International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.3, No.6, June 2014 DOI:10.15693/ijaist/2014.v3i6.92-107

Plastic E-waste Recycling and Management-Scenario - and Technologies- A Review

S.Sugumar & S.K. Nayak
Central Institute of Plastics Engineering & Technology,
Chennai, India

***Abstract*-Electrical and electronic waste is currently the largest growing stream in most of the countries. The increase in production of electronic goods and their rapid obsolescence has resulted in generation of e-waste. Every year around 50 million tones of electrical and electronic waste are generated world-wide, which could bring serious risk to human life and the environment. The European Union (EU), Japan, Taiwan and several states of USA have introduced legislation making producers responsible for their end-of-life products. In India the e-waste generation is more than 8 lakhs tones in the year 2012. The e-waste generated in few countries across the world show an alarming picture. This paper reveals the current scenario of e-waste generation in the world and India and the various work done in e-waste recycling. Mechanical recycling and chemical recycling are the two main types of recycling processes widely adopted by several manufacturers. Mechanical recycling involves separation of various types of plastics shredding them into small pieces and reprocessing it using an extruder and converted into pellets. Chemical recycling mainly involves depolymerisation and unzipping of molecular level constituents which are subsequently processed and converted into petro products. Various strategies are being followed by various countries for the management of e-waste; they are LCA, MFA, MCA, EPR. These strategies are mainly supported by countries like Japan, European Union, Canada and Switzerland. Environmental impacts of E-waste during treatment processes and the concerns in plastics E-waste recycling are also discussed in brief in this article**

***Key Words*: e-waste, legislation, generation, mechanical recycling, chemical recycling, LCA (Life Cycle Assessment), MFA(Material Flow Analysis), MCA(Multi Criteria Analysis), EPR(Extended Producer Responsibility)**

I. INTRODUCTION

Electrical and Electronics Waste or e-waste is a collective name for discarded electronic devices that enter the waste stream or nearing the end of their "useful life". It consists of obsolete electronic devices such as computers, monitors and display devices, telecommunication devices such as cellular phones, calculators, audio and video devices, printers, scanners, copiers and fax machines besides household equipments such as refrigerators, air conditioners, televisions and washing machines[1].

New technologies are rapidly superseding millions of analogue in prescribed landfills despite potentially their adverse impacts on the environment. The consistent advent of new designs, smart functions and technology during the last 20 years is causing the rapid obsolescence of many electronic items. The life span of many electronic goods has been significantly shortened due to advancements in electronics, attractive consumer designs, marketing and compatibility issues, for example the average life span of a new computer has decreased from 4.5years in 1992 to 2 years in 2005 and is further decreasing [2].

The biggest concern with e-waste is the presence of toxic materials such as lead, cadmium, mercury and arsenic, toxic flame-retardants, printer cartridge inks and toners that pose significant health risks. These components can contaminate soil, groundwater and air, as well as affect the workers of the recycling units and the community living around it. The huge range and complexity of component materials in e-products makes it difficult and expensive to dispose or recycle them safely [3].

In the last two decades, the global growth in electrical and electronic equipment production and consumption has been increased tremendously. The global market for electrical and electronic products continues to accelerate, while the lifespan of the products is dropping, resulting in a corresponding explosion in electronic scrap [4]. Eco-designing of products, source reduction, close-loop recycling are potential options to reduce the e-waste stream. Designers could ensure that the product is built for re-use, repair and/or upgradeability. Stress should be laid on use of less toxic, easily recoverable and recyclable materials which can be taken back for refurbishment, remanufacturing, disassembly and reuse. Recycling and reuse of materials are potential options to reduce e-waste. Recovery of metals, plastic, glass and other materials reduces the magnitude of e-waste. These options have a potential to conserve the energy and keep the environment free of toxic material that would otherwise have been released [5].

A. Categorization of E-Waste

Category of e-waste is very diverse and complex. More than 1000 substances are present the e-waste which are classified as the hazardous and non-hazardous substances. Waste Electrical and Electronic Equipment (WEEE) and EU Directive (EU 2002) categorized the e-waste into 10 types which is enlisted in table 1 [6].

B. Global View on E-Waste

As the fastest growing component of municipal waste across the world, it is estimated that more than 50 MT of e-waste is generated globally every year. In other words, these would ill enough containers on a train to go round the world once[7].

Table 1: Various categories of Waste Electrical and Electronic Equipment

Sl. No	Category	Label	% of contribution
1	Large house hold appliances	Large HH	4.2
2	Small household appliances	Small HH	4.7
3	Consumer equipment	ICT	33.9
4	Lighting equipment	CE	13.7
5	Electrical and electronic tools	Lighting	1.4
6	Toys. and leisure and Sports equipment	E&E tools	1.4
7	Medical devices (with the exception of all implemented and infected products)	Toys	0.2
8	Monitoring and control instruments	Medical equipment	1.9
9	Automatic dispensers	M&C	0.1
10	Automatic dispensers	Dispensers	0.7

Note: Cited from Basu, (2009)

However, since the markets in the West have matured, it is expected to account for only 2 per cent of the total solid waste generated in developed countries by 2010.

Therefore, with increasing consumerism and an anticipated rise in the sales of electronic products in the countries experiencing rapid economic and industrial growth, the higher percentage of e-waste in municipal solid waste is going to be an issue of serious concern. A report of the United Nations predicted that by 2020, e-waste from old computers would jump by 400 per cent on 2007 levels in China and by 500 per cent in India. Additionally, e-waste from discarded mobile phones would be about seven times higher than 2007 levels and, in India, 18 times higher by 2020 [8].

China already produces about 2.3 million tonnes of e-waste[9]. The EU and the U.S. would account for maximum e-waste generation during this current decade. As per the Inventory Assessment Manual of the UNEP, 2007, it is estimated that the total e-waste generated in the EU is about 14-15 kg per capita or 5MT to 7MT per annum. In countries like India and China, annual generation per capita is than 1-3kg [10]. In the U.S, e-waste accounts for 1 to 3% of the total municipal waste generation. As per the United States Environmental Protection Agency (USEPA), it generated 2.6 MT of e-waste in 2005, which accounted for 1.4 % of total wastes.

In Europe, e-waste contributes up to 6 million tonnes of solid waste per annum. The e-waste generation in the EU is expected to grow at a rate of 3 per cent to 5 per cent per year. In the past, e-waste had increased by16 per cent to 28 per cent every five years which is three times faster than average annual municipal solid waste generation [11].

According to the newsletter issued by the International Association of Electronics Recyclers (IAER), used electronic equipments including household appliances and IT equipments also get dumped in landfill in the United Kingdom and Japan[11]. China and Brazil has been providing a progress for recycling plastics at rate of 10.2% [12].

Recycling facilities exist in developed countries and stringent measures have been taken by the Governments regarding disposal of e-waste. However, there are difficulties in implementing regulations and dealing with e-waste owing to increased activism by environmentalists and the high cost of recycling. Despite concerns on the issues of fraudulent traders and environmentally unsound practices, it has been easier and cheaper for these countries to ship e-wastes to the developing countries where access to and recycling of such discarded electronic goods make a good economic option. For both sides, it is profitable or a win-win situation. Table 2 given below shows that the total e-waste generated per year in U.S.A. is the highest among top 9 countries of the world [13].

Table 2
Total E-waste generated in top nine countries

S.No	Country	Total e- waste generated tonnes/year	Year
1	Switzerland	66,042	2003
2	Germany	1,100,00	2005
3	United kingdom	915,000	1998
4	U.S.A.	2,124,400	2000
5	Taiwan	14,036	2003
6	Thailand	60,000	2003
7	Denmark	118,000	1997
8	Canada	67,000	2008
9	India	800,000	2012

C. Quantum of E-Waste In India

In India, most of the operations related to e-waste such as collections, segregation, dismantling, recycling and disposal are performed manually. Figure 1 reveals the trend in growth of e-waste in India is steadily increasing [14]. According to the Comptroller and Auditor- General's (CAG) report, over 7.2 MT of industrial hazardous waste, 4 lakh tonnes of electronic waste, 1.5 MT of plastic waste, 1.7 MT of medical waste, 48 MT of municipal waste are generated in the country annually [15].

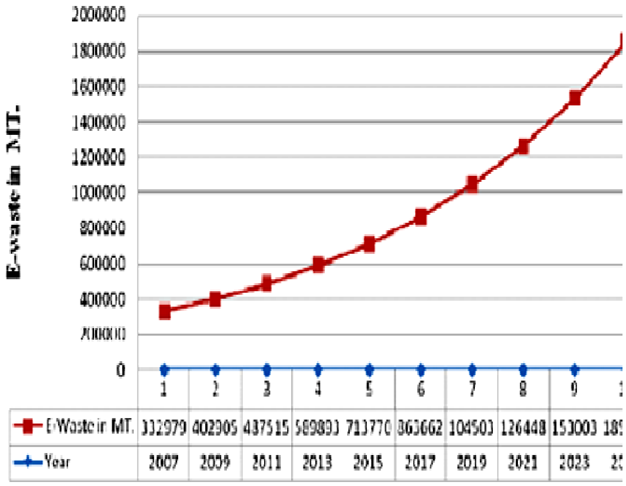

Figure1 .Trend in Growth of E-Waste in India

SOURCE: MAIT, GTZ, 2007

In 2005, the Central Pollution Control Board (CPCB) estimated India's e-waste at 1.47 lakh tonnes or 0.573 MT per day. A study released by the Electronics Industry Association of India (ELCINA) at the electronics industry expo – "Componex Nepcon 2009" had estimated the total e-waste generated in India at 2009 was 4.34 lakh tonnes. The CPCB has estimated that it will exceed the 8 lakh tonnes or 0.8 MT mark by 2013 [16].

The e-waste generation in India is given in the following Table 3 which reveals the projected quantity of WEEE generation in 2012 [17].

Table 3

e-Waste Generation in India

Item	Weight (in MT)
Imports	332979
Domestic (Generation)	50000
Total	382979
WEEE available for recycling	144143
WEEE actually recycled	19000
Projected quantity of WEEE in2012 (without including the imports)	467098

Source: MAIT, GTZ, 2007.

There are 10 States that contribute to 70 per cent of the total e-Waste generated in the country, while 65 cities generate more than 60 per cent of the total e-waste in India (Table 4). Among the 10 largest e-waste generating States, Maharashtra ranks first followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab. Among the top ten cities generating e-waste, Mumbai ranks first followed by Delhi, Bengaluru, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat and Nagpur.

Table 4

WEEE Generating Indian States

S.No	States	WEEE (Tonnes)
1	Andaman and Nicobar Island	92.2
2	Andra Pradesh	12780.33
3	Arunachala Pradesh	131.7
4	Assam	2.176.7
5	Bihar	3.055.6
6	Chandigarh	359.7
7	Chhattisgarh	2.149.9
8	Dadra and Nagar Haveli	29.4
9	Daman and Diu	40.8
10	Delhi	9729.15
11	Goa	427.4
12	Gujarat	8.994.3
13	Haryana	4.506.9
14	Himachal Pradesh	1.595.1
15	Jammu and Kashmir	1.521.5
16	Jharkhand	2.021.6
17	Karnataka	9118.74
18	Kerala	6.171.8
19	Lakshadweep	7.4
20	Maharashtra	20270.59
21	Madhya Pradesh	7800.62
22	Manipur	231.7
23	Meghalaya	211.6
24	Mizoram	79.6
25	Nagaland	145.1
26	Orisssa	2.937.8
27	Puduchery	284.2
28	Punjab	6.958.5
29	Rajasthan	6.326.9
30	Sikkim	78.1
31	Tamilnadu	13486.24
32	Tripura	378.3
33	Uttar Pradesh	10381.11
34	Uttarkhand	1.641.2
35	West Bengal	10059.36
	Total	146.180.7

In all Indian states Maharashtra is the highest producer of WEEE. After that Tamil Nadu and Andhra Pradesh takes place. In the absence of suitable techniques and infrastructure, the workers and labour working in such area are prone to serious

occupational health hazards. The following table shows the amount of wastes generated by each state in India [18].
The Figure 2 depicts the e-waste generation in top 10 cities in India. The situation is alarming as India generates about 1.5 lakhs tones of e-waste annually. In India Mumbai is on the top with 24.02% in terms of e-waste generation followed by Delhi with21.21%e-waste [19]. The key attributes for the generation of large quantity of e-waste are exponential, reason for generation of this large quantity of e-waste due to the growth of IT industries during the last decade, and the early product obsolescence due to the e-waste turning into a fastest growing waste stream [20].

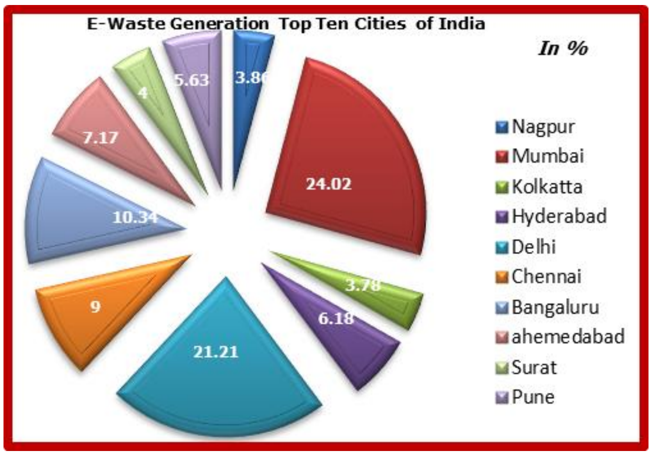

Figure 2. E-Waste Generation in Top Cities in India
SOURCE: IRGSSA (2005)

The growth rate of discarded electronic waste is high in India since it has emerged as an Information Technology giant and due to modernization of using electronic products for last 60 years [21]. As there is no separate collection of e-waste, no reliable figures are available as yet to quantify the e-waste generation**.** In India, most of the operations related to E-waste such as collections, segregation, dismantling, recycling, and disposals are performed manually. In absence of the adequate technologies and equipment, most of the techniques used for the recycling of E-waste are very raw and dangerous. Improper recycling and disposal operations found in different cities of India often involve the open burning of plastic waste, exposure to toxic solders, dumping of acids, and widespread general dumping. As a result, pollutants are dumped into the land, air, and water, which are the cause of serious environmental problems in India [22]. Also, the labors and workers employed in the dismantling and recycling units are poorly literate and uneducated, lacking the basic knowledge about the serious occupational and health risks associated with the operations [23]. Table 5 enumerates typical application of polymers in EEE

Table 5
Typical Application of Polymers in EEE

Polymer	Application
ABS	Housing and casing of phone, small household appliances, microwave ovens, flat screens and monitors enclosures and internal parts of ICT equipment
PS (HIPS)	Component inside refrigerators, housing of small household appliances, data processing and consumer electronics
PC	Housing of ICT equipment and household appliances Lighting
EPOXY POLYMERS	Printed circuit Board
PP	Components inside washing machine and dishwashers, casing of small household appliances Internal electronic components
PPO (Blend HIPS/PPE)	Housing of consumer electronics(TVs) and computer monitors and some household appliances (e.g. hairdryers) Components of TV, computers, printers and copiers
PC/ABS	Housing of ICT equipment and certain small household appliances.

D. Environmental Management of E-Waste

Collection center

Collection of e-waste is prime importance for environmentally sound management of e-waste. Collection center is a store or warehouse where the e-waste are collected and stored safely for necessary channelization for dismantling and recycling [24].

Collection points are designated at various places like residential areas, office complexes, commercial complexes, retail outlets etc to channelize the e-waste to dismantler. The e-waste collected through these points are send to the collection centres.
Mobile collection bins can also act as collection systems for door-door collection of e-waste or from institution/individuals/small enterprises and send for dismantling and recycling [25].

The major criteria for setting up the collection centers are:

- The collection, transportation, storage and handling of E-Waste in the collection centres has to be done carefully without breaking the end of life equipments**.**
- The space used for collection centre has to be clearly demarcated from the space meant for new goods.
- The storage capacity of any collection centre should be commensurate with available area, volume of operations (in weight) and type of E-waste.
- Covered shed/spaces may be used for storage of e-waste generated from IT and Telecommunication equipments.
- Open space can be used for storage of refrigerators/washing machines/air conditioners [26,27].

E. Environmentally Sound Dismantling and Recycling of E-Waste

The e-Waste comprising of IT &TE including TVs can contain up to 60 different elements of which some are valuable, some are hazardous/toxic and some are both. Printed Circuit Board (PCB) commonly called as motherboard or printed wire board (PWB) contains a complex mix of elements and needs a very careful handling for recovery of precious metals and for minimizing impact on the environment during recovery process [28]. The electrical and electronic equipments require very large amounts of non-ferrous/precious/semi-precious metals and are among the major contributors to the demand for non-ferrous/precious/semi-precious metals in the world [29]. The substances within the components of electrical and electronic equipment which have adverse impact on the environment are lead, mercury, cadmium, chromium (VI), halogenated substances (CFCs), polychlorinated biphenyls and poly-brominated di-phenyl ethers. Plastics and Printed circuit board contains brominated flame retardants (BFRs). BFRs can give rise to dioxins and furans during incineration. Recoveries of these non-ferrous/precious/semi-precious metals from e-waste, if not done in a scientific and environmental friendly manner, will result in large emissions of hazardous substances into the environment. In view of this, environmentally sound recycling of e-waste is a must [30]. Environmentally sound recycling with best available technology will lead to efficient recovery of non-ferrous/precious/semi-precious metals and will have low greenhouse gas emissions compared to extraction of these metals from ores. Urban mining of e-waste and recoveries of nonferrous/ precious/semi-precious metals needs significantly low energy compared to recoveries from ore.

Environmentally sound recycling/re-processing of e-waste starts with decontamination/ dismantling where the concentration of hazardous material/chemical is reduced followed by recycling and recovery of the material of economic value and then disposal of the residue in TSDF (Treatment, storage & Disposal facility) [31].

F. Dismantling

Dismantling operations are a dry process that may cover the following operations;

- The first step is to decontaminate E-waste and render it non-hazardous by separating hazardous components and materials. Hazardous electronic components such Hg switches, Poly Chlorinated Biphenyl (PCBs) etc. can be recovered and sent to TSDFs for treatment and disposal. In case of refrigerators and air conditioners, the refrigerant gases such as chlorofluorocarbon (CFCs), hydro chlorofluorocarbons (HCFCs) etc. can be collected by using gas recovery equipment for their recovery and storage. The refrigerant gases may be re-used or may be disposed by thermal destruction adopting any of the following options;
  i. By incineration in existing common HW incinerators.
  ii. By co-processing in cement kiln
  iii. By plasma destruction
- Manual dismantling can be carried out over the dismantling table with space de-dusting hoods connected with bag dust collectors venting out through a chimney of 3 meter above roof levels so as to maintain desirable work zone air quality as per the Factories Act 1948. Collection boxes with adequate capacity in sufficient number should be placed near dismantling table for keeping the dismantled components. The workers involved in dismantling operation should have proper equipment for dismantling the e-waste.
- Mechanized dismantling shall comprise of physical separation after opening the material by manual or semi-mechanical operations or directly feeding into a crusher (attached with bag dust collectors) to crush the wastes into fragments that will be segregated on a moving belt by manual collection. Fine grinding, Wet grinding, gravity separation / magnetic/density/eddy current/electromagnetic separators shall not be employed by dismantlers [32].
- Dismantling operations shall not include Fine grinding / wet shredding / wet grinding operations. Dismantling operations shall not be permitted for chemical leaching or heating process or melting the material. Dismantlers shall not shred segregated LCDs.
- Dismantler shall have adequate facilities for disposal of bag filter residue and floor cleaning dust in secure manner or shall obtain membership with TSDF for safe disposal.
- Dismantlers can be permitted shredding or cutting of printed circuit boards not below the size of 20mm which have to be handled by employing minimal manual handling and with adequate air pollution control systems.
- In case of dismantling refrigerators and air conditioners, only skilled manpower having adequate tools and personal protective equipments (PPEs) must be deployed to manually separate compressors. Prior to dismantling the compressors, adequate facilities should be provided for recovery of safe collection of refrigerant gases and compressor oils.
- Dismantled circuit boards, CRTs, capacitors, batteries, capacitors containing PCBs (Polychlorinated biphenyls) or PCTs (Polychlorinated ter phenyls) etc shall not be stored in open.
- The dismantling operation shall not discharge any process wastewater except workers utilities and re-circulated machine cooling water.
- The premise for dismantling operation should fulfill the following requirements:

  a) Weather proof roofing and Impermeable surfaces for appropriate areas with appropriate spillage collection facilities, decanters, degasser, and degreasers.
  b) Appropriate storage for dissembled spare parts.
  c) Appropriate containers for storage of batteries, capacitors containing PCBs (Polychlorinated biphenyls) or PCTs (Polychlorinated ter phenyls)
- Impermeable working surface or pavement should be constructed and maintained to prevent the transmission of liquids beyond the pavement surface. The impermeable

International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.3, No.6, June 2014 DOI:10.15693/ijaist/2014.v3i6.92-107

surface should be associated with a sealed drainage system connected to a collection sump [32]

- The type of impermeable surface required is likely to depend on a number of factors, including:
  - d) The type and quantity of E-waste being stored or processed including whether the E-waste contains hazardous substances and fluids
  - e) The type and volume of other materials dealt with
  - f) The type and level of activity undertaken on the surface
  - g) The level of maintenance
- Spillage collection facilities include the impermeable pavement and sealed drainage system as the primary means of containment. However, spill kits to deal with spillages of oils, fuel and acids should be provided and used as appropriate.
- The dismantler must provide appropriate storage for dismantled parts from E-waste. Some parts (e.g. motors and compressors) will contain oil and/or other fluids. Such parts must be appropriately segregated and stored in containers that are secured such that oil and other fluids cannot escape from them. These containers must be stored on an area with an impermeable surface and a sealed drainage system.
- Other components and residues arising from the dismantling of E-waste will need to be contained following their removal for disposal or recovery. Where they contain hazardous substances they should be stored on impermeable surfaces and appropriate containers or bays with weatherproof covering [33, 34].

G. Product Lifetime and End of Life of Products

- Recycling of WEEE can be profitable when the contained materials are recovered in the recycling process. However, there are huge differences between different types of products and accordingly, the economic value of the waste depends on the type of the equipment to be recycled. Recycling of a mobile phone is much more profitable than that of a hair dryer, which contains less valuable materials to be recovered [35].

E-waste also contains precious metals which have wide application as contact materials as well as scarce materials. (Fig.3).

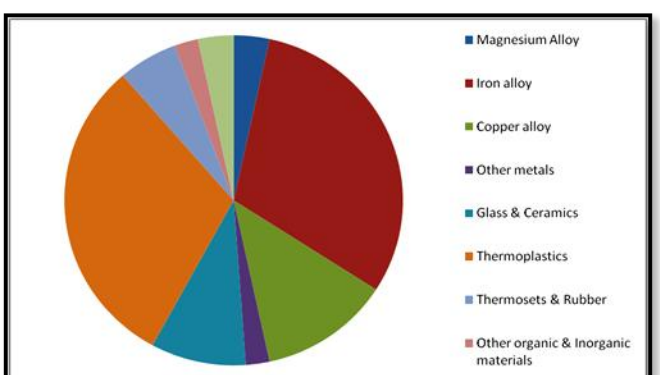

Figure 3. Composition of e-waste

These metals are present only in small amount in e-waste so the recovery process is also very difficult for instance in an mobile phone the content of such materials is only 0.15 wt%. the recycling process also needs to be economically sustainable, the recovery process can be carried out only if it can be profitably sold as secondary material for the reuse in new products [36].

All electronic and electrical equipment which are available in market will become obsolete and will need to undergo an appropriate recycling process in order to recover rare materials for reuse in new products. This leads to resource depletion and avoids virgin resource extraction

Figure 4 illustrates the different options for life cycle of electronic goods. Once they have reached the end of their life there is chances of recycling either properly or improperly. An electronic product can have many numbers of users in its life time. Sometimes there are maintenance or repair steps included in that reuse phase [37].

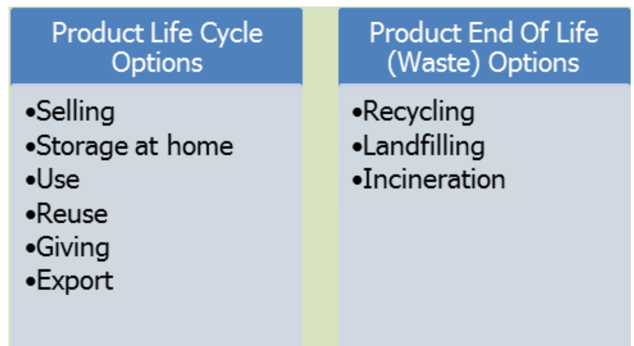

Figure 4. Life cycle of electronic goods

Usually in developing countries, electronics goods are kept as spare devices because the consumer overestimates their residual value and not willing to give it for recycling. Whereas, in developed countries approximately 40% of discarded mobile phones are still kept as spares and only 12% are collected or returned for recycling [38]. The pattern of re-usage/discarding is depicted in Figure 5.

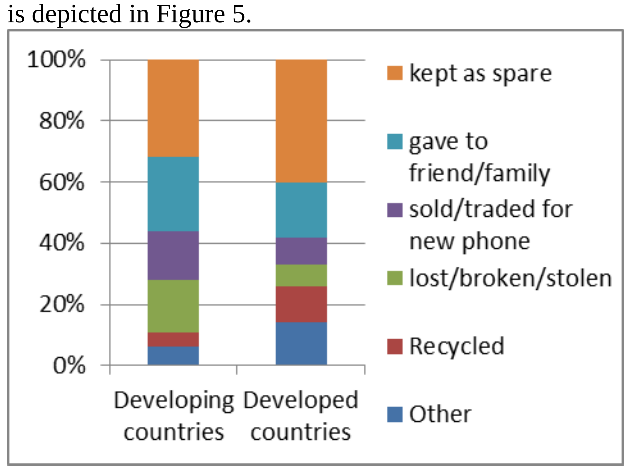

Figure 5. Pattern of re-usage/recycling of electronics goods
[Source: Nokia corporation, consumer study;2011]

H. Plastic Recycling Technologies

Plastics in electrical and electronic equipment are highly visible, for instance in telephones, televisions, and personal computers. However, there are also many plastic components, hidden from view, that provide the infrastructure to connect and support modern lives. The unique electrical insulating properties of plastics and their strength, stress resistance, flexibility and durability make plastics important materials for use in electronics [39].

Recycling technology has advanced tremendously and its use is spreading, but recycling is not an end in itself. As the Basic Law for Promoting the Creation of a Recycling oriented Society enacted in 2000 made explicit, the purpose of recycling is to curb consumption of Finite natural resources such as oil and minimize the burden on the environment through the cyclical use of resources. This means it is necessary to carefully consider whether the method used reduces inputs of new resources or limits the burden on the environment when promoting recycling [40].

It is important to select the recycling method for plastics that imposes the least social cost as well as limiting environmental impact given the situation of the plastic waste to be recycled. The two major types of plastic resins that are used in electronics are thermosets and thermoplastics. Generally, thermosets are shredded when recycled, because they cannot be re-melted and formed into new products [41].
Thermosets are used in electronics for circuit wiring boards, electrical switch housings, electrical motor components, electrical breakers, etc. Thermoplastics are used in a wide variety of applications within computers and other electronic devices. These resins can be re-melted and formed into new products. As a result, thermoplastics show better recyclability than thermosetting materials [42].

II. RECYCLING METHODS

There are three types of recycling processes (Fig.6) for plastics. Chemical recycling processes use waste plastics as raw materials for petrochemical processes or as a reductant in a metal smelter. Mechanical recycling is a conventional method, which uses a shredding and identification process to eventually make new plastic products. In thermal recycling, plastics are used as an alternative fuel [43].

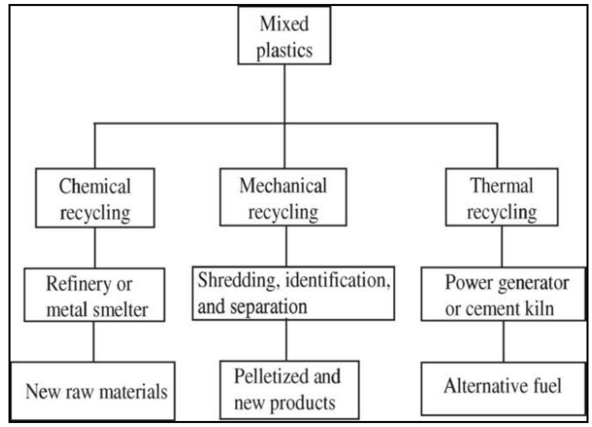

Figure 6. Recycling processes

A. *Mechanical Recycling*

Mechanical recycling is a way of making new products out of unmodified plastic waste. It was developed in the 1970s, and is now used by several manufacturers. The process of recycling is illustrated in Figure 7. Mechanically recycled waste has until now consisted largely of industrial plastic waste. Industrial plastic waste generated in the manufacture, processing and distribution of plastic products is well suited for use as the raw material for mechanical recycling. Used plastics from households, stores and offices are now being mechanically recycled [44].
All kinds of recycled products are made from industrial plastic, including containers, construction sheeting, products for packaging, transportation, and other goods and facilities [45].
Recycled products have a number of attractive characteristics: they are durable, light; easy to process and easy to cut and join, just like wood. We can expect greater adoption of recycled products with these features being used in place of other materials, such as steel, concrete and wood [46].
Used plastics emitted from the home, such as PET bottles and expanded polystyrene, are turned into textile products, packaging materials, bottles, stationery, daily necessities, video cassettes and similar products. The paint and coatings must be removed. If paint and coatings are not completely removed, the properties of recycled plastics can be reduced because of stress concentration created by these coating materials [47].

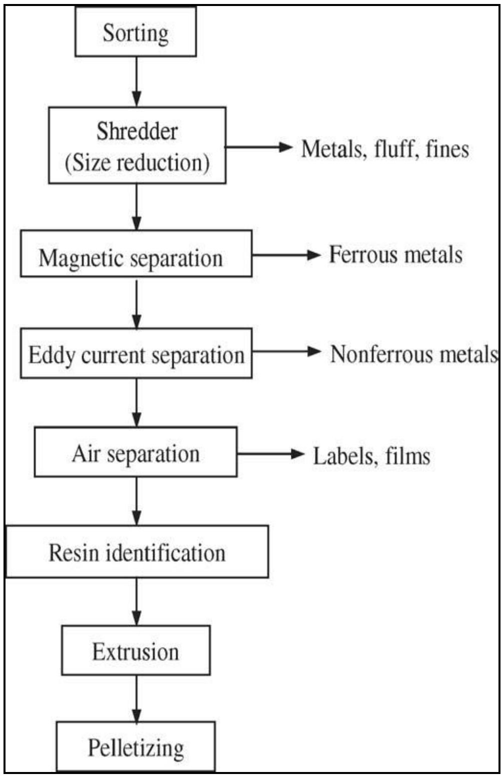

Figure 7. Steps in mechanical recycling

A grinding method can be used to remove coatings. For example, the chrome from plated plastics can be removed by simple grinding, sometimes assisted with cryogenic methods to enhance the liberation process and to prevent the plating materials from being embedded in the plastic granules. These cryogenic methods provide good liberation, but the actual separation of plastic particles from the paint is problematic. Another method of paint removal is abrasion. Abrasive techniques are applicable to large whole parts, but not to small parts. The solvent stripping method, which involves the dipping of the coated plastic into a solvent, liberates coatings from the plastic. This method is applicable for compact disc coating removal Another technique is the high-temperature aqueous-based paint removal method. The high-temperature aqueous environment, which can hydrolyze many coatings, makes it easy to liberate the coating from the plastic. Olefin based car bumpers can be handled with this technique because this plastic is not degraded under these conditions (Plastic Technology, 1994).post separation process the plastic is heated in a extrusion machine and extruded and pelletize to required size and shape [48].

B. Chemical Recycling

i) Depolymerisation and Conversion process

For chemical recycling of plastics several processes have been developed. In this process, mixed plastic waste (MPW) is depolymerized at about 350–400^{0}C and dehalogenated in this stage. During this stage, metals are removed. The remaining polymer chains from the depolymerization unit are cracked at temperatures of 350–450°C in the Hydrogenation Unit. The open carbon bonds are saturated by hydrogen because of high hydrogen pressure, more than 10 million N/m^2. The liquid product goes through the distillation process. Any left-over inert material, which is not separated and removed in the depolymerization step, and the unconverted plastic portion are collected in the bottom of the distillation column and removed as a residue, hydrogenation bitumen. The final highquality products, off-gas and syncrude, are obtained by hydrotreatment (Figure 8). These final products are sent to conventional petrochemical processes [49].

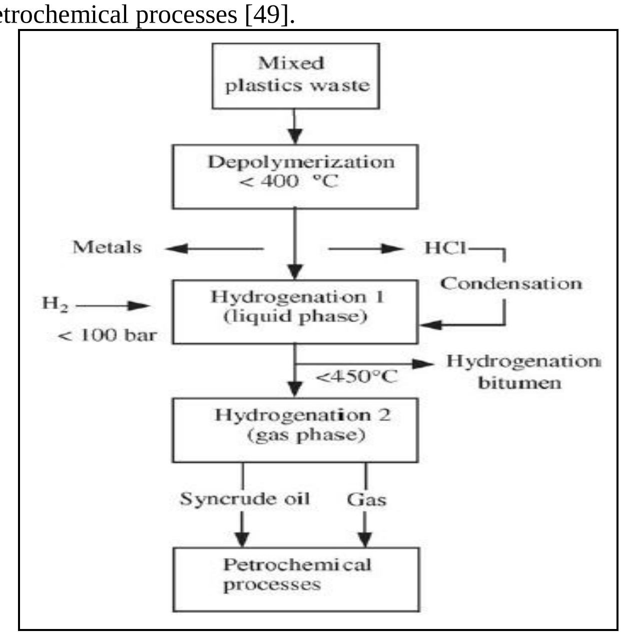

Figure 8. Steps in chemical recycling

The mixed plastic waste is converted into the following products: 80 wt.% into liquid product, 10 wt.% into off-gas (methano-butane), and 10 wt.% residue. The liquid product is free of chlorine and extremely low in oxygen and nitrogen; 85 wt.% can be used as cracker feed (Association of Plastics Manufacturers in Europe, 1997). The rest, depending on the properties of the plastic waste, is ethylbenzene, which is an excellent gasoline component. The solid residue, which could also be blended with the coal for a power plant, can be used to improve the properties of coal for coke production [50].

ii) Coke oven process

This process was developed by Nippon steel company for plastic chemical recycling.[23] The coke making process is essentially the carbonization of coal. The process conditions for carbonization in a coke oven are also suitable for the recycling of waste plastics, because at high temperature in a reducing atmosphere, charged plastics can be decomposed thermally without combustion [51].

In the pretreatment step, foreign materials, such as metal, glass, and sand, are removed. The remaining plastic waste is then crushed and reduced in size, before being charged into a coke oven. This process involves high temperature and a reducing atmosphere (Fig.9) General waste plastics were added to coal at a level of 1 wt.%, and the plastics decomposed easily. In the coking chamber, the waste plastics are heated to about 1200^{0}C in an oxygen-free environment. The charged plastics are pyrolyzed at 200–450˚C, generate gas and are completely carbonized at 500˚C. The hydrocarbon oils and coke oven gas are refined from high-temperature gas generated by pyrolysis, and the residue is recovered as coke. The yields from carbonization of general waste plastics were 20 wt.% of coke, 40 wt.% tar and light oil, and 40 wt.% of gases, approximately. The primary components of the product gas are methane and hydrogen [52].

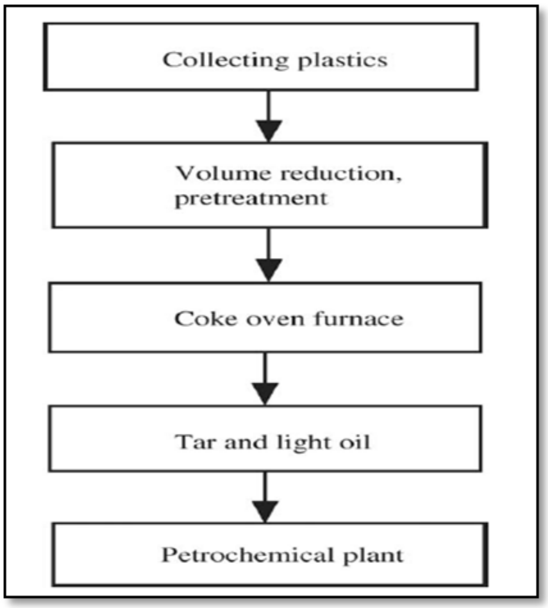

Figure 9. Conversion of waste plastics into petrochemicals

Reducing agent for Fe2O3 in blast furnace

The feedstock recycling of plastics is the use of plastics as a reducing agent in the metal recovery process. For the production of pig iron for steel production, iron ore (Fe2O3) must be reduced to Fe. Conventional reducing agents can be replaced by plastic waste. Generally, coke is used as the reducing agent. Recent research in Sweden showed that using plastics from EOL electronics as an energy and carbon source in metals processing is environmentally sound.[4] Plastic waste collected from factories and homes is cleansed of non-combustible matter and other impurities such as metals, then finely pulverized and packed to reduce its volume. Plastics that do not contain PVC are granulated, then fed into the blast furnace with coke. Plastics that do contain PVC are fed into the blast furnace after first separating the hydrogen chloride at a high temperature of around 350^{0}c in the absence of oxygen, as the emission of hydrogen chloride can damage a furnace. The hydrogen chloride thus extracted is recovered as hydrochloric acid and put to other uses, such as acid scrubbing lines for hot rolling at steel mills [53].

iii) Gasification

Industry plastics are composed mainly of carbon and hydrogen and therefore normally produce carbon dioxide and water when combusted. The gasification process involves heating plastics and adding a supply of oxygen and steam. The supply of oxygen is limited, which means that much of the plastics turn into hydrocarbon, carbon monoxide and water. Sand heated to 600-800^{0}C is circulated inside a first-stage low-temperature gasification furnace. Plastics introduced into the furnace break down on contact with the sand to form hydrocarbon, carbon monoxide, hydrogen and char. If the plastics contain chlorine, they produce hydrogen chloride. If plastic products contain metal or glass, these are recovered as non-combustible matter [54].

The gas from the low-temperature gasification furnace is reacted with steam at a temperature of 1,300-1,500^{0}C in a second-stage high-temperature gasification furnace to produce a gas composed mainly of carbon monoxide and oxygen. At the furnace outlet, the gas is rapidly cooled to 200^{0}C or below to prevent the formation of dioxins. The granulated blast furnace slag also produced is used in civil engineering and construction materials. The gas then passes through a gas scrubber and any remaining hydrogen chloride is neutralized by alkalis and removed from the synthetic gas. This synthetic gas is used as a raw material in the chemical industry to produce chemicals such as hydrogen, methanol, ammonia and acetic acid [55].

C. Thermal Recycling

Thermal recycling means to use plastics as a fuel so that the main purpose of thermal recycling is energy recovery. Plastics have a high heat value. Because plastics are derived
From oil, plastics have a calorific value equivalent to or greater than coal. Plastic materials can be combusted and produce energy in the form of heat. For instance, 1 ton of plastics can replace 1.3 tonnes of coal in cement kilns [56].

Gasification with melting furnace waste power generation first converts waste to gas at a high temperature then uses the emitted pyrolysis gas and char as fuel to turn a steam turbine and generate power. This method turns the burned ash into a solid. Gasification with reformer furnace power generation subjects the waste to pyrolysis, then adds oxygen to the resulting gas, carbonized solids, tar and other substances. Gas rich in carbon monoxide and steam is recovered and used as fuel for power generation or as chemical feedstock. Any method of gasification for waste material can be used with shaft furnaces, fluidized bed furnaces or rotary kilns. Also, power can be generated not only via steam turbines, but also with high efficiency gas engines, gas turbines and fuel cells [57].

This plastic recycling option is considered by the APME to be the most environmentally sound option for managing EOL electronic plastics in Europe. In 2002, Switzerland and Denmark recovered about 70 wt% of their total plastics waste through thermal recycling (Association of Plastics Manufacturers in Europe, 2003). In 2003, about 23 wt% of total plastics waste in Western Europe was thermally recycled, which represented the largest portion compared to other recycling methods (American Plastics Council, 2003). Pilot scale municipal solid waste combustion facilities equipped with suitable wet scrubbing systems have demonstrated that energy recovery from plastic waste that contains brominated flame retardants is technically feasible (Association of Plastics Manufacturers in Europe, 2002).

D. Recent Technologies in Recycling

Plasma Pyrolysis Technology

Plasma pyrolysis is the recent methods of recycling, which integrates the thermo-chemical properties of plasma with the pyrolysis process. The very high heat generation capability of plasma pyrolysis technology enables to dispose all types of waste plastic including polymeric, biomedical and hazardous waste in a safe and reliable manner. Pyrolysis is the disintegration of carbonaceous material in oxygen absence atmosphere, in this method the compounds formed are methane, carbon monoxide, hydrogen carbon dioxide and water molecules [58].

Process Technology:

In this process the plastic waste is fed into the primary chamber at 850^0c with the help of a feeder. The waste material is broken down into carbon monoxide, hydrogen, methane, higher hydrocarbons etc. the plastic waste and the pyrolysis gases is drained into the secondary chamber with help of a induced drafts fans where these gases are combusted in the presence of excess air the inflammable gases are ignited with the help of a high voltage spark the secondary chamber is maintained at 1050^0c. The compounds formed like hydrocarbon, carbon monoxide are combusted into safe carbon dioxide and water. The process condition is maintained so that it eliminates the formation of toxic dioxins and furan molecules.[15] Plasma pyrolysis process kills stable bacteria such as bacillus subtilis, bacillus stereo-thermophilus immediately. This process technology is suitable for all types of plastic wastes. The conversion of organic waste into non toxic gases in this process is more than 99% [59].

III. MANAGEMENT OF E-WASTE

A. International Development of WEEE Management

Globally, numerous legal frameworks are enacted and implemented to control WEEE(Wath et al., 2011). The basel convention is officially known as the Basel convention on the control of trans boundary movements of hazardous wastes and their disposal. Basel conventions main aim is to defend human health and the environment from impacts of WEEE. Basel convention was enforced on 5thMay 1992 [60].

U.S.A.

Green national electronics Action plan was started by environmental protection agency USA. Basel convention is not established in USA yet. The range of NEAP is restricted to computers, televisions and cell phones. Advance recycling fee (ARF) has been collected by the state of California during the purchase of a new product. The advance recycling fee ranges from $6 to $10 for products such as TVs, Computers and Monitors [61].

United Kingdom

The European union directive is enforced by the parliament to control the WEEE in 2007. The legislation has delegated the responsibilities to the operators to report, finance, and control the treatment of WEEE under producer compliance schemes. A registration fees is collected from the producers, preprocessors, and exporters as operational fees for running the scheme. They have to ensure that WEEE selected from different sources must be treated by using the best available treatment, recovery and recycling techniques (Rafia Afroz et al.,2013) [62].

India

In india the ministry of environment and forests (MoEF) is the national authority responsible for formulating legislations related to waste management and environmental protection. At present the hazardous materials found in WEEE are covered under the purview of "The Hazardous and Waste management Rules, 2008" in the category of hazardous and non hazardous waste (MoEF 2008) [63].

China

The administration of control of pollution takes control of WEEE. The manufacturers are mandated to manufacture EEE according to the national industrial standards(Wath et al., 2011) fine is imposed on the manufacturers, sellers who fail to fulfill the established standards [64].

B. Strategies To Manage E-Waste

There has been several tools developed and applied to e-waste management to mitigate problems both at national and international levels. LCA, MFA,MCA, and EPR are some the tools used for the better management of e-waste. In developed countries the management of e-waste has taken to a step further with the release of a waste electric and electronic equipment directive(WEEE Directive 2002/96/EC) that is expected to reduce the disposal of such waste and improve the environmental quality (EU, 2002) [65].

(i) Life cycle assessment(LCA)

Life cycle assessment is a tool used to design environmentally friendly devices to minimize e-waste problems. Research has been conducted on early 1990s on the LCA of electronic devices in terms of eco-design, product development and environmental impacts. For identifying environmental impacts to develop eco-design products such as printers, washing machines LCA is a powerful tool(kim et al., 2001). It is a systematic tool to define many environmental impact categories such as carcinogens, ozone layer, acidification, ecotoxicity, climate change and eutrophication to improve environmental performance of products (Belboom et al., 2011).

In e-waste management life cycle analysis is widely used, research has been conducted in Europe to evaluate the environmental impacts of end of life treatment of e-waste. Environmental impacts of e-waste were much lower than previously determined due to the recycling of plastics instead of incineration (Wager et al., 2011).

In Asia LCA has been applied to estimate the impacts of e-waste. It is found that the recycling potential in terms of environmental score showing the highest value was for glass and circuit boards, followed by copper, aluminium, iron and plastic. In terms of economic score the highest value was found to be for copper, followed bby aluminium, iron, plastic, glass and circuit boards(choi et al., 2006).

In India Life cycle analysis was used as a decision making tool for computer waste management. The results showed that the optimal life cycle of a computer desktop was observed to be shorter by 25% than the optimized cost and the optimized value of computer waste impacts to either the environment or any perceived risk to the public [65].

(ii) Material Flow Analysis

Large volumes of e-waste was exported from developed countries to the developing countries for recycling before the Basel convention came into force. Material flow analysis is a tool used to study the pathway of e-waste flow in recycling sites, or disposal areas and stock of materials in space and time. For proper e-waste management material flow analysis can be applied. Material flow analysis is used in Asia to investigate the flow of material and it is found that secondhand electronic devices from japan are reused in southeast Asia (Shinkuma et al., 2009).

It is found that the domestic disposal and recycling decreased to 37% in japan whereas the export of electronic goods increased to 26%. with the help of material flow analysis it is found that the e-waste generation in India, China, Nigeria and Chile. The quantity of e-waste would increase by 70% by 2020. This will increase four to five times in Chile during 2010-2019. In India it is found that Silver and copper that is extracted from personal computers and mobile phones had high values of these metals resulted in profit for the recyclers. Coupling of material flow analysis(MFA) and economic evaluation can be useful tool when limited data is available and where there id rapid growth in economy [66].

(iii) Multi Criteria Analysis

Multi criteria analysis is a decision making tool developed for solving multi requirement problems which include qualitative and quantitative aspects of problem. In Spain MCA is used for selecting the best location of recycling plants the study was based on quantitative growth. In Cyprus MCA methodology is used to examine alternative systems ofr managing e-waste. There where twelve alternative methods and each one are ranked according to the performance. Although, MCA is not widely used for e-waste it is economically used for solid waste (cheng et al., 2003). Finally it is a useful tool in combination with other tools being used in e-waste management(Hatami- Marbini et al., 2013).

(iv) Extended Producer Responsibility

Environmental producer responsibility is an environment approach that attributes responsibilities to the producer to take back the products after use, it is based on the polluter-pays principle. It is supported by countries like Japan, European union, Switzerland and Canada [67].

European union designated e-waste as priority waste stream in 1991. And a regulation was introduced to producers to take back the products for recycling and reuse in 2004. The legislation establishes the responsibility of producers for downstream e-waste management. The target recycling rate is between 50% and 75%. A Japanese take back system needed to be paid for by the end users who then take their e-waste to retail or second hand shop. After that the e-waste is transferred to recycling facilities to dismantle and recover materials. The recycling rate is 50%-60% by weight [68].

The US federal government couldn't require each state to accept EPR programs and product take back policy at national scale. There was a debate between the manufacturers and the government questioning "who is the polluter". The manufacturers strongly resisted responsibilities as polluters with respect to disposal of products. This program shares the responsibility for e-waste management with three groups they are stakeholders, the generators and the municipality [69].

India is an non OECD country and it has enormous backyard recycling sector. The Indian government provides the guidelines for management of e-waste through central pollution control board (CPCB) in 2007. E-waste management in India is driven by EPR principal policy but it has two barriers due to illegal import of waste materials and huge black market of electronic devices. In 2010, the government of India ministry of environment and forest(MoEF) has proposed a draft of e-waste producer responsibility. The draft was responsible for the whole life cycle of the product from design to scrap, and forced prohibition of import of all second hand electronic devices [70]. The policy adopted by different countries towards EPR is given in table 6.

Table 6
E-waste management approaches to EPR

Country	Policy	Target
The Nether-lands	- Take back (large household appliances and It equipment)	Recycling rate 45-75%By weight Recycle and recovery 50-80%
United Kingdom	-Take back (electronic appliances)	_
Germany	-Take back (electronic appliances)	_
Switzerland	-Take back (electronic appliances) -Disposal ban in landfill Advance recycling fees	-
Japan	-Take back (four large household appliances: TV sets, refrigerators, air conditioners and washing	Recycling rate 50- 60% by weight

	machines). -Product re-design (lead free solder and bromine free printed circuit boards).	–
United States	-Take back household appliances in some states, such as Maine (take back only televisions and computer monitors)	–
Canada	-Take back household appliance in some provinces, including Alberta and Ontario -Develop advanced EPR program	–
India	-Feasibility study.	-
Thailand	-Developing legal framework	Collection and recycling

IV. LITERATURE SURVEY

There are several works and studies have been carried out on recycling of electronic waste. There are many organizations which carry out recycling process in a controlled manner.

In India organizations like E-Parisara has a complete e-waste recycling facility viz. dismantling, recovering the resources, and recycling or value addition. Several studies are done on recycling of various plastic materials which are used in electronic products. Numerous efforts are taken to reduce the electronic waste generation by reusing the wastes [71].

Research has been carried out to recycle pvc with addition of certain fillers to retain its mechanical properties even though after recycling. Plastics like PET and PP are blended together as composites and PET and LDPE are blended together. Rafael Balart et. al., have done a study on recycling of ABS and PC and found that reprocessing and thermooxidation of ABS have significant effect on impact properties and elongation at break yet it can be used for applications which require low impact strength. These are ABS consisting of a SAN thermoplastic matrix with a dispersed elastomeric (polybutadiene rubber) component and polycarbonate (PC). The effect of partial miscibility and previous degradation levels was investigated. Mechanical characterization of ABS/PC systems was carried out to determine the optimum composition range. Previous degradation levels of the two wastes were investigated by FTIR and little degradation was found on ABS due to the presence of a polybutadiene rubber which is more sensitive to thermo-oxidative processes but no significant degradation was found on PC [72].

Martin Schlummer developed HPLC–UV/MS method to identify and quantify flame retardants in post-consumer plastics from waste of electric and electronic equipment (WEEE). Atmospheric pressure chemical ionisation spectra of 15 brominated and phosphate-based flame retardants were recorded and interpreted. The method was applied to detect flame retardant additives in polymer extracts obtained from pressurized liquid extraction of solid polymers. In addition, a screening method was developed for soluble styrene polymers to isolate a flame retardant fraction through the application of gel permeation chromatography (GPC). This fraction was transferred to an online-coupled HPLC column and detected by UV spectroscopy, which allowed a reliable qualitative and quantitative analysis of brominated flame retardants in the polymer solutions [73].

Jirang Cui and Eric Forssberg studied the physical and particle properties of WEEE are presented. Selective disassembly, targeting on singling out hazardous and/or valuable components, is an indispensable process in the practice of recycling of WEEE. Disassembly process planning and innovation of disassembly facilities are most active research areas. Mechanical/physical processing, based on the characterization of WEEE, provides an alternative means of recovering valuable materials. Mechanical processes, such as screening, shape separation, magnetic separation, Eddy current separation, electrostatic separation, and jigging have been widely utilized in recycling industry. However, recycling of WEEE is only beginning. For maximum separation of materials, WEEE should be shredded to small, even fine particles, generally below 5 or 10 mm. Therefore, a discussion of mechanical separation processes for fine particles is also done in their work [74].

R.A. Kudva studied the effects of processing history on the morphological, rheological, and mechanical behavior of blends of nylon 6 and acrylonitrile –butadiene–styrene (ABS) using an imidized acrylic (IA) polymer and a styrene/acrylonitrile/maleic anhydride (SANMA) terpolymer as compatibilizing agents have been investigated. Both compatibilizers yield blends that are super tough at room temperature; however, there are distinct differences in their effects on low temperature impact properties. For blends containing the IA polymer and a 1:1 ratio of nylon 6 to ABS, the low-temperature ductility compromises multiple extrusion steps. In general, the ductile-to-brittle transition temperature of blends containing high IA contents increase more rapidly with the number of extrusions than at lower IA contents. High IA content blends exhibited significant changes in morphology with increased number of extrusion steps; some of the ABS domains became larger, leading to a poorer dispersion of rubber particles. The ductile-to-brittle transition temperature is relatively insensitive to the number of extrusions for blends with less than 1 wt.% IA content or a higher ratio of nylon 6 to ABS. The morphology and low-temperature toughness of blends containing the SANMA terpolymer were generally unaffected by the number of extrusion passes during melt processing. The differences in low temperature toughness with respect to the processing history appear to stem from differences in the reactive nature of these two types of compatibilizers. Blends containing the IA polymer developed higher melt viscosities than blends containing the SANMA polymer (particularly at higher IA contents), since the nylon 6/IA reaction appears to continue with increasing processing time, whereas the nylon 6/SANMA reaction does not. Potential causes for these fundamental differences in blend rheology are considered in terms of the reactive functionality of the IA versus SANMA compatibilizer. When issues of processability, regrind, and recycling are considered, the SANMA material is a more attractive compatibilizer than the IA polymer, particularly at higher compatibilizer contents [75].

V. ENVIRONMENTAL IMPACTS OF E-WASTE DURING TREATMENT PROCESSES

The presence of toxic substances in e-waste was recognized only within twenty years the rapid growth of e-waste and the ineffectiveness of legislation has led to inappropriate management strategies in both developed and developing countries(Ming H. Wong et al.,)management of e-waste by recycling and disposal to landfills has been shown to pose significant risks to the environment.

Vast quantities of ewaste are now being moved around the world for recycling in developing countries using manual processes in backyards of residential properties, resulting in significant contamination of soil, water and air in these countries. It is found that many people who are engaged in recycling are reported for poisoning. Places like New Delhi in India, Accra in Ghana, Karachi in Pakistan, Guiyu and Taizhou in china and Gauteng in south Africa are the large recycling sites where extensive pollution is emitted from the e-waste recycling processes [76]. The investigations from Guiyu China showed heavy metals in air, dust soil, sediment and freshwater around e-waste recycling sites. The major heavy metals released included PAHs, PCBs brominated flame retardents such as PBDEs and polychlorinated dibenzo-p-dioxin/furans(PBDD/Fs), it is apparent from these studies that the entire ecosystem including soil, sediment, water, and air is being contaminated by these toxic substances. A wide range in the concentrations of total PBDEs, PAHs, PCBs has been reported in the soil from e-waste recycling sites. For instance PBDE ranged from 0.26 to 4250 ng/g(dry weight) PAHs from 44.8 to 20,000 ng/g, PCDD/Fs from 0.21 to 89.80 ng/g and PCB from 11 to 5789.5 ng/g in Guiyu and Taizhou china [77].

High concentrations of metals like Ag, Bi, Cd, Cu,Hg, Pb, Sn and Zn were found near recycling areas in Bangalore India on the impact of e-waste on water, wang and Guo(2006) found appreciable concentrations of Pb in surface water downstream of the recycling industry in Guiyu. The concentration of Pb was as high as 0.4mg/l which is eight times higher than the drinking water standard in china(<0.05mg/l)Wong et al.,(2007). Most studies are from the regions of china on air quality, which demonstrates major impacts of backyard e-waste disposal and improper recycling. Results from these studies demonstrate severe contamination of ambient air from chlorinated and brominated compounds. Metal concentration were detected as 1161, 1038 and 483 ng/m^3 for metals Cr, Zn, Cu respectively, which were 4-33 times higher than those on other asian countries. These findings confirm that significant levels of potentially toxic substance released during the recycling processes are building up in the environment. The potential hazards of persistent inorganic and organic contaminants to the ecosystem and human health are expected to persist for many years to come [78].

VI. THE CONCERNS IN PLASTIC RECYCLING IN WEEE

(i) Lack of Labour

In the recycling sites uneducated workers who lack knowledge about plastics and the various process behind recycling are employed for collection of waste plastic materials from various landfills. Inadequate safety health standards and environmental hazards are evident in the case of informal recycling operations. since dyes and chemicals are used as additives during the recycling, the workers are constantly exposed to them and the exposure levels may be very high, cheap detergents like caustic soda are used for cleaning, these detergent solutions are used several times before disposal. This cleaning process requires workers to keep their hands in soap solution for long time which in turn causes skin diseases. Addition of additives and dyes are also evident in these recycling sectors, pigments like carbon black have the tendency to deposit everywhere, this results in inhalation by the worker which deposits in the lungs. Even though a well connected network and human chain is involved in plastic recycling, lack of adequate knowledge in handling e-waste, identification are the real bottlenecks [79].

(ii) Brominated Flame Retardants

Brominated flame retardants are added in consumer products for several decades in order to slow down or prevent the ignition of fire. This intern reduces fire related injury and enhances product life. It is estimated that flame retardant plastics make up around 5.5% of WEEE by weight. Flame retardants are an important component in reducing the devastating impact of fires on people, property and the environment. Their areas of application in electrical and electronic equipment (EEE) vary depending on the materials being used, the function of the product, and the level of fire resistance that must be achieved based on fire safety standards. Flame retardants have unique characteristics, and, as a result, need to be matched appropriately to the materials used [80].

In wires and cables, for example, the flame retardants used must meet fire safety requirements developed specifically for these products because they have the potential for spreading a fire to the electrical socket, and to walls and curtains. The level of flame retardancy required for printed wiring boards used in consumer mobile phones is different than that of wiring boards used in computer servers or in telecommunications or aerospace applications. Higher electrical and mechanical performance demands must be met with flame retardants that can achieve higher flammability and fire resistance standards, without affecting a product’s performance specifications [81].

When it comes to fire safety, one size does not fit all. Specific flame retardants must be selected carefully to meet fire safety standards, electrical and mechanical requirements.

The following classes of flame retardants used in EEE include:

- Bromine-based flame retardants, predominantly TBBPA (help prevent fires from starting or slow down a fire)
- Chlorine-based flame retardants (work to stop flame formation)
- Nitrogen-based flame retardants (stop the decomposition process and prevent the release of flammable gases)
- Phosphorus-based flame retardants (promote charring and prevent the release of flammable gases; provide a barrier between the material and heat source
- Metal hydroxide and oxide flame retardants (slow down the decomposition process and the release of flammable gases; can be used alone or as synergists to boost other flame retardants' benefits
- Combinations of flame retardants are also used for maximum efficiency in specific material applications [82].

VII. CONCLUSION

Thus in this literature review categorization of e-waste, global scenario of e-waste, recycling methods, latest technologies in recycling of e-waste, concerns in plastic recycling impacts of e-waste are discussed in detail.

Generation of e-waste has rapidly increased in both developed and developing countries. U.S.A tops the list in the generation of e-waste. Countries like U.S.A, Japan etc. have introduced legislations for making producers responsible for the end of life products.

There are many strategies followed by each country in order to manage e-waste in an efficient and in eco-friendly manner. Life cycle assessment, material flow analysis, multi criteria analysis and extended producer responsibility are some of the techniques followed for the management of e-waste.

It is found that an extensive pollution is emitted from the recycling processes, and also investigation shows the presence of heavy metals like Ag, Hg, Pb in air and in fresh water near recycling sites. In order to overcome these problems new techniques like plasma pyrolysis are introduced.

A lot of research work is being carried out in plastic e-waste recycling. As PC, ABS, PP forms the major parts of plastic in e-waste stream, researchers pay more attention towards these materials in waste stream for modification, value addition etc.

REFERENCES

[1**]**. Gulshen sikeck managing e-waste in India, international journal of scientific& engineering research volume 3, issue7, july-2012.

[2]. Ashwani Kumar "E-Waste Management in India: Issues and Options" International Journal of Languages, Eduscation and Social Sciences, volume 02, issue 01, September 2012.

[3]. E-Waste India research unit Rajya Sabha, Secretariat, New Delhi, June 2011.

[4].Satish Sinha, 'Downside of the Digital Revolution', Toxics Link, 28 December, 2007, <http://www.toxicslink.org>

[5].Restriction of Hazardous Substances Directive', Wikipedia, http://en.wikipedia.org

[6].'Rotterdam Convention', Wikipedia, <http://en.wikipedia.org/ wiki/Rotterdam_Convention>.

[7]. Schwarzer S., A.D. Bono et al, 'E-waste, the hidden side of IT equipment's manufacturing and use', Environment Alert Bulletin (UNEP Early Warning on Emerging Environmental Threats), No. 5, 2005.

[8]. Tom Young, 'E-waste a growing problem for China and India', 22 February 2010, http://www.computing.co.uk.

[9]. 'Generation of E-waste', Rajya Sabha Unstarred Question No. 24, dated 26.07.2010.

[10]. International News on Electronic Recycling, *IAER* Newsletter, January 2009, http://www.isrielectronics.org/communications/NL0109.html.

[11]. Jayanti Ghosh, 'Digital Dumps', Frontline, Vol. 25, Issue-05, March 01-14, 2008

[12]. Plastics Waste Management, Central Pollution Control Board(cpcb), june,2012.

[13]. Comptroller And Auditor General's (CAG) Report, 2011.

[14]. 'Disposal of e-waste' Rajya Sabha unstarred question no.1887, dated. 07.12.2009.

[15]. The Manufacturers' Association of Information Technology (MAIT-INDIA).

[16]. International Resource Group Systems-South asia private limited, 2005.

[17]. P. Srisudha, 'Tackling e-waste', *The Hindu*, 28 June, 2009.

[18]. P.P. Sangal, 'The challenge of hazardous waste', The Economic Times, 19 May, 2010.

[19]. Asha Krishnakumar, 'Importing danger', Frontline , Vol. 20, Issue 25, 06 – 19 December, 2003.

[20]. Process and about E-Waste, www.ecoreco.com.

[21]. Nippon steel environmental report, 2002

[22]. Recycling and disposal of electronic waste, health hazards and environmental impacts, Swedish environmental protection agency, 2011.

[23].E-Parisaraa, private limited, www.ewasteindia.com.

[24].Nabil Mustafa, Plastics Waste Management, Disposal, Recycling, And Reuse.

[25]. Cornelia Vasile Feedstock Recycling From Plastics And Thermosets Fractions Of Used Computers, Pyrolysis Oil Upgrading 2006.

[26].Association Of Plastics Manufacturers (APME), 1997.

[27].'Bamako Convention', International Maritime Organisation, 09 December, 2005, <http://www.imo.org>

[28]. Rafael Balart.et.al.,Recycling of ABS/PC from Electronic Waste, Effect of Miscbilty and Degradation on Final Performance on Blends.

[29]. Antonio.F.Avalia t.al., A mechanical analysis on recycled PET/HDPE composites, polymer degradation and stability 80(2003) 373-382.

[30]. Daniel Pessey et.al., recycling effects on the rheological and thermomechanical properties of polypropylene based composites, materials and design 33(2012)451-458.

[31]. C.N. Kartalis et.al., polymer degradation and stability 70(2000)189-197, may 2000.

[32].Asante, K.A., Agusa, T., Biney, C.A., Agyekum, W.A., Bello, M., Otsuka, M., Itai, T., takahashi, S., Tanabe, S., 2012.
[33]. Wong MH, WU Sc, Deng WJ, Wong AS, Environmental pollution 2007 september 149(2): 131-140.
[34]. Liu HX, Zhou QF, Wang YW, Zhang QH, Cai ZW, Jiang GB. E-waste recycling induced polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzo-furans pollution in the ambient environment. Environ Int 2008;34:67–72.
[35].Peeranartt Kiddee. Ravi Naidu, Ming H. Wong electronic waste management approaches: An overview (2013).
[36]. R.widmer, H.Oswald-krapf D.Sinha-Khetriwal, M.Schnellmann and H.Boni Global perspective on e-waste, "Environmental impact assessemnet review" vol 25, no.5 (436-458)2005
[37].B. Steubing, B.Boni et al., assessing computer waste generation in chile using material flow analysis, waste management 30(3)473-482.
[38].Hischier, R., Wäger, P. and 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 Assessment Review (25), 525-539.
[39].Hischier, R. (2009) Personal Communication. IVF (2007) Lot 3: Personal Computers (desktops and laptops) and Computer Monitors. In: European Commission DG TREN: Preparatory studies for Eco-design Requirements of EuPs.
[40].Morf L. S., Tremp J., Gloor R., Huber Y., Stengele M. ans Zennegg M. (2005) Brominated Flame Retardants in Waste Electrical and Electronic Equipment: Substance Flows in a Recycling Plant. Environmental Science & Technology 39: 8691–8699.
[41].Morf, L. S., Tremp, J., Gloor, R. and Schuppisser, F. (2006) Metals, Non-Metals and PCB in Electrical & Electronic Waste - Actual Levels in Switzerland. Waste Management 27, 1306-1316.
[42].Rios, P., Stuart, J. A. and Grant, E. (2003) Plastics disassembly versus bulk recycling: Engineering design for end-of-life electronics resource recovery. Environmental Science & Technology 37:5463–5470.
[43].Schlummer, M., Gruber, L., Mäurer, A., Wolz, G. and van Eldik, R. (2007) Characterisation of polymer fractions from waste electrical and electronic equipment (WEEE) and implications for waste management. Chemosphere 67: 1866–1876.
[44].Sepúlveda, A., Schluep, M., Renaud, F.G., Streicher, M., Kuehr, R., Hagelüken, C. and.Gerecke, A.C. (2009) A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. Environmental Impact Assessment Review. In Press. SWICO (2008) 2007 Activity Report.
http://www.swicorecycling.ch/pdf/taetigkeitsbericht_07_e.pdf.
[45] .USEPA (1997) Estimating air emissions from sources of dioxins and furans. Report Number EPA-454/R-97-003. Research Triangle Park, North Carolina: Publ. United States Environmental Protection Agency Office of Air Quality Planning and Standards, Office of Air and Radiation.
[46].Wäger, P., Böni, H., Buser, A., Morf, L., Schluep, M., and Streicher, M. (2008) Verwertung von Kunststoffen aus Elektro- und Elektronikaltgeräten. Interim Report prepared for SENS and SWICO. Empa, St. Gallen, June 23. Wäger, P., Eugster, M. and Hischier R. (2009) Environmental Impacts of WEEE treatment in Switzerland.
[47]. A report on "Managing Electronics Waste (2007).
Dumping old TV? First read the rule", The Hindustan Times, New Delhi Edition, , 15 October,p1 p1
http://www.industelegraph.com/story/2005/9/2/33438/ 17285.
[48].Gao Z, Li J, Zhang HC (2004). Electronics and the Environment, IEEE International Symposium pp.234-241.
[49]. Hanapi BM, Tang BS (2006). Selective Liquid-Liquid Extraction of precious metals from semiconductor wastes, Department of Chemical Engineering Faculty of chemical and Natural Resources Engineering, University of Teknologi Malaysia.
[50].Hanapi BM, Tang BS (2006). Selective Liquid-liquid extraction of precious metals from semiconductor wastes, Department of Chemical Engineering Faculty of Chemical and Natural Resources Engineering University Teknologi, Malaysia, http://eprints.utm.my /2743 /1 /72157.pdf.
[51].http://www.cpcb.nic.in/docs/E-Waste Guidelines-2007/ Front page1.pdf.
http://www.ewasteindia.in/environment.asp: Industrial operation data shared by E-Parisaraa Pvt. Ltd, Bangalore, India.
[52].http://www.toxicslink.org/dn.php?section=1&id=171&atn=0.
[53].Hyunmyung Y, Yong-Chul J (2006). The Practice and Challenges of Electronic Waste Recycling in Korea with Emphasis on Extended Producer Responsibility (EPR). IEEE International Symposium on electronics and the environment, 8-11 May, pp.326 – 330.
[54].John DL, Oladele AO, Andrew A (2006). Shapiro, Meta-analysis of Hazard Criteria Designation for Electronic Waste, Proceedings of IEEE International Symposium on Electronics and the Environment.
[55]. 'China RoHS', Wikipedia, <http://en.wikipedia.org/wiki/ China_RoHS> Last modified: 09 October, 2010. 10-13 May, pp.237- 242.
[56].Recovery of high purity precious metals from printed circuit boards, J.of hazardous materials 164(2- 3): 1152-8, 2009 May 30.
[57].Report on "E-waste Inventorisation in India", MAIT-GTZ Study2007.http://www.e-wasteproject.org/docs/del_amitjain.pdf.
[58].Report on "Study on Status and Potential for E-waste Management in, India", by ELCINA, India sponsored by Department of Scientific and Industrial Research (DSIR), India February 2009, http://toxicslink.org/dn.php?section=1&id=37&atn=0.
[59].Xuefeng W, Yuemin Z, Chenlong D, Xiaohua Z, Hongguang J, Shulei S (2005). Study on metals recovery from discarded printed circuit boards by physical methods, Electronics and the Environment,

Proceedings of IEEE International Symposium, May, pp.121-128.
[60].Antone Gonsalves, ‘LCD TV Sales Boom Foreseen in 2010’, Information Week. The Business Value of Technology, 31 December, 2009, < http://www.informationweek.com>
[61]. Hai-Yong Kang, , Julie M. Schoenung electronic waste recycling: A review of U.S. Infrastructure and technology options, research conservation and recycling 45(2005)368-400.
[62]. Derry. R, plastics recycling in north America, department of trade and technology U.K.
[63].‘Bamako Convention’, Wikipedia, <http://en.wikipedia.org/ wiki/Bamako_Convention>
[64]. Mou P, Wa L, Xiang D, Gao J, Duan G (2004). A physical process for recycling and reusing waste printed circuit boards, Dept. of Precision Instrum. & Mechanology, Tsinghua Univ., Beijing, China,IEEE International Symposium on electronics and the environment, 10-13 May, pp.237- 242.
[65].Electronics.ca Research Network, ‘Optical Components Worldwide: Markets Reach $11.3 Billion by 2015’, 29 September, 2009, <http://www.electronics.ca/presscenter/>
[66].Electronics.ca Research Network ,‘Worldwide Electronic Manufacturing Services Will Return to Steady, But Uneven Growth in 2010’, 26 April, 2010, < http://www.electronics.ca/ presscenter/>
[67].‘Electronics Recycling’, Institute of Scrap Recycling Industries Inc. (ISRI), <http://www.isri.org/>
[68].‘Electronic Waste in the United States’, Wikipedia, <http:// en.wikipedia.org> Last modified: 16 October, 2010.
[69].‘First Session of the Inter-Governmental Negotiating Committee to prepare a global legally binding instrument on Mercury’, 7-11 June, 2010, IISD Reporting Services, Earth Negotiations Bulletin, Vol. 28, No.1, 7 June, 2010, < http://www.iisd.ca/vol28/enb2801e.html>
[70]. ‘IT’s underbelly’, *Down to Earth*, Vol.19, No.1, May16-31, 2010.
[71]. ‘Japan “Twisting Arms” of Asian Neighbours to Take Toxic Waste’, *Greenpeace*, 16 February, 2007, <http:// www.greenpeace.org/seasia/en/press/releases/>
[72]. Rafael Balart, Juan Lopez, David Garcia, M. Dolores Salvador “Recycling of ABS/PC from Electronic Waste, Effect of Miscbilty and Degradation on Final Performance on Blends” European polymer journal, volume 41 (2005), 2150-2160.
[73]. Martin Schlummer, Fritz Brandl, Andreas Maurer, Rudi van Eldik, “Analysis of flame retardents additives in polymer fractions of waste electric and electronic equipment(WEEE) by means of HPLC-UV/MS and GPC-HPLC-UV”. Journal of chromatography A, 1064 (2005) 39-51.
[74]. Jirang Cui, Eric Forssberg “Mechanical recycling of waste electric and electronic equipment: a review” journal of hazardous materials B99 (2003) 243-263.
[75]. R.A. Kudva, H. Keskkula, D.R. Paul “Properties of compatiblized nylon6/ABS blends part II. Effects of compatablizer type and processing history”, polymer 41 (2000) 239-258.
[76]. Markus Zennegg, Mathias Schluep et.al., Fomation of PBDD/F from PBDE in WEEE in recycling processes and a test extruder.
[77]. Karin Lundgren; The global impact of E-waste: Addressing the challenge, safe work and sector, International Labour organization Geneva 2012.
[78]. S. Chatterjee and Krishna Kumar, Effective Electronic Waste Management and Recycling Process Involving Formal and Informal Sectors.

[79].Schwarzer S., A.D. Bono et al, ‘e-waste, the hidden side of IT equipment’s manufacturing and use’, Environment Alert Bulletin (UNEP Early Warning on Emerging Environmental Threats), No. 5, 2005.
[80].‘The great e-waste recycling circus’, <http:// www.grid.unep.ch/waste/download/waste 3637.pdf>
[81].‘The Rotterdam Convention’, Simultaneous Extra-ordinary Meetings of the Conferences of the Parties to the Basel, Rotterdam and Stockholm Conventions, Bali-Indonesia, 22-24 February, 2010, < http://excops.unep.ch/>
[82].‘Waste Electrical and Electronic Equipment Directive’, Wikipedia, http://en.wikipedia.org/

Authors Profile

S.Sugumar received a Post Graduate Degree - **M.Tech (Polymer Science & Technology)** from **IIT – New Delhi** in the year **1982**. He is currently doing research work in the area of Processing and Properties of Engineering Plastics recycled from Waste Electrical and Electronic Equipment (WEEE)
He has More than 3 decades of rich experience in Plastics Processing and Plastics Recycling. Around 60 papers were presented /published in International Conferences in the areas of Plastics Processing, Plastics Recycling & Waste Management.

Prof. Nayak did his Ph.D. in the area of Photo Polymerization initiated by charge transfer complex and D.Sc. in Advanced Thermoplastic Composites and Nanocomposites. He has vast experience in current state-of-art Research, Technology Development, Industrial Consultancy, Testing, Analysis and Quality Management.

He has guided 35 Ph.D and more than 60 Master’s thesis. Prof. Nayak has 12 patents and more than 300 publications in International Journals to his credit. He is a Reviewer for many International Scientific Journals.