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Electronic Components (EC) Reuse and Recycling – A New Approach towards WEEE Management

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Abstract

Waste Electrical and Electronic Equipments (WEEE) is the fastest growing waste stream in the world. In 2014, a total amount of 41.8 metric kilotonnes of WEEE was generated globally. There are two main parts of a WEEE – a) The Printed Circuit Board (PCB) and b) The Casing i.e. the polymer and/or metal portion that covers the PCB. PCBs contain a lot of components like resistors, transistors, microcontrollers, integrated circuits etc. Once a Electrical and Electronic Equipment (EEE) becomes obsolete; Electronic Components (EC) in the PCB remains unaltered. These ECs can be reused based on their status. In most of the cases, the PCBs end up in the informal sector that employs open burning, acid leaching etc to recover valuable metals from it and the residues end up in landfill which is a malpractice. In this work, two case has been considered – a) Small WEEE (mouse, speakers, headphones, mobile, radio, wires etc) and b) Large WEEE (Laptop, desktops, TV, printer etc). PCBs from these two types of WEEE have been examined. A solution is proposed that will help to enhance the reuse and recycling of the ECs obtained from the PCBs. The proper technique for de-soldering of ECs from the PCB and further testing methods has been discussed. Proper recycling routes of the unusable ECs have also been suggested. Finally, a novel framework has been proposed that will enhance the EC reusability and recycling. The findings will help the stakeholders in decision making, the researchers in considering future research direction and overall a sustainable future for both semiconductor and electronics industry.

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1.0 Introduction

Recent trend of lesser life span of Electrical and Electronic Equipments (EEE) have changed the electronics industry in the past decade as it creates more demand. More demand has created expansion of technology accompanied with short innovation cycles that has produced different version of similar electronic products. Thus, the rate of EEE obsolesce have increased many fold and has generated huge amount of Waste Electrical and Electronic Equipments (WEEE). In the year 2014, 41.8 million metric tonnes of WEEE was generated globally whereas India produced 1,641 metric kilo-tonnes of WEEE (Baldé et al. 2015). It is also considered as the fastest growing waste stream in the world.

WEEE contains a wide variety of elements – 50% iron and steel; 21% plastics; 13%non ferrous metals and 16% other constituents (rubber, concrete and ceramics). Presence of metals like lead, mercury, arsenic, cadmium, selenium, hexavalent chromium and flame retardants beyond the permissible limit makes the e-waste to be classified as a hazardous material (Pant et al. 2012). However, the most hazardous part of WEEE is the Printed Circuit Board (PCB). PCBs contain flame retardants, precious metals and lots of electronic components (EC). Electronic components are the components of different shape and size which are soldered on the PCBs. For example, resistor, inductor, capacitor, ICs (Integrated Circuit) etc. These ECs are very essential parts of any PCB. Any electronic device becomes WEEE once it stops working and the device is discarded. If the device is repairable, then it is repaired and sold to other users. These are called Used Electrical and Electronic Equipments (UEEE). Repairing of these electronic items chiefly consists of replacing the inactive or damaged EC. Sometimes unavailability of ECs makes the equipment unusable. However, the WEEE still contains a lot of ECs that are reusable and can be used in repairing or other industries for remanufacturing whereas the inactive ones or the damaged ones should be recycled properly.

In the last decade, WEEE recycling has gained attention of the researchers. Recycling of WEEE can be divided into two categories – a) Physical or mechanical processes and b) Chemical processes. Mechanical processes gained a lot of attention in the beginning of this century and have produced a huge number publications and patents based on mechanical process (Grause et al. 2010). Good review works are present on mechanical recycling of WEEE (Cui and Forssberg 2003). Chemical processes took some time and has now gained pace. In fact, all the chemical processes are followed up by initial physical dismantling processes. The research interests of chemical recycling processes have divided the e-waste into two sections – a) Printed Circuit Board (PCB) recycling and b) Polymer recycling. In general, works on PCB recycling has focused on metal recovery from the PCB. Pyrolysis (Bidini et al. 2015, Hall and Williams 2007, Kantarelis et al. 2011, Rajarao et al. 2014, Terakado et al. 2013), hydrometallurgical techniques (Tunchuk et al. 2012), leaching (Kumar et al. 2014), plasma arc gasification (Kingzett 2010) and plasma torch based treatment (Tippayawong & Khongkrapan 2009) has been attempted by the researchers. Not much work is present on polymer fraction recycling of e-waste. However, pyrolysis has been implemented polymer part processing of e-waste (Jakab et al. 2003). Kinetic studies of thermal decomposition of plastics from e-waste have also been reported (Grause et al. 2010). Bioleaching is another route that has evolved for recovery of precious metals from e-waste that implements different bacteria or mutated bacteria to leach precious metals like gold, copper and nickel (Arshadi and Mousavi 2014, Bryan et al. 2015, Natarajan and Ting 2014, Saidan et al. 2012).

The majority of the works have focused on the WEEE recycling either as a whole or fraction wise i.e. PCB and Polymer part. Works on electronic component reuse and recycle has not been reported so far. Hence, this is a new area of focus for the technologists and practitioners. The research questions that arises are – Is it possible to reuse the ECs after dismantling them from PCB? How the ECs can be reused? What will be the impact of this on the electronic industry? In this study, an attempt has been made to find the answers to these questions. A case study approach has been taken and the findings have been analyzed.

The rest of the paper has been organized in five sections. Section two describes the methodology adopted in this study. Case Studies have been presented in the section that follows. The findings has been analyzed and discussed in the succeeding section. The work has been concluded in the end.

2.0 Materials and Methods

From friends, relatives and colleagues, WEEE is gathered which consists of broken cell-phones, monitors, mouse, key-board, printers, USB-drive, television sets, old laptops, refrigerator etc. The accumulated WEEE is of two types: small and large. Now, the component reusing and recycling steps are mentioned below:

The first step for recycling of Integrated Circuits (ICs) lies in differentiating small WEEE from their large counterparts. Secondly, when these are opened, several electronics components (ECs) of different categories are found out. A few of them are independently mounted inside a WEEE while most of them are mounted on printed circuit boards (PCBs).

The components from PCBs are separated in a two-step method (Wang and Xu 2015):

1) Damage of solder joints between PCBs and ECs by grinding, dissolving solders by chemical reagents, applying heat by hot air, fluids, paraffinic and silicon oil, infrared heaters, electronic heating tubes etc.
2) Applying external force, these ECs are separated from the PCBs.

Now, ECs are classified according to the groups they fall under. Each EC is tested following the method of testing of the group it falls within. An EC is declared reusable if it passes the testing criteria during the test. Reusable ICs are now distributed in Reusable EC market for sell to consumers: organizations as well as individuals. ECs which are not reusable, PCBs as well as cover boxes of WEEE are recycled separating the composition in them: metals, plastic, semiconductors, ceramic, paper etc. In each WEEE, the composition of these substances varies and recycling techniques depend on the percentage of each substance in composition.

3.0 Case Studies

Two case studies were carried out based on WEEE size – a) Case study of small WEEE and b) Case study of large WEEE. They have been discussed in detail below.

ECs inside WEEE are categorized into their respective groups. This is done to facilitate the process of testing of ECs later according to the method of testing of the group it falls under. Functionally, they are categorized into the following five categories:

Analog electronics components: These components includes resistor, capacitor, inductor, diode, BJTs, FETs etc. and analog ICs like op-amp, analog comparator ICs etc. Fig. 1(a) & (b) shows some small and big analog electronic components dismantled from the PCBs respectively.

(a) (b)

Fig. 1. (a) & (b): Small and Big analog electronic components

The following flow-chart will describe the methodology in the form of flow-chart.

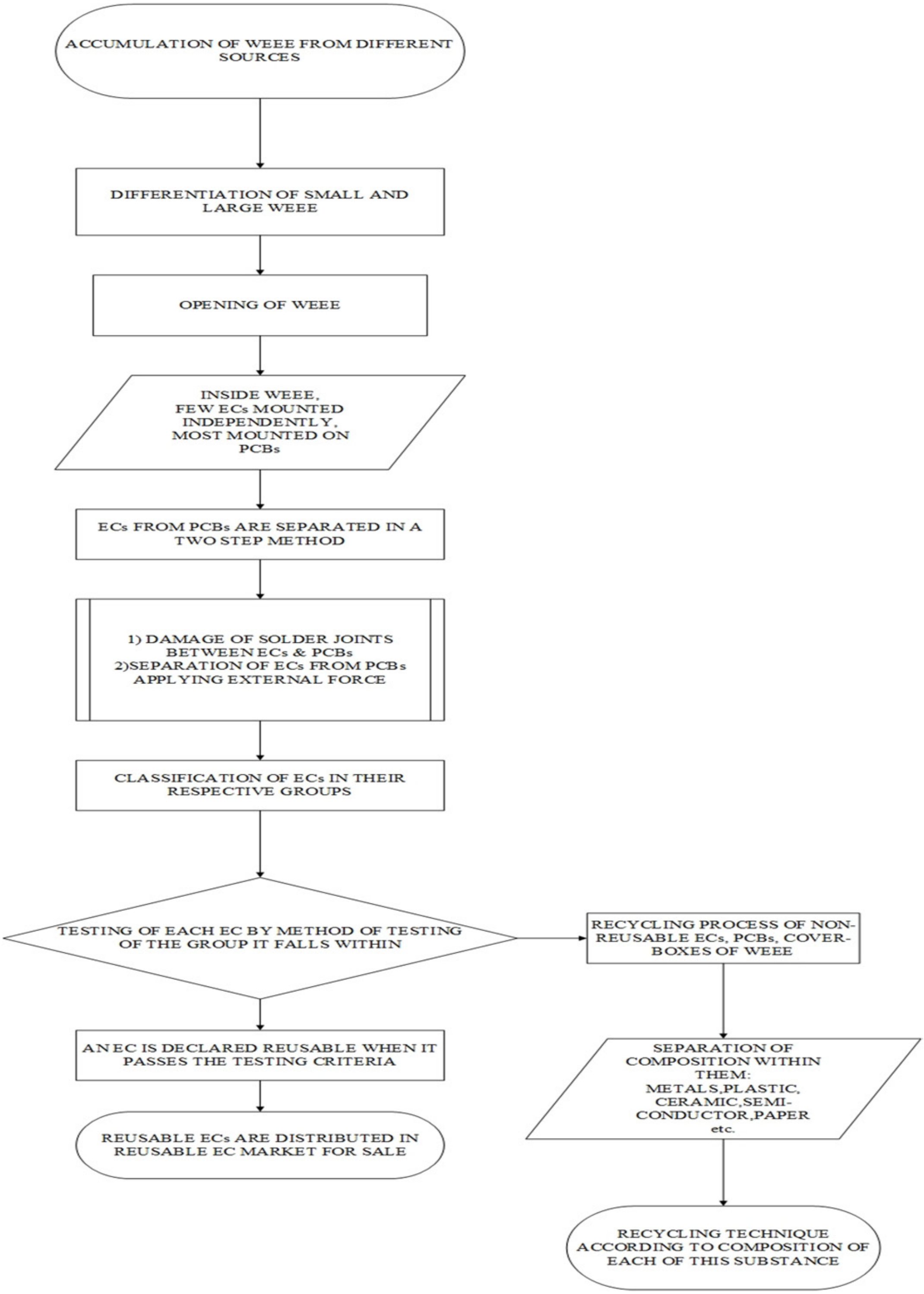
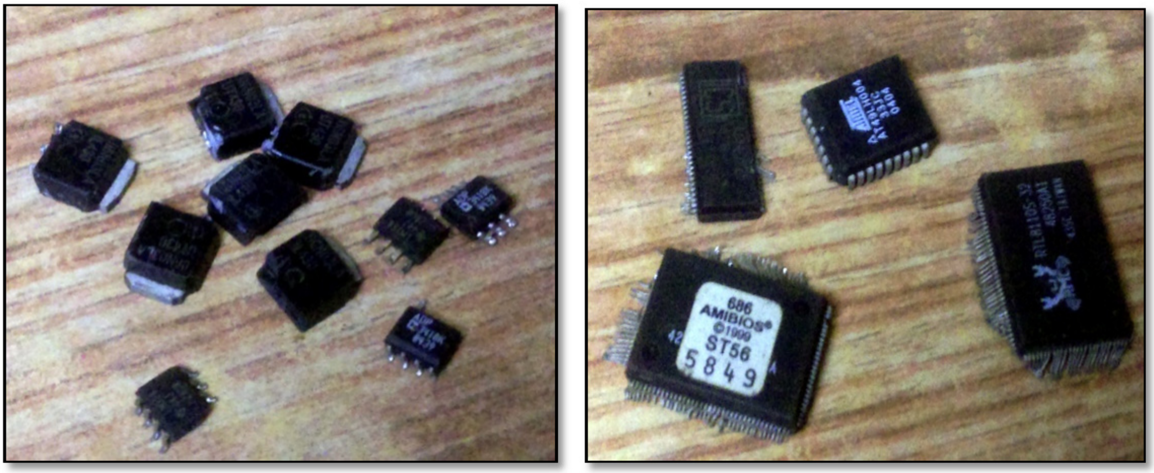


Fig. 2. Flow-chart of Methodology

a) **Digital electronics components**: This includes logic gates ICs, digital ICs like mux, demux, encoder, decoder, comparator etc.



(a) (b)

Fig. 3. (a) & (b): Small and Big ICs.

b) **Mixed signal ICs:** Analog to Digital Converters, Digital to Analog Converters, NE555 etc belongs to this section.
c) **Advanced Digital ICs:** Microprocessors, Microcontrollers are also found and belongs to this category. Some pictures of different ICs are shown in Figure 3 (a) and (b).
d) **Memory components:** RAM, ROM, Hard-drives are the memory components.

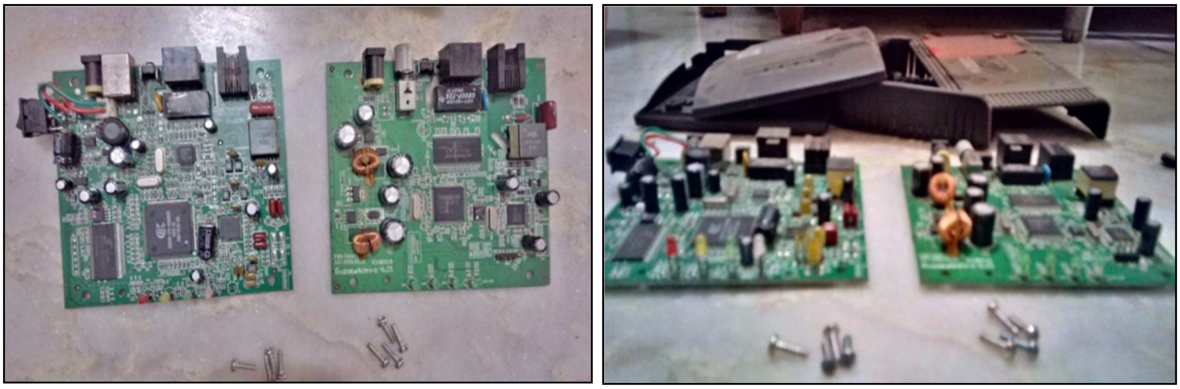
3.1 Case Study 1: Small WEEE

Small WEEE consists of daily electronics gadgets used such as cell phones, laptops, mp3 players, remote controls, hair dryers and trimmers, electronic toys, watches and clocks, torches, small kitchen appliances as well as home safety devices like smoke-detectors, power tools etc. [1]. The size of these items is to an extent such that they can be carried in pockets and bags. The cover-box which is made of plastic or metal is of smaller proportion and PCBs constitute quite a proportion of small WEEE. EC extraction amount from these items is almost equivalent to their size.

Now, illustrations of some small WEEE samples along with their pictures are shown as follows:

3.1.1 Modem

As a sample of small WEEE, a modem is opened and it is found that there are small plastic cover-boxes and screws. Also there are two PCBs which consists of a quite a large no. of ECs. To test these ECs, the desoldering and testing procedures have to be carried out. Proportionality of ECs that can be reused is of high compared to the size.



(a) (b)

Fig. 4. (a) Modem PCBs &(b) Modem cover-boxes with PCBs

Similar is the case when a mouse is dismantled a figure of which is shown below:

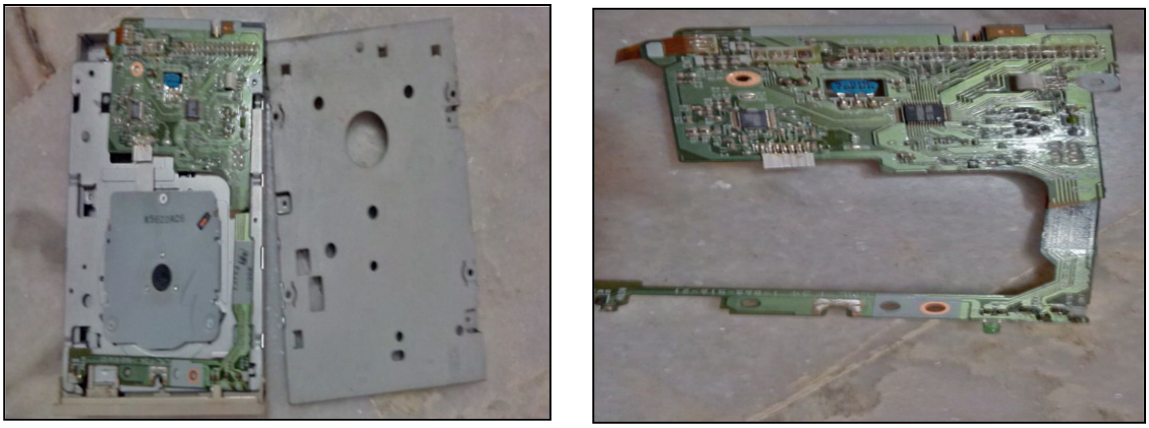
Fig. 5. A dismantled Mouse with PCB

Fig. 6. Dismantled cell-phones

Waste cell-phones also fall under the same category. But cell-phones have another speciality which is every cell-phone runs on battery and contains Li-ion battery. These batteries have to be separated and recycled properly according to the law of a country because cell-phone batteries contain toxic metals and chemicals and cannot be treated as a general waste for land-fill [6].

3.1.2 Floppy Drive

As another kind of sample of small WEEE, a floppy drive is dismantled. It is observed that quite a portion of it constitutes metal that can be recycled while the ECs on the PCBs have high chance to be recycled.



(a) (b)

Fig. 7. a) Dismantled Floppy Drive & (b) PCB portion of dismantled floppy drive

3.1.3 CD Drive

When a CD drive is dismantled, it is observed that it is like a Floppy Drive but the difference is that it contains quite a proportion of metal and plastic as well. There is also large PCB proportion present from which there is high chance of ECs to be recycled.

Fig. 8. A dismantled CD Drive

3.1.4 Memory Cards and Drives

These types of small WEEE have the feature that almost whole of the device constitutes ECs while a few remaining part can be metal or plastic. Since it is a small device, less number of ECs is available here but that number is almost proportional to the size of the device.

Fig. 9. Memory Cards & Devices

3.1.5 Key-board

Fig. 10. A dismantled key-board

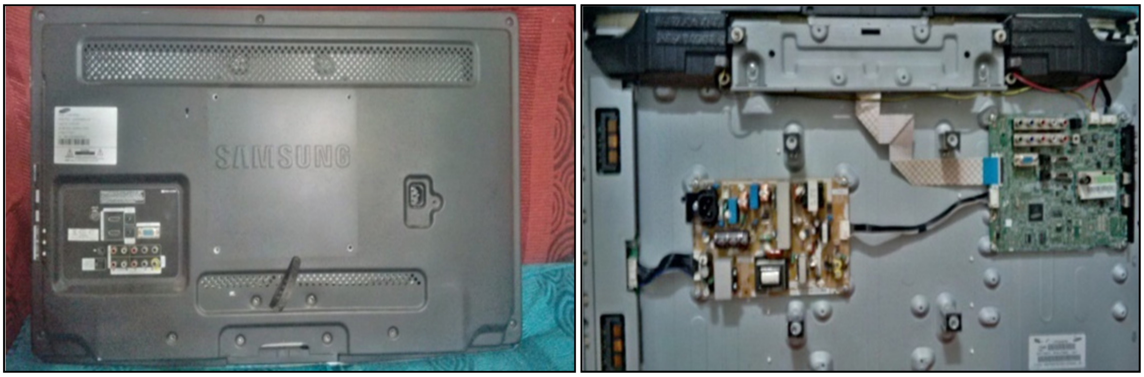
A waste key-board falls under the category of small WEEE but it is an exception which is clearly visible when being dismantled. Almost whole of it contains plastic and polymer in the form of keys and cover but it contains a small PCB which is very small in size compared to other components. So, no. of ECs that can be recovered from it is very small proportional to the other substances.

3.2 Case Study 2: Large WEEE

Large WEEE consists of electronics instruments which occupy quite an amount of space and which are not portable in bags or pockets. It consists of items like TV sets, monitors, desktop computer CPU, printer, refrigerator, washing machine, vacuum cleaners etc (www.chelmsford.gov.uk). Cover-boxes of these items constitute a huge proportion and PCBs are a small part of large WEEE. EC extraction amount from large WEEE is small compared to the size of these items.

Now, illustrations of some large WEEE samples are presented along with the pictures:

3.2.1 LCD TV



(a) (b)

Fig. 11. (a) Cover-box of LCD TV (b) Metal and PCB of LCD TV

This is an illustration of large WEEE. In this case, the plastic covers consist a huge part of the device while the PCBs: the yellow and the green one constitute only a very small portion of the whole equipment.As a result, the number of ECs that will be available from it is very small in number compared to the size of it.

3.2.2 CPU

(a) **(b)**

(c) **(d)**

(c)

Fig. 12. (a) Dismantled CPU, (b) Mother-board, (c) Bus, (d) Screws & (e) RAM

It is an illustration of large WEEE.A mother-board is a small part compared to the total volume of the CPU but number of ECs that are available from a mother-board is much greater than most other PCBs available.

4.0 Results& Discussions

The Electronic Components which are found inside WEEE usually are of two types according to their demand in the market and their applications. The two types are as follows:

1) Versatile Components are the ones which are sold in the market according to some specific categories and specifications and are sold to be used in various kinds of applications by various organizations.
2) Specific components are the ones which are used for a specific application having some unique specifications and may be uniquely by a single organization or even for a single model of equipment sold in the market.

Table 1 and Table 2 show some groups of versatile and specific components respectively according to their functions. Also, examples of each group of components are provided along with their material composition. The criteria that have to be satisfied for these components to be reused and the recycling options are also provided.

Table 1: For Versatile Components

Group of Components [3]	Examples of components in each group	Material Composition	Criteria to be satisfied for Reusability	Recycling Options	References
Passive Components	Resistors, Capacitors, Inductors, Thermistors etc.	Carbon, Graphene,Metals (Steel, Tantalum), metal oxides, dielectrics, ceramics.	Test result of resistance, capacitance, inductance within tolerance value	Plasma arc/torch treatment, Pyrolysis.	Bidini et al. 2015, Cui & Forssberg 2003, Kingzett 2010, Kumar et al. 2014, Spitczok et al. 2014, Terakado at al. 2013, Vanukuru 2015, Yang et al. 2015
Analog Components	Diode,BJT, FET	Semiconductor, amorphous silicon, polycrystalline silicon, silicon carbide (SiC), gallium arsenide (GaAs),	Multimeter Testing	Plasma arc/torch treatment, Pyrolysis	www.madehow.com, www.ee.sc.edu, fourier.eng.hmc.edu, en.wikipedia.org, Hall

Group of Components [3]	Examples of components in each group	Material Composition	Criteria to be satisfied for Reusability	Recycling Options	References
		Indium gallium arsenide (InGaAs), gallium phosphide (GaP), gallium arsenide phosphide (GaAsP), Gold, Metals, graphene, molybdenite, gallium nitride etc.			and Williams 2007, Rajarao et al. 2014, Tippayawong & Khongkrapan 2009.
Analog, Digital and Mixed Signal ICs	LogicICs, Mux, Demux, Encoder, Decoder, Clock&TimerICsA DC, DAC, NE 555 etc.	Plastic, Copper, dielectric, Silicon, other metals.	Functioning of pins, Proper Voltage Level, Proper Timing of output signal, Acceptable SNR	Pyrolysis, Gasification, Plasma treatment.	smithsonianchips.si.edu, madehow.com Grause et al. 2010, Kingzett 2010, Kantarelis et al. 2011, Schwierz 2010.
Connectors	I/O Connectors, IC & Component Sockets, Terminals, Memory Connectors etc.	Metals such as copper, gold, nickel etc.	Isolation & Continuity Test	Pyrometallurgical or hydrometallurgical extraction.	icconnectors.com, Tuncuk et al. 2012, Terakado et al. 2013.
Microprocessors	AMD Turion, Inteli7, HP Capricon	Aluminum, Copper, Aluminum silicon carbide.	Structural Testing,Functional Testing without fault models and using specific fault models	Pyrometallurgical or hydrometallurgical extraction.	dejazzer.com,Slideshare .net, Tuncuk et al. 2012, Rajarao et al. 2014.
Microcontrollers	Atmel AT89 series, PIC 18 series etc.	Semiconductor, metal and plastic.	Generating Test Signals and Testing MCU outputs (cdn.teledynelecroy.com)	Gasification, Plasma treatment.	Instructables.com, Grause et al. 2010, Tippayawong & Khongkrapan 2009.
Circuit Protection Components	Thermal Cutoffs, Fuses etc.	Light metals	Proper functioning of protection mechanism as per requirement	Leaching, metallurgical methods.	eem.com, Hall and Williams 2007, Tuncuk et al. 2012
Power Management Circuits	Batteries, Power Cords, Power Inverters etc.	Li-ion, Nickel etc.	Acceptable Power Output	Leaching, metallurgical methods.	Chan et al. 2008, Kantarelis et al. 2011, Saidan et al. 2012, Tuncuk et al. 2012
Memory Components	RAM, ROM, Hard-drive	Aluminum, Platinum, Steel, Nickel, Gold, Plastics.	Read, Write, Speed, Capacity	Leaching, bioleaching, gasification, pyrometallurgical methods.	Bryan et al. 2015, Redwine 1991, Natarajan and Ting 2014, Grause et al. 2010

Table 2: For Specific Components

Name of Group of Components	Typical Composition	Reusability	Recycling Options	References
Application Specific Processors	Aluminum, Copper, Aluminum silicon carbide.	Testing method of a processor, in this case satisfying the needs of the application it is made for	Metallurgical methods.	Instructables.com, Bryan et al. 2015.
ICs used for Specific Applications	Semiconductor, metal, plastics.	General IC testing technique	Gasification, Plasma treatment, metallurgical methods.	Madehow.com, Bryan et al. 2015, Grause et al. 2010, Tippayawong & Khongkrapan 2009.

The case studies of the small and large WEEE revealed that the small WEEE contains more or less equal volume of PCB and polymer or metal fraction depending upon what the casing is made of. For example, in a floppy drive, there is metal casing and amount of PCB and metal are almost equivalent. However, as exception, in case of a keyboard it was found that very less amount of PCB is there and nearly 90% of the equipment is polymer. Whereas in the large WEEE, metal or polymer fraction is much higher than PCB fraction depending on what the case-box is made of. For example, in the case of LCD TV, polymer and in CPU, metal fractions are higher than PCB portion depending upon the substance of casing box. It was found that implementing this methodology will not only have impact on the environment regarding reduction of WEEE in environment to a considerable amount but also will have influence on semi-conductor industry itself. Presently, whenever a new electronics system is manufactured, ECs are produced in the factories and then used for further usage. But, when EC reusing methodology is implemented, a portion of ECs required for manufacturing new systems will come from reused ones. Countries that do not produce new ECs to a greater extent but import a huge amount of electronic gadgets each year can manufacture new gadgets by assembling of existing ECs which will reduce their import expenditure for electronic gadgets.

A new kind of semi-conductor industry called “Electronics Component Testing Industry” will emerge. Its function will be buying WEEE from organizations and individuals and selling reusable components to Semi-conductor Manufacturing Industry and non-reusable components to recycling industry. Testing Industry being a new industry will increase employment. Also, it will have a boost on electronics testing equipment industry. More advanced testing methods and instruments will also be new trends in research of the domain of electronics.

Also, consumers will get price of their defective electronics equipments by selling WEEE to the Testing Industry or WEEE collecting organizations. This will enhance the formal recycling. Incorporating the informal collectors known as ‘Kabbadiwalas’ in India and ‘Cherrypickers’ in China, will strengthen the supply chain and reduce health hazard to the people associated with the business. Also they will not have any fear of being jobless. It will create a positive impact on economic condition of citizens of a country since the total amount of money they will spend on electronic gadgets will become lower because in the end when these gadgets become waste, they will get back a portion of money they have spent on buying these gadgets.

5.0 Conclusion

Reusability and recyclability of electronic components from WEEE has been investigated in this study. Case study approach has been employed for this purpose. Two types of WEEE have been used – small and large. They have been dismantled and the ECs have been identified. Reusability of these ECs has been suggested and inspection method of their workability has been discussed. However, some ECs can be damaged and needs proper disposal. The disposal technologies for the recycling of those ECs have also been suggested. The probable impacts of EC reuse and recycling on the electronics industry and the supply chain of WEEE management has been discussed.

It has been found that it will affect supply chain and the stakeholders both economically and socially. Keeping the environmental issues in mind, the processes involved in dismantling and testing chosen has very less impact. Hence, EC reuse and recycling can emerge as a new route towards sustainable WEEE management.

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