Taiz University Research Journal, Volume 34 jan2023 ISSN: 2985-7848
Taiz University
2nd ICTSA -2022 Proceedings
Dec, 2022, Taiz University, Taiz, Republic of Yemen.19 -17

THE TREASURES OF PRINTED CIRCUIT BOARDS IN CELL PHONE SCRAP AND THE DANGERS OF CONCERN

Fekri Mohammed Mohammed Noaman [1], Mohammed Suleiman Ali Eltoum[2]

[1]155Street 6,block 6,Salmiya,Kuwait , [2] Chemistry Department, College of Sciences and Technology, Khartoum, Sudan

Email address:

fekrinoaman@gmail.com, abotrteel74@ gmail.com.

Abstract

Telephones play a greater role than ever in global use and the modern telephone industry depends on a variety of resources consisting largely of precious and rare metals, and it is true that some of these mineral sources are common and still available, such as iron ore and aluminum, but others such as Cobalt and indium, these are rare elements and will not last long at current rates of consumption. The problem with the foregoing is that the extractive industries extract irreplaceable mineral resources from the earth's crust, where the use of mineral resources is closely related to technology, energy and the environment, and usually causes disturbances in one field and the presence of disturbances in the other, and the use of motivational devices from phones requires minerals Of the platinum group, which is a valuable and irreplaceable natural resource, moreover, the short lifespan of mobile phones leads to an increase in electronic waste from phones, and because the recycling systems are very low, it follows that scrap waste from phones goes to public waste streams and thus The precious metals contained in that electronic scrap are lost, and this is first, and secondly, this waste has become a cause for concern because of the elements and components it contains that cause environmental pollution and various health diseases. In this study, the components of phones and vehicles were reviewed and how to recycle printed circuit boards. Which are found in mobile phone scrap.

Keywords: mobile phones, discarded printed circuit boards, recycling

Taiz University Research Journal, Volume 34 jan2023 ISSN: 2985-7848
Taiz University
2nd ICTSA -2022 Proceedings
Dec, 2022, Taiz University, Taiz, Republic of Yemen.19 -17

1- Introduction

When the world population reached 7.5 billion people in April 2017, the number of mobile phones reached 4.77 billion by the end of the year [1]. And over the past years, smartphones have rapidly replaced the traditional mobile phone many times. Many studies are concerned with mobile phone waste because it contains many minerals, including many important minerals, even if most of them are in very small absolute quantities [2]. Among the elements of the periodic table the cell phone contains more than 40 elements, and some exaggerate to say that there are 69 elements, basic metals, for example, copper (Cu) and tin (Sn); Unique metals, such as lithium (Li), cobalt (Co), indium (In), and antimony (Sb); and precious metals, such as silver (Ag), gold (Au), and lead (Pd). Most metals can be extracted very successfully, for example, gold (Au), lead (Pd), cobalt, copper and other metals from waste electronic phones unlike metal mining. The metal groups of the periodic table metals have been identified as being related to smart phones through the global interest in the recycling of waste cellular phones [3], and these metals are represented by cobalt, gallium, indium, niobium, tantalum, tungsten, platinum group metals and rare earths, in addition to Base metals like copper, nickel, lead, bismuth, lithium, and of course important precious metals like silver and gold to this list. Among the important metals, rare earth elements can be attached to permanent magnets, cobalt to a battery, indium to an LCD screen and tantalum, gallium, and precious metals to assembled printed circuit boards . And quantitative data for the quantities of important metals in smartphones could not be determined, despite a thorough investigation. However, it should be noted that the future demand for gallium for increasingly powerful processors (GaAs or GaN) for smartphones[4] . Therefore, typical numbers of mobile phones are used as the basis for some important precious metals. However, recycling experts assume that the relative quantities in smartphones will tend to be higher [5], that is, the data following the content of precious metals should be viewed as conservative. With the high value of precious metals and relatively high quantities, it is an important driving force for mobile phone recycling and thus also for smartphone recycling in the future.

Just as phone scrap contains precious and rare metals and carries a side of good and benefit to humans, it also carries evil, as electronic phone waste contains Polybrominated Diphenyl Ethers (PBDEs) (usually fire retardants) mixed with plastic and various elements. Circuit boards in phones and most electrical and electronic devices may contain arsenic (As), cadmium (Cd), chromium (Cr), lead, mercury (Hg) and additional toxic elements.

1-1-What is a mobile phone?

A mobile phone (sometimes called a cell phone or cell phone) is a small, high-tech personal radio transmitting and receiving device. It sends and receives radio signals that carry voice in personal communications with other mobile phones and landline phones. Mobile phones not only serve as a means of personal luxury or in addition to traditional line phones, but they are considered an essential means of communication in many regions of the world where there is no infrastructure for wired communications.

1-2-Components of a mobile phone:

It is useful to know, at least in general terms, how a mobile phone is made and what its contents are. Mobile phones are similar in their components with other electronic devices in that they are made of plastics, metals, ceramics and glass. It also consists of the following physical parts as shown below:

1-	Back Cover	5-	Micro Processor
2-	Power IC	6-	Earpiece
3-	Battery	7-	LCD Display(screen)
4-	Circuit board	8-	Keypad

Figure (2): Physical components of a cell phone

Handspeaker set includes housing (usually plastic); Bumpy, monochromatic or color display with cover glass; keyboard; and antenna.

---

[1] Statistica. (2017). Number of mobile phone users worldwide from 2013 to 2019 (in billions). Retrieved November 6, 2017, from https://www.statista.com/statistics/274774 / forecast-of-mobile-phone-users-worldwide.

[2] Buchert, M.; Schüler, D.; Bleher, D.: Critical Metals for Future Sustainable Technologies and Their Recycling Potential, Öko-Institut e.V. (UNEP edits.) July 2009.

[3] Talens Peiró, L. et al.: Results from the workshop: Preliminary sustainability assessment: multifunctional mobile phone; prosuite project, Brussels 3 February 2011.

[4] Achzet, B. (Universität Augsburg): Substitution kritischer Technologiemetalle, Eurogress Aachen – Hochtechnologiemetalle: Motor für Innovationen, Aachen 4. – 5. Mai 2011. [University of Augsburg: Substitution of critical technological metals, Eurogress, Aachen – Advanced technology metals: drivers for innovation, Aachen 4-5 May 2011.]

[5] Umicore: Informationen zur Materialzusammensetzung verschiedener WEEE-Fraktionen [Information on the material composition of different WEEE fractions]. Daten der Firma Umicore [Data supplied by Umicore]. Hoboken, 2011.

Taiz University Research Journal, Volume 34 jan2023 ISSN: 2985-7848
Taiz University
2nd ICTSA -2022 Proceedings
Dec, 2022, Taiz University, Taiz, Republic of Yemen.19 -17

periods→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Groups ↓																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
Lanthanides			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
Actinides			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Figure (1): The periodic table and mobile phone components of the elements and compounds

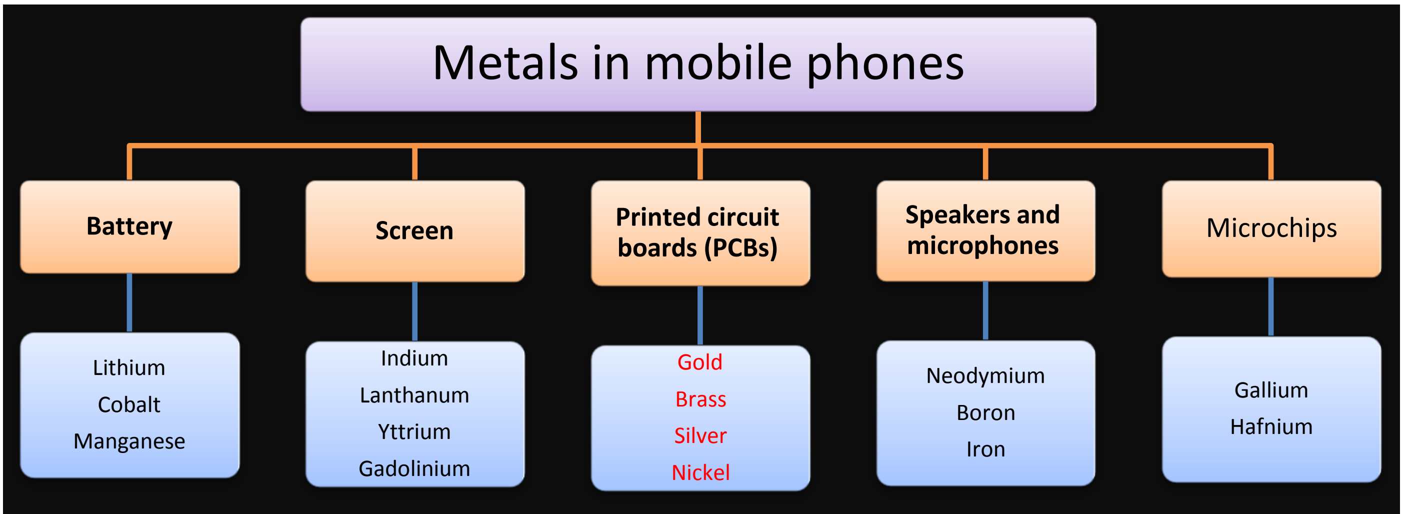


Figure (3): The most important elements in the physical components of cellular phones

None of these parts differ significantly from other electronic devices such as personal computers or portable consumer electronics in terms of components or the way they are made except that they are very small. Mobile phones may differ from one manufacturer to another and from one model to another. Some studies suggest that mobile phones can contain metals, including 16 of 17 rare earth metals. The most commonly used materials in a smartphone are silicon (25%), plastic (23%), iron (20%), aluminum (14%), lead (6.3%), zinc (2.2%), tin (1%), nickel 0.85%) and barium.

(0.03%) [6] . However, many sources indicate and confirm that mobile phones generally consist of 18 chemical elements and other materials that cannot be recovered, such

[6] Statista, 'Most used materials in a smartphones | Statistics', Statista, 2017. [Online]. Available: https://www.statista.com/statistics/270454/top-10-materials-in-a-smartphone/. [Accessed: 13-Nov-2017].

as porcelain, folds, plastic parts, and glue. The eighteen elements that make up mobile phones are classified into metals, precious metals, rare earth elements and other materials. There were 11 elements in the metal category, among which copper had the highest percentage (9.94%), followed by steel (9.74%), cobalt (5%), aluminum (2.35%), nickel (1.6%), zinc (0.4%) and lithium (0.35). %) were present at lower levels. Precious metals such as gold (0.02%), palladium (0.008%) and silver (0.24%), are mainly found in PCB printed circuit boards. These elements are of great commercial importance if they are properly recovered, and there are also some rare earth elements, Such as neodymium (0.04%) and praseodymium (0.0079%), act as magnets in mobile phones. Finally, plastic has the highest representation in mobile phones (42.03%). Accordingly, the materials in any mobile phone are somewhat different from the materials in another model. It is worth noting that phone batteries contain cobalt Co as the most important element that has now become important in the manufacture of lithium-ion batteries[7]. Batteries also contain Li, La, Be, Ce, Sb, In, Ga, Cu, Al and Fe, and the conductive materials in them contain many materials and fire retardants. . Also, LCD phone screens contain the most important element in the periodic table, which is indium, which is rare in nature, in addition to Si flakes. The following table lists substances in three categories: primary components, minor components, and very few or trace components. (Since not all materials are used in every mobile phone, for example, nickel-metal-hydride batteries or lithium-ion batteries can be used, so the sum of the numbers in the table does not equal 100 percent). A more detailed list of materials used in mobile phones is given in the following table. More generally, a mobile phone is made of the following basic components:

Table (1): Mobile phone components

Subject Name	Its position on the mobile phone	Percentage of content in the mobile phone (including batteries and peripherals)
Basic Ingredients		(1 percent or more)
Plastics	Cover, printed circuit board	~40%
glass, porcelain	Indicator of liquid crystals, flakes	~20%
copper compounds	Printed circuit board, wires, connectors, batteries	~10%
nickel compounds	Nickel-cadmium or nickel-metal hydride batteries	~2-10% *
potassium hydroxide	Lithium ion batteries	<5% *
Cobalt	Lithium ion batteries	1-5% *
Carbon	batteries	<5%
Aluminum	Case, frame, batteries	~3% **
steel, iron	Case, Frame, Batteries, Charger	10%
Tin	printed circuit board	~1%
		* Only if these types of batteries are used, and if not used are minor components or very few.
		** If aluminum is used in the casing, this amount is much more about 20 percent
Minor components		(less than 1 percent but greater than 0.1 percent)
Bromine	printed circuit board	
Cadmium	Nickel Cadmium batteries	
Chrome	cover, frame	
Lead	printed circuit board	
liquid crystal polymer	LCD screen	
Lithium	Lithium and iron batteries	
Manganese	printed circuit board	
Silver	printed circuit board, keyboard	
Tantalum	printed circuit board	
Titanium	cover, frame	
Tungsten	printed circuit board	
Zinc	for printed circuit unit	
Very little or no ingredients		(less than 0.1 percent)
Attenimate	cover; circuit boards	
Arsenic	Light-emitting duo	
Barium	printed circuit board	
Beryllium	conductors	
Sismouth	printed circuit board	
Calcium	printed circuit board	
Fluorine	Lithium ion batteries	
Gallium	light source duo	
Gold	Connectors, printed circuit board	
Magnesium	printed circuit board	If magnesium is used in the phone case, the amount will increase a lot, reaching about, ~20%
Palladium	printed circuit board	
Ruthenium	printed circuit board	
Strontium	printed circuit board	
Sulfur	printed circuit board	
Yttrium	printed circuit board	
Zirconium	printed circuit board	

[7] Purchase, D., Abbasi, G., Bisschop, L., Chatterjee, D., Ekberg, C., Ermolin, M., Wong, M.H., 2020. Global occurrence, chemical properties, and ecological impacts of E-wastes (IUPAC Technical Report). Pure Appl. Chem. 92 (11), 1733–1767.

2- Substances of concern and challenges to recycling

To prevent exposure of workers and the general public to materials of concern during material recovery and recycling operations, which include the generation of dust and fumes Shredding and during handling and processing of smelter slag. Vapors can be generated during metal sampling and smelting processes as well as during certain steps in the plastics recovery and recycling process such as granulation. There is worrying exposure to a number of substances: beryllium in dust and fumes, and dioxins and furans generated by burning plastics.

E-waste is an important part of solid waste management worldwide. Being a large part of solid waste, e-waste contains many hazardous components in the form of halogenated compounds like polychlorinated biphenyls (PCBs), tetra-mobiphenol A (TBBPA), polybrominated biphenyls (PBB), etc. along with toxic substances. Others that have a detrimental effect on plants, microbes and humans. One of the main toxic components of e-waste are heavy metals (HMs) such as As, Cr, Cd, Cu and Hg, which must be carefully handled at the time of e-waste dismantling, which are managed by the informal sector in developing countries and exacerbate the problem, and technologies The disposal/treatment available for e-waste is insufficient, and it has a direct and indirect impact on human health and the environment. It is expected that the quantities of electronic waste will rise in the future, and it is not possible to continue the joint disposal of electronic waste with municipal waste [[8]] .Electronic waste contains many recyclable materials such as ferrous metals, aluminum, copper and precious metals, in addition to various engineering plastics. These are usually heavily combined with each other. This means that recycling electronic products is more technologically complex than, say, recycling glass or paper. More importantly, the disposal of e-waste causes the loss of these valuable and non-renewable resources as electronic products contain a wide range of valuable materials, many of which are becoming scarce in nature. The biggest obstacle to recycling is the lack of consumer awareness of the possibilities of collection and recycling, which leads to lower collection quantities. Without returning products for recycling, technical recycling operations cannot take place. For this there must be natural technical processes for separating and purifying recycled materials as well as good data systems that support decision-making processes[[9]][[10]]

An interesting fact is that electronic products are disposed of even before the end of their life span. A large portion of these electronic products end up in landfills or are incinerated in the waste-to-energy process. Countries such as India, China and Africa are more vulnerable as most electrical and electronic equipment is dumped by developed countries, and here it is managed in unsafe ways (such as improper safety precautions, landfill disposal, combustion without concern for water and air quality pollution). This problem is faced by both developed and developing countries. However, in the case of developing countries, this is due to the lack of sufficient political/governmental intervention and monetary support for the construction of high-tech landfills. Many underdeveloped countries like Nigeria for example suffer from a shortage of basic recycling infrastructure units for e-waste management which ultimately depend on informal sectors resorting to techniques of crude oil dismantling and backyard recycling, and copper recovery through burning wires in the air Opening and disposal of e-waste in landfills. These activities expose humans to harmful chemicals [[11]]. Moreover, the main concern regarding e-waste management is its recycling, recovery and disposal[[12]]. A small amount of this waste (about 20% 30%) is recycled worldwide during the recovery of precious metals, such as gold (Au), silver (Ag), platinum (Pt), and copper (Cu) to some extent but not It is extremely safe and takes a heavy toll on human health. Also, e-waste disposal facilities are not well documented and not researched yet, and most e-waste is disposed of in landfill or incinerated at high temperatures, however, both methods are not environmentally safe. Some common pre-treatment practices, i.e., component removal, manual disassembly, crushing, size reduction, etc., may cause significant contamination at the local level [[13]].

Here are the potential exposures to substances of concern when managing expired mobile phones and they are as follows:

2-1- Ground disposal and its toxic effects

1 - The ground disposal of mobile phones may make these phones come into contact with the disposed acids in the same place, and with the passage of long periods of time, the materials that are absorbed by these acids may turn into precipitates. An example of the material that precipitates from mobile phones is lead. There are several studies that show that printed circuit boards deposit lead in landfill conditions simulated by the US Environmental Protection Agency's (TCLP) toxicological deposition procedure.

2- Mobile phones can be disposed of in the public waste stream and end up in landfills, causing negative impacts on the environment and loss of valuable electronic resources. However, although there is no detailed assessment globally, but at the level of the European Union, it is likely that the amount of devices disposed of in general waste is small. According to a German survey, only 2% of consumers who disposed of an appliance have disposed of it as public waste[[14]]. In France, 4.7% of respondents reported that they threw their old devices in the trash [[15]]. However, these figures should be taken with caution as they may not represent general behavior among all EU member states.

3 - If the landfill is not surrounded by barriers that are not exhausted, the materials can move into groundwater, and thus to lakes, streams or wells and increase the possibility of exposure to humans and other species. However, lead does not tend to migrate to soil but remains fixed in soil particles [[16]]. Accordingly, exposure to lead through drinking water

[8] Chancerel, P., Meskers, C.E., Hagelüken, C., Potter, V.S., 2009. Assessment of precious metal flows during preprocessing of waste electrical and electronic equipment. J. Ind. Ecol. 13 (5), 791–810.

[9] ICMM, (2006), Maximizing Value- Guidance on implementing materials stewardship in the minerals and metals value chain, ICMM International Council on Mining & Minerals.

[10] Pia Tanskanen, Electronics Waste: Recycling of Mobile Phones , Nokia Corporation.

[11] Kiddee, P., Pradhan, J.K., Mandal, S., Biswas, J.K., Sarkar, B., 2020. An overview of treatment technologies of E-waste. In: Handbook of Electronic Waste Management. pp. 1–18.

[12] Nnorom, I.C., Odeyingbo, O.A., 2020. Electronic waste management practices in Nigeria. In: Handbook of Electronic Waste Management. Butterworth-Heinemann, pp. 323–354

[13] Khanna, R., Saini, R., Park, M., Ellamparuthy, G., Biswal, S.K., Mukherjee, P.S., 2020b. Factors influencing the release of potentially toxic elements (PTEs) during thermal processing of electronic waste. Waste Manage. 105, 414–424.

[14] Bitkom (2018), "124 Millionen Alt-Handys liegen ungenutzt herum" (https://www.bitkom.org/Presse/Presseinformation/124-Millionen-Alt-Handys-liegenungenutzt-herum.html).

[15] Kreziak D., I. Prim-Allaz and E. Robinot (2017) "Des tiroirs pleins de telephones remplaces: consommateurs et objets a obsolescence percue", ADEME, COOP project research report Consommateurs et Objets a Obsolescence Programmee.

[16] US EPA, National Primary Drinking Water Regulations, Consumer Fact Sheet on Lead.

as a result of sedimentation and transfer to groundwater represents a minimal risk.
4 - The greatest danger from ground disposal is the transfer of hazardous materials into the food chain and from direct ingestion of pollutants, dust and contaminated water from uncontrolled landfills. Some cemeteries, especially in poor areas, are visited by residents, especially young children, in search of valuable materials. The route of exposure is mostly through ingestion, either directly through drinking water or through food absorbed by the body that has been contaminated prior to absorption with substances of concern.

2-2- Toxic effects on the air and burning phone waste

Toxic substances such as lead (Pb), chromium (Cr), beryllium (Be), palladium (Pd), gallium (Ga) etc. pollute our food chain by mixing in air, water and soil [17][18] , when ingested, they cause many effects harmful health to the human body. Burning mobile phones may oxidize the plastics in the casing and in the printed circuit. Depending on the conditions, the oxidation of the plastics may not be complete and thus hydrocarbon particles and other types of soot may form. This happens if the waste incinerators are informal and not fully controlled, such as burning in metal barrels or burning in open spaces, processes that can occur in poor areas. For example, residents may burn printed circuits to concentrate metals in ash to sell for metal recovery and recycling. Some metals, including cadmium and lead, have a relatively low melting point and can melt during combustion with the formation of metal oxide fumes or fine particles that travel to the exhaust outlets of burners with emissions into the air. If these and other metals in mobile phones do not melt at the burning temperature, they remain in bottom ash. If this bottom ash is dumped across the land, it may raise concerns for exposure to hazardous materials as explained above. In addition, deposition from ash under ground disposal conditions may be much faster than deposition from solid mobile phones. Also, if incineration is not carried out at a sufficiently high temperature and continues for a sufficient time, the plastics and other hydrocarbon compounds and chemical pollutants such as phthalates, benzene esters, dioxins, polyaromatic hydrocarbons, and polyvinyl chlorides found in mobile phones may not oxidize completely. to carbon dioxide and water and may combine with halogens to form halogenated hydrocarbons, including dioxins and furans. Thus it is considered hazardous not only to humans directly but also to plants, soil and microbial species present in the vicinity [19] , and several recent studies have shown the effect of e-waste leachates on soil microorganisms (such as bacteria and fungi) as well as other organisms that Living in it, aquatic organisms, plants and humans[[20]][[21]][[22]].

2-3- Dioxins and furans

If waste incinerators are informal and not fully or even somewhat better controlled, the incineration of mobile phones releases substances of concern in the form of emissions into the air and other environmental media in post-management processes for fly ash and bottom ash .

2-4- High emissions of nitrogen oxides, sulfuric acid and chlorine

E-waste incineration contributes to high emissions of nitrogen oxides, sulfuric acid, chlorine and volatile organic compounds. Emissions of toxic and long-lived substances such as synthetic organic pollutants, heavy metal compounds and radioactive substances affect ecosystems. Hazardous materials are used and produced in the life cycle of a mobile phone. For example, in artisanal mining, mercury and cyanide are used to process gold from ore, and uranium and cadmium are by-products of cobalt mining and cobalt processing (resource extraction).

2-5-Danger to workers and communities

E-waste workers, both informal and industrial, and the communities that live near these facilities are at great risk of increased levels of toxicant concentrations in their blood. Many of these substances can lead to severe or long-term health problems. Several studies have been conducted on the effects of e-waste pollutants such as metals (cadmium, lead, chromium, protein, mercury) and organic pollutants (polycyclic aromatic hydrocarbons, polychlorinated biphenyls, etc.)[[23]][[24]] Moreover, HMs in liquid form can easily contaminate water bodies, soil, air and in the food chain through the primary product, affecting living organisms immediately and the following figure illustrates this. Since most minerals and chemicals are in their ionic state which can easily be absorbed and absorbed by plants and animals. For example, but not limited to cadmium: inhaling its vapor causes silicosis and pneumoconiosis, and eating it and its containers causes strong symptoms in the intestines that may lead to pneumonia, pulmonary edema, and then death.. Exposure to it causes cancer, high blood pressure, and a decrease in the effectiveness of certain enzymes. Cadmium poses an occupational hazard in industrial processes such as metal plating, dyes, plastics, and other synthetic compounds. The most important route of exposure to cadmium is inhalation. And in the e-waste stream, waste cell phones are becoming the fastest growing obsolete products. Brominated flame retardants and toxic metals are common toxic materials that are widely added to plastics used in electrical and electronic equipment[[25]].

[17] Akram, R., Fahad, S., Hashmi, M. ., Wahid, A., Adnan, M., Mubeen, M., Nasim, W., 2019. Trends of electronic waste pollution and its impact on the global environment and ecosystem. Environ. Sci. Pollut. Res. 26 (17), 16923–16938.
[18] Li, W. , Achal, V., 2020. Environmental and health impacts due to e-waste disposal in China—A review. Sci. Total. Environ. 737, 139745.
[19] Peng, H., Michael, S., Reid, X., Le, C., 2015. Consumption of rice and fish in an electronic waste recycling area contributes significantly to total daily intake of mercury. J. Environ. Sci. 38, 83–86..
[20] Jiang, L., Cheng, Z., Zhang, D., Song, M., Wang, Y., Luo, C., Zhang, G., 2017. The influence of e-waste recycling on the molecular ecological network of soil microbial communities in Pakistan and China. Environ. Pollut. 231, 173–181.
[21] Jiang, B., Adebayo, A., Jia, J., Xing, Y., Deng, S., Guo, L., Zhang, D., 2019. Impacts of heavy metals and soil properties at a Nigerian e-waste site on soil microbial community. J. Hazard. Mater. 362, 187–195.
[22] Wang, H., Zhang, S., Li, B., Pan, D.A., Wu, Y., Zuo, T., 2017. Recovery of waste printed circuit boards through pyrometallurgical processing: A review. Resour. Conserv. Recycl. 126, 209–218.
[23] Chaperon, S., Sauve, S., 2007. Toxicity interaction of metals (Ag, Cu, Hg, Zn) to urease and dehydrogenase activities in soils. Soil Biol. Biochem. 39, 2329–2338.
[24] Chaperon, S., Sauv, S., 2008. Toxicity in teractions of Cd, Cu, and lead on soil urease and dehydrogenase activity in relation to chemical partitioning. Ecotoxicol. Environ. Saf. 70, 1–9.
[25] Singh, N., Duan, H., Tang, Y., 2020. Toxicity evaluation of E-waste plastics and potential repercussions for human health. Environ. Int. 137, 105559.

Singh et al. In 2019, [26]they analyzed basic phones and smartphones between 2001 and 2015 for their toxicity trends based on 19 chemicals and found that the relative mass of toxic compounds increased over a 15-year time period. Electronic plastic waste is growing at an unprecedented rate globally, which is a serious concern.

Table (2): The most important substances of concern

M	Name of substance	Applications
1-	Lead	Typically used in tin-lead solders in the electronic circuitry of mobile phones.
2-	Cadmium	Used in nickel cadmium batteries of old-fashioned mobile phones. Small amount used also in plated contacts and switches in the electronic circuitry of mobile phones.
3-	Mercury	Used in mercury vapour lamp i.e. a small screen illumination unit of old-fashioned mobile phones.
4-	PBBs * and PBDEs **	Used as flame retardants (FRs) to prevent flammability in the plastics of the printed wiring boards (PWBs). May be found in electronic circuitry of mobile phones.
5-	Hexavalent Chromium	Used in decorative and hard coat plating (usually not used in mobile phones).

(European Council, 2002; IPMI, 2003) - * Polybrominated biphenyls . ** Polybrominated diphenyl ethers

2-6- Other toxic substances

Recycling of e-waste and in particular batteries also results in secondary emissions that are not chemicals in e-waste but reaction products from incineration or smelting processes. Polychlorinated dibenzo-dibenzofurans (PCDDs/PCDFs) and polycyclic aromatic hydrocarbons (PAHs) can also be introduced from open e-waste incinerators. Open burning of e-waste can usually be prohibited. High contents of PCDD/PCDFs were reported in breast milk, placenta and hair samples from e-waste treatment sites in Taizhou, China[27].

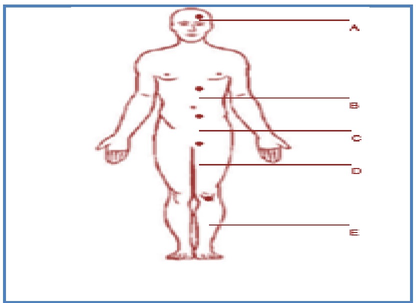
[26] Singh, N., Duan, H., Ogunseitan, O.A., Li, J., Tang, Y., 2019. Toxicity trends in E-Waste: A comparative analysis of metals in discarded mobile phones. J. Hazard Mater. 380, 120898.

[27] Chen A, Dietrich KN, Huo X, Ho S (2011) Developmental Neurotoxicants in E-Waste: An Emerging Health Concern. Environ Health Perspect. 119:431–438. doi: 10.1289/ehp.1002452

Taiz University Research Journal, Volume 34 jan2023 ISSN: 2985-7848
Taiz University
2nd ICTSA -2022 Proceedings
Dec, 2022, Taiz University, Taiz, Republic of Yemen.19 -17

Table (3): shows the toxicity of some elements and components of electronic waste

Products	Mobile phone 	Printed circuit board 	Rechargeable batteries 	USB data Storage 	Wires and cables 
Hazardous elements	Pb, Hg, Cd & Be, Brominated flame retardant, PVC plastic	Cu, Fe, Al Brominated Flame retardants	Cd in recharge able batteries, switches.	Hexavalent chromium	Polyvinyl chloride (PVC) Chlorinated dioxins and furans
Toxicity	Carcinogenic and endocrine disruption	Impaired learning and memory functions, Behavioral problems due to Womb exposure. interfere with thyroid and estrogen hormone	Affects kidneys and bones, Osteo porosis lung disease	Highly toxic disrupt balance b/w ROS & anti oxidants, Carcinogenic, Ulcers DNA adducts	Toxic even in very low concentrations
Eco toxicity	Highly persistent in the Environment	Persistent and bio-accumulative	Bio accumulate in environment	Adverse effects to aquatic life	Highly persistent in the environment



A. Nervous System	D. Urinary system
B. Respiratory system	E. Reproductive system
C. Immune system	F. Bone

Figure (4): Diseases that may affect humans

recycled to recover iron, aluminium, copper, nickel, cobalt and cadmium depending on the type of battery and on the particular recovery processes. A necessary step in the material recovery and recycling process for mobile phones is manual separation of the batteries in order to minimize contamination with other materials during the subsequent material recovery and recycling phases and to maximize the recovery of the materials contained in the batteries.

3-1- Requirements that must be met while recycling waste when recycling mobile phones

1- All pre-treatment, material recovery and mobile phone recycling facilities must have an Environmental Management System (EMS) to ensure adequate controls are imposed on the facility's impact not only on the environment but also on the health of workers and the public. The EMS may include ISO 140001 or an equivalent

3- The importance of recycling

Mobile phones are surface mines of rare and precious metals on the surface of the earth, and the main benefit behind metal recovery from mobile phones is to recover the metals of the largest quantities - copper - and the minerals of greater value - gold, palladium and silver. Moreover, recovering cobalt from lithium-iron batteries is also of economic benefit. If phone cases are made of aluminum or magnesium, these two metals also have an economic benefit. The process usually involves recovering copper and precious metals such as gold, silver and palladium because they are highly valuable. Some material recovery and recycling processes also result in the recovery of materials such as steel, aluminium, magnesium, tin, cobalt, lead and plastics. Batteries that are to be removed from a mobile handset during the early stages of any environmentally sound material recovery and recycling process can be safely

The first stage is waste collection and consolidation: This is a major logistical challenge and requires a high level of awareness among consumers who need to return old products for recycling. In a business environment, the first stage can be controlled in a more effective manner than the post-consumer group. Where electronics waste must be collected separately to recycle and reuse the material content. There is no doubt that the effective collection of expired mobile phones is highly recommended as a necessary first step in material recovery. Uncollected mobile phones - and this is the case for the majority of these phones - cannot be a source for material recovery, so this section is based on the assumption that the separate collection and sorting of used mobile phones for reuse or refurbishment has already taken place.

3-2-2-Manual separation

Manual separation can also be used to separate some accessories from the handset in mobile phones and in some cases the plastic parts can be separated for recycling. Some components can be recovered for possible reuse, but dismantling small devices is very labor intensive.

3-2-3-mechanical separation

Usually mechanical separation, including slicing, grinding and size reduction processes followed by different separation technologies, can also be used. However, if mechanical means are to be used, only devices that process electronic scrap should be used so that waste of precious metals and dust emission are minimized.

3-2-4-Cutting and grinding

Phase III: Processing of metal recovery begins with shredding in dedicated e-waste shredding facilities to turn mobile phones into smaller pieces, about 2 cm, where these small pieces are more convenient to be pushed into smelters. The shredding process generates a lot of noise and some dust particles that may contain any of the materials found in mobile phones. If these particles are not controlled, workers may be exposed to these substances by inhalation and ingestion. However, in normal shredding, the amounts of material released are small, and if batteries are not removed prior to shredding, they release combustible materials and can cause short circuits and fires that may release their own toxic emissions. The second stage is a little more complex in the post-collection of consumer waste than in the business environment, as collected materials usually contain impurities and materials that are not intended to be collected. The second stage can include the use of various techniques from manual disassembly to mechanical and chemical pretreatment.

3-2-5-Separation into Different Components

Fourth stage: The cutting process follows the steps of material separation to separate metals from one another, as well as separate non-metallic components from one another. Various technologies are used to separate materials, including magnets, electromagnetic separators, and flotation. Dust particles from the shredding process are persistent and need to be controlled to prevent worker exposure. Separated materials that have no market value need to be disposed of in approved landfills or incinerators whenever possible.

approved management system such as the European Ecological Management Audit Program (EMAS) or other similar programmes. The facility shall operate in accordance with written procedures regarding the facility's operating methods, equipment, management system, monitoring of site activities, measurement and record keeping, and implementation of site safety rules. The design of the facility must be subject to health and environmental impact assessments. The design of the facility must comply with all applicable health and environmental regulations and be authorized by all appropriate government authorities. The facility must comply with all applicable health and environmental regulations and be authorized by all relevant government authorities. Written plans must be maintained regarding emergency preparedness, emergency financial guarantees and facility closure.

2- Smelting used mobile phones requires special equipment and most smelters do not have the necessary pollution control systems for environmentally sound material recovery and recycling of electronic scrap. Electronic scrap, including mobile phones, contains plastics and halogens (chlorine and bromine) whose burning can lead to the formation of dioxins and furans, which are highly toxic and carcinogenic. However, with good smelting processes and pollution control equipment, controls can be put in place to ensure that metal recovery from mobile phones is environmentally sound. Pretreatment, material recovery and recycling facilities must operate within a regulatory framework that strikes a balance between the need for environmentally sound management and the need for economic efficiency. Therefore, when establishing the appropriate organizational infrastructure for pre-processing, material recovery and mobile phone recycling facilities, Parties should consider the size of the facility, the type and quality of scrap materials as well as the nature of the process. It is known that developing countries as well as countries with economies in transition face the greatest challenges in building the governmental and industrial infrastructure required to achieve the environmentally sound management of end-of-life mobile phones.

3. Thermo-mining processes for electronic nuggets (eg circuit boards) require air pollution control systems that will capture hazardous particulates and gases, such as a Venturi system, a cyclone system, an electrostatic precipitator or a fabric filter. It is often possible to further process the collected particles from these devices to recover metals.

3-2- Steps involved in recycling cell phones

Almost all parts of cellular phones can be recycled. Recycling procedures include :

- Collect the phones and take them to the recycling facility.
- Separate the components of the phones from each other.
- Extraction of metals by melting the components made of them and then refining them.
- Washing plastic components and then shredding or melting them to make new products.
- Purification or additional treatment and then final disposal and recycling.

3-2-1- Waste Collection

3-2-9-Additional treatment

The slag produced from the smelting processes contains substances of concern. If it still contains relatively high concentrations of marketable materials, a batch must be returned to the smelter or other smelting processes to recover these materials. Such continuous smelting may entail the possibility of fumes and particulates being released but this would increase metal recovery and prevent landfill disposal. The slag may be ground into a powder as a preparation for further metal recovery by selective precipitation and thickening of the desired metals. These additional processing steps can increase workers' exposure to metal-containing dust and expose the waste water to high concentrations of toxic metals that need to be controlled using well-engineered and properly managed processes. The slag is often glass silicate and when stabilized and made into an insoluble material through high-temperature processing, it does not precipitate any substances of concern and can be used safely in construction or road building materials. If the slag is unstable and soluble, its use on the ground or its disposal in landfills results in the same potential to release substances of concern as described above. Usually the slag, ie the remnants of pyrometallurgical processes, is a dark, vitreous solid. Slag from WEEE smelting components/nuggets can contain, among others, lead, cadmium, beryllium oxide, silica, alumina, iron oxide and other oxidized metals. It is often reprocessed to recover additional minerals.

4- LCD screen, chips

Phone screens and LCD screen chips are made of glass and ceramics with a percentage of approximately 15%. And other elements, the most important of which is indium.

3-2-6-Separation of the organic layer

After these separation steps, the organic layer is separated into polypropylene waste (called light organics), ebonite separators (called heavy organics).
The light organic matter is then washed to remove traces of toxic element oxides such as lead and cadmium, and ground into small pieces, according to its future use, while the ebonite and separators are conveniently stored.

3 -2-7-Smelter

Smelting, in which copper and other metals and precious metals are separated from other materials, is a high-volume, high-temperature process. Metal fumes and particulates may be released, exposing workers and downwind communities unless emissions are controlled. Beryllium can be the most complex metallic emission from smelters, but concentrations of beryllium in mobile phones are so low that they can be controlled at very low concentrations, which are often well below air quality standards. If hydrocarbons are present in the materials being melted, particles of incomplete combustion can be released from these processes that, in the presence of halogens, can release dioxins and furans. These releases can be controlled through well-engineered processes and emission control systems with attention to proper infrastructure and good management. In general, direct smelting of expired mobile phones allows recovery of metals such as copper, precious metals and most other metals (except iron, magnesium and aluminium), and plastics can be used as a heat source as well as an attenuating agent.

3-2-8- Refining and purification

After smelting, there are a number of electro-metal refining, analysis and sedimentation processes (hydro-metal processes) in which the metals are individually upgraded and purified to reach the market required grade. These steps can result in waste water that may contain high concentrations of toxic metals; This waste water, if not all of it is reused within the refining facility, needs to pay special attention to proper infrastructure and proper management.

4-1- Indium


Phone screens and chips at the same time contain other elements, the most important of which is indium, and about 84% of global consumption is due to the production of liquid crystal displays (LCD) [28]. 90% [29] of this metal is located in a thin film of indium tin oxide (ITO) with

[28] K. S. Park, W. Sato, G. Grause, T. Kameda, and T. Yoshioka, Thermochim. Acta, DOI 10.1016/j.tca.2009.03.003 (2009).
[29] C. H. Lee, M. K. Jeong, M. Fatih Kilicaslan, J. H. Lee, H. S. Hong, and S. J. Hong, Waste Manag., DOI 10.1016/j.wasman.2012.10.002 (2013).

transparent electrode properties [30]. In general, indium is co-extracted from zinc minerals, where it is present in varying concentrations included between 1 and 100 ppm [31]. The low concentration of indium in ore justifies the interest in end-of-life LCD screens, which show indium content in the range of 100-200 ppm [32]. Besides the relatively high indium content, LCDs are interesting due to their short average life, about 3-8 years [33], which leads to a significant increase in LCD waste that must be treated. At present, various processes for recovering indium have been developed including several techniques, such as chlorination reaction [34], electroetching, pyrolysis, acid filtration followed by solvent extraction and demineralization or cementation.It is obtained by electrolysis of solutions of its aqueous salts, especially sulfates. It is worth mentioning here that indium (In) in the discarded LCD reacts with H2SO4 and HCl at elevated temperatures [35]. And Al and Sr are filtered out in concentrated HCl, while HNO3 and H2SO4 concentration are more selective towards In. Kato et al (2013) reached 90% in leaching of 3.2 M (10%, v/v) HCl. Ruan, et, al, 2014 [36] H2SO4 sulfuric acid was used in a liquid to solid (L/S) ratio of 1:1 at 160°C for 1 hour and reached 92% in filtration. Wang et al. (2013) [37] say it was filtered 100% with 0.6M of H2SO4 in 42 minutes, and at a temperature of 68.6°C. And in the washing process, it showed a positive relationship with temperature and acid concentration in all the experimental works reported.

4-2-Gallium, tantalum

There is no quantitative data available for the content of these important minerals in smartphones. There is a fundamental need to research this in order to determine the future importance of smartphones and potential options for the recycling industry.

4-3-Rare earths

There is no quantitative data available on the amount of rare earth elements in smartphones. But it is known that cell phones and smartphones also have small speakers with neodymium iron-boron magnets. The Oeko Institute measured a permanent magnet from a mobile phone weighing 190 mg. Assuming a composition similar to that of notebook speakers (31% rare earth ratio), this gives a REE quantity per smartphone of 60mg with a neodymium to praseodymium ratio of approximately. 5 to 1. Everything in the mobile is in a solid state: there are no moving parts or liquids that can be released during normal use. However, mobile phones contain small amounts of some potentially hazardous substances that can be released into the environment if the phone at the end of its useful life is incorrectly managed. Exposure to specific substances when managing expired mobile phones is covered in Appendix III.

5- Printed circuit boards (PCBs)

Printed circuit boards (PCBs) are used to support electronic components mechanically and electrically connect them using conductive tracks, signal tracks or traces etched from a sheet of copper laminated on a non-conductive substrate, and are used in the manufacture of electrical appliances, including the mobile phone. Essential of almost all electrical and electronic equipment.

5-1- Components of Printed Circuit Boards (PCBs) in Cell Phones

All printed circuit boards (PCBs) mainly consist of basic parts: a non-conductive substrate or a plate, a copper substrate printed on or inside the plate, and the components connected to the substrate:

- Slices (Ga, In, Ti, Si, Ge, As, Sb, Se, Te)
- Conductors (Au, Ag)
- Capacitors (Ta, Al), etc.

Depending on the structure and alignment, printed circuit boards (PCBs) can be classified as single-sided, double-sided, or multilayer. Single-sided and double-sided printed circuit boards (PCBs) have a conductive layer on one or both sides of the chips with or without coated holes to connect the sides. The initial composition of PCBs varies with the type of PCBs and their applications. Compounds of printed circuit boards (PCBs) generally contain 28% metals, 23% plastics, and the remaining percentage is ceramic and glass materials [38].

The materials in printed circuit boards (PCBs) can be classified into three groups: organic materials, metals, and ceramics as follows:

A- Organic Materials: The organic materials in printed circuit boards (PCBs) mainly consist of plastics containing flame retardants and paper. Organic materials commonly consist of the following polymers: acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyvinyl chloride (PVC), polytetrafluoroethylene (PTFE, polyethylene (PE) and polypropylene (PP), as well as High Impact Polystyrene (HIPS). Refractory materials generally consist of silica, titanate and alumina and alkaline oxides. The toxicity of materials in printed circuit boards, especially plastics, is a major concern in the characterization and treatment of waste printed circuit boards. The most common hardener is dicyanodiamide, 4,4-Diaminodiphenylsulfone,4,4-Diaminodiphenylmethane [39]. Losses on ignition can be used to determine the polymeric fraction (volatile organic matter).

B- Metals: The metals found in printed circuit boards (PCBs) consist of:

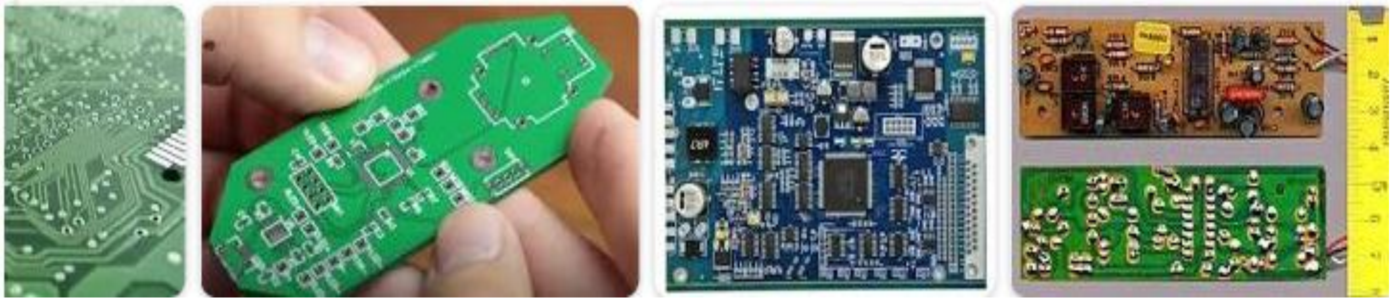
[30] T. Minami, Thin Solid Films, DOI 10.1016/j.tsf.2007.03.082 (2008).
[31] A. M. Alfantazi, and R. R. Moskalyk, Miner. Eng., DOI 10.1016/S0892-6875(03)00168-7 (2003).
[32] Götze, in: Proceedings of the conference Electronics Goes Green 2012+ (EGG), Berlin, Germany, 2012, pp. 1-8.
[33] E. Ma, and Z. Xu, J. Hazard. Mater., DOI 10.1016/j.jhazmat.2013.10.020 (2013).
[34] K. Takahashi, A. Sasaki, G. Dodbiba, J. Sadaki, N. Sato, and T. Fujita, Metall. Mater. Trans. A Phys. Metall. Mater. Sci., DOI 10.1007/s11661-009-9786-4 (2009).
[35] Rocchetti, L, Vegliò, F., Kopacek, B., Beolchini, F., 2013. Environmental impact assessment of hydrometallurgical processes for metal recovery from WEEE residues using a portable prototype plant. Environ. Sci. Technol. 47, 1581–1588. doi:10.1021/es302192t.
[36] Ruan, J., Zhu, X., Qian, Y., Hu, J., 2014. A new strain for recovering precious metals from waste printed circuit boards. Waste Manag. 34, 901–907. doi:10.1016/j.wasman.2014.02.014.
[37] Wang, F., Ruediger, K., Daniel, A., Jinhui, L., 2013. E-waste in China: A country report.Bonn.
[38] Zhou Y., Qiu K., "A New Technology for Recycling Materials from Waste Printed Circuit Boards, *Journal of Hazardous Materials*," 175, (2010), 823–828.
[39] Ghosh B., Ghosh M.K., Parhi P., Mukherjee P.S. and Mishra B.K., "Waste Printed Circuit Boards Recycling: An Extensive Assessment of Current Status," *Journal of Cleaner Production*, 94, (2015), 5-19.

- Base metals: about 10-20% of printed circuit boards (PCBs) are copper, which forms a conductive layer for electrical conductivity between various components and a large amount of base metals; Such as Fe, Al and Sn.
- Rare metals: such as Ta, Ga and other rare platinum group metals (PGMs).
- Precious metals such as Au, Ag and Pa Precious metals, especially Au and Pd, are also used as contact materials at joints. Typical Pb/Sn elements, which are used to join various components in printed circuit boards (PCBs), account for 4-6% of the total weight of printed circuit boards (PCBs).
- Components mounted on printed circuit boards (PCBs) also have different metallic values such as Ga, In, Ti, Si, Ge, As, Sb, Se, Te, Ta, etc. PGMs are located in relays, switches, or in sensors [[40]].
- Hazardous metals such as Cr, Pb, Be, Hg, Cd, Zn and Ni.

C-Ceramics, Porcelain, and Fibers: The ceramics found in printed circuit boards (PCBs) are composed primarily of silica and alumina. The main reinforcing material for the substrate of printed circuit boards (PCBs) is fiberglass or silica cloth. Other inorganic materials such as alumina, alkaline earth oxides and small amounts of other mixed oxides such as barium titanate are also present. Ceramic materials such as BeO and mica can also be found. WEEE plastics contain brominated flame retardants (BFRs), including polybrominated diphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs), and their combustion produces highly toxic gases. The thermosetting resins cannot be recovered or reformulated due to their net structure; Hence, it is considered non-recyclable [[41]].

[40] Sum E.Y.L., The Recovery of Metals from Electronic Scrap, *JOM*, April, (1991), 53-60.
[41] Zhang S. and Forssberg E., "Mechanical Separation-Oriented Characterization of Electronic Scrap," *Resources, Conservation and Recycling*, 21, (1997), 247-269.

Taiz University Research Journal, Volume 34 jan2023 ISSN: 2985-7848
Taiz University
2nd ICTSA -2022 Proceedings
Dec, 2022, Taiz University, Taiz, Republic of Yemen.19 -17



5-2- Methods for determining chemical composition

Reviews and investigations on composites of printed circuit boards (PCBs) have reported that technologies such as AAS, ICP-OES, ICP-MS, flame inspection, XRF and XRD techniques can identify circuit board components. In general, X-ray spectroscopy techniques can provide, Flame, Plasma, Infrared - Good Quality Information, Optical-electronic sorting uses X-rays to sort materials, and allows separation of BFRs from heavy metals through laser-induced breakdown spectroscopy (LIBS) and X-ray fluorescence (XRF) analysis.And for quantitative analysis, every error-prone source (sampling, digestion, dilution, titration, interference, etc.) Aqueous filtration can be used to identify the mineral fraction[[42]]. The ceramic fraction can be calculated by mass difference [[43]].

5-3-Importance of Printed Circuit Boards (PCBs)

Printed circuit boards (PCBs) make up about 3% of all electronic scraps by weight relative to a cell phone. Most of the recycling methods used can recover the metal contents from waste printed circuit boards (PCBs) at only 30% of the total weight. More than 70% of waste printed circuit boards (PCBs) cannot be efficiently recycled and recovered and must be incinerated or landfilled [[44]]. The primary appearance in printed circuit boards (PCBs) is a copper-coated plate consisting of a glass-reinforced epoxy resin and a number of metallic materials including precious metals. The concentration of precious metals especially Au, Ag, Pd and Pt is much higher than their primary resources, making waste printed circuit boards (PCBs) an economical urban ore/secondary resource for recycling. In addition, printed circuit boards (PCBs) also contain various hazardous elements including heavy metals (Cr, Hg, Cd etc.), back-earth element (Ta, Ga, etc.) and flame retardants (Br) which form Serious threat to the ecosystem during conventional waste landfill treatment and incineration [[45]]. Several research works have revealed that the composition of metals, ceramics and plastics in printed circuit boards (PCBs) can reach 40%, 30% and 30%, respectively [[46]]. Meanwhile, the concentrations of precious metals such as Au and Pd in printed circuit boards (PCBs) are richer than in natural ores, making their recycling important from an economic and environmental perspective. Waste printed circuit boards (PCBs) have received a lot of attention from researchers and companies, not only because of their resource-rich content, but also because of the potential risks to the environment and human health through informal recycling. Therefore, the factors affecting mineral extraction are economic feasibility, recovery efficiency and environmental impact.

5-4- Recycling of waste PCBs

The drive to recover valuable metals in particular Au, Ag, Pd and Cu has received much attention in recent years using extraction processes such as mechanical, chemical and aqueous/thermal filtration separation techniques. The following figure shows the sample preparation and recycling methodology.

[42] Ogunniyi I.O., Vermaak M.K.G. and Groot D.R., "Chemical Composition and Liberation Characterization of Printed Circuit Board Communition Fines for Beneficiation Investigations," *Waste Management,* 29, (2009), 2140-2146.
[43] Yamane L.H., Moraes V.T. and Espinosa D.C.R., "Recycling of WEEE: Characterization of Spent Printed Circuit Boards from Mobile Phones and Computers," *Waste Management,* 31, (2011), 2553-2558.
[44] Li J., Shrivastava P., Gao Z. and Zhang H.C., "Printed Circuit Board Recycling: A State of the Art Survey," IEEE Transactions on Electronics Packaging Manufacturing, 27, 1 (2004), 33-42.
[45] Ghosh B., Ghosh M.K., Parhi P., Mukherjee P.S. and Mishra B.K., "Waste Printed Circuit Boards Recycling: An Extensive Assessment of Current Status," Journal of Cleaner Production, 94, (2015), 5-19.
[46] Tenorio J.A.S., Menetti R.P., and Chaves A.P., "Production of Non-ferrous Metallic Concentrates from Electronic Scrap," EPD Congress 1997, TMS, Warrendale, PA, USA, (1997), 505-509.

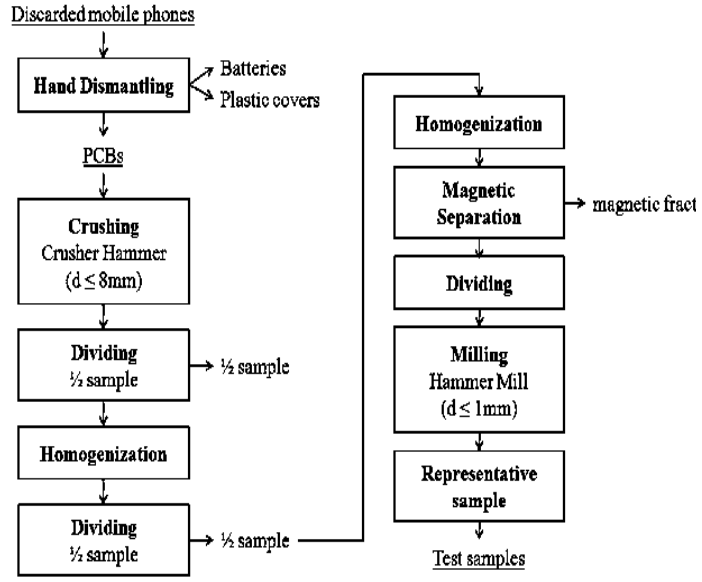
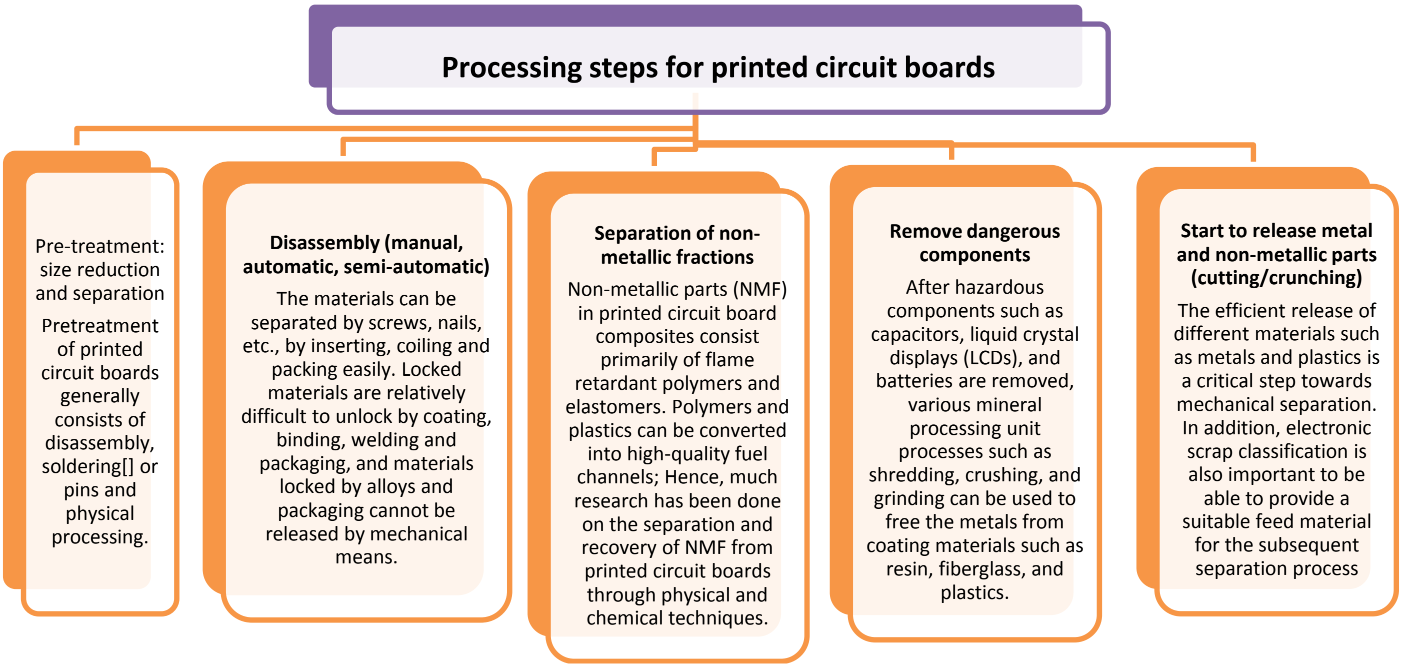


Figure (5) Scheme of representative sample preparation (Laubertov et al. 2016)

5-4-1- Characterization of Waste Printed Circuit Boards (PCBs)

Due to the diverse and complex nature of waste printed circuit boards (PCBs), characterization in terms of types, structure, components and composition is important for determining the recycling pathway and process. Thin films of Sn or Ag are used in printed circuit boards (PCBs) for oxidation protection [[47]]. Base metals are mainly used in printed circuit boards (PCBs) because of their conductive properties. There are two types of printed circuit boards (PCBs) (FR-4 and FR-2) commonly used in personal computers and mobile phones. Type FR-4 consists of a multi-layer epoxy resin, fiberglass coated copper layer. Type FR-2 is a single layer of fiberglass or cellulose paper and laminated with a phenolic layer with a copper layer [[48]][[49]]. Type FR-4 is used in small devices such as cell phones and Type FR-2 is used in televisions and home appliances such as computers [[50]].

[47] Veit H.M., Diehl T.R., Salami A.P., Rodrigues J.S., Bernardes A.M. and Tenório J.A.S., "Utilization of Magnetic and Electrostatic Separation in the Recycling of Printed Circuit Boards Scrap" Waste Management, 25 (2005) 67–74.
[48] Murugan R.V., Bharat S., Deshpande, A.P. Varughese, S. and Haridoss P., "Milling and Separation of the Multi-Component Printed Circuit Board Materials and the Analysis of Elutriation based on a Single Particle Model." Powder Technology, 183, (2008), 169–176.
[49] William, J.H. and Williams, P.T., "Separation and Recovery of Materials from Scrap Printed Circuit Boards*." Resources Conservation and Recycling* 51, (2007), 691–709.
[50] Ladou J., "Printed Circuit Board Industry." *International Journal of Hygiene and Environmental Health*, 209, (2006), 211–219.



5-4-2- Physical techniques

The goal of physical recycling techniques is to recover NMF without any loss of valuable minerals. The physical properties of the particles, including size and shape, may affect the efficiency of the physical separation. There are three main physical separation techniques which are particle-shape-based separation, electrostatic separation, and magnetic separation. Density separation falls under particle-shape-based separation, and the most commonly used form of electrostatic separation is eddy current separation.

(a) Gravity separation

Gravitational separation is based on the fact that each substance has a certain density. Gravity concentration methods separate materials of different specific gravity by their relative motion in response to gravity. However, this separation depends not only on the density of the components, but also on their size. Besides gravity, one or more other forces such as the force exerted by a viscous fluid (such as water or air) can act as a separating medium. By using different heavy fluids, metals can be separated from plastics. Different metal particles can be separated. For this purpose, the material of printed circuit boards (PCBs) is processed on concentration tables. The tables exploit the difference in specific gravity and particle size to achieve the desired separation. The principle of air classification technology is based on the suspension of particles in a flowing air stream and the separation of particles based on their differing densities. Density separation techniques known in the metal processing industry have found their way into electronic scrap recycling based on the fact that electronic scrap mainly consists of plastic, with a density less than 2.0 g/cm3; light metal, mainly aluminum and glass, with a density of 2.7 g / cm3; Heavy metals, mostly copper and ferromagnetic, have a density of more than 7 g/cm3. In the float separation process, both PC and PCB scrap ~50% (weight) can be separated from floats which are mainly plastics at a specific density of 2.0 g / cm 3 [51].

(B) Magnetic separation

Magnetic separation can be used to separate magnetic particles from non-magnetic particles. Magnetic separators, especially low-density cylindrical separators, are widely used to recover ferromagnetic minerals from non-ferrous metals and other non-magnetic waste. Over the past decade, there have been many advances in the design and operation of high intensity magnetic separators, mainly due to the introduction of rare earth alloy permanent magnets capable of providing very high field strengths and gradients. There are some problems associated with this method. A major issue is particle agglomeration which leads to the attraction of some non-ferrous fractions (eg NMF) bound to the ferrous fraction. This will reduce the efficiency of this method. Through the process of magnetic separation, two parts can be obtained: a magnetic part, in which iron is concentrated; and the non-magnetic part in which the copper is concentrated [52]. Two magnetic separation processes were performed at 700 and 3000 Gauss to separate magnetic and non-magnetic materials from ground printed circuit boards (PCBs). Milled PCBs with particle size greater than

[51] Zhang S. and Forssberg E., "Mechanical Separation-Oriented Characterization of Electronic Scrap," *Resources, Conservation and Recycling*, 21, (1997), 247-269.

[52] Yamane L.H., Moraes V.T. and Espinosa D.C.R., "Recycling of WEEE: Characterization of Spent Printed Circuit Boards from Mobile Phones and Computers," *Waste Management*, 31, (2011), 2553-2558

5.0 mm and heavy fraction are separated from PCBs <5.0 mm by gravity separation[[53]].

(c) Corona-electrostatic and Eddy-current separation

Conductivity-based separation separates materials with different electrical conductivity (or resistance). There are three typical separation techniques based on electrical conductivity: (1) eddy current separation, (2) electrostatic separation and (3) electrostatic separation. In the electrostatic electrostatic separation, the electrode system, rotor speed, moisture content and particle size have the greatest influence in determining the separation results. The electrostatic method is perhaps the most effective separation technique for metallic and non-metallic fractions at present. This method is characterized as being environmentally friendly, producing no waste water and no gas emissions. The separation ability depends on the difference in polarity and the amount of charge acquired by the particles to be separated. Corona induction or charge can successfully separate the mixed particles which have a large difference in conductivities, the magnetic deflection force acting on the ferrous particles must be greater than all the competing forces [[54]]. It has been found that particle sizes from 0.6 to 1.2 mm are the most suitable size for separation in industrial applications. Therefore, a two-step crushing process has been proposed to achieve the particle size. Significant work continues in this field with special emphasis on the electrostatic behavior of the system and field strength [[55]]. Electrostatic electrostatic methods are now able to produce two streams of waste printed circuit boards (PCBs) comprising a metallic part and a non-metallic part with little cross-contamination; The method is dry at room temperature and therefore virtually non-polluting depending on the quality of the dust extraction system. Eddy current separation technology is used to recover aluminum, which consists of about 2.8% by weight of typical printed circuit boards (PCBs) scrap [[56]].

5-4-3-Chemical Recycling Techniques

In this type of recycling, composites of printed circuit boards (PCBs) are depolymerized into smaller useful particles through several techniques, such as pyrolysis, gasification, or the application of supercritical fluids. Uncertainty and potential contamination have slowed the expansion process to a field scale []. The obtained products (fuel, gases and tar) are refined by conventional methods and metallurgical methods are used to treat the metallic part. One of the main disadvantages is the presence of a large amount of dioxin precursors in pyrolysis oils, which can be reduced by adding $CaCO_3$, Fe_2O_3 during pyrolysis. In recent years, supercritical fluids have been an effective way to destroy the adhesive epoxy layer.

(a) Thermal treatment

Thermal treatment of metals, an energy-intensive and expensive process, is the traditional method for recovering metals from waste printed circuit boards (PCBs), but the selective recovery of individual metals cannot be done by this method. Refractory metal recovery techniques include incineration, smelting in a plasma arc furnace, blast furnaces or a copper smelter, and high-temperature roasting in the presence of selective gases to recover mainly non-ferrous metals. Currently, more than 70% of waste printed circuit boards (PCBs) is processed in smelters rather than mechanical processing [[57]]. The main advantage of metal heat treatment is its ability to accept any form of scrap. Hence, electronic scrap can be used as a part of raw materials in smelters to recover Cu along with Au and Ag. Waste printed circuit boards (PCBs) can be used to produce an alloy of copper, nickel, silicon, mixed oxide (mainly Pb and Zn) and slag by an overhead blown reactor. Vacuum metal separation (VMS) is suitable for Bi, Sb, Pb and other heavy metals with high vapor pressure.

Table (4): Thermal mining processes used to recover metals in waste electrical and electronic equipment

Technology	Recovered metal	The main characteristics of the process	base output
Noranda Process Quebec, Canada	Cu, Au, Ag, Pt, Pd, Se, Te, Ni	Copper smelting and concentrating, converting device, smelting furnace, electro-refining	**High recovery rate of copper and precious metals**
BolidenSmelting, Ronnskar, Sweden	Cu, Au, Ag, Pt, Pd, Zn, Pb, Ni	Concentration reactor, 100,000 tons per year, copper conversion and purification, precious metal purification	**High recovery rate of Copper and precious metals**
Umicore, Belgium	Precious metals, Se, Te base metals	Copper filtration, Electropurification of precious metals, 250 tons of e-waste per year, Melting furnace with monitoring gas transmitters, Plastic substitutes for coke	**precious metal recovery Sb, Bi, Se, Te, In**
Dunn's patent for gold refining	gold	Reaction of electronic waste with chlorine. Temperature	**Recovering 99.9% of pure gold from**

[53] Yoo J.M., Jeong J., Yoo K. Lee J.C. Kim W., "Enrichment of the Metallic Components from Waste Printed Circuit Boards by a Mechanical Separation using a Stamo Mill," *Waste Management*, 29, (2009), 1132-1137.

[54] Li J., Shrivastava P., Gao Z. and Zhang H.C., "Printed Circuit Board Recycling: A State of the Art Survey," IEEE Transactions on Electronics packaging Manufacturing, Vol: 27, No: 1, (2004), 33-42.

[55] Hadi P., Xu M., Lin, C.S.K., Hui C.W., and McKay G., "Waste Printed Circuit Board Recycling Technologies and Product Utilization," Journal of Hazardous Materials, 283, (2015), 234-243.

[56] Li J., Shrivastava P., Gao Z. and Zhang H.C., "Printed Circuit Board Recycling: A State of the Art Survey," IEEE Transactions on Electronics packaging Manufacturing, Vol: 27, No: 1, (2004), 33-42.

[57] Zeng X., Zheng L., Xie H., Lu B., Xia K. Chao K., Li W., Yang J., Lin S. and Li J., "Current Status and Future Perspective of Waste Printed Circuit Boards Recycling," *Procedia Environmental Sciences*, 16, (2012), 590-597.

		from 300 ° C to 700 ° C, dissolution of impurities in hydrochloric acid, dissolution of silver in nitric acid and ammonium hydroxide; samples of gold recovery	**electronic waste**
Day Patent for Recovering Metals in Waste with Heat Resistant Porcelain	Precious metals, platinum and palladium	Placing the waste in a plasma furnace at a temperature of about 400 °C, ceramics in the slag, also recovering silver and copper	**Platinum and palladium recovery of e-waste, with a recovery rate of 80.3% and 94.2%, respectively**
Alexandrovich patent for recovery of platinum-gold group metals from electronic waste	**platinum and gold set**	**Metal smelting with carbon return device**	**Restore the platinum and gold group**

b) hydrotreating processes (filtration)

The hydrometallurgical process is more selective to recover metals from waste pretreated PCBs, facilitates reaction control and results in fewer environmental risks than the thermometallurgical approach. The recovery of base metals has a significant impact on the economics of the process due to the larger quantities available in waste printed circuit boards (PCBs). Moreover, the recovery of base metals also ensures that the precious metals are enriched in the solid tailings, facilitating the leaching process afterwards . Low-cost hydrometallurgical processes are primarily used for recycling ferrous metal parts where extracting the metal content is profitable. Depending on the substrate material (ceramic, glass, or polymer) there are different metallurgical extraction processes used [[58]].

Table (5): Liquid mining processes used to recover minerals from waste electrical and electronic equipment

Recovered metal	The main characteristics of the process	base output
Gold	Telephone chips are treated with HN03 for base metal dissolution, aqueous filtration, and ferrous sulfate gold precipitation	gold
gold and silver	E-waste less than 0.5 mm is treated by KI, I2 or NaCl, solvent extraction for gold and silver recovery	gold and silver
gold (98%), palladium (96%), platinum (92%)	Dissolve base metals in H2SO4 and MgCl, dissolve precious metals in HCl and bromide ions, bind gold to zinc powder	A set of gold and platinum powders
copper and silver (93%) palladium (99%), Gold (95%)	leaching of copper by sulfuric acid, leaching of palladium by chlorine, leaching of gold and silver by thiourea compound, adsorption of gold, silver and palladium by activated carbon	palladium and copper and silver chloride and gold
Gold (92%) silver and palladium	Dissolution of base metals in HCl or H2SO4, leaching of silver, gold and palladium by HCI and NaClO3, precipitation of gold by FeCl	squishy gold
gold	E-waste filtration with basic solutions NaCl, CuCO3, and HCl	gold left

Source: - Oliveros, H., Metodología para recuperar metales preciosos: oro, plata y grupo del platino, presentes en desechos electrónicos, Universidad Nacional de Colombia, Medellín, 2011

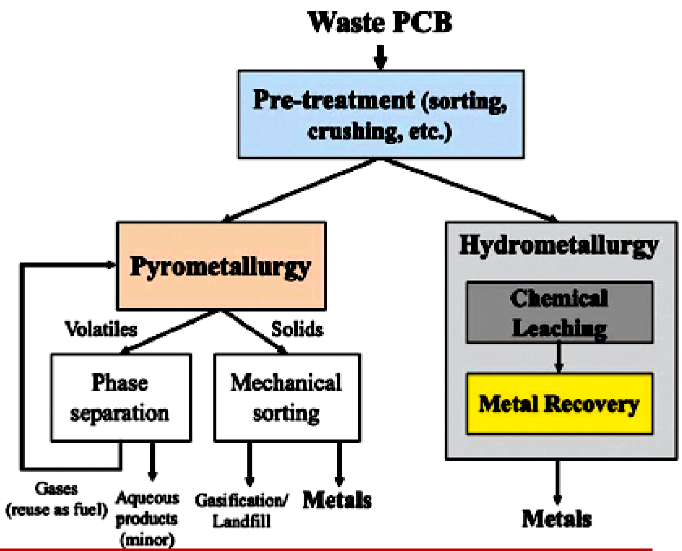


Figure (6) shows: a summary of the mineral separation and recovery processes.

(c) Recovery of precious and base metals by acid spraying

Currently, about 300 tons of Au are used in electronic industries along with other precious and strategic metals such as Ag, Pd, Pt, Nb, Ta, etc. [[59]]. Most precious metals are present in elemental form and in close proximity to other metals, which makes it very difficult to separate individual minerals. To improve the selectivity of precious metals and reduce impurities, leaching is preferred after the base metals have been removed or recovered. In the sequential steps the base metals were first dissolved in nitric acid, followed by filtration of the first step of filtration residues in aqua regia to extract Au and finally the precipitation of Au with ferrous

[58] Li J., Shrivastava P., Gao Z. and Zhang H.C., "Printed Circuit Board Recycling: A State of the Art Survey," *IEEE Transactions on Electronics packaging Manufacturing*, Vol: 27, No: 1, (2004), 33-42.

[59] Montero R., Guevara A. and de la Torre E., "Recovery of Gold, Silver, Copper and Niobium from Printed Circuit Boards using Leaching Column." *J. Earth Sci. Eng*, 2, (2012), 590-595.

sulfate.However, the construction of an appropriate filtration reactor for the highly corrosive nitric acid and aqueous aqueous, limits their industrial viability. Currently, active research has been shifted towards the development of less corrosive reagents such as cyanide, halide, thiourea, potassium persulfate, and thiosulfate for leaching of precious metals from waste printed circuit boards (PCBs) [60]. Figure 4 summarizes the reaction reagents, results, conditions, advantages and disadvantages of precious metal leaching with references. Washing of Au by cyanide follows the following reactions:

$$4 Au + 8 (K/Na)CN + O_2 + 2 H_2O \rightarrow 4 (K/Na)[Au(CN)_2] + 4(K/Na)OH \quad (1)$$

$$\text{Overall}: 4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)_2^- + 4OH^- \quad (2)$$

In recent years, gold recovery by thiourea has gained worldwide attention due to its less environmental impact. Unlike cyanide, thiourea forms a cationic compound with gold in an acidic medium and can dissolve up to 99% of gold according to the following reaction:

$$Au + 2CS(NH2)2 \rightarrow Au[CS(NH2)_2]^{2+} + e^- \quad (3)$$

Table(6) : Chemistries of main leaching methods and key considerations in the assessment of each method

Leaching type	Example	Overall reactions	Considerations
Acid	HNO_3	$4HNO_3 + Cu \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$	Nitric acid cannot be used directly for electroplating
Acid	H_2SO_4 : H_2O_2	$Cu + 2H^+ + H_2O_2 \rightarrow Cu^{2+} + 2H_2O$	Stronger corrosion → stricter reactor requirements
Acid	Aqua regia	$2Au + 11HCl + 3HNO_3 \rightarrow 2HAuCl_4 + 3NOCl + 6H_2O$	Highly corrosive, metal specificity (targeted towards Cu recovery with chlorides)
Cyanide	NaCN	$4Au + 8CN^- \rightarrow 4Au(CN)_2^- + 4e^-$	Slow leaching rate, harmful wastewater
Thiourea	$CS(NH_2)_2$	$Au + 2CS(NH_2)_2 \rightarrow Au(CS(NH_2)_2)^{2+} + e^-$	Poor stability, high reagent consumption
Thiosulfate	$(S_2O_3)^{2-}$	$Au + 5S_2O_3^{2-} + Cu(NH_3)_4^{2+} \rightarrow Au(S_2O_3)_2^{3-} + Cu(S_2O_3)_3^{5-} + 4NH_3$	High selectivity, but high reagent consumption

Table(7) : Metal content of various PCB per pretreatment and assay method.

PCB type	Pre-treatment	Particle size (mm	Dissolution	Analytical instrument	Weight (mg/kg) Cu	Fe	Al	Pb	Ni	Au	Ag	Pd	References
Mobile	Manual dismantling	Not specified	Fire ass	ICP	13	5	1	0.3	0.1	350	1340	210	Hagelüken, 2006
Mobile	Mechanical + magnetic	Various <4 mm	A.R. f	ICP-OES	34.5	10.6	0.3	1.9	2.6	n.d. 8	210	n.m.	Yamane et al., 2011
Mobile	Manual dismantling + magnetic/	<1 mm	A.R. at 60 °C for 2 h	ICP-AES	39.6	1.4	0.3	1.2	3.4	600	600	n.m.	Kasper et al., 2011

5-4-4-Biomineral filtration processes

Although the recovery of valuable metal parts from waste printed circuit boards (PCBs) is mostly targeted, biological bleaching can benefit the recovery of materials from electronic waste in two ways. The use of microorganisms to extract minerals by generating weaker organic acids will save on the manufacture of the strong inorganic acids currently used for mineral leaching and also significantly save the environment in terms of processing and disposal of the waste of strong inorganic acids compared to the weaker and more easily processed organic acids that have been Created by microorganism farms. Biological bleaching has a great potential to be introduced by selective extraction of metals at low temperatures by microorganisms generated from organic acids, thus reducing pollution caused by strong acid filtration and also leaving uncontaminated non-metallic residues for further processing. Hydrometallurgical bioremediation is well established as an alternative route for recovering minerals especially Cu and Au from very low grade ores and concentrates. The investigations have also been extended to other minerals due to lower investment cost, lower environmental impact, lower energy consumption and better control than traditional hydrometallurgical or thermal mining methods [61].

6-Important metals that can be recovered from printed circuit boards

6-1- Noble metals

It is known that the noble metals are metals that are resistant to corrosion and oxidation in moist air conditions, unlike most base metals. They tend to be overpriced, due to their rarity in the Earth's crust. And the noble metals (in order of increasing atomic number) ruthenium, rhodium, palladium, silver, osmium, iridium, platinum and gold [62].There are some sources that add to the above minerals mercury [63][64]

60 Ghosh B., Ghosh M.K., Parhi P., Mukherjee P.S. and Mishra B.K., "Waste Printed Circuit Boards Recycling: An Extensive Assessment of Current Status," *Journal of Cleaner Production*, 94, (2015), 5-19.

61 Brierley J. and Brierley C., "Present and Future Commercial Applications of Biohydrometallurgy," *Hydrometallurgy*, 59, (2001), 233-239.

62 A. Holleman, N. Wiberg, "Lehrbuch der Anorganischen Chemie", de Gruyter, 1985, 33. edition, p. 1486.

63 Dictionary of Mining, Mineral, and Related Terms", Compiled by the American Geological Institute, 2nd edition, 1997.

and rhenium. While titanium, niobium and tantalum are not considered among the noble metals despite their high resistance to corrosion. Noble metals should not be confused with precious metals although most of the noble metals belong to precious metals.

6-2-Precious Metals

Precious Metals or Precious Metals are rare naturally occurring mineral chemical elements of high economic value. These metals are gold, silver, platinum and palladium. Chemically, precious metals are less reactive than most elements, more lustrous, softer and more malleable, and have a higher melting point than other metals. Historically, precious metals were used as currencies, but now they are the basis for investment, industrial goods and most importantly mobile phones.

6-3-Palladium

Palladium is a platinum group metal (PGM) used in the electronics industry. Its main use in mobile phones is in electronic components and printed circuit boards [[65]]. According to the Royal Australian Chemical Institute (2011), palladium is one of the rarest materials, with Russia and South Africa together accounting for most of the world's production. The European Union depends to some extent on imports of precision munitions, which are difficult if not impossible to replace with other materials. Almost half of EU imports of palladium come from a single source, specifically 46% of EU imports of the material come from Russia [[66]]. As such, the importance of their supply is obvious. Furthermore, Manhart et al. (2016) note that there is significant environmental and social issues associated with mineral mining among the major global producers. While mining and smelting in Russia has caused significant pollution and released heavy metals and sulfur dioxide, the frequency of frequent knocks highlights the difficult working conditions for South African miners.

6-4-Gold

Gold is used in electronic components and printed circuit boards for mobile phones [[67]]. As a precious metal with great monetary value, it is widely used in anything from electronics to jewelry.

6-5-Silver

Silver: As a precious metal, silver has an important economic value. In the production of mobile phones, its main applications are in soldering paste and printed circuit boards. The electrical and electronic industry is responsible for about a quarter of global demand for the metal. No source country is responsible for silver production, unlike many of the other substances considered in this study. It is mined largely as a by-product of other ores, and production is distributed among multiple countries. As such, the potential environmental issues associated with mining are related to the mining of ores from which they are mined as a by-product. In the case of lead and zinc ores, these issues mainly relate to environmental pollution and emissions of heavy metals and other hazardous substances. Literary studies confirm that Europe provides [[68]] more than a quarter of the world's scrap silver supply.

6-6-platinum

Although traces of platinum are also found in cell phones, these concentrations are negligible compared to silver, gold, and palladium.
Based on analysis values from Umicore for mobile phones, Hagelüken and Buchert, (2008)[[69]] give the following quantities of 29 precious metals for each device:

Silver:	250 mg
Gold	24 mg
Palladium	9 mg

Assuming that the average weight of a mobile phone (without battery) is 90 grams and the average weight of a smartphone is 110 grams (also without battery), a linear extrapolation can be made to the minimum content of precious metals in smartphones:

Silver:	305 mg
Gold	30 mg
Palladium	11 mg

These amounts of precious metals per unit may seem small. However, it can be indicated using the example of palladium that at 100ppm, the content of palladium in mobile phones/smartphones is at least 10 times greater than the natural ore used to exploit the platinum group metals. Moreover, smartphone recycling provides synergies from the potential recovery of other metals such as copper, lead, nickel, bismuth, etc.

6-7-Copper

Copper was found in relatively large amounts in mobile phones compared to the other substances in focus in this study. It is generally used in mobile phones to make wires, alloys, electromagnetic shielding, printed circuit boards, amplifiers, and vibration alarms[[70]], and in smaller quantities in batteries, Chile and Peru play an important global role in copper mining and trade and are the main exporters of the metal to the European Union [[71]]. Copper mines also exist within the European Union, specifically in Finland, Poland, Portugal, Spain and Sweden, which supply about a fifth of the European Union's demand for the material. Notably, in

---

[64] Scoullos, M.J., Vonkeman, G.H., Thornton, I., Makuch, Z., "Mercury - Cadmium - Lead: Handbook for Sustainable Heavy Metals Policy and Regulation",Series: Environment & Policy, Vol. 31, Springer-Verlag, 2002.
[65] Manhart et al., 2016.
[66] European Commission (2017a), “Communication on the 2017 list of Critical Raw Materials for the EU”, COM(2017) 490 final.
[67] Manhart, A. et al. (2016), “Resource Efficiency in the ICT Sector”, Oeko-Institut e.V. (https://tinyurl.com/y4mwregm).
[68] Manhart, A. et al. (2016)
[69] Buchert, M.; Schüler, D.; Bleher, D.: Critical Metals for Future Sustainable Technologies and Their Recycling Potential, Öko-Institut e.V. (UNEP edits.) July 2009.
[70] Manhart, A. et al. (2016), “Resource Efficiency in the ICT Sector”, Oeko-Institut e.V. (https://tinyurl.com/y4mwregm).
[71] Schüler, D. (2017), “EU’s ore and metal import flows and engagement towards responsible sourcing in industry supply chains”, GREAT Insights, Vol. 6, Issue 3 (https://ecdpm.org/wpcontent/uploads/GREAT-6-3-July-August-2017-1.pdf).

contrast to many other materials considered in this study, 43% of the demand is supplied by copper recovered from domestic and industrial scrap from within the European Union [72].

8- Plastics recovery and recycling

Plastics from mobile phones are not yet widely recovered for use as plastics, because few facilities can effectively sort plastics and break them down into clean quantities of each type separately. In smelters that have appropriate flue gas processing facilities, plastics can be used in metal recovery processes as a heat source, as a substitute for other hydrocarbon fuels and as a damping agent. If mobile phone cases are designed to be easy to remove and are free from contaminating materials such as coatings, identification cards and metals, and if they can be collected in fairly large quantities, then the engineered plastics for mobile phones (usually ABS-PC) can be recycled for a return positive economics. Manual dismantling of mobile phones, before the recovery of precious metals, can lead to obtaining relatively clean quantities of these plastics. There is ongoing research in the field of identifying and sorting plastics, and this option may become economically viable in the future. The well-known German Fraunhofer Institute presented a practical statement in its pioneering project launched in the period 2001-2002 called “Region Plast”, in which it clarified that recycling plastics from electrical and electronic waste is technically feasible and economically viable for clean and larger plastic parts .

The plastics recovery process begins with the sorting of the plastics, a process that does not involve any exposure to hazardous materials. The sorted plastics are then ground, a process that can generate heat and, if not managed well, can generate smoke and fires. Plastic casings can contain brominated flame retardants, mostly decabromodiphenyl ether (DBBE), and DBBE is a flame retardant additive and some of it can be released from the plastic during the grinding process, but studies show that these quantities are small.

After grinding, the plastics are poured into the desired shape under high pressure and heat. In this process, exposure to the materials contained in the plastics may occur, but there will be no difference from the same type of plastic extracted from other sources.

BFR/BFR separation and polymer recovery:

Common screening methods are based on "cherry harvesting" of the most valuable components of electronic inputs/polymers. Their quantity is usually relatively low and is usually in the range of 20% to 60% depending on the input, design of the devices and the techniques used. However, POP-PBDEs, BFRs and BFRs are augmented (enriched) through the remaining waste fraction. The CreaSolv ® process extracts PBDEs/BFRs from target polymers from the enriched (augmented) polymer fraction and is able to remove insoluble contaminants (such as non-target polymers and other interfering materials) and dissolved pollutants (such as POPs from PBDEs, PBDEs or other BFRs) are target polymers using a proprietary CreaSolv® solvent formulation. The by-products contain high levels of BFR, and since the market price of bromine is about 4000 US dollars, these by-products can be used for bromine recovery. Alternatively it can be chemically treated or incinerated by incinerators. Some parts of WEEE plastics have been developed and are capable of producing high quality polymers with RoHS-compliant properties even from enriched BFR parts.

9-Conclusion

Mineral wealth is undoubtedly one of the basics of the current industrial age and the mainstay of the present civilization. Today’s permanent and continuous depletion of these wealth by man poses a future threat to human resources, and that the current consumption rates portend the extent of what future generations will suffer from an increasing shortage that may reach the point of starvation in these resources and energies. . They are non-renewable sources in general, and what is depleted of them goes forever, at least in a time that we do not say we realize, but we can hardly imagine it.

Also, throwing phone scraps into the waste poses a great health and environmental danger. Therefore, it is important to recycle this waste to avoid its evils, and at the same time recycle what it contains of metal treasures. Most of the items are critically important as resources. The availability and annual use of the mineral varies widely depending on the type of mineral. Some metals are abundant and widely used in structural applications; such as iron and aluminium. And some other metals, especially those in the platinum group (platinum, palladium, iridium, rhodium) are very precious. Such as cobalt used in phone batteries, or indium used in phone screens, in addition to gold, silver and other important metals in printed circuit boards, and through the study, we find that recycling steps are subject to environmental requirements and important conditions, and they need

[72] European Copper Institute (2019), “Europe’s Copper Industry” (https://copperalliance.eu/aboutus/europes-copper-industry/).

highly trained expertise, in addition to that There are other challenges represented in collecting scrap from phones and how to educate people about the need to deliver it to the places designated for this type of waste, and for this the study recommends more studies in this field and to clarify what has not been clarified in this study, and the study also recommends the concerned authorities to pay attention to this type of waste In the interest of the safety of the environment and humans, and the recovery of the treasures of precious and rare metals in the waste of cellular phones.

References

1. Achzet, B. (Universität Augsburg): Substitution kritischer Technologiemetalle, Eurogress Aachen – Hochtechnologiemetalle: Motor für Innovationen, Aachen 4. – 5. Mai 2011. [University of Augsburg: Substitution of critical technological metals, Eurogress, Aachen – Advanced technology metals: drivers for innovation, Aachen 4-5 May 2011.]
2. Akram, R., Fahad, S., Hashmi, M. ., Wahid, A., Adnan, M., Mubeen, M., Nasim, W., 2019. Trends of electronic waste pollution and its impact on the global environment and ecosystem. Environ. Sci. Pollut. Res. 26 (17), 16923–16938.
3. Bitkom (2018), "124 Millionen Alt-Handys liegen ungenutzt herum" (https://www.bitkom.org/Presse/Presseinformation/124-Millionen-Alt-Handys-liegenungenutzt-herum.html).
4. Brierley J. and Brierley C., "Present and Future Commercial Applications of Biohydrometallurgy," Hydrometallurgy, 59, (2001), 233-239.
5. Buchert, M.; Schüler, D.; Bleher, D.: Critical Metals for Future Sustainable Technologies and Their Recycling Potential, Öko-Institut e.V. (UNEP edits.) July 2009.
6. C. H. Lee, M. K. Jeong, M. Fatih Kilicaslan, J. H. Lee, H. S. Hong, and S. J. Hong, Waste Manag., DOI 10.1016/j.wasman.2012.10.002 (2013).
7. Chancerel, P., Meskers, C.E., Hagelüken, C., Potter, V.S., 2009. Assessment of precious metal flows during preprocessing of waste electrical and electronic equipment. J. Ind. Ecol. 13 (5), 791–810.
8. Chaperon, S., Sauv, S., 2008. Toxicity in teractions of Cd, Cu, and lead on soil urease and dehydrogenase activity in relation to chemical partitioning. Ecotoxicol. Environ. Saf. 70, 1–9.
9. Chaperon, S., Sauve, S., 2007. Toxicity interaction of metals (Ag, Cu, Hg, Zn) to urease and dehydrogenase activities in soils. Soil Biol. Biochem. 39, 2329–2338.
10. Chen A, Dietrich KN, Huo X, Ho S (2011) Developmental Neurotoxicants in E-Waste: An Emerging Health Concern. Environ Health Perspect. 119:431–438. doi: 10.1289/ehp.1002452
11. Dictionary of Mining, Mineral, and Related Terms", Compiled by the American Geological Institute, 2nd edition, 1997.
12. E. Ma, and Z. Xu, J. Hazard. Mater., DOI 10.1016/j.jhazmat.2013.10.020 (2013).
13. European Copper Institute (2019), "Europe's Copper Industry" (https://copperalliance.eu/aboutus/europes-copper-industry/).
14. European Commission (2017a), "Communication on the 2017 list of Critical Raw Materials for the EU", COM(2017) 490 final.
15. Ghosh B., Ghosh M.K., Parhi P., Mukherjee P.S. and Mishra B.K., "Waste Printed Circuit Boards Recycling: An Extensive Assessment of Current Status," Journal of Cleaner Production, 94, (2015), 5-19.
16. Götze, in: Proceedings of the conference Electronics Goes Green 2012+ (EGG), Berlin, Germany, 2012, pp. 1-8.
17. Hadi P., Xu M., Lin, C.S.K., Hui C.W., and McKay G., "Waste Printed Circuit Board Recycling Technologies and Product Utilization," Journal of Hazardous Materials, 283, (2015), 234-243.
18. Holleman, N. Wiberg, "Lehrbuch der Anorganischen Chemie", de Gruyter, 1985, 33. edition, p. 1486.
19. ICMM, (2006), Maximizing Value- Guidance on implementing materials stewardship in the minerals and metals value chain, ICMM International Council on Mining & Minerals.
20. Jiang, B., Adebayo, A., Jia, J., Xing, Y., Deng, S., Guo, L., Zhang, D., 2019. Impacts of heavy metals and soil properties at a Nigerian e-waste site on soil microbial community. J. Hazard. Mater. 362, 187–195.
21. Jiang, L., Cheng, Z., Zhang, D., Song, M., Wang, Y., Luo, C., Zhang, G., 2017. The influence of e-waste recycling on the molecular ecological network of soil microbial communities in Pakistan and China. Environ. Pollut. 231, 173–181.
22. K. S. Park, W. Sato, G. Grause, T. Kameda, and T. Yoshioka, Thermochim. Acta, DOI 10.1016/j.tca.2009.03.003 (2009).
23. K. Takahashi, A. Sasaki, G. Dodbiba, J. Sadaki, N. Sato, and T. Fujita, Metall. Mater. Trans. A Phys. Metall. Mater. Sci., DOI 10.1007/s11661-009-9786-4 (2009).
24. Khanna, R., Saini, R., Park, M., Ellamparuthy, G., Biswal, S.K., Mukherjee, P.S., 2020b. Factors influencing the release of potentially toxic elements (PTEs) during thermal processing of electronic waste. Waste Manage. 105, 414–424.
25. Kiddee, P., Pradhan, J.K., Mandal, S., Biswas, J.K., Sarkar, B., 2020. An overview of treatment technologies of E-waste. In: Handbook of Electronic Waste Management. pp. 1–18.
26. Ladou J., "Printed Circuit Board Industry." International Journal of Hygiene and Environmental Health, 209, (2006), 211–219.
27. Li J., Shrivastava P., Gao Z. and Zhang H.C., "Printed Circuit Board Recycling: A State of the Art Survey," IEEE Transactions on Electronics Packaging Manufacturing, 27, 1 (2004), 33-42.
28. Li J., Shrivastava P., Gao Z. and Zhang H.C., "Printed Circuit Board Recycling: A State of the

Art Survey," IEEE Transactions on Electronics packaging Manufacturing, Vol: 27, No: 1, (2004), 33-42.
29. Li, W. , Achal, V., 2020. Environmental and health impacts due to e-waste disposal in China—A review. Sci. Total. Environ. 737, 139745.
30. M. Alfantazi, and R. R. Moskalyk, Miner. Eng., DOI 10.1016/S0892-6875(03)00168-7 (2003).
31. Manhart et al., 2016.
32. Manhart, A. et al. (2016), "Resource Efficiency in the ICT Sector", Oeko-Institut e.V. (https://tinyurl.com/y4mwregm).
33. Montero R., Guevara A. and de la Torre E., "Recovery of Gold, Silver, Copper and Niobium from Printed Circuit Boards using Leaching Column." J. Earth Sci. Eng, 2, (2012), 590-595.
34. Murugan R.V., Bharat S., Deshpande, A.P. Varughese, S. and Haridoss P., "Milling and Separation of the Multi-Component Printed Circuit Board Materials and the Analysis of Elutriation based on a Single Particle Model." Powder Technology, 183, (2008), 169–176.
35. Nnorom, I.C., Odeyingbo, O.A., 2020. Electronic waste management practices in Nigeria. In: Handbook of Electronic Waste Management. Butterworth-Heinemann, pp. 323–354
36. Ogunniyi I.O., Vermaak M.K.G. and Groot D.R., "Chemical Composition and Liberation Characterization of Printed Circuit Board Communition Fines for Beneficiation Investigations," Waste Management, 29, (2009), 2140-2146.
37. Peng, H., Michael, S., Reid, X., Le, C., 2015. Consumption of rice and fish in an electronic waste recycling area contributes significantly to total daily intake of mercury. J. Environ. Sci. 38, 83–86..
38. Pia Tanskanen, Electronics Waste: Recycling of Mobile Phones , Nokia Corporation.
39. Purchase, D., Abbasi, G., Bisschop, L., Chatterjee, D., Ekberg, C., Ermolin, M., Wong, M.H., 2020. Global occurrence, chemical properties, and ecological impacts of E-wastes (IUPAC Technical Report). Pure Appl. Chem. 92 (11), 1733–1767.
40. Rocchetti, L, Vegliò, F., Kopacek, B., Beolchini, F., 2013. Environmental impact assessment of hydrometallurgical processes for metal recovery from WEEE residues using a portable prototype plant. Environ. Sci. Technol. 47, 1581–1588. doi:10.1021/es302192t.
41. Ruan, J., Zhu, X., Qian, Y., Hu, J., 2014. A new strain for recovering precious metals from waste printed circuit boards. Waste Manag. 34, 901–907. doi:10.1016/j.wasman.2014.02.014.
42. Schüler, D. (2017), "EU's ore and metal import flows and engagement towards responsible sourcing in industry supply chains", GREAT Insights, Vol. 6, Issue 3 (https://ecdpm.org/wpcontent/uploads/GREAT-6-3-July-August-2017-1.pdf).
43. Scoullos, M.J., Vonkeman, G.H., Thornton, I., Makuch, Z., "Mercury - Cadmium - Lead: Handbook for Sustainable Heavy Metals Policy and Regulation",Series: Environment & Policy, Vol. 31, Springer-Verlag, 2002.
44. Singh, N., Duan, H., Ogunseitan, O.A., Li, J., Tang, Y., 2019. Toxicity trends in E-Waste: A comparative analysis of metals in discarded mobile phones. J. Hazard Mater. 380, 120898.
45. Singh, N., Duan, H., Tang, Y., 2020. Toxicity evaluation of E-waste plastics and potential repercussions for human health. Environ. Int. 137, 105559.
46. Statista, 'Most used materials in a smartphones | Statistics', Statista, 2017. [Online]. Available: https://www.statista.com/statistics/270454/top-10-materials-in-a-smartphone/. [Accessed: 13-Nov-2017].
47. Statistica. (2017). Number of mobile phone users worldwide from 2013 to 2019 (in billions). Retrieved November 6, 2017, from https://www.statista.com/statistics/274774 / forecast-of-mobile-phone-users-worldwide.
48. Sum E.Y.L., The Recovery of Metals from Electronic Scrap, JOM, April, (1991), 53-60.
49. T. Minami, Thin Solid Films, DOI 10.1016/j.tsf.2007.03.082 (2008).
50. Talens Peiró, L. et al.: Results from the workshop: Preliminary sustainability assessment: multifunctional mobile phone; prosuite project, Brussels 3 February 2011.
51. Tenorio J.A.S., Menetti R.P., and Chaves A.P., "Production of Non-ferrous Metallic Concentrates from Electronic Scrap," EPD Congress 1997, TMS, Warrendale, PA, USA, (1997), 505-509.
52. Umicore: Informationen zur Materialzusammensetzung verschiedener WEEE-Fraktionen [Information on the material composition of different WEEE fractions]. Daten der Firma Umicore [Data supplied by Umicore]. Hoboken, 2011.
53. US EPA, National Primary Drinking Water Regulations, Consumer Fact Sheet on Lead.
54. Veit H.M., Diehl T.R., Salami A.P., Rodrigues J.S., Bernardes A.M. and Tenório J.A.S., "Utilization of Magnetic and Electrostatic Separation in the Recycling of Printed Circuit Boards Scrap" Waste Management, 25 (2005) 67–74.
55. Wang, F., Ruediger, K., Daniel, A., Jinhui, L., 2013. E-waste in China: A country report.Bonn.
56. Wang, H., Zhang, S., Li, B., Pan, D.A., Wu, Y., Zuo, T., 2017. Recovery of waste printed circuit boards through pyrometallurgical processing: A review. Resour. Conserv. Recycl. 126, 209–218.
57. William, J.H. and Williams, P.T., "Separation and Recovery of Materials from Scrap Printed Circuit Boards." Resources Conservation and Recycling 51, (2007), 691–709.
58. Yamane L.H., Moraes V.T. and Espinosa D.C.R., "Recycling of WEEE: Characterization of Spent Printed Circuit Boards from Mobile Phones and Computers," Waste Management, 31, (2011), 2553-2558
59. Yoo J.M., Jeong J., Yoo K. Lee J.C. Kim W., "Enrichment of the Metallic Components from Waste Printed Circuit Boards by a Mechanical

Separation using a Stamo Mill," Waste Management, 29, (2009), 1132-1137.

60. Zeng X., Zheng L., Xie H., Lu B., Xia K. Chao K., Li W., Yang J., Lin S. and Li J., "Current Status and Future Perspective of Waste Printed Circuit Boards Recycling," Procedia Environmental Sciences, 16, (2012), 590-597.
61. Zhang S. and Forssberg E., "Mechanical Separation-Oriented Characterization of Electronic Scrap," Resources, Conservation and Recycling, 21, (1997), 247-269.
62. Zhou Y., Qiu K., "A New Technology for Recycling Materials from Waste Printed Circuit Boards, Journal of Hazardous Materials," 175, (2010), 823–828.