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Review: Current Status of Recycling of Waste Printed Circuit Boards in India

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ABSTRACT

Printed Circuit Boards (PCBs) are an integral part of any electronic equipment. The growth of e-waste as end-of-life electronic equipments at an exponential rate is producing large quantities of discarded PCBs. In India, current recycling and processing of PCBs is managed almost entirely by the informal sector or the unskilled labor (95%). The crude recycling activities cause irreversible health and environmental hazards and the loss of valuable materials due to the poor recovery of base and precious metals. With the disclosures of the recycling being done by unskilled labor, alternative recycling strategies are being sought with the aim of higher recovery of materials in an environment friendly manner. There is an urgent need to establish effective and efficient methods for recycling the metals presented in the waste PCBs. In this study, the existing methods practiced for recycling of waste PCBs in India and the management strategies for handling them are assessed.

KEYWORDS

Printed Circuit Boards; India; E-Waste; Informal Recycling

1. Introduction

Growth rate of discarded electronic waste is high in India since it has emerged as a giant hub for Information Technology. There is a rapid modernization of life style. Printed Circuit Boards (PCBs) are an integral part of any electronic equipment. They act as a base and provide electrical connections to all mounted components presented in any electronic equipment. With the rapid growth of electronic goods combined with rapid rate of obsolescence, e-waste is the fastest growing waste producing large quantities of waste printed circuit boards. Concerns about waste PCBs began to mount after investigations by several environmental groups such as Basel Action Network (BAN), the Silicon Valley Toxicity Coalition (SVTC), Greenpeace and Toxics Links. It revealed that e-waste is being illegally brought into India and other developing countries by misleadingly labeling it as metal scrap or second hand computers. Absence of any specific law regulating e-waste till 2012, the lax environmental standards and cheap labor have made India an attractive site for recycling.

In India, it is believed that almost 40% of obsolete electronic products are unused at homes or in warehouses as people are unaware as what to do with them and there is a lack of systematic mechanism for their disposal. Recycling and processing of the waste PCBs in e-waste is managed almost entirely by informal sector and is purely market driven. It is a source of livelihood for unorganized recyclers. Very crude methods which are used cause occupational and environmental hazards and the loss of valuable materials due to the poor recovery of base and precious metals. These methods cause irreversible health and environmental hazards.

In this study, the existing methods practiced for recycling and the management strategies of handling the huge quantities of waste PCBs in India are assessed. It gives a review of current status of informal recycling and the emerging trends of formal recycling due to the awareness

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by NGOs like Greenpeace, Toxics Link, etc.

2. Technology Options for Recovery of Metals from PCBs

PCBs in e-waste are complex mixtures of metals, ceramics and organics. For the determination of composition the Printed Circuit boards the comminution fines wet analysis is not only very dependent on the digestion conditions, determination of absolute assays of all constituents will also require comparison of data from more than one digestion condition. The effect of digestion procedure on the final assays in wet spectroscopic analyses has been assessed by Ogunniyi, *et al*. [1]. Recovery of precious metals as gold, silver, platinum, palladium and base metals as copper, nickel, aluminum, zinc, tin, iron, etc. is the main driving force for the recycling of PCBs. The heterogeneous composition of the PCBs poses problems for separation of the various constituents. **Table 1** shows the weight and price of the various metallic components in PCBs [2].

Technologies to retrieve metals from the waste PCBs without harming the environment are required. Successful recycling of PCBs depends on the efficient and economical technology for recovering the valuable metals from PCBs which account for more than 80% of the intrinsic value, though weight of these is less than 1%. Retrieving of metals can be done either by pyrometallurgical or hydrometallurgical process in combination with mechanical pretreatment. PCBs recycling process usually includes three stages: pretreatment, separation/concentration, and mechanical/chemical refining [3].

For efficient liberation and separation of metallic components from non-metallic components as plastics and ceramics, the PCBs are first to be crushed. Grinding is followed by material separation based on physical properties as magnetic, electrostatic properties, density, visual or other characteristics. A series of permanent magnets may be used to remove ferrous metals as iron and nickel from non ferrous materials. Eddy current separators can separate non-ferrous metals as copper and aluminum. Further separation of the precious and base metals can be done by hydrometallurgical or pyrometallurgical treatment.

Table 1. Market value of the metal recovered from 1000 Kg of PCBs (Chaterjee and Kumar, 2009) [2].

Recovered metal	Weight	Approximate cost (in US$)
Gold	279.93 g	6115 (@685.00 per 31 g)
Precious metals (Pt, Pd, In)	93.31 g	3852 (@1284.00 per 310 g)
Copper	190.512 Kg	1470 (@3.50 per 453.59 g)
Aluminium	145.152 Kg	448.00 (@ 1.28 per 453.59 g)
Lead and Tin	30.844 Kg	144.16 (@2.12 per 453.59)
Silver	450 g	213.15 (@14.70 per 31 g)

N. B. Data generated on average recovery of one ton of populated PCBs and value is taken from the prevailing rate at that point of time. These are only to give a perception of value from the metal recovery from e-waste.

The main steps in hydrometallurgical processing consist of leaching which is selective separation of metals from solid mixtures by dissolving in an acid or a reagent to form metallic salts or leachates and then metal recovery from the leachates by methods such as precipitation, solvent extraction, adsorption, ion-exchange, and cementation. In hydrometallurgy, solvent extraction is a well established technology in processing of nuclear materials and in mineral processing of metals like copper, nickel, zinc, cobalt, gold and silver on a commercial scale and can be extended to retrieve metals from PCBs. Park and Fray [4,5] have reported a promising method to separate the metals in PCBs using solvent extraction.

In pyrometallurgy processing, the PCBs, connectors and all the scrap containing the precious metals are processed in smelters. Smelters turn fractions into metals of high purity in an environment friendly and economic way. It is successfully used to extract metals in a few countries. Modern integrated smelters recover a large wide range of metals from complex precious metals bearing materials as gold, silver and platinum group metals (palladium, platinum, rhodium, iridium, ruthenium), and also base metals as copper, lead, nickel, etc., and can make use of organics such as plastics in place of coke as a reducing agent and fuel as an energy source. Kim et al. [6] have proposed a novel process to simultaneously extract precious metals such as gold, palladium and platinum from spent printed circuit boards and honeycomb type autocatalysts by smelting without addition of any collector metals.

3. Sources of Waste PCBs

Discarded e-waste account for the generation of huge quantity of waste PCBs. Waste PCBs are generated from overstock, obsolete and end-of-life computers, medical appliances, fax and copying machines, household appliances such as televisions, refrigerators, washing machines, ovens, electronic toys, mobile phones, video cassette players and recorders, MP3 players, air conditioners, etc.

According to study carried by GTZ (German Technical Collaboration agency) MAIT (Manufacturers' Association for Information Technology) in 2007, the total quantities of generated and recycled E-waste were 380,000 tons and 19,000 tons respectively. Above this about 50,000 tons got imported illegally into the country. About 14 million mobile handsets had been replaced in 2007. But there is lack of authentic and comprehensive data on E-Waste which is further exaggerating the problems associated with E-waste management in the country. Although various State Pollution Control Boards have initiated the exercise to collect data on E-Waste generation, such exercises are not practiced with utmost sincerity. [7].

The exponential increase of this waste every year might soon turn the nation into the world's largest e-waste graveyard. 70% of e-waste is generated in ten states. Maharashtra ranks the first followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab. Maharashtra produces 20,270.6 tons per year due to presence of large number of InfoTech Parks and electronic products manufacturing companies situated in these areas. Sixty five cities in India generate more than 60% of e-waste. Among the cities, Mumbai ranks first followed by Delhi, Bangalore, Chennai, and Hyderabad. Mumbai alone generates approximately 19,000 tons of e-waste excluding those from import. Bangalore generates 8000 tons of e-waste annually [8]. Toxics Link survey revealed that huge quantity of computer scrap also comes into India from the USA, Singapore, Malaysia and West Asia.

4. Legislation

With many countries having introduced legislation to ban the import of e-waste, India has emerged as the prime destination for dumping of e-waste. In China the State Environment Protection Administration (SEPA) is in charge of the general solid waste management and the import of all kinds of waste. Import of abandoned computers, monitors, CRTs, copiers, microwave ovens, air conditioners, video cameras, electric cooking devices, rice cookers, telephones, video games (except for processing for re-export), televisions, picture tubes and refrigerators has been restricted [9]. European Union (EU) has already released two directives in 2003. One was the "Directive on Restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment" (RoHS), which directs all its member states to ensure that from 1 July 2006 all new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) or polybrominated diphenyl ethers (PBDEs). The second "EU Directive on Waste Electric and Electronic Equipment (WEEE)" includes producers, distributors, consumers and all parties involved in the treatment of WEEE. Producers are requested to finance the collection, treatment, recovery for environmentally sound disposal of WEEE [10,11].

According to the "California Electronics Waste Recycling Act" 2003, the State of California directs each manufacturer that sells electronic devices to either collect an equivalent of 90% of the number of devices they sell or they must pay the alternative fee for recycling the devices they sell [12]. In US, different stake holders, like the original equipment manufacturers (OEMs), government agencies, environmental organizations and others are coming together with joint nationwide plan for managing electronic waste. In Japan the manufacturers and importers are forced to take back their products at designated collection sites and to recycle them according to the regulations set by the government. Retailers take back used home appliances that they sell and transfer them to the corresponding manufacturers and importers. The two major laws covering broad range of e-waste items are "The Law for Recycling of Specified Kinds of Home Appliances" (LRHA) and "The law for Promotion of the Effective Utilization of Resources" (LPUR). In Malaysia, the guidelines for the classification of used electronic and Electronic Equipments entered into force in January 2008, which prohibits the import of WEEE.

Though India is one of the most affected countries by e-waste problem, yet there had not been any effective e-waste policy till the year 2012. This may be because it was not considered as a potential threat which needed to be handled effectively. Earlier the Ministry of Environment and Forests (MoEF), Government of India, had issued notifications related to hazardous wastes which were implemented through the State Pollution Control Boards, Central Pollution Control Board and control committees in States and Union Territories.

But none of the environmental legislations mentioned above had direct and specific reference of handling of electronic waste as hazardous in nature. According to the Hazardous Wastes Rules (1989), e-waste was not treated as hazardous unless proved to have higher concentration of certain substances. With the collaborative efforts by Greenpeace, MAIT, GTZ and Toxics link along with support from major electronic companies in India, the Ministry of Environment and Forests notified the E-waste (Management and Handling) Rule on May 30, 2011. The rule is implemented throughout the country from May 1, 2012. Every producer, consumer involved in the manufacture, sale, purchase and processing of electrical and electronic equipment or components, collection centers, dismantlers and recyclers of e-waste come under this law. The rule gives guidelines for management, handling and disposal of e-waste and places responsibility on the producers for the entire lifecycle of a product from design to disposal *i.e.* it is based on Extended Producer Responsibility (EPR). Disposal of e-waste in municipal landfills will be prohibited by the new regulations. Manufacturers will be made financially and legally responsible for the safe disposal of their products.

Producers will have to provide all information regarding disposal of the equipment after use to prevent e-waste from being dropped in domestic waste and about the hazardous components present. All commercial consumers and Government departments will be responsible for recycling of e-waste. The new Legislation includes mechanisms for better designs for recycling, reuse and reduction in the use of toxic material and encourage introduction of green electronic products in the market. It is mandatory to register all handling and recycling of hazardous wastes with Central Pollution Control Board (CPCB).

But there are certain loopholes in the existing legislation. There is no directive on ban of import of second hand electronic goods brought to the country for charity and reuse purpose which finally finds its destination in informal recycling. Also, India being a signatory to the Basel Convention, a UN treaty on the control of transboundary movement of Hazardous Wastes and Disposal, it cannot export hazardous waste listed in Annex VIII of the convention to countries that have ratified the agreement. However the Convention does not restrict the import of such wastes from countries that have not ratified the Basel agreement. Thus there is no provision to ensure the ban of imports of electronic waste. Greater scrutiny and vigilance by the custom authorities on the cross-border movements can prevent the dumping of obsolete electrical and electronic products from developed countries.

5. Review of Informal Recycling

Printed circuit boards in e-waste contain both valuable materials such as gold, palladium, silver and base metals such as copper, nickel, iron, and aluminum. Recovery of precious metals is the main driving force for the recycling of PCBs. Lack of access to appropriate technologies and methodologies and the infrastructure capable of handling the increasing volumes of the scrap lead to informal recycling. Informal sector consists of small workshops which cannot handle large quantity of e-waste at a time. There are scrap dealers or Kawarees who collect domestic e-waste as well as from offices and educational institutes and corporates. The scrap dealers pay consumers a price for their waste appliances and they in turn sell them to dismantlers and recyclers in the informal sector. It is the livelihood for the unorganized recyclers and they risk their lives and environment due to lack of awareness. Over 25,000 people handle 50,000 tons of e-waste in various scrap yards in Delhi every year (Toxics Link). There are similar scrap yards at Meerut, Ferozabad, Chennai, Bangalore and Mumbai.

The informal recycling system includes small to medium scale units and are involved in dismantling, sorting and also harmful processes such as burning and leaching in order to extract metals from the e-waste particularly the PCBs. The accrued electronic and electric waste is first dismantled and sorted to fractions as printed circuit boards, cathode ray tubes, cables, plastics, metals, condensers and others. The methods of salvaging material from circuit boards drawn from monitors, CPU disc, floppy drives, printers, etc. are highly destructive as they involve heating and open burning for extraction of metals. Toxic chemicals are used to recover valuable metals such as gold, silver and copper from the PCBs. Working in poorly ventilated areas without proper personal protective equipment leads to exposure to dangerous and slow-poisoning chemicals. Even after such harmful methods are used, only a very few of the metals are recovered and the recovery percentage is very low.

According to a comprehensive report by Maharashtra Pollution Control Board, 2007, there is no organized mechanism for collection, transportation and disposal of WEEE. The dismantling of the e-waste is done by the crudest methods by use of hammer, chisel, screw driver and bare hands to separate copper containing parts, steel, plastic and other metals. Recyclers are mainly interested in recycling PCBs as they contain the precious metals. Precious metals are present as thin layer on surface of copper, nickel and iron in pins, condensers, etc. on PCBs. Preheating process is applied to remove the resalable components like ICs, condensers, bearings (pulleys) from floppy drive and hard drive. Pre-heating means simply putting the mother board on a stove. Then resalable chips, condensers, bearings, etc. are plucked out manually from the pre-heated PCBs from TV, PC, cell phone, etc. The gold-plated pins are manually removed. The core of each mother board has a flat laminated gold plate which is cut down and sold to goldsmiths for gold recovery. The pre-heated circuit boards are taken by other dealers for recovery of solder (consisting of lead and mercury). The method of solder recovery is very rudimentary [13].

6. Impact of Informal Recycling

The Basel Convention, a UN Treaty, defines Printed Circuit Boards as hazardous. In the absence of suitable techniques and protective measures, PCBs recycling by crude methods result in toxic emissions to the air, water and soil and pose a serious health and environmental hazard. Improper recycling can cause irreversible damage to the human body and environment. Women and children are often directly exposed to lead and other hazardous materials in this process. The acid treatment and burning cause occupational hazards to the workers and contaminate the environment through effluents and toxin laden smoke. Highly toxic fumes as dioxins and furans are produced when plastics casings are burnt to retrieve metals and these are released into the air. Waste acid water is discharged into neighboring grounds. Working in poorly ventilated enclosed areas without masks and technical expertise results in exposure to dangerous and slow poisoning chemicals. Thus with almost all recycling being done in illegal scrap yards, there are no controls on the processes and discharge of effluents. Even after such harmful methods are used only a few of the materials are recovered.

7. Management Strategies for Formal Recycling of PCBs

Proper management for recycling of waste PCBs will depend not only on the effectiveness of local government but also on the attitude of consumers and manufacturers. Collaborative campaigns are required for educating the consumers. Encouragement of donation of e-wastes to underdeveloped areas and second-hand markets can help reduce the quantity of waste PCBs produced. An efficient collection and recycling infrastructure is required. For financing, either the consumers can pay via fee at purchase or shared by producers (for transport and recycling) and municipalities (for collection). In Switzerland, Advance Recycling Fee (ARF) is charged on all new appliances. The ARF is used to pay for the collection, transport and recycling of the disposed appliances. The effective collection of e-waste in Switzerland is primarily due to efficient management of the waste by two Producer Responsibilty Organisations (PROs)-SWICO (The Swiss Association for Information, Communication and Organisational Technology) and S.EN.S. (Stiflung Entsorgung Schweiz) [14].

Integration of the existing informal recyclers into the formal sector can be done by giving them incentives. Proper knowledge transfer and skill upgrading through seminars and training are required. Since the informal sectors have their own limitations to implement all processes, there is a need for responsibility being given to formal sector which would be responsible to pay the informal sector an attractive price for the scrap material. For environmentally sound management of waste PCBs proper collection, transportation, storage, recovery and disposal facility at regional and national levels certified by the regulatory authorities are required. E-waste collection, exchange and recycling centers should be encouraged in partnership with government, NGOs and manufacturers. Proper recycling of materials present in PCBs requires sophisticated technology and specific skills and training for the operation. Thus involvement of both formal and informal players is required. The informal sector should concentrate more on collection, disassembly and segregation and be discouraged from treating PCBs. The formal sector should purchase the PCBs from the informal sector and concentrate only on the core activity of PCB recycling.

Rochat *et al*. 2008 [15], have discussed the working of "baseline scenario" and "alternate business models" for different qualities of PCBs. Presently, the collection and segregation of e-waste is done by middleman, scrap dealers and rag pickers (kabadiwallas). In the baseline scenario, the PCBs are collected and dismantled in order to segregate the gold-containing parts as pins, connectors, chips from which gold is extracted by wet chemical processes. The rest is thrown away, or sold to vendors for the extraction of copper. In the alternate business model, the recyclers collect and segregate the boards in order to accumulate them until they obtain the minimal required amount to be shipped to an integrated smelter abroad. By replacing the traditional wet chemical leaching process for the recovery of gold with the export towards integrated smelters and refineries, safer practice and higher revenue per unit of e-waste collected are generated. A refining charge is agreed beforehand in a refining contract. An accurate determination of the exact composition and the precious metal content of the received materials is crucial to enable a correct settlement with the customers but also to steer the optimum processing of the material through the plant [16].

In another model S. Chaterjee and Krishna Kumar, 2004 [2] have proposed for equal participation of the formal and non-formal sector to make e-waste management business a profitable one. The non-formal operators will concentrate on collection, disassembly, segregation of e-waste, whereas formal sector will concentrate on the processing of the PCBs to extract precious metals. The 95% - 97% of the e-waste by weight contains metal, glass and plastics which can be easily disassembled and segregated manually without damaging the environment; whereas 3% - 5% by weight which actually contains PCBs need environmentally friendly recycling techniques and the formal recyclers will concentrate on that. Segregated items like PCBs and connectors will be converted into powder by a professional agency for which they will charge fee and then sell the PCB powder to the established recyclers at the right market price based on the assessment of assay.

7.1. Initiatives by the Producers

Industry has shown considerable initiative for handling e-waste responsibly. Dell has instituted recycling programs by offering a take-back program for free. Hewlett Packard (HP) complies with RoHS norms and has started recycling program by offering a take-back program for consumers. It has started a reuse approach where the products recycled can be used again. HCL has all its products RoHS compliant and started a take-back facility to all its consumers (both corporations and individuals). Lenovo also offers a take-back facility to all its consumers. Products are picked from consumer premises by a third party enlisted by Lenovo and the service is free of cost to its customers. Wipro has become 100% RoHS compliant and started a take-back policy for all its end-of-life (EOL) products.

7.2. Initiatives by Private Parties

There are a few firms that have taken up the task of efficient disposal of PCBs from e-waste. Formalizing the informal sector (particularly the processes with the highest environment and health impacts) with improved technology and skills along with improved working and living environment of the people working in the informal sector has been the main objective of the newly formed "Clean E-Waste Channels" in India (e-waste guide, 2008).

"Clean E-Waste Channel" is based on a voluntary agreement amongst producers formed by the Electronics City Industries Association (ELCIA), Bangalore, to organize the take back of e-waste through authorized recyclers. A "Clean E-Waste Channel" is supposed to provide convenient collection points for consumers, provide transportation of e-waste to a trader/recycler, involve trained informal sector for certain tasks and ensure that the e-waste is processed by licensed recyclers only. For this the consumers should also be made aware and should give their obsolete electronic waste to authorized recyclers only. The producers should agree on individual or collective take- back system at authorized collection points. The recyclers should have proper and sustainable recycling facility of e-waste along with license from the State Pollution Control Board and also contractual agreements with the producers about receiving e-waste. The producers of electronic goods are supposed to form a "Producer Responsibility Organization" (PRO) which will manage the take-back and ensure that the e-waste particularly the PCBs will be processed in an environmentally friendly manner.

With the growing recognition of business prospects and opportunities many companies have cropped up in India and are doing business in this field recently. Few leading brands active in India have been trying to provide takeback and recycling services in India. There have been a few private parties which are coming forward in this direction to invest in PCBs recycling. Electronic waste recyclers and processors have to be registered with Central Pollution Control Board. 23 recycling units have been registered as of 2010. Table 2 gives the list registered e-waste recycling units in India.

Table 2. List of registered e-waste recycling units in India.

SN.	Company	Location	Recycling capacity (MTA)
1.	M/S Ramky E-Waste Recycling Facility (Ramky Enviro Engineers Ltd)	Maheshwaram, Andhra Pradesh	10,000
2.	M/S Earth sense Recycle Pvt. Ltd.	Rangareddy Andhra Pradesh	1800
3.	M/S Ash Recyclers Unit II	BangaloreKarnataka	120
4.	M/S New Port Computer Services (India) Private Ltd.	Bangalore,Karnataka	500
5.	M/S EWA RDD & Co.	Bangalore,Karnataka	600
6.	M/S E-R3 Solutions Pvt. Ltd.	Bangalore, Karnataka	120,000 Units
7.	M/S Ash Recyclers, Unit I	Bangalore, Karnataka	120
8.	M/S E-Parisara Pvt. Ltd.	Bangalore, Karnataka	1800
9.	M/S Surface Chem Finishers	Bangalore, Karnataka	600 Kg/Annum
10.	M/S Jhagadia Copper Ltd.	Bharuch, Gujarat	12,000
11.	M/S Eco Recycling	Thane, Maharashtra	7200
12.	M/S Earth Sense Recycle Pvt. Ltd.	Thane, Maharashtra	360
13.	M/S Hi- Tech Recycling India (P) Ltd	Pune, Maharashtra	500
14.	M/S Greenscape ecomanagement Pvt. Ltd	Alwar, Rajasthan	450
15.	M/S Trishyiraya Recycling India Pvt. Ltd	Chennai,Tamil Nadu	740
16.	TES AMM Private Ltd.	Kanchipuram, Tamil Nadu	30,000
17.	M/S Global E-waste Management and Services (GEMS)	Kanchipuram, Tamil Nadu	387
18.	M/S Victory Recovery and Recycle Technologies India Pvt. Ltd.	Thirivalluvar, Tamil Nadu	6000
19.	M/S Ultrust Solutions (India) Pvt. Ltd.	Thiruvalluvar, Tamil Nadu	1500
20.	M/S INAA Enterprises	Chennai,Tamil Nadu	300
21.	M/S TIC Group India Pvt. Ltd.	Noida,Uttar Pradesh	1000
22.	M/S Attero Recycling Pvt. Ltd.	Roorke, Uttarakhand	12,000
23.	M/S Earth Sense Recycle Pvt. Ltd.	Gurgaon, Haryana	1200

7.3. Initiatives by Government

Government of India has initiated various activities for dealing with issues of hazardous waste management. The State Governments are in the process of identifying hazardous waste disposal sites. WEEE Task Force has been constituted comprising the Ministry of Environment and Forests, Central Pollution Control Board, Ministry of IT, Manufacturers Association for Information Technology (MAIT), The National Association of Software and Services Companies (NASSCOM) and some industry associations and various NGOs such as Sahaas and Toxic Link. The Task Force has set up guidelines for formulation of Regulation Policy for e-waste on issues such as: 1) Policy and Legislation; 2) Baseline Studies; 3) Restructuring and Recycling; 4) System of Extended Producer Responsibility; 5) Awareness-building. Based on these guidelines the legislation regarding e-waste has been passed which has come into effect from May, 2012.

8. Actual Problems to the Formal Recycling of PCBs in India

The new legislation regarding e-waste with effect from May, 2012 does not have any provision for ban on import of second hand electronic equipment for charity and reuse purpose. Absence of this strong clause will not be able to curb the import of large quantities of e-waste thereby producing huge amount of waste PCBs which end up in informal recycling yard.

In developing and industrializing countries waste is viewed as a resource and income-generating opportunity. There is a general reluctance to pay for waste recycling and disposal services, particularly when consumers can make some money by selling their old and broken appliances [17]. Also due to lack of awareness of hazards of the e-waste, consumers sell their electronic waste to informal recyclers for quick money as it is easier and faster. Informal collectors take at a lower price. Thus a regular supply of PCBs is an issue which the registered recycling units face. The formal recyclers should have a steady supply of PCBs from e-waste for their sustenance. Currently the authorized e-waste recycling facilities in India capture only 3% of the total e-waste generated and rest make way in informal recycling.

As mentioned by Rochat *et al.* [15] in the "alternate business model" after dismantling, the PCBs are removed and exported collectively for smelting abroad to recover precious and base metals. However, the cost linked to the transportation to the integrated smelters is the main limiting factor. Hence new alternative treatment processes to recover the precious metals which will be viable and attractive for the investors in this field need to be developed for recycling of metals in PCBs indigenously in India for greater returns.

Huge investments are made by the producers on production and delivery of goods as compared to their refurbishments and recycling. Few leading companies are offering take-back services for cleaner recycling. According to the report "An Assessment of E-waste take-backs in India", 2008 which reviews the company policies and practices on take-back in India nine of twenty brands surveyed had no take-back and recycling services in India despite many of these same global brands provide voluntary take-back service in countries like US. Only one global brand, Toshiba and two Indian brands, HCL and Wipro are offering voluntary take-back services to their customers in India. HP offers take-back service only for its corporate customers but small business and individual customers are missing in this service. Study shows that information related to take-back services is not easily accessilble. Some of the brands, notably LG Electronics and Dell have not posted information on take back in India on their respective Indian websites. One has to visit their global portals to get this information (www.designouttoxics.org) [18]. **Table 3** gives a list of companies and their take back programmes in India

But there are few favorable factors for PCBs recycling in India. The tradition to reuse the electronic products in India has an advantage of slightly reducing the quantity of waste PCBs. Due to low manpower cost, managing the recycling of PCBs with appropriate technology will be more cost effective.

9. Conclusions

It is clear that many initiatives have been started to deal with the problem of recycling of PCBs. Measures such as specific product take-back obligations, greater attentions to the new product design, ban or restriction on the use of certain substances will help reduce the problem to a great extent. In order to develop newer ways to deal with the problem of recycling in an eco-friendly way and to make it continuous and sustainable at the same time, more research work needs to be undertaken. There should be regulations and standards besides incentives on investment. Effective implementation of the new e-waste law will help to tackle the problem.

Environmentally, sound recycling of printed circuit boards from e-waste requires development of proper e-waste collection, transportation, storage, treatment, recovery and disposal facilities at the regional and national level. Producers are to be made more responsible. Though the original equipment manufacturers may have their own limitations, it should be imperative on their part to take the responsibility for recycling the risky parts particularly.

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Table 3. How companies line up on take-back in India (www.designouttoxics.org).

Take back service available in India	Take back service not available in India
Acer	Apple
Dell*	Microsoft
HCL	Panasonic
Hewlett Packard (HP)**	PCS Technology
Lenovo	Philips
LG Electronics^	Sharp
Motorola	Sony
Nokia	Sony Ericsson
Wipro	Toshiba
Zenith	
Samsung	

*Information regarding take back in India is only available on global website; ^Take back service is only available for mobile phone; **Take-back service is only available for corporate customers.

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