# A Study On Emerging Techniques For E-Waste Management

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***Abstract***- *The electronic industry is the world's fastest and largest growing manufacturing industry in the planet. Unwanted electronic and electrical equipment with all of their components at the end of life is termed e-waste. E-waste is a general name for electronic and electric components or products nearing the expiration of their "life span". E-wastes are considered harmful, as some components of some electronic products contain dangerous materials, which are depending on their condition and used material. The general way of disposing electronic gadgets at the end of their life span period includes grounding in landfills or burnt, which causes serious environmental harm in the form of toxic gases or leached hazardous solutions. Electronic waste contain some amounts of precious and base metals; like Cu, Ag, Ni, Au, Fe, Al , Pd etc. and also a sufficient amount of hazardous elements which create soil pollution on dumping. These kind of waste materials found in dumping land are huge source of metals that can be extracted by recovery of such metals using various selective technique. The extraction of these metals from waste is both profitable and Eco-friendly. Hence, this study wishes to list out various techniques for metal recovery from such e-waste and new emerging technologies in the field of e-waste management that can be commercialized as well. The general extraction process has been divided into two steps physical separation and metal recovery. In the first part of the paper, the definition, composition and sources of e-wastes are elaborated. In the second part of the paper, separation of metals from e-waste using mechanical processing, Air classification method, gasification method, pyro metallurgical, hydrometallurgical and biochemical methods and magnetic and electrostatic separation methods are critically analyzed depending upon the type of e-waste.*

***Keywords***- Hazardous component, electronic waste (e-waste); recycling; pyro metallurgy; precious metals (PMs) extractions; copper.

## I. INTRODUCTION

There is no actual meaning for WEEE (The Waste Electrical and Electronic Equipment) or e-waste. E-waste or WEEE comprises various forms of electronic waste that have no much more value to their owners. E- waste described as per different bodies are different. E-Waste term is express as all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the people as a waste without much intension of its re-use. According to European WEEE Directive, E- waste is Electrical or electronic equipment which is waste comprising all ingredients, sub-assemblies and consumables, which are part of the product at the time of clearance.[2, 3]

In today's era of technology, use of electronic Equipment has been tremendously increased. Almost all of us are having cell phones and half of the population have televisions, computers and other household electronic gadgets. Curiosity of people towards new gadgets and their will toward upgrading themselves with technology had increased the production of electronic equipments and at the same time had increased the amount of electronic waste. This demand for new high-tech gadgets is increasing day by day may be also because of the shorter duration of life of the electric gadgets. This has been resulted in the generation of huge extents of e-waste.

E-waste, which is increasing on equivalence with municipal waste is throwing a great challenge for environmental condition and human health at the same time. End of used electronic products alike Computers, televisions, mobile phone, refrigerators, batteries, originates under e-waste. Any electronic product when safe and in use do not create a problem. But, if e-waste is liable along with other waste, becomes a threat to the environment.

E-waste contains many poisonous elements like mercury, lead, cadmium, tin, bromide dioxins that leach into the earth. When e-waste is grounded in a land fill or thrown into water body, they can originate incredible harm to the soil and water resources, thus causing severe diseases like Cancer, Liver Damage, Kidney problems etc., for the mankind and several disease for sea-creature. Thus treatment of e-waste is very important.

## II. SOURCES OF E-WASTE

E-waste is a general name for electronic and electric material or products at the end of their "life span". Some common electric and electronic products are widely used in our life are:

- Televisions, Monitors and Computers
- Cathode Ray Tube
- Wireless Devices
- Audio/Stereo Equipment
- DVD Players
- Video Cameras
- Telephones
- Fax and Copy Machines
- Liquid crystal displays (LCDs)
- Computer Peripherals
- Cellular Phones
- Batteries
- Printed Circuit Board
- Polychlorinated biphenyl (PCB) containing capacitors
- Mercury holding components such as switches
- Plastics containing halogenated flame retardants
- Gas discharge lamps

## III. MATERIAL AND COMPOSITION OF E-WASTE

E-waste is composed of a huge number of constituents of various sizes, shapes and nature. Some of them contain hazardous metals including Hg, Cd and Pb. Such components are removed through separation treatment and recycling processes. [23]Composition of e-waste is very diverse and differs in products of different sources. The different components of E-waste, which can classify under the "hazardous" and "non-hazardous" classes.

Table 1. Major Hazardous component and material in WEEE. [2, 3]

| E-waste | Contents |
|---|---|
| Batteries | Includes Heavy metals such as lead, mercury and cadmium |
| Cathode ray tubes (CTRs) | CTR Contains Lead, Antimony, Mercury, Phosphors etc. |
| Mercury containing components such as switches | Used in thermostats, sensors, relays and switches. Besides it is used in medical apparatus, data broadcast, telecommunication, and mobile phones |
| PCBs | In PCBs, cadmium, Lead, Beryllium, Antimony and BFR is present. |
| Polychlorinated biphenyl (PCB) comprising capacitors | PCB-containing capacitors have to be removed for safe destruction |
| Liquid crystal displays (LCDs) | It contains Mercury. |
| Plastics containing halogenated flame retardants | During burning/combustion of the plastics, halogenated flame retardants can yield toxic components |
| Fluorescent lamp | It contains Mercury, Phosphorous and Flame retardants. |

Widely, it can be made up of of ferrous and non-ferrous metals, plastics, glass, wood, printed circuit boards, concrete and ceramics, rubber and other items. The presence of elements in e-waste like lead, mercury, arsenic, cadmium, selenium and hexavalent chromium and flame retardants. Beyond it classifies as hazardous waste or component. Major hazardous components of e-waste are plotted in Table 1.

There are several e-waste material that gives diverse amounts of metals and non- metals. The e-waste material like TV, PCB, mobile phone, portable audio, Dvd-player, calculator, etc. gives a metal and non-metal. The recovery of precious and base metals is significant for e-waste management, reutilizing, sustainability and resource preservation used for manufacturing of E-waste. The value spreading of precious metal in PCBs and calculators is more than 80%. After precious metal, copper is the next highest metal to be take out from e-waste [5]. It is nonworthable that sustainable resource management demands the separation of hazardous metals from e-waste and also maximizes the recovery of Precious metals. The loss of Precious metals through the recycling process will undesirably disturb the process economy.

The data is given in Table 2 and Table 3 ofWeight vs. value distribution of precious metals. [5]

Table 2. Amount of Cu, Fe, Al and Plastics present in e-waste. [5]

| E-waste | Cu (wt%) | Fe (wt%) | Al (wt %) | Plastics (wt %) |
|---|---|---|---|---|
| TV-board | 10 | 28 | 10 | 28 |
| PCBs | 20 | 7 | 5 | 23 |
| Mobile phone | 13 | 5 | 1 | 56 |
| Portable audio | 21 | 23 | 1 | 47 |
| DVD-player | 5 | 62 | 2 | 24 |
| Calculator | 3 | 4 | 5 | 61 |

Table 3. Amount of Pd, Ag and Au present in e-waste. [5]

| E-waste | Pd (ppm) | Ag (ppm) | Au (ppm) |
|---|---|---|---|
| TV-board | 10 | 280 | 20 |
| PCBs | 110 | 1000 | 250 |
| Mobile phone | 210 | 1380 | 350 |
| Portable audio | 4 | 150 | 10 |
| DVD-player | 4 | 115 | 15 |
| Calculator | 5 | 260 | 50 |

## IV. SOURCES OF E-WASTE

In India the main source of e-waste is Ahmedabad, Mumbai, Chennai, New Delhi, etc. The other sources of e-waste from world is Australia, china, South Korea, Pakistan, Europe, Singapore etc.

Major sources includes Individuals and Small Productions. Here, the useful period of a computer has come down to about two years due to enhanced versions being launched about every year. Often, new software is mismatched with older hardware so that customers are enforced to buy new computers. Large corporations, Institutions and Government employee upgrade their computers regularly. The other major source is Equipment Manufacturers (EMs), they generate e-waste when units coming off the production line and do not meet superiority criteria, and so must be disposed off. Some of the computer manufacturers deal with recycling companies to handle their electronic waste, which are often e-waste distributor.

Apart from computers, the other major sources of e-waste is the cellular phone, ovens, switchboards, air-conditioner, refrigerators, batteries, TV etc.

Figure 1 Shows that import of e-waste and generation of electrical and electronic equipments in various country.

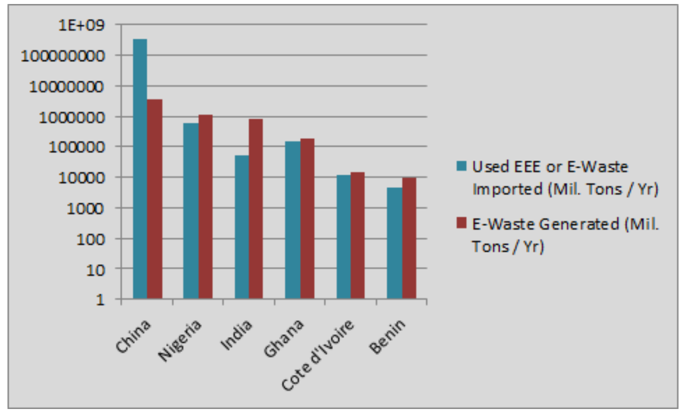


Figure 1: E-waste generated and imported by different countries.

## V. PRE-PROCESSING OF E-WASTE

**E-waste processing:** E-waste recycling comprises of three main steps are collection, dismantling and end processing. E-waste collection is very important because without it the recycle chain is not possible and also quantity of waste is affected to recycling chain. Then E-waste collection is simplified by appropriate government plans, actual advertisement for civic awareness also for fixing separate collection facilities of e-waste at public places. E-waste after collection, is dismantled and individual components are separated for further use. Here, harmful materials are separated as well disposed safely without creating any harmful effect on environment and valuable material like battery, capacitors, drives etc., are collected for Re-use. A basic flow sheet of pre-processing is shown in Figure 2. Mechanical processing is a combined part of this stage where e-waste scrap is shredded into parts by using hammer mills [7]. In the early stage, housing wiring boards as well drives and other components are liberated. Metals and non-metals are separated during this step using physical methods.

The last stage in the recovering process of e-waste is the end processing, where the separated metal fractions and non-metal of e-waste are further processed. Other non-metallic materials like plastic, synthetic polymer, glass fiber etc., are recycled based on chemical processes that are gasification, pyrolysis, magnetic separation, de-polymerization and hydrogenolytic degradation for generating chemical ingredients and fuels. From this non-metallic fractions the generating fuel can be used in pyro metallurgical method.

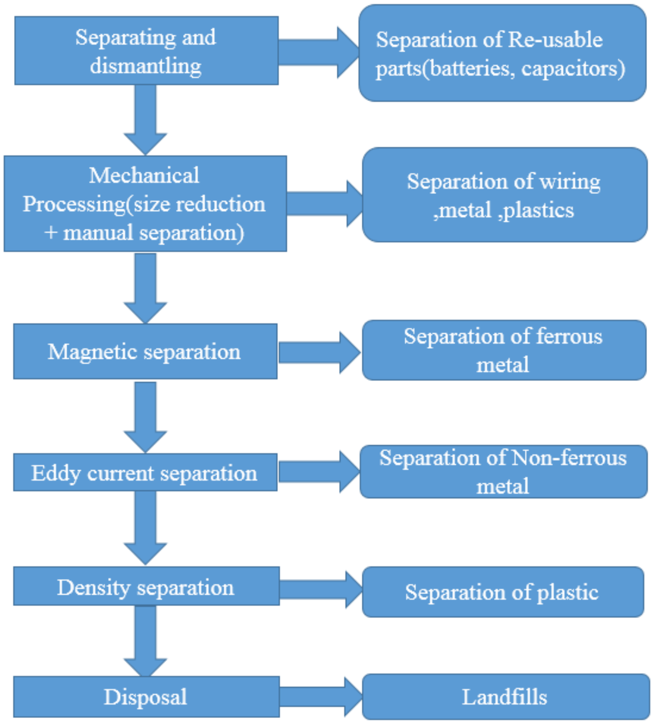


Figure 2. The pre-processing of e-waste to isolate metal and non-metal portions.

## VI. VARIOUS PROCEDURES FOR EXTRACTING PRECIOUS METALS

### 6.1. Hydrometallurgical Process

In hydrometallurgical processes, valuable metals present in e-waste are first leached into alkali or acid solutions as well as then concentrated by using various chemical methods.

Various researchers Quinet et al, Veit et al, Mecucci and Scott, park and fray and Sheng and Estell studied the extraction of precious metal copper, gold, silver and lead from e-waste via hydrometallurgical methods. Related steps of acid or caustic leaching are employed for selective termination of precious metal from e-waste. The leached solution is separated and purified for the improvement of metal content thereby impurities are removed as gangue. The separation of metal of concentration is directed over various chemical processes solvent extraction, adsorption on activated carbon and ion exchange procedures.

At the end, metals are recovered from solution through electro refining or chemical reduction processes [30–34]. It has been reported that hydrometallurgical processes have more benefited compared to other processes because they are more exactable, predictable, and easily controllable. Solvents especially halides, cyanides, thio urea and thiosulfates are used for the leaching of precious metal. Leachants especially aqua regia, nitric acid, sulfuric acid and cyanide solutions are used for this method.

Table 4: Recovery of precious metals from e-waste done by few investigators. [23]

| **Researcher** | **Leaching agent** | **Process environment** | **Recovered metals** |
|---|---|---|---|
| Quinet et al [50] | $H_2SO_4$, chloride, thio urea and cyanide filtering | Leaching & metals recovery by cementation, precipitation, ion exchange as well carbon adsorption | Au, Ag, Pd and Cu |
| Park and Fray [55] | Aqua regia | Ratio of leachant to metal = 20:1 g/mL | Au, Ag and Pd |
| Sheng and Estell [49] | $HNO_3$ (1st stage), epoxy resin (2nd stage), and aqua regia (3rd stage) | Extraction can be done in the three steps (self-agitation) | Au |
| Chielewski et al[51] | $HNO_3$ and aqua regia | Roasting can be done in presence of carbon; leaching with HNO3 and aqua regia; and solvent extraction with diethyle malonate | Au |
| Zhou et al. [52] | HCl, $H_2SO_4$and $NaClO_3$ | Combustion of e-waste at high temp. and followed by leaching | Ag, Au and Pd |
| Kogan [53] | HCl, $MgCl_2$, $H_2SO_4$ and $H_2O_2$ | Dissolution of e-waste in different solvents and then leaching and recovery of metals in stages. | Al, Sn, Pb and Zn (1st stage), Cu and Ni (2nd stage), Au, Ag, Pd and Pt (last stage) |
| Veit et al. [30] | Aqua regia and $H_2SO_4$ | Mechanical processing and then dissolution of e-waste in different solvents | Cu |
| Mecucci and Scott [54] | $HNO_3$ | Electrochemical deposition of Cu at cathode from solution | Pb and Cu |

This method is considered to be more flexible, eco-friendly, energy saving and gives more revenue generating then other methods.

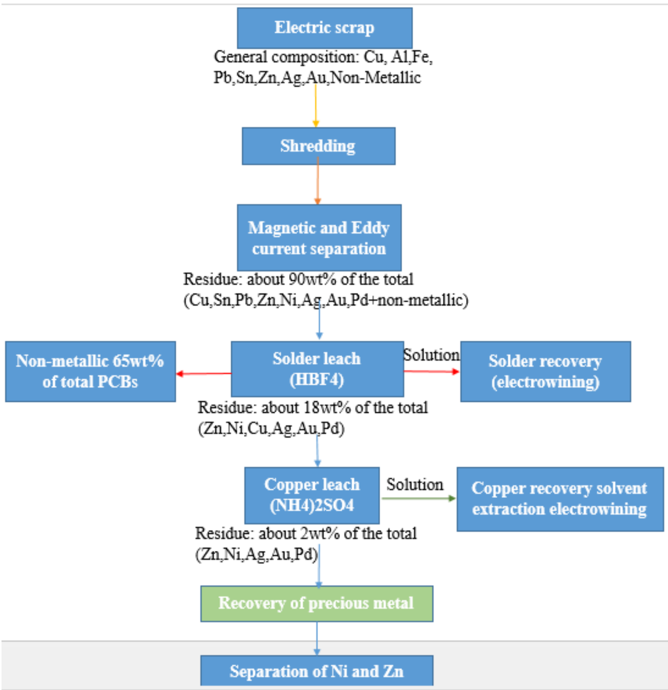


Figure 2: Example of hydrometallurgical reprocessing of PCBs for the recovery of precious metal. [23]

Hydrometallurgical routes have been successfully used to recover precious metal as of e-waste. Though, these processes are associated with certain disadvantages that boundary of their application on the industrial scale. Some common restrictions of hydrometallurgical methods for recovering Precious metal from e-waste are described.

Overall, hydrometallurgical routes are slow and time overriding and impact on recycling economy. Cyanide is a dangerous and hazardous leachant and should therefore be used with high well-being principles. It can effect contamination of rivers and seawater, especially near gold mines, which poses serious health risks to the inhabitants. Halide leaching is difficult due to oxidizing circumstances and strong corrosive acids. For halide leaching specialized apparatus made from non-corrosive material is required for leaching from e-waste.

### 6.2. Pyro Metallurgical Process

In the pyro metallurgical procedure, e-waste is dissolved with some flux constituents as slag formatives. The melted material involving significant metals contacts with a condensed metal into which the important metals dissolvable and amass. Typically utilized liquid metals comprise of iron, copper, nickel, lead-copper and some time ago, the take out profitable metals might be further treated keeping in mind the end goal to isolated and virtue of them. Pyro metallurgical procedures work with the progressions of freedom, division/overhauling and refining that are fundamentally identified with those of mechanical or hydrometallurgical strategies. However, the freedom of important metals is not accomplished by filtering, pounding or pulverizing but rather by throwing in heaters at high temperatures. In these procedures, metals are sorted by controlling their concoction and metallurgical belonging, e.g. valuable metal are isolated into a dissolvable metal stage.

The metal fractions separated throughout the preprocessing of e-waste are collected of Fe, Al, Cu, Pb and PMs. After Al and Fe, Pb and Cu are the main ingredients of a typical e-waste. Formerly, copper and lead smelters effort as e-waste recyclers for the recovery of Pb, Cu and precious metal. In these pyro metallurgical processes, copper/lead scrap is fed to the furnace, whereby metals are collected in a liquefied bath and oxides form a slag phase. More facts about the lead and copper smelting methods are clarified in the next segments.

There are two processes routes are available for pyro metallurgical process:

(1) Lead smelting Method

(2) Copper smelting Method

**(1) Lead Smelting Method**:

Primary lead is made from sulphide ores comprising iron, zinc, copper, precious metal and other trace elements. The process consists of sintering, reduction and refining segments. The plastics fraction of e-waste can some extent replace coke as a reducing agent during the reduction step, and the metals segment ends up in the metal phase. The lead junk is processed by adding wood chips, sulphur and fine coke. The heating of lead junk in the reverberator furnace splits the lead bullion (rich in lead), matte and spies.

In the last step of e-waste processing by the lead smelting method, precious metals and other components are separated from the lead bullion. Precious metal are separated through the Parks process, in which zinc forms an insoluble intermetallic compound with silver and gold. Other impurities including antimony, tin, arsenic, bismuth, and trance elements are also separated in the refining stage. Ending products of refining stage include lead, precious metal and other components.

**(2) Copper Smelting Method:**

Primary and secondary copper smelting method are implemented to recover and extract precious metal from e-waste. It is indicated that copper smelting method are more eco-friendly compared to lead smelters that create toxic fumes [18]. Copper smelting amenities near inhabitants will minimize the cost of e-waste conveyance and therefore the recycling economy will be enhanced. In these processes, precious metal are separated and recovered via electro refining process [19]. Generally, copper smelting method including matte and black copper for e-waste recycling. In the sulfur-based method, copper matte (40%) and blister copper (98.5%) are formed. Finally, blister copper is refined through fire refining to produce pure copper. The black copper is an attractive method because it can receive high levels of impurities including Fe, Son, Zn and Pub. These impurities are removed via oxidation as shown in Figure 3. Impurities are mostly isolated into the vapor phase and are discharged in the off gas.

Some reaction of recovery of copper and zinc are as under:

$$Fe + Cu2O \longrightarrow FeO + 2Cu$$

$$2ZnO + C \longrightarrow 2Zn\,(g) + CO_2$$

The product of the blast furnace, called black Copper, contains 70–85 wt.% Copper. It is fed into the converter to be oxidized.. Impurities (Sn, Pb, Zn) are burned out and Fe is removed as slag. Blister Copper is obtained with purity of 95 wt. %. It is fed in an anode furnace, where by adding a reducing agent, molten Cu is reduced. Less noble metals than Copper are oxidized. The reduction reaction in the anode furnace is:

$$2CuO + C \longrightarrow 2Cu + CO_2$$

Obtained material contains approximately 98.5 % Cu. It is further purified (to 99.99 wt. % Cu) by cathodic deposition after dissolving it in $H_2SO_4$ electrolyte.

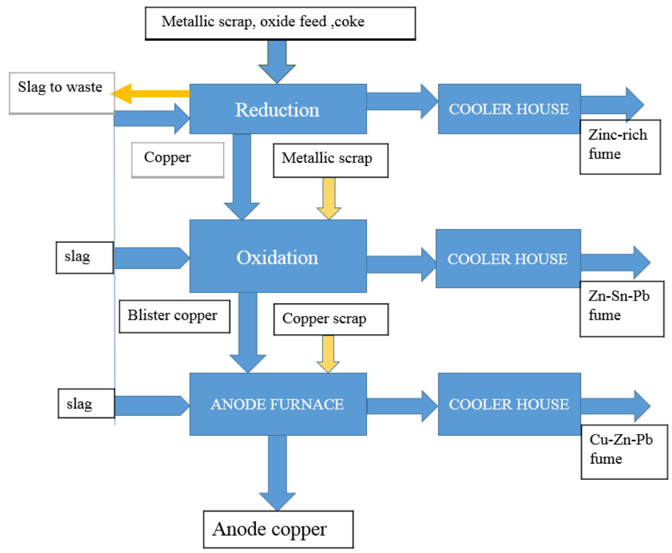


Figure 3. Basic flow sheet of black copper smelter process (secondary copper smelting).

Pyro metallurgical process are generally more economical and maximize the retrieval of precious metal, still, they have certain disadvantage that are summarized here:

In Pyro metallurgical process, recycling of plastics is not possible because plastics needs coke as a source of energy. Also Iron and aluminium recovery is not easy in this process. Some components in feed material can increase the volume of slag generated in the furnaces, which causes the losing precious metal from base metal. Then recovery and purity of precious metal, it is necessary to use other methods to get pure metal.

Overall, this process releases harmful gases such as dioxins are generated during smelting process. Therefore, special installations are mandatory to minimize environmental pollution.For this method huge investment is prerequisite for installing e-waste recycling plants that maximize the separation of valuable metals and also save environment by controlling hazardous gas emissions.

**6 3. BIO LEACHING:**

This technique includes bacterial draining of metals for recovery of valuable metals and copper from mineral for a long time yet at the same time the procedure is not all around created. It utilizes a normal for microorganisms to change over metals existing in the strong structure to a solvent structure.

Each sort of microorganism has a trademark inclination to tie with a specific metal in a specific situation and microbes and organisms can be developed within the sight of electronic scrap. Aside from the possibility of bioleaching of metals in basic environment, the acidic environment likewise assumes a critical part in the bio-draining strategy.

Amongst real gathering of microscopic organisms, the most as often as possible utilized are: acidophilus and chemolithotrophic microbial gatherings of Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, Leptospirillum ferrooxidans and heterotrophs, for instance Sulfolobus sp. Likewise of parasites, for example, Penicillium sp. furthermore, Aspergillus Niger are case of a few microorganisms utilized as a part of bioleaching over metal recuperation from E-squanders.

**Points of interest**

Bioleaching is less expensive and simple as contrast with different techniques and it is adaptable (creates less measure of waste and high income) and eco-accommodating. Bio-draining is viewed as a green innovation and it gives appealing choices over physical and substance strategies.

**Burdens**

In bioleaching the rate at which the microscopic organisms can break down metal in an answer is essentially moderate procedure and it requires the material being drained to be in little parts

Table 5. Modern E-waste treated with microscopic organisms filtering [22, 26-29].

| Waste Material | Filtered metal | Used microorganisms |
|---|---|---|
| Electronic scrap | Ni, Al, Zn, Cu | Acidithiobacillus thiooxidans+ Acidithiobacillus ferrooxidans |
| Lithium batteries | Co ,Li | Acidithiobacillus ferrooxidans |
| Used cracking catalysts, hydro-processing catalysts | Al, Ni, Mo, V, Sb | Aspergillus Niger, Acidithiobacillus thiooxidans |
| Slag from copper production | Zn, Fe, Cu, Ni | Acidithiobacillus spp., Leptospirillum spp. |

**6.4 Pyrolysis Method**

Pyrolysis is a compound method, broadly utilized for reusing manufactured polymers including polymers that are blended with fiber, plastic and so forth. Pyrolysis of such polymers gives gasses, oils and burns that can be further utilized as synthetic feedstock or energizes [36].

The printed circuits are warmed to a high Temperature to dissolve down the patch, within the sight of oxygen. After pyrolysis blackish metal substance is left, that on filtering gives great yield of copper. Additionally, by this technique little amount of iron, nickel, zinc and aluminum could likewise be recuperated.

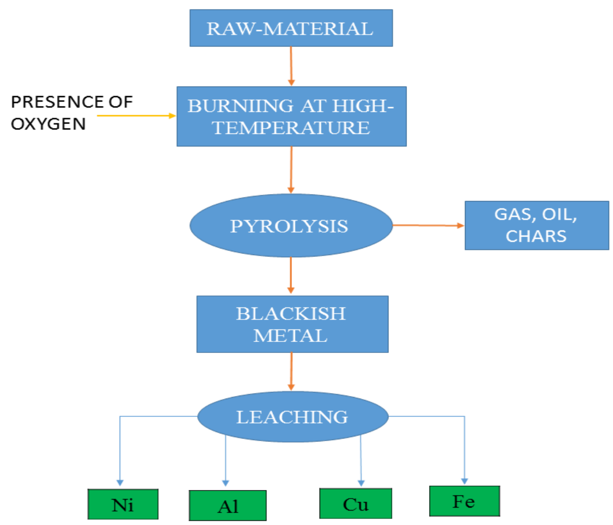


Figure 4: Shows the schematic flow diagram of pyrolysis method.

**6.5 Mechanical recycling**

Mechanical recycling is a physical recycling method. In this method, the disassembled samples are first cut into small Sizes depending upon the need of crusher. Then the pieces are put through a grinding process resulting into fine pulverized powder. This powder is subjected to eddy current separators that separates the metal by their eddy current characteristics [37]. Finally the pulverized samples are subjected to density separation process [38] and metals are separated. Mechanical processing of e-waste takes longer time to reduce particle size for efficient dissolution in solvent. It is proved that 20% precious metal is lost by mechanical force through the liberation process that subsidizes to a significant loss in the overall economy and revenue.

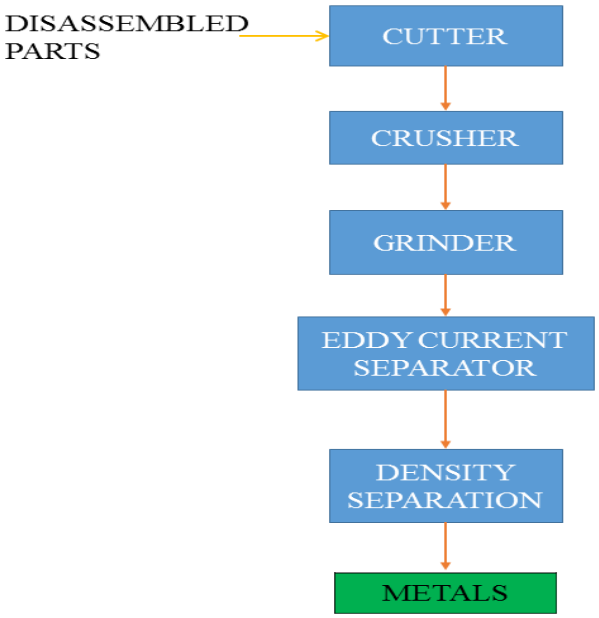


Figure 5. Shows the flow diagram of Mechanical recycling method.

### 6.6 Air classification method

In this technique, the division of scattered strong particles happens on the premise of the molecule sizes and their thickness. The standard of division depends on the way that the particles suspended in the gas, for the most part air, move to various areas affected by various powers. Henceforth they get isolated from each other. PCB particles experience drag and gravity power in inverse bearings [39]. Overwhelming particles have terminal settling speed bigger than the speed of air while lighter particles have terminal settling speed littler than the speed of air. Subsequently substantial particles move downwards against the air stream, while the light particles ascend alongside the air stream to the highest point of the section [39].

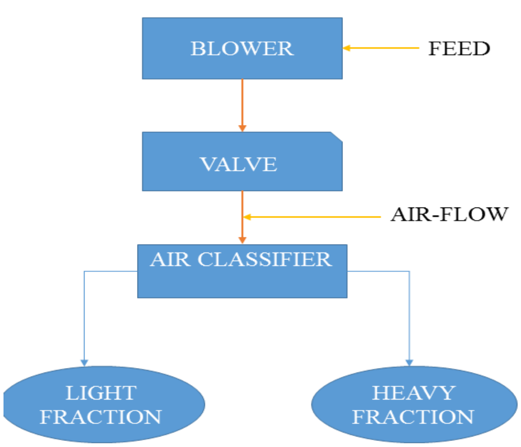


Figure 6. Shows the schematic drawing of an air classification set up

### 6.7 Recycling of metals from waste PCB by electrostatic separation method

In electrostatic separation technologies, electric force acting on charged or polarized bodies is used for the separation of granular materials [40]. These technologies have been applied for recycling of metals and plastics from industrial wastes [41]. Electrostatic separation technologies can be used to recycle Cu, Al, Pb, Sn and iron, certain amount of noble metals and plastic from scrapped printed circuit board (PCB) [42].

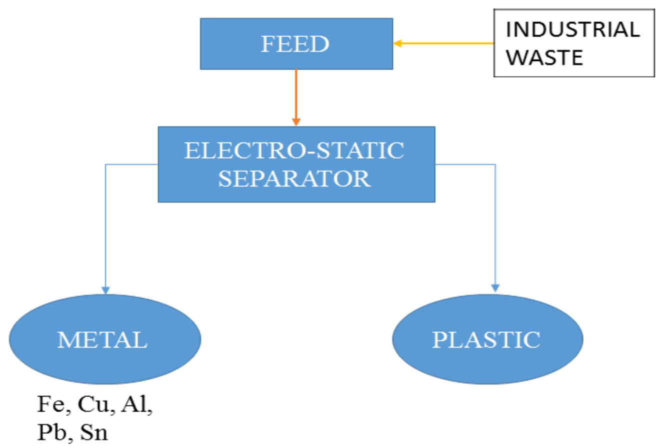


Figure 7. Shows the schematic diagram of electrostatic separation method.

### 6.8 Magnetic separation method

Magnetic separators with low intensity drum separators are widely used for the recovery of ferromagnetic metals from non-ferrous metals and other non-magnetic wastes [43]. The disadvantage of magnetic separation is agglomeration of the particles. This agglomeration causes the magnet to also pull the non-metal materials which agglomerate with the ferrous materials [35].Hence efficiency of separation lacks. Most of the processes mentioned above are for the recovery of precious metals from waste PCB and reuse it for commercial purposes. After metal recovery, remaining is the non-metallic fractions that usually end up in a landfill [46-48]. Hence there is a strong need for new methods that can make use of these redundant nonmetallic fractions from PCB waste. In the next section we will discuss methods for reuse of non-metallic fraction from waste PCBs.

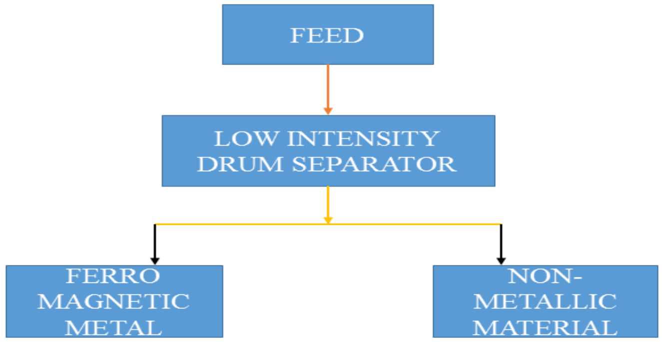


Figure 8. Shows the schematic drawing of magnetic separation method.

**6.10 Recycling of non-metallic fractions by gasification process** Gasification process mainly involves the generation of synthesis gas (CO, H2) and it performed at a high temperature of 1600o C and about 150 bar pressure. The hydrogen rich gas stream is the most important product and it used for the feed of methanol synthesis. After that, remaining fractions of this gas can be used for generation of heat and electricity [44]. Yamawaki studied gasification recycling of plastic, containing brominated flame retardants, from non-metallic fractions in waste PCBs [45]. He developed a gasification model by which gasification can be achieved at a low decomposition rate, of brominated flame retardants (BFRs), including polybrominated biphenyls (PBB) and Polybrominateddiphenyl ethers (PBDEs), which on combustion gives toxic gases, the dibenzodioxins and polybrominateddibenzofurans and dioxins and furans. Hence due to the low decomposition rate of BFRs, the toxicity level drops to a large extent [44]

## VII.SUMMARY

The recycling and reuse of e-waste is important for save natural resources and waste management. Traditional methods of managing e-waste consist of disposing in landfills, burning in incinerators or exporting to other countries, all of which are not permitted anymore yet. The presence of PMs in e-waste makes reprocessing an attractive and viable option both in terms of environment and revenue. Industrially, hydrometallurgical, pyro metallurgical or a combination of both routes and Bio leaching is used for recovering PMs from e-waste. Essentially, hydrometallurgical routes are alike to those used in the mineral industry, which include leaching and metal extractions from leachates. Pyro metallurgical routes are economical, eco-efficient and eco-friendly for the recovery of PMs. However, dangerous emissions should be controlled to diminish environmental pollution. Both processes have some advantages and disadvantages, which therefore should be careful for a specific feed materials and desired final product. It must be notedthat the recycling of e-waste in India is limited due to the challenges including insufficient collection facilities, lack of integrated, higher transportation cost and automatic smelting and refining facilities.

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