Chapter 12
Recycling Processes and Plastic in Electronic Waste Is an Emerging Problem for India: Implications for Future Prospect

K Ronnie Rex, Revathy Rajakumaran, Omkar Gaonkar, Elvis Dsouza, and Paromita Chakraborty

Abstract A steady rise in demand of electronic equipment is prevalent in both developed and developing nations. The high consumption rate of electronic goods has given rise to a new stream of waste known as electronic waste or e-waste. The informal sector is dominant and critically active in developing countries like India to recover precious metals from e-waste. The illegal trade of electronic waste products also adds up to a good proportion of e-waste. Recent studies from India reported that the crude processes involved in the informal e-waste recycling sector is a major cause for the emission of persistent toxicants into the environment. Some of those studies mentioned that the open burning of e-waste in dumpsites and landfills have

K. Ronnie Rex
Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India

SRM Research Institute, SRM Institute of Science and Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India

R. Rajakumaran
Environmental and Water Resource Engineering Division, Department of Civil Engineering, IIT Madras, Chennai, Tamil Nadu, India

O. Gaonkar
Nuevo Chakra, Mumbai, Maharashtra, India

SRM Research Institute, SRM Institute of Science and Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India

E. Dsouza
EDPC Polymer Industries, Vasai, Maharashtra, India

P. Chakraborty (✉)
Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India

Nuevo Chakra, Mumbai, Maharashtra, India

SRM Research Institute, SRM Institute of Science and Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India
e-mail: paromitc@srmist.edu.in

M. Z. Hashmi, A. Varma (eds.), *Electronic Waste Pollution*, Soil Biology 57,
https://doi.org/10.1007/978-3-030-26615-8_12

further contributed to the release of persistent organic pollutants in the environement. Burning of plastics present in e-waste (e-plastics) is another serious problem. This chapter presents a review of both formal and informal e-waste recycling and how informal sector is proving to be of a major environmental concern in India. Further, we have discussed the sustainable recycling methods for plastic and metal recovery and the future prospects of e-waste recycling sector.

Keywords E-waste · Persistent organic pollutants · Informal recycling sector · Metal recovery

12.1 Introduction

The revolutionary impact of information and technology due to globalization has commercialized a wide range of electronic products in the economy, thereby drastically changing the lifestyle and perspective of people all over the world (Hischier et al. 2005; Pradhan and Kumar 2014; Robinson 2009; Røpke 2001; Wagner 2009). The increase in population density and desire to improve the standard of life has increased the demand for electrical and electronic equipment (EEE), eventually leading to an enhanced production of EEE to meet the availability.

Electronic waste or e-waste are various forms of electronic gadgets at their end of serviceable life and are disowned by their users. E-waste is generically referred to all forms of electrical and electronic waste which has ceased the value period and is of minimal use to the consumer (Mohan and Bhamawat 2008; Raghupathy et al. 2010). Among the different types of wastes defined in the Basel Convention, e-waste is an emerging concern due to the incremental rates of production and disposal in the waste stream. Due to inexpensive manpower in developing countries, e-waste is imported for recycling purposes mostly by the informal sector and therefore possess serious public health concern (Chakraborty et al. 2016a, b; Robinson 2009; Terazono et al. 2006).

In India, the electronic industry stepped up into action in the year 1965 with the preliminary focus on the technological advancement in space, defence and communication divisions. Thus, with the increasing growth of information and technology industry, the production rate of such products started to increase keeping pace with the economic growth of the country (Ganguly 2016; GOI 2011).

E-waste in the year 2010 constituted nearly 2% of the municipal solid waste generated, that is, about 50 million tonnes (MT) in developed countries (Ganguly 2016; GOI 2011). In the year 2017, it was estimated to increase to 65 MT and is expected to perpetually increase in the forthcoming years (Balde et al. 2017; Heacock et al. 2016). Among the top five e-waste-generating countries, the United States ranks first, with 3 MT in the year 2007 which increased to 11.7 MT in the year 2016 and still accounting to perish the concurrent limit (GOI 2011; Kumar et al. 2017). China is in the second position with a production rate of 2.3 MT in 2007 with a considerable increase of 6.1 MT in the year 2016 (Kumar et al. 2017). Recent studies have shown that in the present decade, contribution of e-waste in the global expanse is parentally by the United States and European Union (EU) which is roughly estimated to be 30% and 28%, respectively (GOI 2011; Kumar et al. 2017). According to the study conducted in EU in 2007, it has been found that 14–15 kg per capita e-waste is generated and contributed to an annual production of roughly 7 MT and is expected to propagate at a cumulative increase of 3–5% per year (Kumar et al. 2017; Zoeteman et al. 2010). Plastic in e-waste (e-plastic) is the end of life plastic component covering or integrated in any discarded and thrown away electronic equipment, such as refrigerators, air conditioners, computers, televisions, VCRs, stereos, copiers and fax machines (Yang et al. 2013). Annually 50 million tons of e-waste is generated, resulting in 10 million tons of plastics in e-waste (Jiang et al. 2012).

Given the fact that there is e-waste transported from developed countries with a reasonably good quantity of waste generated in India, we are presenting a review of scientific literature and articles from the government and nongovernment organizations with the aim to report the current problems associated with e-waste recycling in India. This chapter is based on the following objectives in Indian context to elucidate the: (1) generation and production of e-waste, (2) recycling of e-waste by the formal and informal sectors, (3) plastic waste in e-waste as an emerging problem and (4) prospect for sustainable recycling of e-waste for recovery of metals and plastics.

12.2 Generation and Production of E-waste in India

India ranks fifth in e-waste generation. Central Pollution Control Board (CPCB) estimated it to be 0.573 MT per day in the year 2005 and 1.8 MT in 2016 (Khattar et al. 2007; Ganguly 2016). India is estimated to generate below 1 kg per capita e-waste. United Nations (UN) reports estimated that e-waste such as old computers will increase up to 500% in terms of quantity from 2007 to 2020 (Ganguly 2016). Mobile phones, being the most popular and consumable product, are estimated to increase by 18 times from 2007 to 2020 because of the rise in unusable and discarded phones. During the year 2007, 382,979 tonnes of waste were generated in India with major contribution from discarded televisions, computers and mobile phones. It is noteworthy that about 50,000 tonnes were found to be imported illegally from developed nations where the United States and the EU were the major benefactors with 80% and 20% of contribution, respectively (Ganguly 2016; Khattar et al. 2007). There has been an increasing trend in illegal export of almost 50–80% of e-waste from these countries to developing countries, where the environmental regulations are not so stringent and labour wages are low (Agoramoorthy 2006; Chan et al. 2007; Pradhan and Kumar 2014). Predominant hot spots include China, India, Pakistan, Vietnam, and the Philippines where the informal recycling of e-waste is conducted on a larger scale (ToxicsLink 2016).

In India, there are ten states which majorly contribute to over 70% of total e-waste produced in the country. Among the Indian states, Maharashtra tops the list, Tamil Nadu is in the second position, followed by Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab (Begum 2013).

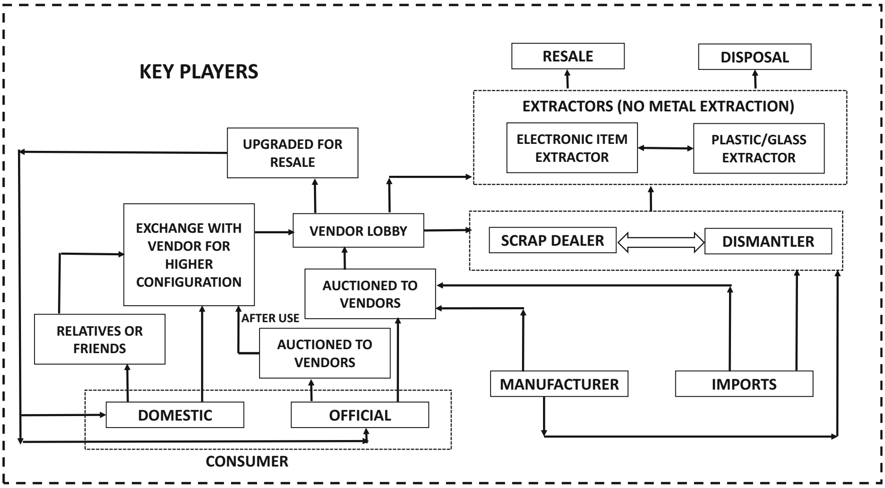

Fig. 12.1 E-waste recycling in India as explained by Wath et al. (2010)

Mumbai tops the list of 65 cities contributing nearly 60% of e-waste generated in India followed by New Delhi, Bengaluru, Chennai and Kolkata (Ganguly 2016; Jog 2008). Only 5% of e-waste generated in India is recycled by the formal sector (Chakraborty et al. 2016b; Khattar et al. 2007). But the high import rates and predominant e-waste generation is being extensively supported by the informal e-waste recycling sectors in India, where unrefined primitive methods are used to recover precious elements such as expensive valuable metals primarily gold, silver and copper (Chakraborty et al. 2018, 2019; GOI 2011; Ha et al. 2009; ToxicLink 2014). The extraction process involves dismantling of discarded e-waste materials which are shredded and treated with acid for metal recovery (Fig. 12.1) (Wath et al. 2010). Metal recovery processes are carried out by the unorganized sector and poses environmental and health threats due to release of persistent toxic substances (Chakraborty et al. 2016b).

12.3 Recycling of E-waste by the Formal Sector and Regulatory Framework in India

Out of 41.8 MT e-waste generated in India, informal sector receives 35.3 MT of e-waste (Baldé et al. 2015; Chakraborty et al. 2016b). Formal sectors are licensed organizations regulating recycling activities according to strong technical and environmental standards (Wang et al. 2013). Formal sector is expensive in setting up and have better control on health and environmental protection aspects. They usually deal with refurbishment, reselling, dismantling and shredding electronics to plastic and metals which are further recycled separately through sound environmental processes (Ceballos and Dong 2016).

The growing environmental concern in India has initiated the development of environmentally sound methods by organized sectors engaged in the reduction of the accumulated e-waste in a cost-effective manner by recycling and retrieving raw materials beneficial to the society. Initiatives are taken by the organized sector regarding proper training on recycling and reusing strategies with a major focus to develop such practices in the unorganized sector. This will help to reduce environmental pollution and in turn lead to conservation of natural resources and even employment generation. Training regarding proper recycling and reusing is initially being incorporated into unorganized sector with emphasis on reducing environmental pollution and natural resource conservation leading to employment and revenue generation.

India faces a major problem in the management of e-waste not only because of the import of e-waste but also due to the huge amount of domestically produced e-waste. The lack of appropriate cost-effective technology and uncontrolled disposal in the waste stream has affected the growth of formal sectors in India. Due to higher profit margin, the unorganized sector plays an important role in hampering the collection of e-waste by the formal sector (Ganguly 2016).

The three rules governing e-waste management in India are: Hazardous Wastes Management, Handling and Transboundary Movement Rules of 2008 and The Batteries Management and Handling Rules. The e-waste Management and Handling Rules 2010 is the most recent attempt to regulate e-waste in India. However, a final outcome of this rule is yet to come and is much awaited (Ganguly 2016). The Ministry of Environment, Forest and Climate Change (MoEFCC) updated the e-waste management rules in 2016 which requires producers to have Producer Responsibility Organisation (PRO) and can therefore ensure sustainable collection and disposal of e-wastes (Chakraborty et al. 2018). The implementation of these rules by the formal e-waste recycling sector becomes difficult as the responsibilities of certain activities fall within the state jurisdiction while other activities are governed by the central government. Hence, proper monitoring becomes increasingly difficult, sometimes leading to increasing role of informal sector. The rules put forward by MoEFCC in 2016 has created a powerful awareness in the government level regarding e-waste generation (Chakraborty et al. 2018).

12.4 Recycling of E-waste by the Informal Sector in India

The informal sector recycles about 95% of e-waste in India (Chakraborty et al. 2018). Urban slums and suburbs are the major locations where unorganised recycling sector endeavours in and around major metropolitan cities of India. Such localities have unskilled labour and reduces labour investment. Hence, maximum profit can be extracted from this business sector (Fig. 12.2) (Williams et al. 2013).

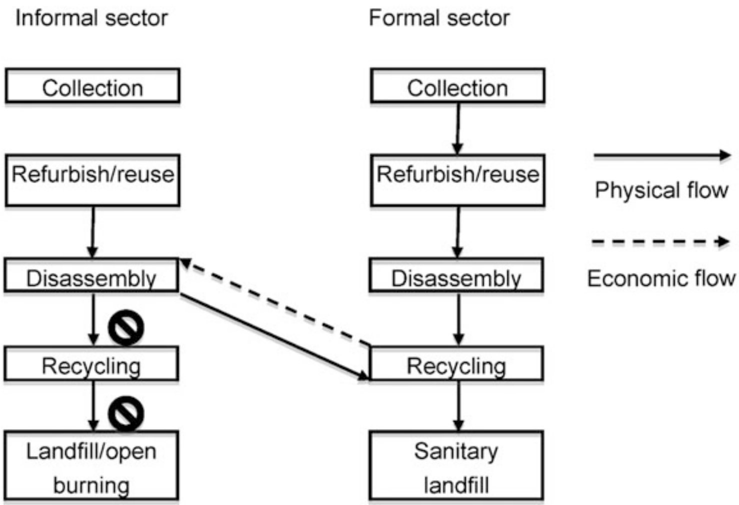

Fig. 12.2 Formal versus informal recycling of e-waste as described by Williams et al. (2013)

The unorganized nature and the revenue generation from e-waste explains why this sector adopts rudimentary methods to extract precious metals. Less complicated methods involve three major stages—dissembling of e-waste, followed by shredding and finally the metal recovery process involving the extraction of precious metals from e-waste (Chakraborty et al. 2016b). Remnants are discarded directly into the environment and majority of it is plastic waste. Retrieval of iron and steel, present in 48% of electronic equipment, has prime significance. The plastic component in e-waste contributes about 15% of non-flame-retardant plastics and 5% flame-retardant plastics with an average gauging of 25–35% of its weight making it the second largest component of EEE (ToxicsLink 2016).

The drop in price of electronic products has not only benefitted mankind but also increased the production of electronic goods. This has significantly affected the product life span overshooting the quantitated proportion of electronic detritus. All the reusable components are refurbished and sent to the market again. Hence, the waste generation rate do not subside and the quantitative flow is further increased by the inflow of illegal e-waste from developed countries. The extraction of precious metals from e-waste is a major profit-earning component which in turn leads to high import rates of e-waste in India. This exploitation has contributed to the dangerous health hazards associated with each activity during informal e-waste recycling process. The most affected class include women and children who are somewhat forcefully drifted into this industry due to poor employment options and sustenance. Environment is impacted heavily due to the release of toxicants from each step carried out during the crude recycling process and related waste disposal.

The plastic components in e-waste, especially the ones having potential of forming smaller fragments and are recyclable in nature, are removed by means of

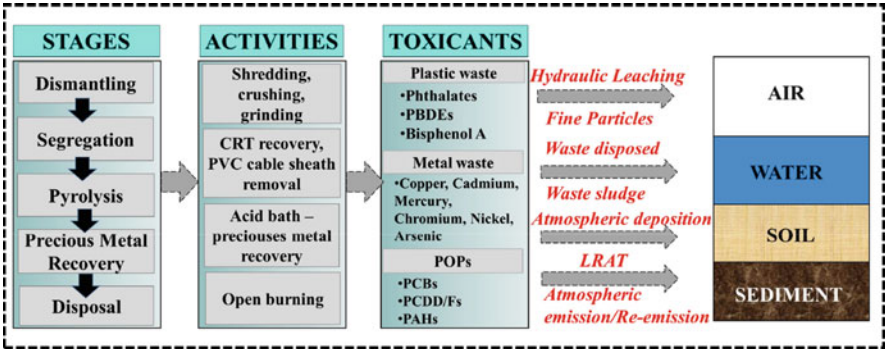

Fig. 12.3 Stages, activities and toxicants released during informal e-waste recycling in India as described by Chakraborty et al. (2016b)

mechanical shredding (GreenPeace 2005). A major proportion of e-waste plastics, rich in both secondary and primary toxicants, are disposed essentially using crude methods by the informal recycling sector, thus extensively promoting emission levels of several toxicants to a precarious limit.

Acid recovery is the most toxic step of all the processes where the emission of toxicants are expected to be predominant (Chakraborty et al. 2016b). Once the recycling materials are removed in the preliminary stage after collection, segregated e-waste is processed through shredding and then transferred to acid leaching sites where precious metals including gold, silver and copper are recuperated (GreenPeace 2005). Since e-waste mainly constitute of metals and plastics, this procedure of acidic leaching is performed by dissolving the preprocessed waste in strong acidic solutions. Cathode ray tubes (CRTs) are mostly disassembled and recycled so that valuable materials can be recovered. Printed circuit boards are major contributors of e-waste category since they are the principal components in most electrical equipments (Begum 2013). After recyclable components are extracted from the printed circuit boards via dismantling or heat treatment, the rest is subjected to acid treatment for metal extraction (Chakraborty et al. 2016a, b). The remaining parts are openly burnt (GreenPeace 2005). The burning of e-waste is also practiced in the recycling workshops to remove the plastic or polyvinyl chloride (PVC) coatings and recover copper (Chakraborty et al. 2018, 2019; Chakraborty et al. 2016b; GreenPeace 2005). Rudimentary methods used during informal e-waste recycling activities in India subsequently release toxic pollutants like polychlorinated biphenyls (PCBs) (Chakraborty et al. 2013), polycyclic aromatic hydrocarbons (PAHs) (Chakraborty et al. 2019), polybrominated diphenyl ethers (PBDEs) (Chakraborty et al. 2017) and polychlorinated dibenzo-*p*-dioxins and furans (PCDDs/Fs) (Chakraborty et al. 2016a, b; 2018) (Fig. 12.3). These semi-volatile persistent organic pollutants (POPs) are capable of long range atmospheric transport (LRAT).

The most severe concern regarding the informal e-waste recycling sector in India (Chakraborty et al. 2018, 2019; Chakraborty et al. 2016b; Ha et al. 2009) and China

(Ha et al. 2009) is the metal extraction, involving various crude methods leading to the release of toxic substances. The disposed wastes such as sludge and discharges from industries due to its improper treatment led to accumulation of contaminants in environmental matrices dominantly air, water and soil. As mentioned earlier, the people working in these unorganized sectors have direct exposure to these hazardous substances due to lack of protective aids. The labourers are mostly affected by irregular working schedule concurrent to the operational facilities in the workspace. Improper ventilation and high temperature usually causes physical abnormalities including injuries, vision obstruction, skin diseases and lung afflictions such as asthma. Thus, e-waste is a growing problem pertaining to rudimentary methods practiced during informal recycling for revenue generation.

12.5 E-plastic: An Emerging Issue

Plastics can be efficiently processed into light, durable and affordable goods having very less thermal and electrical conductivity (Brebu et al. 2004). Hence plastics constitute an integral component of EEE and majority of applications include insulation purpose, reduce noise, sealing, housing, interior structural, functional and interior electronic parts. The usage of plastics in electronic sector over the last decade has helped in lowering raw material consumption and minimizing the total manufacturing cost, which resulted in reduction of the total weight of the equipment (Fisher et al. 2004).

The waste e-plastics constitute complex mixture of wide variety of substances including a large range of polymers which are mostly incompatible. E-plastics consist of more than fifteen non-identical polymers which makes it difficult to recycle. To characterize plastic composition, a total of 3417 appliances including large cooling equipment (refrigerators, freezers), small waste electrical and electronic equipment (WEEE), central processing units (CPU), coping equipment, printers, cathode ray tube (CRT) monitors and CRT televisions were characterized by Martinho et al. (2012). The percentage of plastic in large cooling appliances, small WEEE, printers, coping equipment, CPU, CRT monitors and CRT televisions were reported to be 10.4%, 49.1%, 23.6%, 15.7%, 3.5%, 17.5% and 16.5%, respectively. The types of polymers analysed in appliances are given in Fig. 12.4 (Martinho et al. 2012). The most predominantly found polymers were polystyrene (PS), acrylonitrile-butadiene-styrene (ABS), polycarbonate blends (PC/ABS), high-impact polystyrene (HIPS) and polypropylene (PP) (Martinho et al. 2012).

Flame retardants (FR) are used in e-plastics to increase the fire-resisting property of the electronic products which in turn reduces the threat of fire. More than 175 types of FR plastics are present, which include about 27% halogenated organic compounds and the rest are non-halogenated FRs. Around 30% FR plastics used in electronic equipment comprises of halogenated or non-halogenated plastics (Vehlow et al. 2002). The FR plastics accounts for 4,50,000 tonnes containing about 41% of halogenated FRs as shown in Fig. 12.5 (Vehlow et al. 2002).

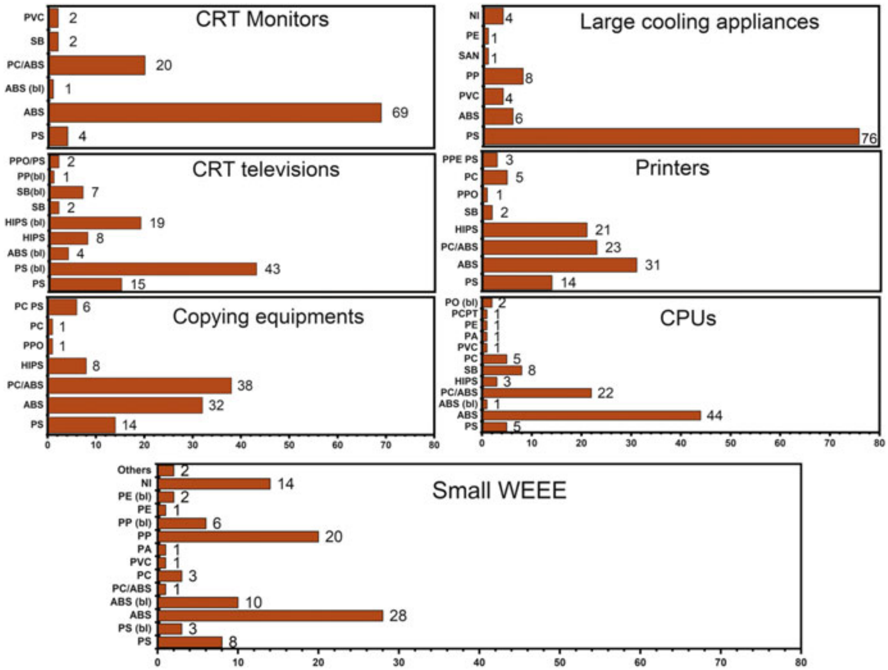

Fig. 12.4 Characterization of different polymer types from waste electrical and electronic equipment (WEEE) (values are in percentage) (Martinho et al. 2012)

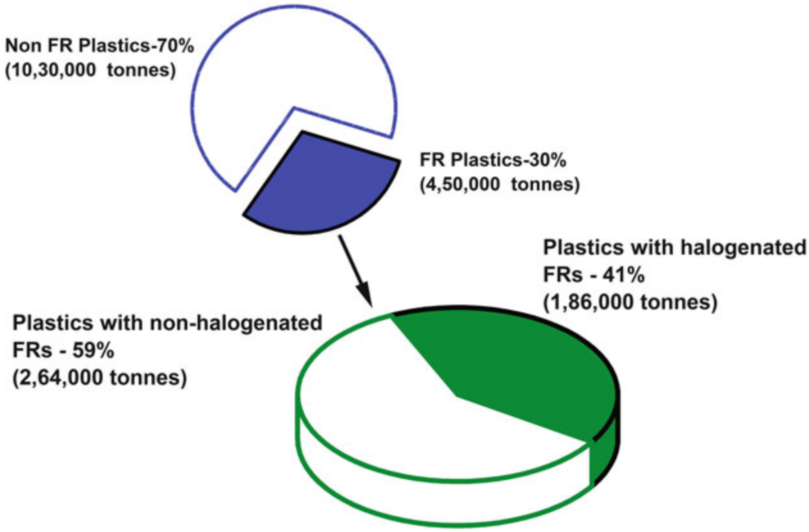

Fig. 12.5 Usage of flame retardants plastics in EEE (Vehlow et al. 2002) (FR—flame retardants, E&E—electrical and electronic)

Table 12.1 Health risks of some BFRs

BFRs	Health risks	References
PBDE	Human milk associated with cryptorchidism and increased serum LH	Main et al. (2007)
PBDE	Elevated levels in the human milk correlated with lower birth weight, length, lower head and chest circumference	Chao et al. (2010)
PBB	Diabetes	Lee et al. (2010)
TBBPA	Thyroid hormone interference and neurotoxicity	Van der Ven et al. (2008)
TBBPA	Binds to oestrogen hormone receptors at high concentrations	Gosavi et al. (2013)
HBCD	Evidence of biomagnification in aquatic food webs	Morris et al. (2004)
HBCD	TH-mediated brain development is disruption by HBCD	Ibhazehiebo et al. (2011)

Brominated flame retardants (BFRs) are the most frequently used FRs in e-plastics, containing about 50–90 wt% of bromine. BFRs are applied to 2.5 million tonnes of polymers annually (Tohka and Zevenhoven 2002). Among the 75 categories of BFRs available, only around 30–40 are extensively used. Tetrabromobisphenol A (TBBPA), decabromodiphenyl oxide (DBDPO), 1,2,5,6,9,10-hexabromocyclodecane (HBCD) and decabromodiphenyl ethane (DBDPE) (health risks as given in Table 12.1) are the highly used BFRs (Freegard et al. 2006; Tohka and Zevenhoven 2002).

Generally, these BFRs are persistent in nature and have the prime susceptibility to bioaccumulate in the ecosystem and human beings. Further, they are presumed to be major carcinogens, neurotoxins and endocrine disruptors (Brown et al. 2004; De Wit 2002). Liver tumours, neurodevelopmental problems and thyroid dysfunctions are the major expected disorders caused by BFRs (Siddiqi et al. 2003). All the major matrixes including air, water, sewage sludge, sediments and biota have been quantified for BFRs. The water solubility of BFR is exceptionally small. When plastic wastes with FR composition is reprocessed, BFRs predominantly PBDEs have the tendency to form brominated dibenzo dioxins and furans (PBDD/Fs) (Siddiqi et al. 2003). It is evident that PBDE with less brominated fractions have high potential to bioaccumulate and biomagnify in human, fish and other animal adipose tissues. PBDEs have been detected in human blood, serum, adipose tissue, breastmilk, placental tissue and the brain (Bjermo et al. 2017; Meironyté et al. 1999; Sellström et al. 1993; Siddiqi et al. 2003; Sjödin et al. 2001). Studies conducted in Sweden quantified the concentration of PBDE for a time span of thirty years in human milk samples reported that the concentration doubled approximately after every 5 years (Meironyté et al. 1999).

Regardless of the existence of Basal Convention which regulates and controls the transboundary movement of hazardous wastes from the United States, Canada, Australia, EU, Japan and South Korea to Asian countries such as China and India, the rate of inflow of toxic waste is still increasing in developing countries

Table 12.2 Management options of e-plastics

Options	Definitions	Comments
Landfilling	Landfilling is the least preferred option, e-plastics is dumped and interlayer with municipal solid wastes	Landfilling is a risky method. Leaking of landfills is a problem because pollutants will infiltrate and contaminate surrounding soil and aquifers
Material recycling	Plastics with FRs can be reprocessed mechanically to form new consumer plastic products or can be brought back to the system with close properties of the principle product	It is essential to segregate heterogeneous e-plastics before material recycling. In addition, the reprocessing leads to formation of toxic PBDD/Fs when heat treated (Schlummer et al. 2007), special measures are adopted during recycling process
Energy recycling	Objective of energy recycling is to produce thermal energy by incineration of e-plastics	Due to the emission of toxic substances like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and polychlorinated dioxins (PCDs) incineration is considered to be very dangerous (Wang and Xu 2014)
Feedstock recycling	Method of converting plastics to their original chemical constituents. These are applicable for mixed polymers in e-plastics, for example, pyrolysis and gasification	Pyrolysis is one of the feedstock recycling methods; 10% of energy is produced and the rest is used to transform material scrap into useable and costly hydrocarbon products (Brebu et al. 2004)

(Schlummer et al. 2007). However, in most of the developing countries, e-plastic is presently managed based on unsafe disposal practices majorly burning or burying. This inadequate waste management approach is no more secure on international level. Rising knowledge about the environmental issues in population has resulted in most developing countries adopting sound waste management practices. The risk associated with open burning of e-plastics and emission of various toxins from it is oblivious to majority of population in the developing countries and corresponding regulating authorities. Landfilling, material recycling, energy recycling and feedstock recycling are the current options available for managing e- plastics (Table 12.2).

The pyrolysis technology is proven to be consuming lowest energy and the oil generated in the process can be a raw material substitute in petrochemical industry. Nevertheless, BFRs present in plastics make this process somewhat problematic. However, the dehalogenation measures are mandatory to avoid the impact on reuse of pyrolysis oil. The debromination efficiency of the process can be improved by adding catalyst or incorporating supercritical fluid extraction (SCF) technology. The two processes can be combined to avoid the release of brominated dioxins and furans (Onwudili and Williams 2009).

12.6 Prospect for Sustainable Recycling of E-waste

Due to high market value, precious metals in e-waste are recycled to a credible extent but e-plastic waste is not significantly recycled to that level. Although recycling of e-plastics may seem to be impractical today because of high energy required and significant financial costs involved but, upcoming technologies and systems are making it a viable option for the long term. China is an ideal example where large recycling options for e-plastics are available. In the United States, over 99% of their e-plastics are collected and shipped to China. This is because of the high labour costs associated with dismantling and dissociation of e-waste in the United States. A recycling facility in Qing dao, northern China, managed by e-plastic consolidators ParcCorporation, USA, uses recycled e-plastics for devices like water coolers. A large US-based reclaimer Fortune Metals and Plastics has set up a Chinese joint venture to sort and upgrade e-waste metals and plastics 10 years ago in Nanjing. Other companies in this sector which have developed new techniques for e-waste and e-plastic recycling include MBA polymers, USA; Plas-Sep Ltd., Canada; Electrocycling GmbH in Goslar, Germany; Plastic Herverwerking Brabant in Waalwijk, The Netherlands (Schut 2007).

Axion Recycling Ltd., UK, is a recycling consultant engaged in testing several methods to separate brominated FRs from e-plastics and developed its own Centrevap method. Separation and recycling of e-plastic scrap generated by WEEE regulations can process 28 million lb/year of e-plastics via size reduction, wet and dry cleaning, automatic polymer identification and separation and repalletizing of e-scrap plastics. The polystyrene recycled from refrigerators is supplied by Axion Polymers, UK, to Brookhaven Instruments Corporation (BIC) for manufacturing pencils that is being marketed under its 'Ecosolutions' product lines. About 640 pencils could be typically made from one refrigerator (Recycling Today Staff 2011). Thus, various players in the recycling business and technological innovations can be the right way forward in handling e-plastic waste.

In India, there are some well-known companies involved in e-waste recycling. An e-waste management company named 'Attero', based in Roorkee, handles about 500 tonnes of e-waste per month. Another company based in Bangalore 'E-Parisaraa Pvt Ltd' is authorized by the government and involved in extraction of precious metals, such as gold and silver, from e-waste since 2005 (Ecoideaz 2016).

E-plastic recycling usually takes place along with the normal plastic recycling by the informal sector in India. The e-plastic recycling line should be separated because of the toxic nature of e-plastics and more environmentally friendly recycling techniques with minimal health impacts needs to be adopted. EDPC Polymer Industries located in Dadra and Nagar Haveli in western India is a pencil manufacturing company using recycled plastic for manufacturing pencils under the brand Ecocils. Their unique material and special extrusion technology supports production of more pencils and can be compared with the conventional pencil manufacturing methods. Presently, the company is exploring the potential use of e-plastics for the production of pencils in addition to other recycled products.

12.7 Conclusion

Being a developing nation, India stands reasonably high in e-waste generation at local level as well as import of e-waste from developed nations. The increasing trend of recycling e-waste by informal sector has also weighed in the illegal import of e-waste. Due to the lack of properly practised environmental regulations in India, the disposal is diverted towards landfills and dumpsites. The rules and regulations are stringent and the growth of formal sectors considering the legal constraints are really poor.

Being economically viable and environmentally sound, recycling is considered as the major significant policy for end-of-life electronic products. However, there are challenges that exist both on technological aspects and social issues associated with collection and processing of recyclable e-plastics. The increase in the use of plastics in electronic products is forcing companies to look for alternatives apart from landfilling.

Absence of stringent rules adds up to the concern regarding e-waste recycling in India. The informal recycling trend has affected the environmental matrices making it susceptible to organic and inorganic contaminants both directly and indirectly. Proper channel for collection and segregation of waste need to be practised with sustainable cost-effective recycling techniques. Separate recycling of plastic components into useful products or useable raw materials should be encouraged by providing subsidies from government.

Acknowledgement This work was supported by the grant from the Environmental Health Cell, Ministry of Environment, Forest and Climate Change, Government of India (File No.Q-14011/43/2013-CPW(EHC).

References

Agoramoorthy G (2006) Computer 'recycling' builds garbage dumps overseas. Nature 441:25

Baldé C, Wang F, Kuehr R, Huisman J (2015) The global e-waste monitor 2014, Institute for the Advanced Study of Sustainability (IAS) and Sustainable Cycles (SCYCLE). Technical report, United Nations University and Institute for Advanced Study of Sustainability

Balde CP, Forti V, Gray V, Kuehr R, Stegmann P (2017) The global e-waste monitor 2017: quantities, flows and resources. United Nations University, International Telecommunication Union, and International Solid Waste Association, Bonn

Begum DKJA (2013) Electronic waste (e-waste) management in India: a review. IOSR J Human Soc Sci (IOSR-JHSS) 10:46–57

Bjermo H, Aune M, Cantillana T, Glynn A, Lind PM, Ridefelt P, Darnerud PO (2017) Serum levels of brominated flame retardants (BFRs: PBDE, HBCD) and influence of dietary factors in a population-based study on Swedish adults. Chemosphere 167:485–491

Brebu M, Bhaskar T, Murai K, Muto A, Sakata Y, Uddin MA (2004) The individual and cumulative effect of brominated flame retardant and polyvinylchloride (PVC) on thermal degradation of acrylonitrile-butadiene-styrene (ABS) copolymer. Chemosphere 56:433–440

Brown DJ, Van Overmeire I, Goeyens L, Denison MS, De Vito MJ, Clark GC (2004) Analysis of Ah receptor pathway activation by brominated flame retardants. Chemosphere 55:1509–1518
Ceballos DM, Dong Z (2016) The formal electronic recycling industry: challenges and opportunities in occupational and environmental health research. Environ Int 95:157–166
Chakraborty P et al (2013) Atmospheric polychlorinated biphenyls in Indian cities: levels, emission sources and toxicity equivalents. Environ Pollut 182:283–290
Chakraborty P, Prithiviraj B, Selvaraj S, Kumar B (2016a) Polychlorinated biphenyls in settled dust from informal electronic waste recycling workshops and nearby highways in urban centers and suburban industrial roadsides of Chennai city, India: levels, congener profiles and exposure assessment. Sci Total Environ 573:1413–1421
Chakraborty P, Selvaraj S, Nakamura M, Prithiviraj B, Ko S, Loganathan BG (2016b) E-waste and associated environmental contamination in the Asia/Pacific region (Part 1): an overview. In: Persistent organic chemicals in the environment: status and trends in the pacific basin countries. I: Contamination status. ACS Symposium Series, vol 1243. American Chemical Society, pp 127–138. doi: https://doi.org/10.1021/bk-2016-1243.ch006
Chakraborty P, Zhang G, Cheng H, Balasubramanian P, Li J, Jones KC (2017) Passive air sampling of polybrominated diphenyl ethers in New Delhi, Kolkata, Mumbai and Chennai: levels, homologous profiling and source apportionment. Environ Pollut 231:1181–1187
Chakraborty P, Selvaraj S, Nakamura M, Prithiviraj B, Cincinelli A, Bang JJ (2018) PCBs and PCDD/Fs in soil from informal e-waste recycling sites and open dumpsites in India: levels, congener profiles and health risk assessment. Sci Total Environ 621:930–938
Chakraborty P, Sampath S, Mukhopadhyay M, Selvaraj S, Bharat GK, Nizzetto L (2019) Baseline investigation on plasticizers, bisphenol A, polycyclic aromatic hydrocarbons and heavy metals in the surface soil of the informal electronic waste recycling workshops and nearby open dumpsites in Indian metropolitan cities. Environ Pollut 248:1036–45
Chan JK et al (2007) Body loadings and health risk assessment of polychlorinated dibenzo-p-dioxins and dibenzofurans at an intensive electronic waste recycling site in China. Environ Sci Technol 41:7668–7674
Chao HA et al (2010) Concentrations of polybrominated diphenyl ethers in breast milk correlated to maternal age, education level, and occupational exposure. J Hazard Mater 175:492–500
De Wit CA (2002) An overview of brominated flame retardants in the environment. Chemosphere 46:583–624
Ecoideaz (2016) E-waste recycling in india – managing a growing crisis. http://www.ecoideaz.com/expert-corner/managing-the-e-waste-crisis-in-india. Accessed 21 Jan 2019
Fisher M, Kingsbury T, Headley L (2004) Sustainable electrical and electronic plastics recycling. In: Electronics and the Environment, 2004. Conference record, IEEE International Symposium on, 2004. IEEE, pp 292–297
Freegard K, Tan G, Morton R (2006) Develop a process to separate brominated flame retardants from WEEE polymers. Final report. Waste & Resources Action Programme (WRAP), UK
Ganguly R (2016) E-waste management in India–an overview. Int J Earth Sci Eng 9(2):574
GOI (2011). http://rajyasabha.nic.in/rsnew/publication_electronic/E-Waste_in_india.pdf. Acessed 21 Jan 2019
Gosavi RA, Knudsen GA, Birnbaum LS, Pedersen LC (2013) Mimicking of estradiol binding by flame retardants and their metabolites: a crystallographic analysis. Environ Health Perspect 121:1194
GreenPeace (2005). http://www.greenpeace.org/international/en/publications/reports/recyclingelectronicwasteindiachinafull/. Acessed 21 Jan 2019
Ha NN et al (2009) Contamination by trace elements at e-waste recycling sites in Bangalore, India. Chemosphere 76:9–15
Heacock M et al (2016) E-waste and harm to vulnerable populations: a growing global problem. Environ Health Perspect 124:550
Hischier R, Wäger P, Gauglhofer J (2005) Does WEEE recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems

for waste electrical and electronic equipment (WEEE) environmental impact. Assess Rev 25:525–539
Ibhazehiebo K, Iwasaki T, Xu M, Shimokawa N, Koibuchi N (2011) Brain-derived neurotrophic factor (BDNF) ameliorates the suppression of thyroid hormone-induced granule cell neurite extension by hexabromocyclododecane (HBCD). Neurosci Lett 493:1–7
Jiang P et al (2012) Improving the end-of-life for electronic materials via sustainable recycling methods. Procedia Environ Sci 16:485–490
Jog S (2008) Ten states contribute 70% of e-waste generated in India. The financial express, 13 March 2008
Khattar V, Kaur J, Chaturvedi A, Arora R (2007) E-waste assessment in India: specific focus on Delhi. http://www.weeerecycle.in/publications/reports/GTZ_MAIT_E-waste_Assessment_Report.pdf
Kumar A, Holuszko M, Espinosa DCR (2017) E-waste: an overview on generation, collection, legislation and recycling practices. Resour Conserv Recy 122:32–42
Lee D-H, Steffes MW, Sjödin A, Jones RS, Needham LL, Jacobs DR Jr (2010) Low dose of some persistent organic pollutants predicts type 2 diabetes: a nested case–control study. Environ Health Perspect 118:1235
Main KM et al (2007) Flame retardants in placenta and breast milk and cryptorchidism in newborn boys. Environ Health Perspect 115:1519
Martinho G, Pires A, Saraiva L, Ribeiro R (2012) Composition of plastics from waste electrical and electronic equipment (WEEE) by direct sampling. Waste Manag 32:1213–1217
Meironyté D, Norén K, Bergman A (1999) Analysis of polybrominated diphenyl ethers in Swedish human milk. A time-related trend study, 1972–1997. J Toxicol Environ Health Part A 58:329–341
Mohan D, Bhamawat P (2008) E-waste management-global scenerio: a review. J Environ Res Dev 2(4):817–823
Morris S et al (2004) Distribution and fate of HBCD and TBBPA brominated flame retardants in North Sea estuaries and aquatic food webs. Environ Sci Technol 38:5497–5504
Onwudili JA, Williams PT (2009) Degradation of brominated flame-retarded plastics (Br-ABS and Br-HIPS) in supercritical water. J Supercrit Fluids 49:356–368
Pradhan JK, Kumar S (2014) Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. Environ Sci Pollut Res 21:7913–7928
Raghupathy L, Krüger C, Chaturvedi A, Arora R, Henzler MP (2010) E-waste recycling in India: bridging the gap between the informal and formal sector. In: International Solid Waste Association, World Congress, Hamburg, Germany
Recycling Today Staff (2011) BIC makes pencil with recycled plastic supplied by axion polymers - recycling today. In: Recycling today. https://www.recyclingtoday.com/article/bic-axion-partner-on-pencil/. Accessed 21 Jan 2019
Robinson BH (2009) E-waste: an assessment of global production and environmental impacts. Sci Total Environ 408:183–191
Røpke I (2001) New technology in everyday life–social processes and environmental impact. Ecol Econ 38:403–422
Schlummer M, Gruber L, Mäurer A, Wolz G, Van Eldik R (2007) Characterisation of polymer fractions from waste electrical and electronic equipment (WEEE) and implications for waste management. Chemosphere 67:1866–1876
Schut JH (2007) Recycling E-plastics: new material stram brings its own set of problems. Plastics Technol 53:48–53
Sellström U, Jansson B, Kierkegaard A, de Wit C, Odsjö T, Olsson M (1993) Polybrominated diphenyl ethers (PBDE) in biological samples from the Swedish environment. Chemosphere 26:1703–1718
Siddiqi MA, Laessig RH, Reed KD (2003) Polybrominated diphenyl ethers (PBDEs): new pollutants–old diseases. Clin Med Res 1:281–290

Sjödin A, Patterson DG, Bergman Å (2001) Brominated flame retardants in serum from US blood donors. Environ Sci Technol 35:3830–3833

Terazono A et al (2006) Current status and research on E-waste issues in Asia. J Mater Cycles aste Manag 8:1–12

Tohka A, Zevenhoven R (2002) Brominated flame retardants–a nuisance in thermal waste processing. In: TMS extraction and processing division meeting on recycling and waste treatment in mineral and metal processing: technical and economic aspects, Lulea, Sweden.

ToxicLink (2014). http://toxicslink.org/docs/Impact-of-E-waste-recycling-on-Soil-and-Water.pdf. Accessed 21 Jan 2019

ToxicsLink (2016). http://toxicslink.org/docs/Report-WEEE-plastics.pdf. Accessed 21 Jan 2019

Van der Ven LT et al (2008) Endocrine effects of tetrabromobisphenol-A (TBBPA) in Wistar rats as tested in a one-generation reproduction study and a subacute toxicity study. Toxicology 245:76–89

Vehlow J et al (2002) Recycling of bromine from plastics containing brominated flame retardants in state-of-the-art combustion facilities. APME Technical Report No. 8040, APME, Brussels

Wagner TP (2009) Shared responsibility for managing electronic waste: a case study of maine, USA. Waste Manag 29:3014–3021

Wang R, Xu Z (2014) Recycling of non-metallic fractions from waste electrical and electronic equipment (WEEE): a review. Waste Manag 34:1455–1469

Wang F, Huisman J, Stevels A, Baldé CP (2013) Enhancing e-waste estimates: improving data quality by multivariate input-output analysis. Waste Manag 33:2397–2407

Wath SB, Vaidya AN, Dutt P, Chakrabarti T (2010) A roadmap for development of sustainable E-waste management system in India. Sci Total Environ 409:19–32

Williams E, Kahhat R, Bengtsson M, Hayashi S, Hotta Y, Totoki Y (2013) Linking informal and formal electronics recycling via an interface organization. Challenges 4:136–153

Yang X, Sun L, Xiang J, Hu S, Su S (2013) Pyrolysis and dehalogenation of plastics from waste electrical and electronic equipment (WEEE): a review. Waste Manag 33:462–473

Zoeteman BC, Krikke HR, Venselaar J (2010) Handling WEEE waste flows: on the effectiveness of producer responsibility in a globalizing world. Int J Adv Manuf Technol 47:415–436