooker	60	10
Iron	1	10
Food mixer	1	5
Microwave	15	7
Hair dryer	1	10
Vacuum cleaner	10	10
Toaster	1	5

Source: Premalatha et al. (2014)

boards, rubber, concrete and ceramics, etc. Iron and steel constitute a major part of Waste Electrical and Electronic Equipment (WEEE). Non-ferrous metals include copper, aluminium, precious metals like gold, silver, platinum, palladium, etc. Heavy metals like lead, mercury, arsenic, cadmium, etc. are also present in large quantities.

1.1 Problems Associated with E-Waste

Proper care, management and handling procedures should be taken into account when dealing with e-waste. Improper handling may cause serious damage to human health as well as to the environment. Table 12.3 shows some of the constituents present in e-waste and their effects on human health and on the environment.

2 E-Waste Generation

2.1 Global Perspective of E-Waste Generation

In a United Nations University-Institute for the Advanced Study of Sustainability (UNU-IAS) report published in 2015, global generation of e-waste was estimated to be 41.8 million tons per year (Baldé et al. 2015). Asia was found to be the largest producer of e-waste with a generation rate of 16 million tons per year which amounts to a per capita generation rate of 3.7 kg/person-year. In comparison, Europe had the highest per capita generation rate of 15.6 kg/person-year. A list of the top ten e-waste generating countries in order of the annual e-waste generated is provided in Table 12.4 based on the UNU-IAS report. India is the fifth largest generator of e-waste at the global level and third in Asia behind China and Japan. However, per capita e-waste generation rates in India are amongst the lowest (1.3 kg/capita-y) in comparison to the highest per capita e-waste generation rates of 28.3 kg/capita-y in Norway (a complete list of all countries ranked in order of per capita e-waste generation rates is provided in Appendix C, based on the UNU-IAS report, 2015).

Major generators of e-waste are developed countries such as the USA, several European nations and Brazil. They produce large amounts of e-waste each year and in the name of international trade, many developed countries are dumping their e-waste in developing countries like India and China. Developed countries mainly adopt the "reuse" procedure to save their environment and money flow.

In the global scenario, the demand for certain metals like rare earth metals, platinum group elements, certain base metals and precious metals, etc. has increased day-by-day but the supply has become negative. So to maintain the demand and supply ratio of the requisite metals, various technologies are used. This process is also known as 'Urban mining'. Urban mining is the process of recovering different compounds and elements from various products and wastes which would otherwise be left open in the environment to cause different levels of pollution (Fig. 12.1). By changing our way of thinking, we can reuse and recycle valuable components from the wastes, paving the way towards a zero-landfill future and can also save our environment.

Table 12.3 Effects of e-waste on human health and environment

E-waste	Constituent	Effect on human health	Effect on environment	References
Solder in printed circuit boards, glass panels and gaskets in computer monitors, CRT screens, batteries	Lead (Pb)	Damages central and peripheral nervous systems, kidney and affects brain development of children	Bioaccumulation, disrupts photosynthesis	Ramachandra and Saira Varghese (2004)
Chip resistors and semiconductors, rechargeable Ni-Cd batteries, fluorescent layer (CRT screens), printer inks and toners	Cadmium (Cd)	Irreversible toxic effects on human neural health, accumulates in kidney and liver, teratogenic	Bioaccumulation in the aquatic as well as terrestrial environment	Ramachandra and Saira Varghese (2004)
Relays and switches, printed circuit boards, fluorescent lamps and some batteries	Mercury (Hg)	Chronic damage to the brain, respiratory systems and skin disorders	Bioaccumulation in fishes	Ramachandra and Saira Varghese (2004)
Corrosion protection of untreated and galvanized steel plates, decorator or hardener for steel housings	Hexavalent chromium VI (Cr)	Asthmatic bronchitis, DNA damage, allergic reactions	Leads to air and water pollution	Ramachandra and Saira Varghese (2004)
Cabling and computer housing	Plastics	Incineration generates dioxins.It causes reproductive problems, immune system damage, and interferes with hormones	Non-degradable so can affect the environment in every respect	Ramachandra and Saira Varghese (2004)
Plastic casing of electronic equipment and circuit boards	Brominated Flame Retardants (BFR)	Disrupts endocrine system functions	Persistent in the environment	Ramachandra and Saira Varghese (2004)
Front panel of CRTs	Barium (Ba)	Muscle weakness, damages heart and liver	May result in explosive gases (hydrogen) if wetted	Ramachandra and Saira Varghese (2004) and Begum (2013)
Motherboard, power supply boxes which contain silicon controlled rectifiers, beamline components	Beryllium (Be)	Carcinogenic causes chronic beryllicosis, skin diseases likewarts		Begum (2013)

Condensers, transformers	PCB (polychlorinated biphenyls)	Causes cancer, affects the immune system, reproductive system, nervous and endocrine system	Persistent and bioaccumulation	Begum (2013)
Fire retardants for plastics. TBBA is widely used as flame retardant in printed wiring boards and covers for components	TBBA (tetrabromo- bisphenol-A) • PBB (polybrominated biphenyls) • PBDE (polybrominated diphenyl ethers)	Causes long-term problems health and is more poisonous when burned		Begum (2013)
Cooling unit, insulation foam	Chlorofluorocarbons (CFC)	Combustion results in toxic emissions		Begum (2013)
Light emitting diodes (LEDs)	Arsenic (As) in the form of gallium arsenide	Acutely poisonous and injurious to health		Begum (2013)
Li-batteries	Lithium (Li)		May produce explosive gases (hydrogen) if wetted	Begum (2013)
Rechargeable Ni-Cd batteries or NiMH batteries, electron gun in CRT	Nickel (Ni)	May cause allergic reactions		Begum (2013)
Fluorescent layer in CRT- screen	Rare earth elements (Yttrium, Europium, Neodymium, etc.)	Irritates skin and eyes		Begum (2013)
CRT screen	Zinc sulphide	Toxic when inhaled		Begum (2013)
Condensers, liquid crystal display	Toxic organic substances			Begum (2013)
Toner cartridges for laser printers/ copiers	Toner dust	Health risk when dust is inhaled		Begum (2013)

Source: Report on Assessment of Electronic Wastes in Mumbai-Pune Area – MPCB, March, 2007

Table 12.4 Top ten e-waste generating countries in terms of kilotons/year

Rank	Country	Continent	Kg/person-year	Kilo tons/year	Regulations[a]	Population (in 1000s)
1	USA	Americas	22.1	7072	no	3,19,701
2	China	Asia	4.4	6033	yes	13,67,520
3	Japan	Asia	17.3	2200	yes	1,27,061
4	Germany	Europe	21.6	1769	yes	81,589
5	India	Asia	1.3	1641	no	12,55,565
6	UK andN Ireland	Europe	23.5	1511	yes	64,271
7	France	Europe	22.1	1419	yes	63,996
8	Brazil	Americas	7	1412	no	2,01,413
9	Russia	Europe	8.7	1231	no	1,40,955
10	Italy	Europe	17.6	1077	yes	61,156

Source: Baldé et al. (2015)
[a]National regulations in effect, 2013

Fig. 12.1 Management of e-waste through urban mining (http://ecyclingusa.com)

Table 12.5 E-waste/WEEE generation in ten states of India

Rank	States	WEEE (tons)	Percentage (%)
1	Maharashtra	20,270.59	18.49
2	Tamil Nadu	13,486.24	12.30
3	Andhra Pradesh	12,780.33	11.66
4	Uttar Pradesh	10,381.11	9.47
5	West Bengal	10,059.36	9.18
6	Delhi	9729.15	8.87
7	Karnataka	9118.74	8.32
8	Gujarat	8994.33	8.20
9	Madhya Pradesh	7800.62	7.11
10	Punjab	6958.46	6.35
Total		**109,578.93**	**100**

Source: Vats and Singh (2014)

2.2 Indian Scenario of E-Waste Generation and Management

The most recent estimate (2013) of e-waste generation in India is 1.6 million tons/y (Baldé et al. 2015). The top ten states in India generating e-waste are shown in Table 12.5. These 10 states generate 70% of the total e-waste and 65 cities are responsible for generating 60% of the total e-waste in the country (Vats and Singh 2014). E-waste generation in India is estimated to be increasing by 10% annually. Issues regarding collection of information from industry and compliance with regulations are major deterrents in e-waste management in India.

In response to the E-waste (Management and Handling) Rules, 2015, CPCB now has 138 registered e-waste recyclers as of Nov 2014 with a total handling capacity of 0.35 million tons/annum.

3 Management Practices for E-Waste

For the proper management of e-waste, effective and practical solutions are required. First of all, generation of waste from source has to be reduced. Second, collection centres should be located where transportation is available. After collection, wastes should be safely transferred to different recycling centres for further processing. Various rules, regulations and methods are adopted for the management of e-waste (Fig. 12.2). A comprehensive review of e-waste management issues is available in Terazono et al. (2006).

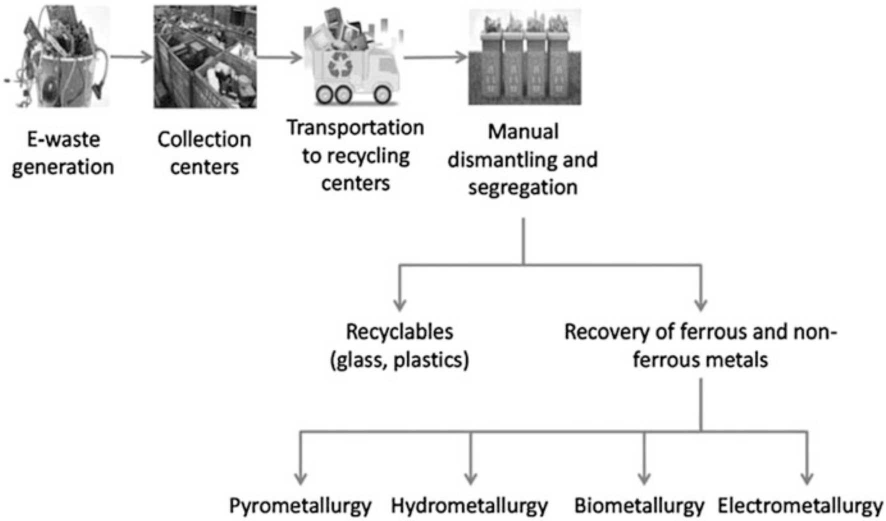

Fig. 12.2 Steps involved in E-waste management

3.1 E-Waste (Management and Handling) Rules

The E-waste (Management and Handling) Rules, 2011 have been modified in the year 2015 and apply to every manufacturer, producer, consumer, bulk consumer, collection centres, dealers, refurbishers, dismantlers and recyclers involved in the manufacture, sale, transfer, purchase, collection, storage and processing of e-waste or electrical and electronic equipment (EEE). It also explains the role of the producer clearly. Producer Responsibility Organizations (PROs) are also included in the new rules of 2015 in addition to the Extended Producer Responsibility (EPR).

Penalty and punishment for non-compliance are defined in Sections 15 and 16 of the Environment (Protection) Act, 1986 which says that whoever fails to comply with the rules will be punishable with imprisonment for a certain period which may be extended to 5 years or with penalty which may extend to Rs 1 lakh. More details regarding these rules can be found in Appendix B of this book and the full text of the rules is available at the Ministry of Environment and Forests (MoEF) website (http://www.moef.gov.in/).

3.2 Extended Producer Responsibility (EPR)

EPR is an environment protection strategy which makes the producer responsible for the entire life-cycle of the product and principally for take-back, recycling and final disposal. EPR uses financial incentives to encourage manufacturers to design environmentally-friendly products and hold them responsible for the costs of managing their products to the end-of-life (EOL). A summary of EPR legislation in different countries is provided in Table 12.6.

3.3 Take-Back Policy

Several countries have policies related to return of appliances to their manufacturers, also called 'take-back' policies. Europe has a WEEE directive which requires manufacturers to take-back their products. Asian countries like China, Japan, and Korea have policies that require recycling of discarded appliances. Special national funding is available in China for doing so while manufacturers in Japan are allowed to charge consumer fees for return of appliances. Manufacturers are required to pay recyclers a fee in Korea (Terazono et al. 2006).

Considering the take-back policy in India, most manufacturers of electrical and electronic appliances like Apple, Microsoft, Panasonic, PCS, Philips, Sharp, Sony, Sony Ericsson and Toshiba provide a take-back option. Samsung has a take-back service but only one collection centre for all of India; HCL and WIPRO have the best take-back policies in India. Other brands like Nokia, Acer, Motorola and LGE perform comparatively well. There is also a discount process where old products can be exchanged for new ones at a discounted price. However, these policies apply only to some electrical and electronic companies and needs to be adopted by developed and under-developed countries for managing e-waste.

3.4 Collection Centres and Deposit Boxes

Some electronic companies like HP, Nokia and Microsoft operating in India in various towns and cities have deposit boxes in their stores for the collection of end-of-life products for recycling purposes. There are certain collection centres in different parts of the states which collect e-waste and transport them to different recycling units for further processing.

3.5 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, generally shortened to "Basel Convention" is an international treaty that was designed to reduce the movement of hazardous waste between nations, and particularly to prevent transport of hazardous waste from developed to developing countries. The twelfth meeting of the Conference of Parties (COPs) to the Basel Convention was held from 4 to 15 May 2015 in Geneva and

Table 12.6 The role of EPR and e-waste legislation in different countries

Countries	EPR concept
European Union	The directive mainly focuses on reuse, recycle and recovery of e-wastes and dismantling of electronic parts and recycling of materials, proper collection systems to reduce disposal and incorporate best management practices.
Switzerland	This country was the first to develop and implement methods for collection, transportation, recycling/treatment and disposal of e-waste. Three producer responsibility organizations (PROs): The Swiss Association for Information Communication and Organizational Technology (SWICO); the Stiftung Entsorgung Schweiz (SENS); and Swiss Lighting Recycling Foundation (SLRS) oversee these systems based on the concept of EPR.
The United States of America	Established funding for the collection and recycling of e-waste. Consumers pay a fee called Advance Recycling Fee (ARF) at the time of purchase that goes to the state and is used to reimburse recyclers and collectors.
Japan	Manufacturers and importers are responsible for taking back end-of-life electronics for recycling and waste management. Consumers pay a fee that is directly used to meet the expenses of recycling and transportation.
South Korea	Local manufacturers, distributors and importers of e-goods are required to achieve official recycling targets. Government keeps an account for depositing funds for recycling, which are refundable depending on the amount of waste recycled.
Australia	Importers, manufacturers and distributors have to subscribe to mandatory, co-regulatory, or voluntary schemes for managing the disposal of computers and televisions.
Singapore	Export, import or transit waste requires a permit from the Pollution Control Department (PCD) of Singapore. If documents are available to support that the products are in good condition and can be reused, only then permission is granted.
China	(a) Pollution prevention and controls on the use, dismantling and disposal of e-waste, under "Technical Policies for Controlling Pollution of WEEE, 2006", (b) Certificate is required for e-waste recycling systems, under "Administrative Measures for the Prevention and Control of Environmental Pollution by WEEE, 2008", and (c) All producers and importers responsible for their products, collection and treatment funds, under "Regulation on the Administration of the Recovery and Disposal of WEEE, 2011".
India	According to MoEF, 2011, producers are responsible for collection of e-waste generated after the end-of-life of the e-products. The legislation has been modified in 2015 with new responsibilities for the producers as well as consumers.
African countries	The use of e-goods is very less in the African countries. No specific e-waste legislation has been implemented in those countries.

Source: Premalatha et al. (2014)

included the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants, respectively. One of the major outcomes of this meeting was the formulation of technical guidelines regarding the transboundary movement of e-waste which is a matter of growing concern for less developed countries. This meeting also deliberated over the definition of ‘waste’ and ‘non-waste’ since waste in one country is a usable second-hand appliance in another country. The need for inventorizing the amount of e-waste generated in different countries was also highlighted (UNEP 2015).

Major issues that were pointed out in this meeting were:

(a) Residual lifespan and age of used equipment;
(b) Management of hazardous wastes from repairing and refurbishment operations in developing countries;
(c) Obsolete technologies like cathode ray tubes; and
(d) Existence of hazardous components in used equipments.

4 Techniques for Recycling and Recovery

The most useful techniques for management of electronic wastes are recycling and recovery.

Recycle The first level of environmentally sound e-waste treatment includes decontamination, dismantling and segregation. After dismantling, the parts which can be recycled are transported to the respective industries for further use and the remaining parts are used for recovery of metals. Each of the electronic products consists of glass, plastics, ferrous and non-ferrous metals. Plastics constitute about 20.6% of the product (ETC/RWM 2003). Iron and steel comprise the largest fraction in WEEE materials, 47.9%. The non-ferrous component contributed 12.7% of which Cu weighed 7% (Bandyopadhyay 2008). After dismantling electronic products, segregation of the different parts is done and these are recycled and processed accordingly. The idea of developing economic and environmental benefits through inter-firm waste exchange is known as ‘Industrial Symbiosis’ in which one firm’s waste becomes the raw material of another firm.

Currently in India, there are two segments managing the recycling and disposal of the electronic wastes namely: formal recyclers and informal recyclers. Formal recyclers deal with a very small percentage which is close to 5% of the total e-waste recycled in India (19,000 MT) whereas the rest is recycled by informal recyclers. Formal recyclers are less in number and follow environmental, health and safety rules as they are frequently audited and certified by renowned regulatory agencies. Informal recyclers are more in number, better networked and more skilled in collection and recycling of e-waste.

4.1 Glass

Glass in electronic products can be recycled and used for different applications. Cathode Ray Tube (CRT) glass in old computer monitors and televisions are used as raw materials for ceramic glazes (Andreola et al. 2005). CRTs contain hazardous materials like lead, so they should be handled properly and recycled before reuse or disposal. LCD screens in television sets contain several thin mercury lamps and liquid crystals which makes them a challenge for recycling.

4.2 Plastic

All plastics are transferred to recyclers who use them as raw material to manufacture new products without altering their properties. However, there is a big challenge in separating the high value plastic streams from the mixed plastics present in electronic waste. CreaSolv process has been developed for the recovery of polymer fraction from the plastics present in mobile phones (Maurer et al. 2004). Plastic recovery techniques are difficult due to the variety of polymers used in e-goods and the labour-intensive nature of separation of plastic from e-waste.

4.3 Ferrous Metals and Non-ferrous Metals

Magnetic separation of ferrous metals and non-ferrous metals can be done to separate the two fractions. Recovery of various non-ferrous metals can be done by using any of the following processes:

1. Pyrometallurgy
2. Hydrometallurgy
3. Biometallurgy or Bioleaching
4. Electrometallurgy

4.3.1 Pyrometallurgy

Pyrometallurgy is the thermal treatment of minerals and metallurgical ores resulting in the physical and chemical transformation of valuable metals. In this process, electronic waste is heated above 1500 °C in a closed reactor, i.e. in the absence of oxygen, especially designed to ensure zero emissions. This process includes a number of procedures like calcining, roasting, smelting and refining. Elements that can be recovered by pyrometallurgical process include oxides of less reactive elements like iron, zinc, copper, manganese, chromium, tin, etc. Some pyrometallurgical studies for metal recovery are summarized in Table 12.7.

4.3.2 Hydrometallurgy

Appropriate chemical reagents are used in hydrometallurgy to dissolve metals from e-waste. The various chemical reagents used are aqueous and organic solvents, mineral acids, some bases, and mixed acids. The various types of solvents used are cyanides, thiourea, and thiosulfate, for the recovery of precious metals from e-waste. The different processes involved in hydro-metallurgy are:

Table 12.7 Pyrometallurgical methods for recovery of metals from electronic waste

Techniques	Metals recovered	Main results	References
Noranda process, Quebec, Canada	Cu, Au, Ag, Pt, Pd, Se, Te, Ni	Recovery of base metal like copper and precious metals.	Veldbuizen and Sippel (1994)
Boliden Rönnskår Smelter, Sweden	Cu, Ag, Au, Pd, Ni, Se, Zn, Pb	Recovery of copper and precious metals.	Cui and Zhang (2008)
Test at Rönnskår Smelter, Sweden	Copper and precious metals	Recovery of copper and precious metals in the zinc fuming process.	APME (2000)
Umicore's precious metal refining process, Hoboken, Belgium	Base metals, precious metals, platinum group metals and selenium, tellurium, indium	Almost complete recovery of base metals, precious metals and special metals such as Sb, Bi, Sn, Se, Te, In.	Hageluken (2006)
Full scale trial at Umicore's smelter	All metals present in the electronic scrap	Metal recovery was not affected by the presence of 6% plastics in e-waste.	Brusselaers et al. (2005)
Dunn's patent for gold refining	Gold	Gold with 99.9% purity was recovered from gold scraps.	Dunn et al. (1991)
Day's patent for refractory ceramic precious metals scraps	Precious metals such as platinum and palladium	Recovery of platinum and palladium of about 80.3% and 94.2%, respectively.	Day (1984)
Aleksandrovich's patent for recovery of gold and platinum group metals from electronic scraps	PGM and gold	PGM and gold were recovered.	Aleksandrovich et al. (1998)
Thermal treatment	Phosphate and rare earth metals (REMs) from Korean monazite ore	>90% REMs	Kumari et al. (2015)

Source: Cui and Zhang (2008)

Table 12.8 Hydrometallurgical methods for recovery of metals from electronic waste

Materials	Metals recovered	Efficiency	References
Computer chips	Au	Gold flakes	Sheng and Etsell (2007)
Ceramic capacitors	Ni	Ni in solution	Kim et al. (2007)
E-waste	Au, Pd, Pt, Ag	Au – 98%; Pd – 96%; Pt – 92%; Ag – 84%	Kogan (2006)
E-waste	Au, Ag, Pd	92% for Au, Ag, Pd	Zhou et al. (2005)
E-waste	Cu, Pb, Sn	Cu, Pb, Sn	Mecucci and Scott (2002)
E-waste	Au, Ni	Au, Ni	Zakrewski et al. (1992)
Solder of waste printed circuit boards	Lead	Pb – 99.99%	Kumari et al. (2010)
Printed circuit boards	Cu, Fe, Ni, Pb	Cu, Fe, Ni – 99.99% Pb – 36.7%	Jha et al. (2010)

(a) Leaching: The most efficient leaching agents are acids as they have the capacity to solubilise both, base and precious metals.
(b) Solution concentration and purification: The main purpose is to remove undesired impurities so that metal concentration in solution increases. Purification of the solution is done by ion exchange, adsorption and solvent extraction processes.
(c) Recovery of metal: After solution purification, metal is to be recovered chemically or electrochemically.

Applications of hydrometallurgical methods for metals recovery from e-waste are summarized in Table 12.8.

4.3.3 Biometallurgy

Biometallurgy involves the use of microbes in an aqueous environment to produce metals and has been used for decades for the recovery of metals like copper, gold and uranium. Almost a quarter of the global production of copper is done by bioleaching (Madigan et al. 2015). Bioleaching is defined as the mobilization of metal cations from mineral ores by biological oxidation. Biometallurgical methods used for metal recovery are summarized in Table 12.9.

4.3.4 Electrometallurgy

Electrometallurgy involves the use of electro-plating or electro-deposition methods. In these methods, electrolytic cells with different types of electrolytes and electrodes are used for deposition of expensive metals on the surface of the appropriate

Table 12.9 Biometallurgical methods for metal recovery from electronic waste

Materials	Metals recovered %		Microorganism used	References
	Nickel	Cadmium		
Ni-Cd battery	96.50	100	*A. ferrooxidans*	Cerruti et al. (1998)
	66.10	100	Indigenous acidophilic thiobacilli in sewage sludge	Zhu et al. (2003)
	–	84	*A. ferrooxidans* and *A. thiooxidans*	Velgosova et al. (2010)
Electronic scrap	Cu, Sn, Ni, Pb, Zn, Al		*A. ferrooxidans, A. thiooxidans, A. niger* and *P. simplicissimum*	Brandl et al. (2001)
Electronic waste	Cu, Zn, Al, Ni		*Thermosulfidooxidans sulfobacilllus* + *Thermoplasma acidophilum*	Ilyas et al. (2010)
Electronic waste	Cu, Pb, Zn		*A. ferrooxidans, A. thiooxidans* and mixture	Wang et al. (2009)
Electronic waste	Cu		*A. ferrooxidans* and *A. thiooxidans*	Mražíková et al. (2013)

Source: Willner et al. (2015) and Natarajan et al. (2015)

Table 12.10 Electrometallurgical methods for recovery of metals from electronic waste

Materials	Metals recovered	Efficiency	References
Printed circuit boards	Cu	12%	Kumar et al. (2013)
Printed circuit boards	Cu	98%	Masavetas et al. (2009)
Electronic waste	Au, Ag, Cu, Cd, Zn, Ni, Pb, Sn	–	Wiaux (1990)

electrode. Methods and efficiency of metal recovery from e-waste are summarized in Table 12.10. The most common processes used in electrometallurgy are:

(a) Electro-winning: A leach solution containing the metal of interest is added to an electrolytic cell. When current is passed through the cell, the metal is deposited on the cathode while the anode remains inert.
(b) Electro-refining: An acidic electrolyte is added to an electrolytic cell with anode made of impure metal. When current is passed through the cell, the anode dissolves into the electrolyte from where pure metal is deposited on the cathode resulting in greater metal purity.
(c) Electro-forming: Thin metal parts are moulded on pre-formed cathodes and manufactured through electroplating.

5 Conclusions

E-waste management has become a serious concern for the world after municipal solid waste and hazardous waste. Best methods from different countries can be incorporated to develop and design safe and hazard-free e-waste management systems. Proper e-waste management will help in efficient resource recovery and in e-waste management from cradle-to-grave. In India, E-waste (Management and Handling) Rules, 2011 have been modified to E-waste (Management) Rules, 2015, in which producers, distributors, and importers are held responsible for the proper recycling and disposal of e-waste. Efficient collection of e-waste and its treatment can lead to a better environment and huge piles of e-waste can be turned into lucrative products and business opportunities.

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