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

Electronic display screens between the benefits and harms

Fekri Mohammed Mohammed Noaman Al-Braihi[1,*] , Niyazi A. S. Al-Areqi[2]

[1]55Street 6,block6,Salmiya, Kuwait.

[2]Department of Chemistry, Faculty of Applied Science, Taiz University, Taiz, Yemen.

Email address:

fekrinoaman@gmail.com (Al-Baraihi, Fekri), niyazi75.alareqi@gmail.com (Al-Areeqi, Niyazi)

To cite this article:

Abstract

Electronic display equipment is developing day by day. However, the global waste electrical and electronic equipment problem is rooted in a lack of technically mature solutions, weak enforcement and high costs of legal processes, and it is simply cheaper for end users to ship waste materials abroad. The lack of an effective technical solution, for efficient and selective mineral recovery plays a major role. The danger of electronic waste lies in the fact that it contains more than 1,000 different substances, many of which have toxic components, including lead and arsenic, which are found in a high percentage in television screens, dioxin and antimony trioxide, bromide compounds that are produced as secondary sources, and the dangerous element selenium that is found in integrated circuit boards and helps on regulating the passage of electric current in them, cadmium, which is also found in integrated circuits, chromium, which is used in steel packaging to protect it from rust and corrosion, cobalt, which is used in some devices to take advantage of its magnetic properties, and mercury, which is used in the manufacture of circuit breakers, as we find it in keyboard and flat screens. In addition to all the risks arising from WEEE, the manufacture of electrical and electronic equipment (EEE) screens consumes large amounts of metal. The electronics industry is the third largest consumer of gold (Au), and is responsible for 12% of global demand, 10% for indium, along with 30% for copper (Cu), silver (Ag) and tin (Sn). Rare or other minerals are of critical importance to ICT equipment (mobile phones, computers, etc.), and are of great value in human life. The most common rare metals in display equipment and information and communication technology are indium, yttrium and gallium. This study sheds light on the contents of the display screens of important minerals and clearly reveals the danger of some elements, and methods of treatment and recovery of the most important elements.

Keywords: waste of electronic displays, minerals that contain them, Processing and recovery techniques.

1-INTRODUCATION

On the occasion of World E-Waste Day 2021, which falls on Thursday, 14 October, the WEEE Forum - an international not-for-profit association based in Brussels, representing 45 organizations interested in reporting E-waste - "Total waste expected this year, worldwide, is 57.4 million tons, which exceeds the weight of the Great Wall of China, which is the largest human structure by weight on Earth." The huge increase in the generation of WEEE is particularly prevalent in countries with developed economies, where the markets for electrical and electronic equipment are saturated. In developed countries, WEEE accounts for up to 8% of municipal waste by weight [1], with the relative proportion increasing. Modern devices include up to 60 elements, with the complexity increasing with different mixtures of compounds [2]. The number of metals used in devices has increased over the years, as the fluorescent, conductive and alloying properties of technological metals have been revealed [3]. These elements are used to manufacture microprocessors, printed circuit boards (PCB), and displays , such as cathode ray tubes (CRT), liquid crystal displays (LCD), light-emitting diodes (LED), and permanent magnets, usually in small quantities and often complex alloys. . The wealth of society depends on many minerals, including base metals, precious metals and increasingly rare earth elements (REE). They are collectively called technology minerals. E-waste represents a growing challenge in line with the growth of the Information and Communication Technology (ICT) industry. Also, many electronic and electrical applications depend on the use of metals, and their supplies are at risk of depletion due to high demand and uneven geographical distribution of these metals. That is why its stable supply is critical to the transition to a sustainable circular economy. That is why the growing interest in secondary sources of these minerals appeared. On the other hand, e-waste contains many valuable raw materials such as gold, copper and iron. In 2019, the raw materials contained in e-waste generated were estimated to be worth 57 billion US dollars. At the current collection and recycling rate (17.4 per cent), US$10 billion worth of raw materials can be recovered. Under the right conditions, and after due health and safety precautions, e-waste recycling and regeneration activities can create green jobs around the world. This study summarizes electronic waste and its management and the latest technological developments in metal recovery from various displays. It focused on liquid crystal displays (LCDs), organic light-emitting diodes (OLEDs), cathode ray tubes (CRTs), computer and mobile phone screens with regard to their important metal content. And a review of techniques for extracting minerals by physical, thermal and (biological) methods for recovering minerals. In addition, perspectives on e-waste as a secondary source of important minerals are given.

2-The importance of studying

Increased demand for precious and rare metals in the electrical and electronic equipment industry will encourage recycling and the development of alternative materials that can perform the same functions. In order to carry out this type of recycling, the responsible industries need information on the type and quantity of rare metals used in components and units of ICT devices. More and more technologies must be made available that help in metal recovery. This study focuses on the chemistry and engineering of electronic displays in terms of the most commonly used screens and the minerals they contain, while addressing traditional and innovative separation and recovery techniques for electronic waste, with special attention to overall sustainability.

[1] Robinson, B., 2009. E-waste: an assessment of global production and environmental impacts. Sci. Total Environ. 408, 183–191. doi:10.1016/j.scitotenv.2009.09.044.
[2] Graedel, T.E., 2011. Metal Stocks & Recycling Rates, Recycling Rates of Metals: A Status Report, UNDP.
[3] Tunsu, C., Petranikova, M., Gergorić, M., Ekberg, C., Retegan, T., 2015. Reclaiming rare earth elements from end-of-life products: A review of the perspectives for urban mining using hydrometallurgical unit operations. Hydrometallurgy 156, 239–258. doi:10.1016/j.hydromet.2015.06.007.

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→ Groups ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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 important elements in the manufacture of electronic displays

3- GLOSSARY

Environmentally sound management: Take all feasible steps to ensure that used or end-of-life products or waste are managed in a manner that protects human health and the environment[4].

Dismantling : The dismantling of display equipment, components, or assemblies to separate materials and/or maximize options for reuse, refurbishment or recycling and maximize recovery value.

Separation: The removal of specified components (such as batteries), components or materials from electronic equipment such as displays by manual or mechanical means.

Mechanical separation: The process of using machines to separate display equipment into various materials or components.

Treatment: Any physical, chemical, or mechanical activity at a facility that processes display equipment, including dismantling, removal of hazardous components, material recovery, recycling, or preparation for disposal.

4-Waste electric and electronic equipment

Waste electronic displays represents any electronic product complete or in the form of discarded components. It is the waste of electrical or electronic equipment, including all components, sub-assemblies and consumables that are part of the equipment at the time the equipment becomes waste [5] . WEEE waste consists of a group of materials that are called "clean" (that is, they do not contain harmful substances), including copper (Cu), aluminum (Al), transparent glass, plastic, rubber and ferrous metals. But there are other wastes that contain harmful substances such as lead (pb), arsenic (As), chromium (Cr), mercury (Hg), nickel (Ni), beryllium (Be), selenium (Se), and cadmium (Cd), as well as precious and rare metals, all of which They require advanced processing in order to eliminate their evils or recover and reuse them. Experimental studies indicate that the important metal content of electronic waste is distributed in several components, namely display screens such as mobile phone screens, computer screens and televisions. In addition to the Active Matrix Liquid Crystal Display (AMLCD) and E-paper: E Ink, Gyricon, Electroluminescent Display (ELD), Digital Light Processing (DLP) and FED Displays. which is also called nano-emission display (NED), inline interference display (IMOD), light-emitting diode (LED), liquid crystal display (LCD), and organic light-emitting diode (OLED). Plasma panel screens (PDP), quantum dot matrix display (QLED), and surface conduction electronic emitter display (SED, SED-tv), and it is evident that the production rate of electrical and electronic equipment (EEE) is very high all over the world due to The increase in the use of this equipment and advances in the electronics, information technology and communications industries are improving the living standards of consumers.Moreover, discarded PCB

[4] Partnership for Action on Computing Equipment - UNEP/CHW.10/20- 11 July 2011

[5] Guidelines and Certification Schemes for E-waste Recyclers - Recommendation ITU-T L.1032 2019

printed circuit boards are offered as a secondary source of platinum group metals (PGM), and liquid crystal displays (LCD) as a secondary source of indium (In) , and engines Hard disks (HDD) as a secondary source of light rare earth elements[6]. WEEE tailings contain precious metals such as gold (Au), silver (Ag), platinum (Pt), gallium (Ga), palladium (Pd), tantalum (Ta), tellurium (Te), germanium (Ge) and selenium (Se), as well as rare earth metals. Such as yttrium (Y), europium (Eu), and crude coltan.

5- Displays

Displays have been upgraded in recent years, in line with the rapid innovations in the electronics sector. The popularity of LCD monitors is due to their small size and lower costs compared to CRT monitors. LCDs are made of an average of 85% glass and are used in various parts of equipment such as televisions, computer monitors, laptops, tablets and cell phones [7]. Light-emitting diode (LED) displays are a product developed for LCDs and are expected to replace LCDs in the short to medium term. Thus, a trend to recover critical minerals from discarded LCDs and other displays such as LEDs can be expected in the coming years. Also, display screens generally have a life cycle and at the end of it is considered waste.

5-1- The plasma display panel (PDP)

They are screens that consist of cells made up of a huge amount of very fine glass crystals that are sandwiched between two plates of glass with high transparency, and these crystals are trapped between a mixture of gases that emit less ultraviolet radiation, and when the device is turned on, it spreads the image between them It reflects it to a very clear degree and pure colors. The screen works with the inert gases, neon and xenon, in hundreds of thousands of cells confined to a flat glass enclosure of two charged plates. In the color screen version, gas ions emit ultraviolet photons which result in a phosphor on the back plate to emit colored light. Each pixel consists of three sub-pixels (for red, green, and blue) with three different colored phosphors.

5-2- LCD - Liquid Crystal Display

It is an optical device consisting of crystals arranged on a thin surface divided into many elements supported by a backlight, the crystal converts polarized light to show an image, symbol or signal. LCD screens are used in modern computer monitors, portable displays, and television screens. Nowadays, they are being replaced by OLED screens, because they are good light emitters, have lower mass and better resolution, better color contrast, and use less electricity than LCD screens. Despite all the advantages mentioned above, OLEDs have a very short life compared to LCD screens, which creates a large portion of electronic waste However, the amount of different metals in OLED screens is greater than in LCD screens, for example silver, beryllium, chromium, copper, nickel tin; While the presence of copper and titanium has been reported at more than the threshold limits in California.

[6] HIWA SALIMI,2017,Extraction and Recovery of Gold from both Primary and Secondary Sources by Employing A Simultaneous Leaching and Solvent Extraction Technique and Gold Leaching In Acidified Organic Solvents -Department of Chemistry-University of Saskatchewan. Saskatchewan S7N 5C9 Canada.

[7] Rotter, V.S., Ueberschaar, M., Chancerel, P., 2013. Rückgewinnung von Spurenmetallen aus Elektroaltgeräten, in: Proceedings of Berlin Recycling and Raw Materials Conference. Berlin, pp. 481–493.

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 plasma display panel (PDP)

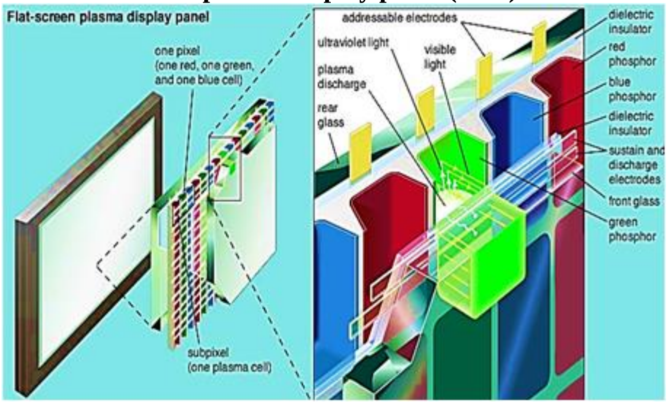


Figure 2 : **The plasma display panel (PDP)**

LCD - Liquid Crystal Display

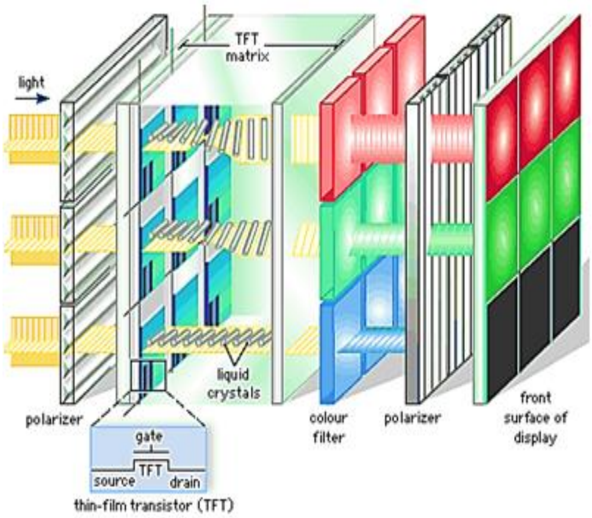


Figure 3: **LCD - Liquid Crystal Display**

5-3-Electrical illumination (ELD) screens

In an electroluminescent display (ELD), the image is produced by sending electrical signals to the plates that cause the phosphor to glow. Improvements in the luminous efficacy of white LEDs, the quality of light guides, as well as increases in actual LCD film transparency nearly halved the number of LEDs used in LCD panel backlighting between 2009 and 2010. In 2010 this was about 100 LEDs per screen. However, it is possible that this current evolution towards fewer LEDs could fall or be reflected due to the trend towards larger flat screens that require more LEDs for backlighting. Besides larger screens, flat screens with 3D capability also require improved backlighting. The main technologies used in 3D TVs, the shutter method and the use of polarizing filters, reduce brightness by 80% and 60%, respectively. Therefore the decrease in brightness must be compensated for by a stronger backlight[8]. These increased demands on backlighting power will likely be primarily met by direct lighting methods or hybrid designs.

[8] Young (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

Electroluminescent (ELD) displays 	**Television screens** 

Figure 4: Electroluminescent (ELD) displays and Television screens

5-4-Television screens

Televisions are one of the most widespread and important electronic display applications, in 2006 190 million units were sold worldwide. In recent years, the market has been boosted by the availability of low-cost flat-panel LCD monitors. The global market for LCD TVs was estimated at nearly $40 billion in 2008[[9]], thanks to the rapid growth in demand for flat-screen TVs and the move to larger screens and sizes. The growth prospects for OLED TV since its inception, although broadcast TV is largely influenced by an industry that is currently seeking to reap the benefits of its investment in LCD manufacturing. Half of total OLED panel revenue in 2012, growing rapidly from just $150 million in 2011 to $1.5 billion in 2013 [[10]].

5-5- screens IT

After televisions, LCD monitors, TI is the second largest segment of the display industry with revenues of approximately $24 billion in 2007 [[11]]. Display Search (2008) has predicted that the desktop monitor market grew at least until 2015, with LCD continuing to dominate. Current trends are towards replacing laptops and notebooks with desktop computers and moving to larger and larger screen sizes. Shipments of CRT monitors, which are still available as a display technology, will continue to shrink.

5-6- Screens of e-paper Definition of e-paper

E-paper: A portable and reusable storage and presentation medium, usually thin and flexible. It is a type of electronic display screen. It is also technically defined as controlling the arrangement of magnetic granules in shades between white and black on a smooth surface by means of electric current so that it is possible to control the drawing of information on that surface by controlling the passage of electric current over a specific place or granule (the electric current produces a magnetic field that affects the arrangement and clarity magnetic granules).

[9] iSuppli (2008), Display Market Outlook.

[10] http://www.idtechex.com/products/en/articles/00000934.asp

[11] Display Search (2008), 'Total flat panel display shipments will grow 5% per year through 2015; consumer and industrial applications driving growth', Press Release, 5 February, http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/flat_panel_displays_more_t han_99_percent_of_display_sales.asp.

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

IT . screens

Definition of e-paper

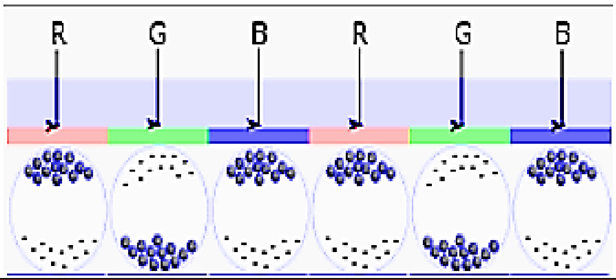


Figure 5: IT . screen and e-paper

5-7-The organic light-emitting diode is called an organic light-emitting diode, or OLED for short:

It is a light-emitting diode (LED) in which the electrical emission layer consists of a film or layer of organic compounds that emit light in response to an electric current. This layer of organic semiconductor material is sandwiched between two electrodes. Generally, at least one of these electrodes is transparent. There are two main types of OLEDs: those that use small molecules and those that use polymers. OLEDs are used in television screens, computer screens, small, portable system screens such as mobile phones, PDAs, watches, advertisements, information, and a signal. It is also used on a large field of public lighting. Organic Light-Emitting Diodes (OLEDs) are a next-generation display technology that collects tiny dots of an organic polymer that emits light when charged with electricity.

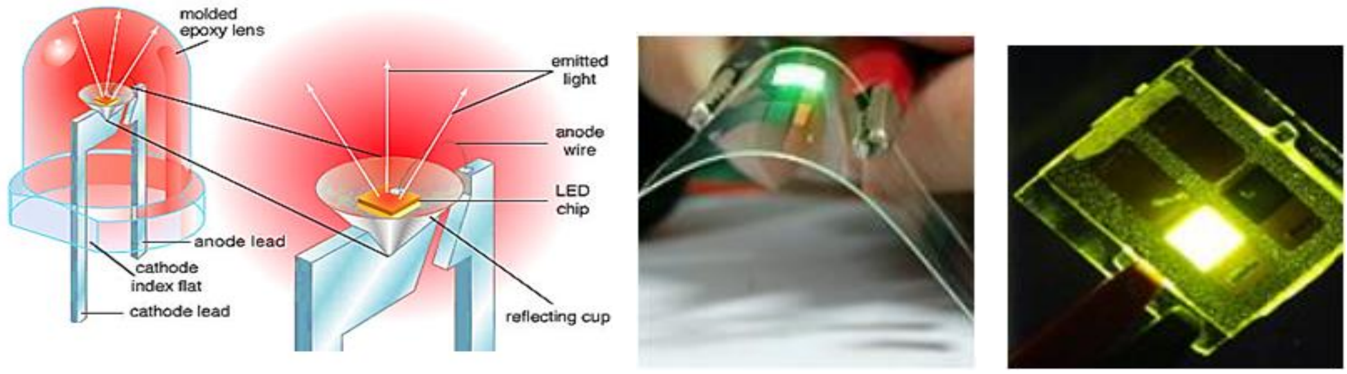


Figure 6: Organic Light Emitting Diodes (OLEDs)

Much of the first research was done in Europe, particularly in the Netherlands, Germany and the UK, although Kodakin in the USA did some very early research. In percentage terms, OLEDs are the fastest growing field of flat display today, with European gaming technology developer. Because OLED displays are multi-pixel color, they have many ICT applications in consumer goods and industrial applications. In the single-pixel form, OLEDs are also a candidate for new forms of lighting so that European lighting manufacturers, such as GE Osram and Philips, are working in a new fashion using unique properties. OLED screens, have good light emitters, have less mass and better resolution, better color contrast, and use less electricity than LCD screens. Despite all the advantages mentioned, OLEDs have a very short life compared to LCD screens, which creates a significant portion of waste However, the amount of different metals in OLED screens is greater than in LCD screens, for example silver, beryllium, chromium, copper, nickel and tin.

5-8- CRT screens

Cathode ray tube monitors (CRT - Cathode Ray Tube) are monitors that contain an electronic valve that produces a flood of electrons in the form of a microbeam. This tube was found in older versions of computers, monitors, and televisions. The amount of lead content in them varies depending on the age of the device, the older version contains 2-3 kg, while the newer versions of CRTs contain 1 kg of lead. The frame and bearing of an electron pistol consist of 1 to 2 grams of barium and its compounds. The advent of light-emitting diode (LED) and plasma screens that are lightweight [[12]] , space-saving and energy-saving has greatly reduced the demand for the new CRT used in television and computer monitor, as CRT takes up a lot of space due to its massive size and heavy weight. Glass

[12] Yamashita M, Wannagon A, Matsumoto S, Akai T, Sugita H, Imoto Y, Komai T, Sakanakura H (2010) Leaching behavior of CRT funnel glass. J Hazard Mater 184:58–64. https://doi. org/10.1016/j.jhazmat.2010.08.002.

recycling cathode ray tube are reluctant to dispose of cathode ray tube and instead store glass cathode ray tube due to the high cost of disposal and negative economic incentives. Storage of this cathode ray tube presents a major challenge for environmental pollution (soil and air) caused by lead leaching. The harmful environmental impact is the driving force for the search for an alternative technology and the development of solutions for CRT glass recycling.
Cathode ray tubes (CRTs) are a major component of CRT monitors and CRT televisions. CRTs contain a large amount of hazardous substances such as lead, cadmium and barium oxide and therefore must be handled carefully in a suitable plant to avoid personal injury.

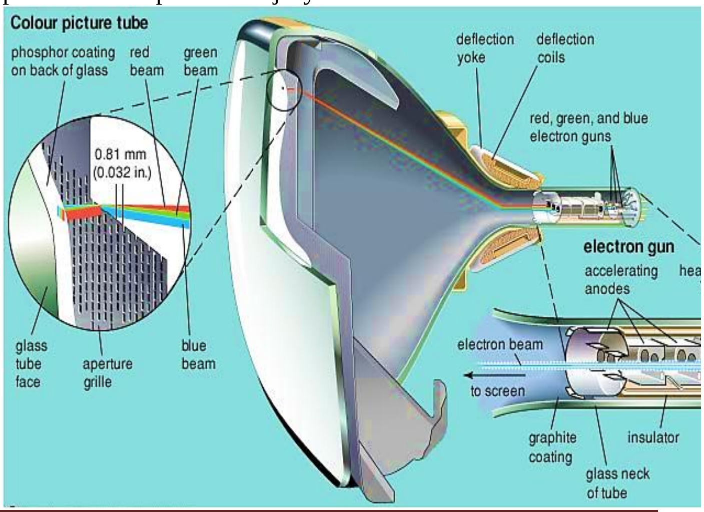


Figure 7: CRT screens

6-Current Status of Waste Electronic Monitors and Performance Evaluation

6-1- Performance Tests for Display Equipment

Hardware	Functional performance tests	Tests results
projectors	Plug in a projector and test the image quality in terms of dots, colour, contrast and brightness. Diagnostic test software for display devices already exists online and should be used. Visual inspection for screen burns (in the case of CRTs) or image persistence (in the case of flat screens), scratches, or other damage to the screen or frame[13]. Cables should be inspected and checked for presence.	Display devices: The image should not be fuzzy, have bad spots, or be excessively dark. All LCD backlights should be working. Colors, brightness, hue and straightness of lines should be checked. A diagnostic test of the software should prove that it is working. Cables must be free of any damage.
Components (removed from equipment)	Components should be tested for functionality, either	Components should be fully working. The electrical supply

including motherboards and other circuit boards, sound cards, graphics cards, hard disk drives, power supplies, and wires/cables.	prior to removal from the host computer or laptop or insertion into a test bench computer using diagnostic software or known working hardware, as applicable. .	units and wires/cables should be complete and free from damage, eg with no cracked insulation.

6-2- Service life and collection rates for flat screens

The average life of computer monitors has been estimated as 6.6 years as part of the European Union's environmental design process[14] This figure includes both the first use and the average length of the second use. According to Zangl et al. (2009) [15] , the average life of televisions can be assumed to be 10 years.

The following possibilities can be considered:

- These values do not include any delay from the hardware usage phase. It is just an estimate of actual collection rates.
- Delayed disposal (storage of old devices by the user) Disposal by household waste
- Export to other countries

Referring to the last point in particular, both televisions and computer monitors are known to be frequently exported to Eastern Europe or West Africa where the devices are repaired and sold to local or regional markets[[16]] . Currently, it is exported to China, India, Ghana, Nigeria, Brazil and many developing countries.

6-3-Status of pre-treatment technology for flat screens

In Germany and the EU, flat panel monitors are introduced into a separate recycling process after they are collected, mainly for the purpose of recovering mercury from gas-discharge lamps (LCD monitors with CCFL backlight). To achieve the best recovery, the tubes must be removed manually. Although this procedure is implemented by a variety of companies, it should only be done under strict health and safety standards due to mercury emissions from damaged lamps. In general, when using this procedure, it should be assumed that during unwinding, 5-20% of the capillary tubes will be damaged until mercury escapes [[17]].
Complete manual disassembly of CCFL backlit LCD monitors results in the following fractions:

- Plastic parts (sometimes divided according to different types of polymers) steel and aluminum plates
- Printed circuit boards CCFL lights
- display boards
- The flat screens currently entering the waste stream are primarily LCD screens with CCFL backlighting.

[13] LOOK AT : www.softpedia.com/progDownload/Nokia-Monitor-Test-Download-464.html

[14] Preparatory studies for Eco-design Requirements of EuPs, Lot 3: Personal Computers (desktops and laptops) and Computer Monitors. Brussels, 2007.
[15] Zangl , S.; Brommer , E.; Grießhammer, R.; Gröger, J.: PROSA Fernsehgeräte [PROSA television sets]. Oeko-Institut e.V., Freiburg, 2009.
[16] Manhart, A.; Griesshammer, R.: Soziale Auswirkungen der Produktion von Notebooks [Social impacts of the production of notebook PCs]. Oeko-Institut e.V., Freiburg, 2006.
[17] Böni. H.; Widmer, R.: Disposal of Flat Panel Display Monitors in Switzerland. EMPA, St. Gallen, 2011.

- Newer technologies such as LED-backlit LCD or OLED displays are not quantitatively significant in the waste stream.

The plastic, steel, aluminum and printed circuit board part are transported to the relevant markets for material recycling. CCFL lamps are sent to general lamp recycling where proper treatment of mercury is a priority. In addition, the glass and some metal components found in the sockets are sent for material recycling. The luminous materials themselves and any contaminants from broken glass, mercury, and other materials are usually deposited underground[[18]]. Instead of manual disassembly, the complete or partially disassembled display unit can be sent for mechanical pretreatment where the devices are shredded in an airtight shredder and mercury is removed from the process air. However, this process also failed to address all issues, and another option is to heat treat disassembled or partially disassembled display units [[19]] . The displays are usually thermally recycled in waste incineration plants or in a steel mill dust wael furnace process. The organic components (liquid crystals, polarizing filters, resins) are burned and the glass is bonded with oxidized metals in an inert slag [[20]].

6-4- Current Status of the Waste Cathode-Ray Tube

Many countries such as the United States, China, India, Brazil, South Africa and Turkey are facing serious challenges in dealing with cathode ray tube. While electronic devices such as smartphones, tablets, and laptops seem to have shorter and shorter lifespans, consumers tend to stick to televisions for more than a decade before they hit the recycling stream. Therefore, it is difficult to completely eliminate the possibilities of cathode ray tube recycling in television sets in the near future even though their number is decreasing exponentially. In 2015, the Consumer Electronics Association (CTA) conducted a survey to determine how many cathode ray tube devices may still be in use or stored somewhere in American homes. The study found that about 34% of households in the US still have at least one home, down from 41% in 2014. Supply seems to be shrinking, but it's still big. It is estimated that 6.9 million tons of CRT waste (43% of all e-waste) in the United States has yet to be collected from residential and commercial buildings for recycling [[21]][[22]] . The situation is becoming more bleak in Asian countries such as China and India. Even countries like Turkey produced 0.22 kg of cathode ray tube per person in 2015 [[23]].

---

[18] Martens, H.: Recyclingtechnik – Fachbuch für Lehre und Praxis [Recycling technology – a textbook of theory and practice]. Heidelberg, 2011.

[19] Böni & Widmer 2011 ،Martens 2011.

[20] Martens 2011.

[21] Singh N, Wang J, Li J (2016a) Waste cathode rays tube: an assessment of global demand for processing. Procedia Environ Sci 31:465–474. https://doi.org/10.1016/j.proenv.2016.02.050.

[22] Singh N, Li J, Zeng X (2016b) Solutions and challenges in recycling waste cathode-ray tubes. J Clean Prod 133:188–200. https://doi.org/10.1016/j.jclepro.2016.04.132

[23] Öztürk T (2015) Generation and management of electrical–electronic waste (e-waste) in Turkey. J Mat Cycles Waste Manag 17:411–421. https://doi.org/10.1007/s10163-014-0258-6

7- Methods of Analysis

Spectroscopic Analysis

The internal interaction between the radioactive energy and the substance can be used to reach information about the materials, as the measurement of the energy emitted or absorbed from the impact sample gives information about the nature and degree of concentration of the elements or compounds present in the substance. Emission Spectroscopy is concerned with measuring the amounts of energy emitted by atoms while they are in an excited state With a specific wavelength, the excitation occurs either by using a high voltage electric current or by a very high temperature torch or by high energy radiation, which is very useful for the analysis of inorganic materials such as metals

X-Ray Diffraction Analysis

Where this analysis is done by examining the structural composition of the mineral crystal, determining the internal defects, studying the atoms, identifying the atomic number and energy levels of the elements, determining the size of the crystals, and knowing the products of corrosion. The methods of analysis depend on the vertical dimensions of the atomic surfaces of materials ranging from parts to a double number and a few angstroms.

X-Ray Fluorescence Analysis

By examining in this way, it is possible to identify most of the elements, which is a non-destructive method, and results in a graphic model with Peaks curves for the intensity of the recorded reflection compared to the angle of reflection, as the relative height of the curve expresses the percentage of the element.

8-Mineral content and chemicals in electronic displays

8-1- Chemicals used in crystal screens

Several different families of liquid crystals are used in liquid crystals. The particles used must be anisotropic, and exhibit mutual attraction. Polarizing rod molecules (diphenyl, terphenyl, etc.) are common. The common form is a pair of aromatic benzene rings, with a nonpolar moiety (pentyl, heptyl, octyl, or alkyl oxy) moiety on one end and a polar (nitrile, halogen) moiety at the other. Sometimes the benzene rings are separated by an acetylene or ethylene group, CH = N, CH = NO, N = N, N = NO, or an ester group. In practice, eutectic mixtures of several chemicals are used, to achieve a wider operating temperature range (−10..+60°C for the low end and 20..+100°C for high performance screens). For example, an E7 mixture consists of three bisphenyl and one terphenyl: 39% by weight of 4'-pentyl[1,1'-biphenyl]-4-carbonitrile]nematic 24..35°C), 36 wt. %4'-heptyl[1,1'-biphenyl]-4-carbonitrile (nematic range 30..43°C), 16 wt.% of 4'-octoxy[1,1'-biphenyl]-4-carbonitrile (nematic range 54...80 °C), and 9 wt% of 4-pentyl[1,1':4',1-terphenyl]-4-carbonitrile (nematic range 131...240 °C).

8-2- Indium

Indium (In) is an essential element for displays, especially in liquid crystal displays, due to its semiconductor and optoelectronic properties. Indium tin oxide (ITO) films serve as electrodes in liquid crystal displays and account for more than 70% of worldwide use [[24]]. Indium is used in the form of indium tin oxide (ITO) as the electrode material in flat screens as well. LCDs are interesting due to their short average life, around 3-8 years [[25]], 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 [[26]], electroetching, pyrolysis, acid filtration followed by solvent extraction and demineralization or cementation. The advantage of indium tin oxide is that it is transparent, conductive and highly heat-resistant. The ITO layers applied in the screens consist of 90% In_2O_3 and 10% SnO_2, which is equivalent to 78% by weight of indium [[27]]. While two layers of ITO are applied to LCD screens, OLED screens have only one layer. The importance of indium is associated with the manufacture of electrical and electronic equipment (EEE), in particular, 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 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

[24] Dang , M.T., Brunner, P.-L.M., Wuest , J.D., 2014. A green approach to organic thin-film electronic devices: Recycling electrodes composed of Indium Tin Oxide (ITO). Sustain. Chem. Eng. 2, 2715–2721. doi:10.1021/sc500456p

[25] E. Ma, and Z. Xu, J. Hazard. Mater., DOI 10.1016/j.jhazmat.2013.10.020 (2013).

[26] 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).

[27] Böni. H.; Widmer, R.: Disposal of Flat Panel Display Monitors in Switzerland. EMPA, St. Gallen, 2011.

[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).

[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).

end-of-life LCD screens, which show indium content in the range of 100-200 ppm [[32]]. Besides the relatively high indium content.

FEM & IUTA 2011 [[33]] has set an average indium content of 174 g/ton of supply waste for a supply recycling stream. If this value is related to individual monitors, this approximation refers to average amounts between 464 and 864 mg/m2 (see the following table), so that an average value of 700 mg/m2 for LCD monitors is assumed below. A similar value will be assumed for plasma screens with only 10% market share in the TV segment.

Table 1: Approximation calculation of indium content in LCD displays

	Mean weight of Display [g]	Mean content of In [g/t]	Mean In content per device [mg]	Mean screen Area [cm^2]	Mean content of In [mg/m^2]
Notebooks	250	174	43.5	552	788
LCD monitors	300		52.2	1126	464
LCD televisions	1800		36.3	3626	864

Data sources: FEM & IUTA 2011, Displaybank 2011 (size of displays)

This allows estimating the average of the following indium contents for selected display devices:

Table 2: Mean indium content of different display devices

	Mean screen area [cm2]	Mean In content per device [mg]
Notebooks	552	39
Computer monitors	1.126	79
Televisions	3.626	254

These values are in close agreement with the data on the indium content of 15.4-inch (686 cm2) laptop screens provided by the manufacturers. According to data from Prakash et al. 2011 [[34]] contains about 0.5 g of indium tin oxide, which corresponds to an indium content of 0.39 g.

Table 3: Metals used in electrical and electronic equipment (EEE), the concentration of the earth's crust, the concentration in primary ores, primary production, the concentration in discarded equipment, abundance, and the recycling rate for aluminum, indium and lead

Metal	Form	Usage in EEE	Crustal concentration (ppm)	Concentration in primary ores (%, w/w)	Production from primary ores (kTons)	Demand for electronics (%)	Recycling rate (%)	Concentration in WEEE (%)	References
Al	Elemental/alloy	Alloys, wiring, casing, heat sink	80,000	20 – 24	44,900	14	34	1.5 - 5	Graedel et al., 2011a; Yamasue et al., 2007; Hadi et al., 2015
In	Alloy/oxide	LCD4, semiconductors	0.5	0.1 - 0.2	0.6	79	<1	0.05 - 1	Graedel et al., 2011a; Zhang et al., 2015
Pb	Alloy	CRT5 funnel (14.7%), CRT neck (14.7%), solder (40%)	15	3 - 15	5,200	No data	63	0.9 - 5	Graedel et al., 2011a; Yamasue et al., 2007

8-3- Precious metals

Flat panel monitors contain one or more printed circuit boards with electronic components and connectors. Significant amounts of precious metals are found in both components and connectors as well as in solder.

Table 4: Weight and Concentration of Precious Metals in Compounds of Printed Circuit Boards in Flat Panels

	Weight per unit [g]	Ag [mg/kg]	Au [mg/kg]	Pd [mg/kg]	Source of data
PCB from an LCD monitor	400	1,300	490	99	FEM & IUTA 2011, Huismann et al. 2007
PCB from an LCD television	2,300	250	60	19	FEM & IUTA 2011, 2007

Table 5: Gold concentration (mg/g of discarded printed circuit boards) in various WEEE

Metals	Particle size (µm)	Desktops	Computer parts	Desktops w/o components	Laptops	Mobile phones	Telecom 1	Telecom 2
Au (ppm)	<500µm	31.4 ± 3.2	21.8 ± 0.5	30 ± 0.2	290.0 ± 26.0	297.4 ± 32.4	320.7 ± 17.1	298.2 ± 12.2
	500 - 1600 µm	44.2 ± 5.1	34.4 ± 2.8	32.4 ± 1.0	310.1 ± 21.0	310.4 ± 26.6	314.6 ± 28.2	300.4 ± 38.8
	1600 -	26.4 ±	28.6 ±	44.1 ± 4.4	243.8	246.4	286.1 ±	310.2 ±

[32] Götze, in: Proceedings of the conference Electronics Goes Green 2012+ (EGG), Berlin, Germany, 2012, pp. 1-8.

[33] For schungs institut Edel metalle und Metall chemie & Institut für Energie- und Umwelttechnik. [Research Institute Precious Metals & Metal Chemistry and Institute of Energy and Environmental Technology e.V.] Metall urgische Rückgewinnung von Indium, Gallium und Germanium aus Elektronikschrott und Entwicklung entsprechender Aufarbeitungsmethoden für die Verwertungsindustrie [Metallurgical recovery of indium, gallium and germanium from electronic waste and development of suitable pre-treatment methods for the recycling industry]. Project report, Schwäbisch Gmünd & Duisburg, 2011.

[34] **Prakash, S.; Manhart, A.: Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana. Öko-Institut e.V., Freiburg, 2010**

	2500 µm	4.7	6.1		± 33.1	± 41.4	17.4	24.2

Table 6: Metals used in electrical and electronic equipment (EEE), crust, concentration in primary ores, primary production, concentration in discarded equipment, abundance, and recycling rate for precious metals

Metal	Form	Usage in EEE	Crustal concentration (ppm)	Concentration in primary ores (%, w/w)	Production from primary ores (kTons)	Demand for electronics (%)	Recycling rate (%)	Concentration in WEEE (%)	References
Au	Alloy/elemental	PCB, contacts, integrated circuits (ICs)	0.002	5 - 10	2.35	12	43	30 - 350	Graedel et al., 201 1a; Ongondo et al., 2011
Ag	Alloy	PCB, brazing alloy (3%), lead-free solder (3%)	0.08	5 - 10	20	30	16	80 - 1000	Graedel et al., 201 1a; Yamasue et al., 2007; Ongondo et al., 2011
Pd	Alloy/elemental	MLCC6, PCB	0.0005	1 - 10	0.3	14	50	30 - 200	Graedel et al., 201 1a; Heart and Agamuthu, 2012

8-4- Rare earths

Rare earth metals or rare earth elements as defined by the International Union of Pure and Applied Chemistry are a group of seventeen chemical elements in the periodic table, specifically scandium, yttrium, and lanthanides.
The 17 rare-earth elements are: scandium (Sc), yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Rare earths (also known as rare earth metals) are used as luminescent material in VDUs. Depending on the display technology, rare earth elements are used in the displays themselves (PDP and OLED technology) or in the backlighting (LCD technology). The available data on the use of REE in this context is of a very general nature, as all information regarding quantities and concentrations of particular products is usually covered by trade secrets. However, the following statements can be made: For luminescent materials, a distinction can be made between the support matrix and the actual luminescent material (doping). In addition to non-rare earth compounds, compounds containing yttrium (Y2O3), cerium (CeMgAl11O19) and lanthanum (La2O3) are used in the support matrix [35]. Data from the US Department of Energy and others [36][37][38] show that these three minerals exhibit the largest proportions of all rare earth elements in luminescent materials. Gambarella et al. 2010 [39] The proportion of yttrium, lanthanium and cerium in all rare earths used in luminescent materials was 69.2%, 11.0% and 8.5%, followed by europium (4.9%), terbium (4.6%) and gadolinium (1.8%). Europium, terbium, and gadolinium are used in various compounds for the actual luminescent materials. samarium, erbium, dysprosium, thulium and lutetium play a quantitatively minor role. According to Rieger. 2009 [40], the following rare earth compounds are used in plasma screens: **Red: (Y, Gd)BO_3:Eu (Y_2O_3:Eu^{3+}) - Green: (Y, Gd)BO_3:Tb - Blue: $BaMgAl_{10}O_{17}$:Eu**
Cold cathode tubes (CCFLs) are used to backlight LCD screens, especially in older devices. While only one or two bulbs are generally used in laptops, TVs come with up to 82 tubes [ ] . The diameter of the cold cathode tubes in a laptop is approx. 1.5 mm and weighs less than 1 g.

Table 7: Estimated mean weights of rare earth metals in LCD screens with CCFL backlight

	Yttrium [mg]	Europium [mg]	Lanthanum [mg]	Cerium [mg]	Terbium [mg]	Gadolinium [mg]
Notebooks	1.8	0.13	0.11	0.076	0.038	0.011
Monitors	16.0	1.20	1.00	0.680	0.340	0.095
Televisions	110.0	8.10	6.80	4.500	2.300	0.630

Newer LCD screens sometimes come with white LED-based backlighting. In 2010, the market share of LCD monitors and LCD TVs with LED lights was about 30% while about 90% of all new laptops were already equipped with LED backlights. Like CCFL tubes, white LEDs also use a luminescent material that converts the short-wave light produced in the LED into the visible spectrum. The support matrix is usually made of yttrium aluminum garnet (YAG) with significant gadolinium additives. Doping consists of a small percentage by weight of cerium and sometimes europium. The actual LED semiconductor chip that produces the light consists of indium gallium nitride. The

[35] **Schüler, D.; Buchert, M.; Liu, R.; Dittrich, S.; Merz, C.: Study on Rare Earths and Their Recycling. Öko-Institut, Darmstadt, 2011**

[36] **U.S. Department of Energy: Critical Materials Strategy. Washington D.C., 2010.**

[37] **Graedel, T. E.; Reck, B.; Buchert, M.; Hagelüken C. et al. "Recycling rates of metals", United Nations Environment Programme, (UNEP edits.) 2011.**

[38] **Gambardella, M.F.; Lanton, T.J.; Ossenbeck, B.P.: Molycorp. North American Equity Research. J.P. Morgan, New York.**

[39] Rieger, R.: Die Verwendung von "seltenen Erdmetallen" in der Elektrogerät- und Fahrzeugproduktion und ihre Erfassungsmöglichkeit im Materialrecycling [The use of rare earths in the production of electronic equipment and vehicles and options for collection for materials recycling]. Diplomarbeit an der Technischen Universität Dresden [Dissertation for Dreseden University of Applied Sciences], Dresden, 2009.

[40] Forschungsinstitut Edelmetalle und Metallchemie & Institut für Energie- und Umwelttechnik. [Research Institute Precious Metals & Metal Chemistry and Institute of Energy and Environmental Technology e.V.] Metallurgische Rückgewinnung von Indium, Gallium und Germanium aus Elektronikschrott und Entwicklung entsprechender Aufarbeitungsmethoden für die Verwertungsindustrie [Metallurgical recovery of indium, gallium and germanium from electronic waste and development of suitable pre-treatment methods for the recycling industry]. Project report, Schwäbisch Gmünd & Duisburg , 2011.

number of white LEDs in the screen required for projection is a quantity that varies by manufacturer, and therefore can only be estimated for a general survey. Based on model data in Young, 2011 [[41]], estimates were made for 100 LEDs for an LCD computer screen, 150 LEDs for an LCD TV, and 50 LEDs for a laptop screen.

Table 8: Estimated mean weights of rare earth metals (incl. indium and gallium) in LCD displays with CCFL background illumination

	Yttrium [mg]	Europium [mg]	Cerium [mg]	Terbium [mg]	Gadolinium [mg]	Indium[1] [mg]	Gallium [mg]
Notebooks	1.6	0.03	0.1	0.0	0.75	1.5	1.6
Monitors	3.2	0.06	0.2	0.0	1.50	2.9	3.3
Televisions	4.9	0.09	0.3	0.0	2.30	4.4	4.9

Table 9: Metals used in electrical and electronic equipment (EEE), the concentration of the earth's crust, the concentration in the primary ores, the primary production, the concentration in the discarded equipment, the abundance, and the recycling rate of the lanthanides

Metal	Form	Usage in EEE	Crustal concentration (ppm)	Concentration in primary ores (%, w/w)	Production from primary ores (kTons)	Demand for electronics (%)	Recycling rate (%)	Concentration in WEEE (%)	References
La	Alloy/ Oxide	Lenses, batteries, alloys	18	0.5 - 20	32	No data	<1%	-	Binnemans et al., 2013; Simoni et al., 2015
Dy	Alloy/ Oxide	Permanent magnets, HDD 7	0.3	0.1 - 8.6	0.1	No data	<1%	1.4	Cotton, 2006; Ueberschaar and Rotter, 2015; Binnemans et al., 2013
Nd	Alloy/ Oxide	Permanent magnets, HDD	24	0.1 - 15	19	82	<1%	5.0-22.9	Cotton, 2006; Ueberschaar and Rotter, 2015; Binnemans et al., 2013
Pr	Alloy/ Oxide	Permanent magnets, HDD	5.5	0.1 - 4.5	6.1	No data	<1%	1.5 - 2.5	Ueberschaar and Rotter, 2015; Binnemans et al., 2013; Simoni et al., 2015
Y	Alloy/ Oxide	Florescent phosphors, alloys, LCD	n/a	0.05 - 2.5	No data	No data	<1%	5 - 15.5	Cotton, 2006; Binnemans et al., 2013; Innocenzi et al., 2014; Simoni et al., 2015

8-5-Summary of critical metals in flat screen

The concentrations of rare earth metals, gallium, and indium in LED-backlit LCDs are based on the data in Table 8. This assumes that an average LCD has 100 white LEDs and an LCD TV has 150 white LEDs in the backlit [[42]]. Data from LCD TVs were used as a basis for calculating the additional capabilities of PDP TVs.

Table 10: Average Weight of Critical Raw Materials in Computer LCD Screens (Private Market Sector)

Metal		Content per LCD monitor (CCFL4) [mg]	Content per LCD monitor 5 (LED) [mg]	Content in all LCD monitors sold in Germany in 2010 [kg]	Occurrence
Silver	Ag	520	520	1,340	PCB and contacts (100%)
Gold	Au	200	200	505	PCB and contacts (100%)
Indium	In	79	82	206	Internal coating on display (100%)
Palladium	Pd	40	40	102	PCB and contacts (100%)
Yttrium	Y	16	3.20	32	Background illumination (100%)
Gallium	Ga	0.000	3.30	2.51	LED background illumination (100%)
Europium	Eu	1.200	0.06	2.23	Background illumination (100%)
Lanthanum	La	1.00 0	0.00	1.84	CCFL background illumination (100%)
Cerium	Ce	0.680	0.20	1.38	Background illumination (100%)
Gadolinium	Gd	0.096	1.50	1.33	Background illumination

[41] **Ross Young; "Global Manufacturing Trends: What Can We Learn from the HB LED Market Explosion?", in 2011 Solid-State Lighting Manufacturing R&D Workshop, Boston, MA, 2011-04-12.**

[42] **Ross Young; "Global Manufacturing Trends: What Can We Learn from the HB LED Market Explosion?", in 2011 Solid-State Lighting Manufacturing R&D Workshop, Boston, MA, 2011-04-12.**

					(100%)
Terbium	Tb	0.340	0.00	0.61	CCFL background illumination (100%)
Praseodymium	Pr	< 0.019	0.00	<0.05	CCFL background illumination (100%)

It can be seen from the above table that it consumes silver (more than 1.3 tons/year) and gold (about half a ton/year) which are currently in use across all LCD PCs sold in Germany and offer interesting potential for the post-expiration phase recycling industry. use it. These minerals are followed by indium (about 200 kg / year) and the precious metal palladium (about 100 kg / year). LCD screens[43] contain only small amounts of the rare earth elements and gallium.

8-6- Critical Raw Materials in LCD TVs

The corresponding data for LCD TVs is shown in the following table. Silver [44] (more than 4.7 tons / year), indium (more than 2.1 tons / year) and gold (more than 1.1 tons / year) enter the German market in the range of tons by LCD TVs annually. The gold content alone is worth about 40 million euros at current market prices. Yttrium as a representative of rare earths and the precious metal palladium is sold at several hundred kilograms per year in LCD TVs in Germany. Gallium and other rare earths exhibit less significant amounts.

Table 11: Average weight of critical raw materials in LCD TVs

Metal		Content per LCD television (CCFL[6]) [mg]	Content per LCD television (LED[7]) [mg]	Content in all LCD TVs sold in Germany in 2010 [kg]	Occurrence
Silver	Ag	580	580	4,748.35	PCB and contacts (100%)
Indium	In	260	260	2,157.86	Internal coating on display (100%)
Gold	Au	140	140	1,139.60	PCB and contacts (100%)
Yttrium	Y	110	4.8	647.02	Background illumination (100%)
Palladium	Pd	44	44	360.87	PCB and contacts (100%)
Europium	Eu	8.10	0.09	46.84	Background illumination (100%)
Lanthanum	La	6.80	0.00	39.33	CCFL background illumination
					(100%)
Cerium	Ce	4.50	0.30	26.96	Background illumination (100%)
Terbium	Tb	2.30	0.00	13.11	CCFL background illumination (100%)
Gallium	Ga	0.00	4.90	12.08	LED background illumination (100%)
Gadolinium	Gd	0.63	2.30	9.22	Background illumination (100%)
Praseodymium	Pr	< 0.13	0.00	<1.07	CCFL background illumination (100%)

Table 12: Weight and Concentration of Precious Metals in Printed Circuit Board Compounds in Laptops

Components	Weight per unit [14] [g]	Ag [mg/kg]	Au [mg/kg]	Pd [mg/kg]
Motherboard	310	800	180	80
Memory cards	20	1,650	750	180
Small PCBs	28	800	180	80
Hard disk drive PCB	12	2,600	400	280
PCB for optical drive	25	2,200	200	70
Display PCB	37	1,300	490	99

Table 13: Quantities of precious metals in the printed circuit boards of a laptop computer

	Ag [mg]	Au [mg]	Pd [mg]
Motherboard	248	56	25
Memory cards	33	15	4
Small PCBs	22	5	2
Hard disk drive PCB	31	5	3
Printed circuit boards for optical drive	55	5	2
Display PCB	48	18	4
Total	**438**	**104**	**39**

Table 14: Metals used in electrical and electronic equipment (EEE), the concentration of the earth's crust, the concentration in primary ores, primary production, the concentration in discarded equipment, abundance, and the recycling rate for base metals such as copper, nickel and chromium

Metal	Form	Usage in EEE[1]	Crustal concentration (ppm)	Concentration in primary ores (%, w/w)	Production from primary ores (kTons)	Demand for electronics (%)	Recycling rate (%)	Concentration in WEEE[2] (%)	References
Cu	Elemental/alloy	PCB3, alloys, wiring, connectors, transformers	60	0.5 – 3	15,000	30	31	12 - 35	Graedel et al., 201 1a; Yamasue et al., 2007; Ongondo et al., 2011;

[43] LCD monitors (PC) with CCFL background illumination (approx. 70% of all new LCD monitors in 2010).
[44] Matthias Buchert, Andreas Manhart , Daniel Bleher, Detlef Pingel , Recycling critical raw materials from waste electronic equipment , 2012, Commissioned by the North Rhine Westphalia State Agency for Nature, Environment and Consumer Protection.

									Hadi et al., 2015
Fe	Alloy	Steel, casing, magnets, casings	58,000	30 – 60	1,100,000	3	28	5 - 11	Graedel et al., 201 1a; Yamasue et al., 2007; Hadi et al., 2015
Zn	Alloy/oxide	Steel, Zn-Al-Cu alloy (94%), plating	80	0.15 - 0.65	13,000	12	18	0.1 - 2.5	Graedel et al., 201 1a; Yamasue et al., 2007; Hadi et al., 2015
Cr	Alloy	Steel (18%)	100	0.1 - 0.5	7,900	25	20	0.1 - 2.9	Graedel et al., 201 1a; Yamasue et al., 2007; Hadi et al., 2015
Ni	Elemental/alloy	Steel (8%)	80	1 – 5	2,100	5	29	1 - 7.2	Graedel et al., 201 1a; Yamasue et al., 2007; Hadi et al., 2015

9- The most important environmental issues

E-waste is an emerging issue in environmental health, and its potential importance is now being recognized by both scientists and policy makers. However, there are serious data gaps in the quantification of exposures and health effects. The following are the most important minerals that are used in the installation of electronic screens, their equipment and accessories.

9-1- Lead

In electronic equipment, lead is found in cathode ray tubes (CRTs), fluorescent tubes, found as solder in printed circuit boards, as well as in cathode ray displays, liquid crystal displays, and batteries. One of the main uses of lead in electrical and electronic devices is the use of cathode ray tubes in television and computer monitors. The purpose of lead in CRTs is to protect against ultraviolet and X-rays from operating CRTs. CRT monitors consist of a front panel or screen, a funnel or back part of the CRT, and a neck. The front plate contains up to 3% Pb, while the funnel contains up to (~25%) PbO lead oxide. The neck is also made of PbO. In recent years, CRT monitors have been replaced by LCD, plasma, or LED displays. And when lead is released into the environment, it remains a significant period compared to most pollutants. It can also remain in the food chain and human metabolism. There are many published studies that have documented the harmful effects of lead on children and adults [[45]] as lead is highly toxic to humans as well as to many animals and plants. These studies in children have shown an association between blood level toxicity and decreased intelligence, decreased IQ, delayed or impaired neurobehavioral development, decreased hearing acuity, speech and language impairments, developmental delays, impaired attention span, and antisocial behaviors [[46]]. In the adult population, reproductive effects, such as lower sperm counts in men and spontaneous abortions in women, have been associated with higher exposure to lead [[47]] where acute exposure to lead leads to brain damage, kidney damage and gastrointestinal disease, while chronic exposure may cause adverse effects on the blood and system Central nervous system, blood pressure, kidney and vitamin D metabolism.

9-2- Global Hg Problems

Mercury is mainly found in mercury lamps and is also found in batteries, LCD screens, switches, thermostats, and sensors. The function of mercury in lightning equipment is to convert electrical energy into radiant energy in the ultraviolet range. The phosphorous compounds then convert the radiant energy into the visible spectrum. Mercury lamps include fluorescent tubes, compact fluorescent lamps (CFLs), mercury vapor, sodium vapor, polymetallic vapors, and mixed lamps. Once in the atmosphere, mercury can circulate around the globe before being deposited in land and water where it can be transported, re-transmitted to the atmosphere, or transformed by a variety of biological processes. It is known that this global mobility of mercury means that even regions where there are no significant releases of mercury, such as the Arctic, are also negatively affected by mercury [[48]].

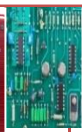
[45] Yedjou CG, Milner J, Howard C, Tchounwou PB (2010) Basic apoptotic mechanisms of lead toxicity in human leukemia (HL-60) cells. Intl J Environ Res Public Health 7(5):2008–2017. doi: 10.3390/ijerph7052008.
[46] Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012) Heavy Metal Toxicity and the Environment. In: Luch A. (eds) Molecular, Clinical and Environmental Toxicology. Experientia Supplementum, Springer, Basel. 101:133-164.
[47] Leonard SS, Harris GK, Shi X (2004) Metal-induced oxidative stress and signal transduction. Free Radic Biol Med 37:1921–1942. doi: 10.1016/j.freeradbiomed.2004.09.010.
[48] Initial evaluation of the Minamat agreement in Yemen - March 2019 NGO Directory 2014

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

Figure 8: A group of children with congenital malformations in some artisanal small-scale gold mining hot spots in Indonesia, and in the second picture: many women who work in gold processing using mercury in ASGM sites bring their children to processing facilities (Source / First Conference of the Parties to the Mina Mata Convention, August 2017).

The people of the Arctic, especially the indigenous peoples, are particularly exposed to mercury, as the climate of the region does not allow them to grow grains or vegetables, which are often considered basic food commodities in other parts of the world. Since they live in remote areas, food storage is very expensive, especially healthy food that is perishable quickly. So they have no other choice but to survive on their diets which are not only prolific fish but also the mammals and birds that feed on fish. We see that the life of indigenous peoples in the Arctic and in the northern regions of many industrialized countries is very similar to the life of the inhabitants of developing countries [49]. Likewise, the Inuit people in the coastal arctic regions of northern Canada, Greenland and Alaska (USA), and Chukotka (Russia). Marine mammals are the main component of their traditional diet. In a study on mercury exposure, approximately 17% of preschool children living in Nonafoot, Canada were exposed to mercury at rates higher than the tolerable weekly intake rate for children established by the World Health Organization in 1228, equal to 1.1 micrograms of methyl mercury per kilogram. one body weight per week. The livelihoods of the people of Norway, Sweden, Finland and the Russian Kola Peninsula include coastal hunting, hunting for fur animals, and herding sheep 60 . There are some suggestions that the depletion of mercury in the atmosphere in the polar region, which resulted in the deposition of large hundreds of biological mercury compounds on the arctic tundra forests, led to an increase and inflation of mercury in the food web in the tundra forests. This, along with water pollution with methyl mercury, contributed to the accumulation of mercury in large quantities in the traditional foods of those peoples [50].

Table 15: shows the toxicity of some electronic waste components and components

Products	 Mobile phone	 Printed circuit board	 Cathode Ray tube	 Rechargeable batteries	 Lighting screens display	 USB data Storage USB	 Wires and cables
Hazardous elements	Pb, Hg, Cd & Be, Brominated flame retardant, PVC plastic	Cu, Fe, Al Brominated Flame retardants	Al, Zn, Ni Cs, Sr High quantity of of Pb	Cd in rechargeable batteries, switches & Old CRTs	Hg in Lighting devices, flat screen display	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. interf	Cause intellectual impairment in children Damage the nervous system blood and reproductive systems in adults	Affects kidneys and bones, Osteoporosis lung disease	Damage of brain CNS during early development, Kidney Damage	Highly toxic disrupt balance b/w ROS & antioxidants, Carcinogenic, Ulcers DNA adducts	Toxic even in very low concentrations

[49] Initial evaluation of the Minamat agreement in Yemen - March 2019 NGO Directory 2014
[50] Critical Review of Mercury Fates and Contamination in the Arctic Tundra Ecosystem," cited above.

		ere with thyroid and estrogen hormone					
Ecotoxicity	Highly persistent in the Environment	Persistent and bio-accumulative	Pb is toxic to aquatic species, Cs effected badly to fish and mammals	Bioaccumulate in environment	Adverse effects on soil invertebrates	Adverse effects to aquatic life	Highly persistent in the environment

Table 16: The most important materials and minerals that cause damage from waste electrical equipment

metal or composite	its damages
Aluminium	Lung irritation, nerve cell poisoning
Americium	Irritation of body parts, for example. Digestive system, lungs and eyes, carcinogenic
Antimony	Irritation to the lungs, eyes, and stomach
Arsenic	Hemolysis and endocrine disorders
Barium	Neurotoxicity, gastrointestinal irritation, cardiac muscle toxicity
Beryllium	Beryllium poisoning, a carcinogen
Cadmium	Carcinogenic, cardiotoxic, endocrine disruptor
Cobalt	Allergic reactions, possible human carcinogenesis
Copper	Irritation to the eyes, lungs and digestive system
Gallium	Irritation of the skin, eyes and mucous membranes
Chromium (hexagonal)	Allergy induction, lung carcinogen and skin irritant
Indium	May be carcinogenic to humans, neurotoxic, lung disease
Lead	Carcinogenic potential, cardiotoxicity, neurotoxicity, endocrine disruption
Manganese	Cardiotoxic, neurotoxic, lung irritant, endocrine disruptor
Mercury	endocrine disorders
Nickel	Carcinogen, induction of allergy
Platinum	Irritating to eyes and lungs
Selenium	Selenium, in higher concentrations, is irritating to the eyes, lungs and skin
Silver	Toxicity of nephrons and defects of the reproductive organs
Tin	Irritating to lungs, eyes and skin
Tungsten	Irritant to lungs and skin, kidney toxicity or kidney failure
Lithium and yttrium	Irritant to lungs and eyes
zinc	Induction of smoke fever
Acids (nitric acid, sulfuric acid, hydrochloric acids)	Breathing problems, corrosive damage, burning eyes and skin on contact, sore throat if swallowed
Cyanide	Neurotoxic, cardiotoxic, can cause chest pain and breathing difficulties

10- Environmentally sound management considerations when recovering metals from waste electrical and electronic equipment

Because electronic waste poses environmental risks and concerns in many countries, some environmental agreements have issued some directives for the recovery of metals and waste, from printed circuit board compounds, flat screens, turntables, batteries, thermoplastics, inks, ink dust, packaging, ink bottles, etc. In addition, for the treatment to take place in environmental management facilities or by parties assigned to them by environmental management, according to the capacities and licenses available to treat and dispose of each type of waste. Storage must also be ensured under watertight covers to prevent hazardous materials from entering the environment. One of the main concerns related to the sound management of waste electrical and electronic equipment (WEEE) is the presence of hazardous materials that have to be recovered and used with the help of advanced technologies, rather than treatment and disposal. The treatment and disposal of hazardous waste from these devices may have a number of undesirable environmental impacts, even if the processes themselves are conducted in an appropriate manner (eg using safe burial cells) environmental responsibilities may arise one way or another. These responsibilities are undesirable, but they may be preferred to the effects of simply dumping these wastes in nature or burying them without taking into account the minimum technical conditions (impact on surface water, groundwater, soil and the general environment). However, recovery and use of hazardous waste may be a better option than treatment and disposal.

11- Disassemble CRT monitors and flat screens

Since there is a lot of difference in disassembling CRT monitors and flat panels, the steps for disassembling both devices will be briefly explained:

Table 17: The difference between the steps for dismantling flat screens and CRT screens

Flat screen dismantling	Disassembling CRT Monitors
When disassembling a flat screen display, it is especially important to carefully remove the crystal liquid that contains the glass and CCFLs. Protective equipment must be worn because these lamps often contain mercury and because there is a high chance they will actually break during transportation. The disassembly steps are: 1. Place the screen with the glass side down. This is to avoid breaking the glass. Next,	In a typical CRT monitor, one will find a cathode ray tube, a magnetic reflector, an electronic gun, printed wiring boards, cables, and of course the plastic case usually made of ABS or polycarbonate (PC). CRT glass contains a large amount of lead, which is why glass breakage should be avoided and its dismantling should be carried out in appropriate facilities. The disassembly steps are as follows: 1. Remove the plastic case and clean the plastic 2. To avoid collapse of

remove the monitor stand. Screen mounts usually contain plastic and rust. 2. Remove and clean the casing. 3. Remove the front frame, cut all cables, and unscrew the mounting screws. This will allow you to access the PWBs. 4. Remove the hard cover protecting the seams and check if the LCD is lit by LEDs or CCFLs 5. If it is illuminated by LEDs, remove the dark liquid crystal layer. Also remove all other layers so you can access the backlight. 6. If it is lit by CCFLs, remove the hard cover at the rear coupling at the bottom left and right. This is where the backlight bulbs are attached. Next, remove the backlight. Since they contain mercury, be careful while doing this and place the bulbs in a container after removing them for the screen. 7. Separate the remaining materials by type. Make sure not to mix them up.	the CRT body, the pressure in the CRT body must be equalized. To do this, position the screen side up with the tongue away from your face before removing the cover. After removing it, carefully make a hole in the CRT glass where the cover was held with a screwdriver. 3. Cut and remove cables. Then, the printed wire boards (PWBs) and the magnetic inverter can be removed. While doing this, make sure not to destroy the electron gun on the top of the reflector. 4. Disconnect the electron gun from the tube. Be sure to wear protective equipment and only break the glass under the electron gun, not the full funnel glass. 5. Remove all remaining screws.

11-1- Flat panel processor

An example of this technology is the Flat Panel Processor (FPP), a flat panel processor is a versatile machine for disassembling a wide variety of LCD panels. The processor allows safe extraction of fluorescent lamps and their separation into different fractions. The processor can be fed manually or mechanically by means of conveyor belts. FPP cutters automatically make two cuts at the perimeter of the panel, allowing for a clean and safe separation. The processor can be fed with plates up to 1600 mm x 1200 mm and 60 kg. Flat plate treatments require that the FPD mounts be removed before they are fed into the machine. For best handling, it is advisable to do this when the boards are received and sorted. Several studies have been conducted to evaluate whether manual or automatic separation is the most efficient form of recycling for FPD. One of the first studies on LCD disassembly compared the time taken to disassemble them using different techniques: manually, by waterjet cutting, laser cutting, and circular saw cutting. This study found that manual dismantling is the preferred option because it involves the lowest cost per component and results in higher quantities and quality of material recovered. Kopacek, 2008 [[51]] also estimated that a backlight systems disassembly time of less than 1.4 minutes would make manual disassembly better than other systems, even with higher labor costs. This is then directly compared to the fully automated recycling option with less clean parts. Assuming an average content of precious metals in printed circuit boards, it was calculated that manual extraction of PCBs, compared to shredding-based processing, would allow for additional recycling of 46.2 g of copper, 0.44 g of silver and 0.15 g of gold. and 0.03 g of palladium from a small screen (51 cm); And 80.7 grams of copper, 0.77 grams of silver, 0.25 grams of gold and 0.05 grams of palladium for a large display (94 cm)[[52]]. Based on current market values of the metals, estimates of the revenue that can be earned from these recycling activities range from €3.5 to €4.3 (for the small screen) and between €6.1 and €7.6 (for the large screen). In addition, it will leave the LCD screen intact and can be restored if necessary in a separate clean step. The average indium content in the screen is assumed to be 234 mg/m2, which corresponds to 58.5 mg/kg of width [[53]]. Once the displays are disassembled, thin-film transistor (TFT) panels can be sent for selective processing; For example, the indium content can be separated by acid leaching or evaporation, which has a recovery yield of about 85%[[54]]. Indium can then be purified by solvent extraction, electrophoresis, or smelting. Refining processes can recover approximately 99% of indium-22. In general, it is estimated that about 80% of the indium in displays can be recycled. Therefore, after the first stages of sorting the metallic and non-metallic parts of the WEEE tailings (using physical and chemical means), the separated fractions can be subjected to metallurgical processes (liquid, thermal, electrical and biological, and any combination of these processes). The high complexity of WEEE components requires a careful approach to freeing the metals of interest from separate components. Physical treatment also includes the removal of hazardous substances, such as Hg, from the backlight of the LCD screen [[55]].

11-1-1-Manual sorting and separation

51 Kopacek (2008): ReLCD : Recycling and re-use of LCD-panels.
52Ardente & Mathieux (2012): Application of the project's methods to three product groups.
53 Kissling et al. (2012): Definition of generic re-use operating models for electrical and electronic equipment.
54 Götze & Rotter (2012): Challenges for the recovery of critical metals from waste electronic equipment - A case study of indium in LCD panels.
55 Zhang, K., Wu, Y., Wang, W., Li, B., Zhang, Y., Zuo, T., 2015. Recycling indium from waste LCDs: A review. Resour. Conserv. Recycl. 104, 276–290. doi:10.1016/j.resconrec.2015.07.015

Many minerals are concentrated in certain parts of WEEE components, and manual separation is often required. In the recycling process, dismantling these parts is the most time consuming process. Disassemble and disconnect the main case, PCB board and LCD panel lasting 133, 67, and 64 seconds respectively [56] discarded LCDs should be disassembled to break the plastic casing, remove the ITO boards [57].

11-1-2- Pyrolysis and gasification

Pyrolysis of printed circuit boards, performed at elevated temperatures of up to 900 ° C in the presence of inert gases, generates 23% oil, 5% gases and 70% metal-rich residue [58]. As such, discarded LCD panels are subjected to pyrolysis in ceramic kilns at 700°C, and the polarizing film rich in organic matter is converted into oil and pyrolysis gas, while the liquid crystal is eliminated through deformation and detoxification of hazardous materials under high temperature conditions. . However, this method is ineffective due to the high costs associated with the high consumption of energy and reagents. Moreover, pyrolysis is likely to be a dangerous method, as with burning, toxic compounds are formed at high temperatures. A certain amount of bromine is found in the coal or ash product, possibly due to the brominated flame retardant (BFR) content of printed circuit boards [59].

11-1-3- Thermal treatment

Smelting is currently BAT and a few WEEE processing plants are already in operation. In Runskar polyden smelters (Skelleftehamn, Sweden), idler printed circuit boards are processed directly in a copper transformer to recover Cu, Ag, Au, Pd, Ni, Se, and Zn [60]. At the Umicure Integrated Smelter and Refinery in Hoboken (Belgium), the printed circuit boards are first processed in an IsaSmelt furnace for precious metal recovery. It is also refined by hydrometallurgical and electro-metallurgical processes [61]. At the Ausmelt TSL reactor in Outotec (Spoo, Finland), WEEE is processed at Cu/Pb/Zn smelters in a combined process to recover Zn, Cu, Au, Ag, In, Pb, Cd and Ge . The disadvantages of smelting are high energy consumption, adverse environmental effects, and low selectivity towards individual metals.
Similar to liquid mining [62], pyroclastic mining involves the use of high temperatures to recover and purify minerals. By using heat, metals can be extracted from their ores, directly or from concentrates. The temperatures used usually exceed 950 °C. This is a rapid technique that can be used to process large quantities of metallic minerals.

11-1-4-Hydrometallurgical processing

Hydrochemistry is used to recover metals from ores, concentrates, waste, or recyclable products. Accordingly, liquid mining: involves extracting and extracting minerals from liquid solutions. The process takes place in a solution containing one or more metals of interest in the form of ions, which are specifically separated and isolated by reversible reactions and physical differences between the solutions. Metallurgical mineral recovery processes include oxidative leaching to extract the minerals, followed by separation and purification procedures [63]. It has advantages over thermoplastic recovery such as less toxic residues and emissions, and higher energy efficiency. However, these processes still pose a threat due to the use of large quantities of toxic, corrosive and flammable reagents and the generation of large amounts of effluent and other solid waste [64]. In general, liquid and pyrometallurgical processes are the most widely used, and can be followed by electro/chemical mining processes (eg electropurification or electrofiltration) for the separation and recovery of selected minerals.

11-1-5- Oxidative acid leaching

Acid leaching of metals from WEEE has been investigated using various acids and oxidizers or mixtures thereof. It is an essential process when extracting valuable metals from circuit boards [65], indium from ITO glass [66], and neodymium from HDDs. In oxidizing acid filtration, the important parameters are temperature, concentration and contact time with the former being the most important. Metal leaching in various acidic and oxidizing media has been investigated for their efficacy in recovering metals from waste printed circuit boards, including hydrochloric acid, sulfuric acid [67], nitric acid, sodium hypochlorite, thiosulfate, thiourea and halides. Indium (In) in the discarded LCD screen reacts with H2SO4 and HCl at elevated temperatures [68]. Al and Sr leached into concentrated HCl, while HNO3 and H2SO4 concentration are more selective towards In. Kato and others. (2013) reached 90% in leaching of 3.2 M (10%, v/v) HCl. Ruan et al. (2012)[69] used sulfuric acid H2SO4 in a liquid to solid

56 Fan, S.K.S., Fan, C., Yang, J.H., Liu, K.F.R., 2013. Disassembly and recycling cost analysis of waste notebook and the efficiency improvement by re-design process. J. Clean. Prod. 39, 209–219. doi:10.1016/j.jclepro.2012.08.014.
57 Zhang, K., Wu, Y., Wang, W., Li, B., Zhang, Y., Zuo, T., 2015.
58 Hall, W.J., Williams, P.T., 2007. Separation and recovery of materials from scrap printed circuit boards. Resour. Conserv. Recycl. 51, 691–709.doi:10.1016/j.resconrec.2006.11.010.
59 Havlik, T., Orac, D., Petranikova, M., Miskufova, A., Kukurugya, F., Takacova, Z.,2010 Leaching of copper and tin from used printed circuit boards after thermal treatment. J. Hazard. Mater. 183, 866–873. doi:10.1016/j.jhazmat.2010.07.107
60 Ghosh, B., Ghosh, M.K., Parhi, P., Mukherjee, P.S., Mishra, B.K., 2015. Waste Printed Circuit Boards recycling: An extensive assessment of current status. J. Clean. Prod. 94, 5 .19 –doi:10.1016/j.jclepro.2015.02.024
61 Zhang and Xu, 2016.
62 Ebin, B., Isik, M.I., 2016. Pyrometallurgical processes for the recovery of metals from WEEE, in: Chagnes, A., Cote, G., Ekberg, C., Nilsson, M., Retegan, T. (Eds.), WEEE Recycling. Elsevier Inc, pp. 107–138.

63 Schlesinger, M.E., King, M.J., Sole, K.C., Davenport, W.G., 2011. Extractivemetallurgy of copper, 5th ed. Elsevier.
64 Tuncuk, A., Stazi, V., Akcil, A., Yazici, E.Y., Deveci, H., 2012. Aqueous metal recovery techniques from e-scrap: Hydrometallurgy in recycling. Miner. Eng. 25, 28–37.
65 Ghosh, B., Ghosh, M.K., Parhi, P ., Mukherjee, P.S., Mishra, B.K., 2015. Waste Printed Circuit Boards recycling: An extensive assessment of current status. J. Clean. Prod. 94, 5–19. doi:10.1016/j.jclepro.2015.02.024.
66 Zhang, K., Wu, Y., Wang, W., Li, B., Zhang, Y., Zuo, T ., 2015. Recycling indium from waste LCDs: A review. Resour. Conserv. Recycl. 104, 276–290. doi:10.1016/j.resconrec.2015.07.015.
67 Kumar, M., Lee, J., Kim, M., Jeong, J., Yoo, K., 2012. Leaching of metals from waste printed circuit boards (WPCBs) using sulfuric acid and nitric acid. Environ. Eng. Manag. J. 3613.
68 Rocchetti, L., Amato, A., Fonti, V., Ubaldini, S., De Michelis, I., Kopacek, B., Vegliò, F., Beolchini, F., 2015. Cross-current leaching of indium from end-of-life LCD panels. Waste Manag. 42, 180–187. doi:10.1016/j.wasman.2015.04.035.
69 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..

(L/S) ratio of 1:1 at 160°C for 1 hour and reached 92% in filtration.

Table 18: Precious metal leaching reagents, reactions, conditions, advantages and disadvantages

Lixiviant	Cyanide	Thiourea	Thiosulfate	Potassium persulfate	Halide
Reagent	CN^-, O_2 (air) KCN 65.12 g/mol 1.52 g/cm^3 71.6 g/100 mL (25°C) NaCN 49.10 g/mol 1.596 g/cm^3 63.7 g/100 mL (25°C)	$SC(NH_2)_2$, Fe^{3+} CH_4N_2S 76.12 g/mol 1.405 g/mL 14.2 g/100mL (25°C)	$S_2O_3^{2-}$, NH_3, Cu^{2+} $(NH_4)_2S_2O_3$ $Na_2(S_2O_3).5H_2O$ hypo 158.11 g/mol (anhydrous) 248.18 g/mol (pentahydrate) 1.667 g/cm^3 70.1 g/100 mL (20 °C)	$2[SO_4]^-$ $K_2S_2O_8$ 270.322 g/mol 2.477 g/cm^3 4.49 g/100 ml (20 °C)	Chlorine/chloride Cl^-/Cl_2 NaCl, hypochlorite, HCl, $HClO_4$, NaClO Iodide I^-/I_2 KI Bromide Br^-/Br_2
Reactions	$4Au+8CN^- +O_2+2H_2O \rightarrow 4Au(CN)_2^- +4OH^-$	$2Au+4CS(NH_2)_2+2Fe^{3+} \leftrightarrow 2Au(CS(NH_2)_2)_2^+ +2Fe^{2+}$	$4Au+8S_2O_3^{2-} + O_2 + 2H_2O \rightarrow 4Au(S_2O_3)_2^{3-} + 4OH^-$	Dissolve all base metals retaining only gold in solid residue	$2Au+11HCl+3HNO_3 \leftrightarrow 2HAuCl_4+3NOCl+6H_2O$
Species and Their Stability	$Au(CN)_2^-$ (log K: 38.3) $Ag(CN)_2^-$ (log K:20.3)	$Au(CS(NH_2)_2)_2^+$ (log K: 22) $Ag(CS(NH_2)_2)_2^+$ (log K: 13)	$Au(S_2O_3)_2^{3-}$ (log K:28.7) $Ag(S_2O_3)_2^{3-}$ (log K:13)		$AuCl_4$ (log K: 29.6)
Conditions	E°:-0.67 V, pH>10, 25°C	E°:0.38 V, pH: 1-2, 25°C	E°:0.274-0.038V, pH>8-11, 25°C		E°:1.0 V, pH<4, 25°C
References	[70] Column leaching of crushed PCBs: 46.4% Au, 51.3% Ag, 47.2% Nb, 62.3% Cu	[71], Crushed PCBs, 10 g/L H_2SO_4 and $CS(NH_2)_2$ 5 g/L ferric sulfate, 2h 90% Ay, 68% Cu, 45%Fe, 43%Pb and 28% Zn	[72] 0.2 M $(NH_4)_2S_2O_3$ 0.02M $CuSO_4$ 0.4M NH_4OH 400C, 48 h 95% Au, 100% Ag	[73] 99.5% Au with melting	[74] Oxidative leaching using HNO_3 or H_2O_2 in chloride medium (HCl and NaCl), 75°C 93-95% Pd
References	[75] Bench scale, PCBs Oxidative H_2SO_4 leach to dissolve Cu and Ag. Oxidative chloride leaching to dissolve Pd and Cu. Cyanide leaching Au, Ag and Pd.95% Au, 93% Ag and 99% Pd	[76] 20 g/L $CS(NH_2)_2$ 6 g/L 5 g/L ferric sulfate 10 g/L H_2SO_4 S/L: 1/10 (g/mL) Ambient temp., 3h 85.76% Au, 71.36% Ag	[77] 0.12 M $(NH_4)2S_2O_3$ 20 mM $CuSO_4$ 0.2 M NH_4OH 2h 98% Au PCB 10 h 90% Au mobile phone		[78] Iodide leaching 1-1.2% iodide conc. 1-2% H_2O_2 S/L: 1/10 pH: 7 Ambient temp., 4h 95% Au
Commands Ads/Pros	Toxic and have serious environmental issues	Non-toxic, non-corrosive, less environmental impact. Cost and consumption important factors.	Oxygen carrying catalyst $Cu(NH_3)_4^{2+}$ is required. Non toxic and non-corrosive	Non-toxic, strong oxidizing agent	Non-toxic, non-corrosive, very selective. Consumption, reagent cost, chlorine gas, special reactor requirement

Table 19: Summary of the different treatment techniques [79]

Environmental Impact	Metal reclamation	Energy use	Process
High	High	Low	Grinding (shredding)
High	None	High	Incineration
Large energy required	High	Low	Pyro metallurgical Recovery
Low. Process is efficient	None	High	Thermal de-Polymerization
Low. Process is efficient	None	High	Plasma arc gasification
Very low energy process	High	Low	Bio-Leaching

11-1-6-The best technology for processing plastics associated with electronic displays

A range of processing technologies are used to convert the plastics produced from recycling (primary polymers) into the desired shape of the final product. The processing step itself is essentially a physical conversion step through the

[70] 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.
[71] Ficeriova J., Bal A.Z.P., Dutkova E. and Gock E., "Leaching of Gold and Silver from Crushed Au-Ag Wastes.," Open Chem. J., 2, (2008), 6-9.
[72] Oh C.J., Lee S.O., Yang H.S., Ha T.J. and Kim, M.J., "Selective Leaching of Valuable Metals from Waste Printed Circuit Boards." Air & Waste Management Association, 53, (2003), 897–902
[73] Syed S., "A Green Technology for Recovery of Gold from Non-metallic Secondary Sources," Hydrometallurgy, 82, (2006), 48-53.
[74] Quinet P., Proost J. and Van Lierde A., "Recovery of Precious Metals from Electronic Scrap by Hydrometallurgical Processing Routes." Minerals Metallurgical Process, 22, (2005), 17–22.
[75] Quinet P., Proost J. and Van Lierde A., "Recovery of Precious Metals from Electronic Scrap by Hydrometallurgical Processing Routes." Minerals Metallurgical Process, 22, (2005), 17–22.
[76] Behnamfard A., Salarirad M.M. and Veglio F., "Process Development for Recovery of Copper and Precious Metals from Waste Printed Circuit Boards with Emphasize on Palladium and Gold Leaching and Precipitation," Waste Management, 33, (2013), 2354-2363 (Oxford).
[77] Ha V.H., Lee J., Jeong J., Haia H.T. and Jha M.K., "Thiosulfate Leaching of Gold from Waste Mobile Phones." Journal of Hazardous Materials, 178 (1–3), (2010), 1115–1119.
[78] Xu Q., Chen D., Chen L. and Huang, M.H., "Gold leaching from waste printed circuit board by iodine process." Nonferrous Met., 62, (2010), 88-90.
[79] Hafiz Zaid Ahmad,others,2015, Extraction of Metals from Electronic Waste,Department of Chemical Engineering,-COMSATS Institute of Information Technology, Defense.

use of different techniques [80] such as: injection (for products of different shapes and often very complex such as machine parts, electric compressors and medical devices such as syringes, hard thermoplastics and thermoplastics). Melting , extrusion, pressing, etc.

11-2- Available Technologies for Recycling of Cathode-Ray Tube

There are different types of techniques available to recycle the material extracted from the cathode ray tube. In general, the cathode ray tube recycling process is categorized into two types: (1) open loop and (2) closed loop recycling process as shown in the figure:

[80] European Commission. 2011a. Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector. Draft 2, 20 July 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

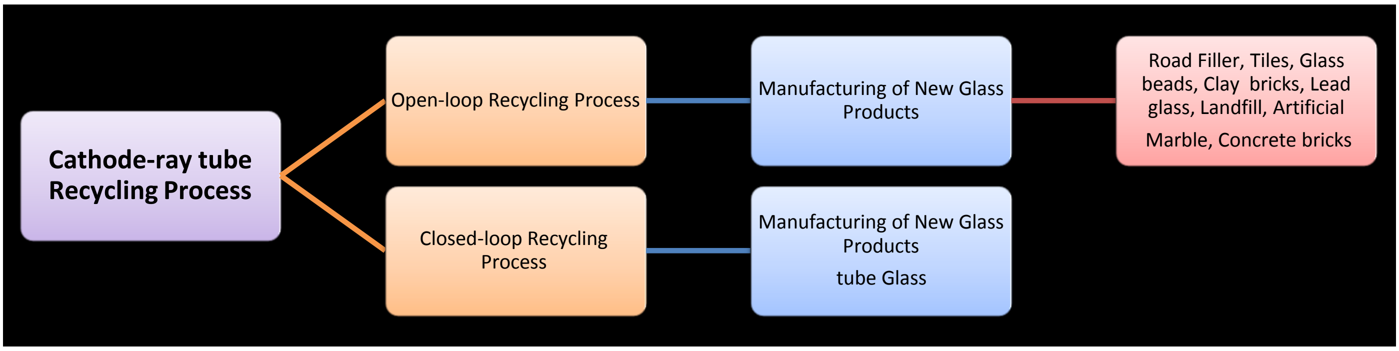


Figure 9: An overview of the cathode ray tube recycling process. (Source: adapted from Singh et al. 2016a)

Table 20: The difference between open and closed loop recycling

Open-Loop Recycling Process	Closed-Loop Recycling Process
The open-loop recycling (glass-to-lead recycling) process uses recycled cathode ray tube (CRT) glass to make new glass products. It is not recommended to obtain raw CRT glass during the open loop process due to many unknown compositions. CRT applications in new products are a barrier [81] because they require an understanding of CRT composition [82]. Unless the lead does not exceed the standards[83]. Taking into account this limitation of the use of suppressive glass, the open loop process uses only sheet glass for new glass products due to its well-known and stable composition.	Closed-loop recycling (glass-to-glass recycling) recycles the old CRT into the manufacture of the new CRT. Both the funnel and the glass plate are broken into small pieces without any separation in the closed loop process [84]. Closed-loop process was appropriate when enough old cathode ray tube (CRT) was available to meet the continuing market demand.

Table 21: summary of cathode ray tube screen processing methods

M	Processing method	the description
1-	Technology for Segregation of Funnel Glass from Panel Glass	Glass is one of the major components of a cathode ray tube that requires special attention due to its different chemical composition while being recycled. In particular, challenges arise when it comes to separating the suppressive (lead) glass from the plate glass (lead-free) of the cathode ray tube. Therefore, recycling technology focuses on avoiding pollution and efficient extraction of lead. There are different recycling methods for separating glass funnel glass from sheet glass.
2-	Magnetic separation	During the separation of metals according to their magnetic properties, iron and nickel accumulate in the magnetic part [85]. On the other hand, copper accumulates in the conductive part. As with electrostatic separation, this process is usually applied after crushing. Thus, particle size plays an important role. A small fraction may be left in the non-magnetic part, possibly due to its presence in paramagnetic or magnetic

[81] Lee J-S, Cho S-J, Han B-H, Seo Y-C, Kim B-S, Heo SP (2012) Recycling of TV CRT panel glass by incorporating to cement and clay bricks as aggregates. Adv Biomed Eng 7:257.
[82] Lairaksa N, Moon AR, Makul N (2013) Utilization of cathode ray tube waste: encapsulation of PbO-containing funnel glass in Portland cement clinker. J Environ Manag 117:180–186. https://doi.org/10.1016/j.jenvman.2012.12.014
[83] Yot PG, Mear FO (2011) Characterization of lead, barium and strontium leach- ability from foam glasses elaborated using waste cathode ray-tube glasses. J Hazard Mater 185:236–241. https:// doi.org/10.1016/j.jhazmat.2010.09.023
[84] Ertug B, Unlu N (2012) An evaluation study: recent developments and processing of glass scrap recycling. Epd Congress:381–388. https://doi.org/10.1002/9781118359341.

[85] Kasper, A.C., Berselli, G.B.T., Freitas, B.D., Tenório, J.A.S., Bernardes, A.M., Veit, H.M., 2011. Printed wiring boards for mobile phones: Characterization and recycling of copper. Waste Manag. 31, 2536–2545. doi:10.1016/j.wasman.2011.08.013.

		particle as alloying elements.
3-	Electric-Wire Heating Method	In this method, thermal shock from alternating heating and cooling is applied by rolling nichrome along the line of the frit mixture of the cathode ray tube causing fracture, thus separating the funnel glass from the plate glass. Requires 1 to 3 minutes depending on the size and type of the cathode ray tube . This method is suitable for mass production due to its ease of operation, high efficiency, reasonable costs and absence of noise [86]. However, difficulty arises if the wire is placed incorrectly, creating sharp edges on chipped parts.
4-	Gravitational-Fall Method	The cathode ray tube going down from a certain height is dropped due to the force of gravity which causes the funnel glass to break through the impact of the upper surface. Thus, the tablet glass is separated from the funnel glass during this method. The main challenge with this method is to achieve a clear separation. This method is low cost and simple [87] . Gravitational separation depends on the density and size of the particles: their movement in a liquid, for example air, allows the different particles to separate. One of the major drawbacks of this method is the simultaneous difference in particle size and density.
5-	Thermal Shock	In this method, both the funnel glass and the platen glass are separated along the glazed line due to the thermal shock caused by the heat subsequently bound by the cold air. This method uses heating and quenching of electrical wires. This method is widely used in China.
6-	Pyrometallurgical Process lead removal	Lead has incomparable properties such as corrosion resistance, ductility, ductility, and malleability, and therefore it is widely used in the manufacture of batteries, welding and X-ray shielding [88]. It is very difficult to extract a good amount of lead under normal pressure and temperature [89] which consists of an O-Si-O and/or partially -O-Si-O-Pb-O- network in fis-sure laminated glass assembly. Therefore, for a better performance of lead extraction, importance is given to the selection of lead extraction methods by removing the glass assembly. The known lead recovery process is as follows: Thermal metallurgical treatment is used to remove lead and other metals by adding sodium carbonate powder (a fusion agent), sodium sulfide (a catalyst) and carbon powder as a reducing agent with a lead removal efficiency of 94% [90] , besides, metallic iron is used for thermal reduction to extract lead with an efficiency of 99%. of cathode ray tube glass. The addition of Na2CO3 also aids in the reduction process by restricting the temperature below 1000°C, to avoid lead evaporation [91].
7-	Diamond Cutting Method	This method can be performed in both wet and dry conditions. During wet condition, the diamond saw blades cut along the cathode ray tube frit mix line with cooled water spray while the cathode ray tube kept in a container continues to rotate. The wet condition is suitable for all thicknesses and sizes of the cathode ray tube. During the dehydration process, the diamond wheel and diamond belt are used together with the abrasive in the absence of water. The dry state is more suitable for large-scale operation due to the better performance in terms of clean separation [92] . However, the disadvantage of applying drought condition is the high investment costs at the outset. The diamond cutting method is faster than the

[86] Heart S (2008) .
[87] Heart S (2008) Recycling of cathode ray tubes (CRTs) in electronic waste. Clean Soil Air Wat 36:19–24. https://doi.org/10.1002/clen.200700082.
[88] Yu M, Liua L, Li J (2016) .
[89] Miyoshi H, Chen D, Akai T (2004) A novel process utilizing subcritical water to remove lead from wasted lead silicate glass. Chem Lett 33:956–957. https://doi.org/10.1246/cl.2004.956.
[90] Hu B, Hui W (2018) Lead recovery from waste CRT funnel glass by high-temperature melting process. J Hazard Mater 343(5):220–226. https://doi.org/10.1016/j.jhazmat.2017.09.034
[91]. Okada T, Yonezawa S (2013) Energy-effcient modifcation of reduction-melting for lead recovery from cathode ray tube funnel glass. Waste Manag 33:1758–1763. https://doi.org/10.1016/j. wasman.2013.04.009
[92] Lee CH, Chang CT, Fan KS, Chang TC (2004) An overview of recycling and treatment of scrap computers. J Hazard Mater 114:93–100. https://doi.org/10.1016/j.jhazmat.2004.07.013.

		traditional mechanical cutting method due to its vacuum absorption capacity, dust recovery ability, automatic edge search and laser positioning [[93]]. This method is generally carried out in three stages. In the first stage, the vacuum is removed and the electron gun is disassembled. In the second stage, the front panel, the funnel glass and the shade mask are all separated, and in the last stage, the front plate is cleaned and the funnel glass is painted.
8-	Laser Cutting Method	It is similar to the heat shock method, but in this method, a laser beam is used instead of heating electrical wires followed by spraying with cold water [[94]]. This energy-intensive method is suitable for large-scale operations although it is costly due to the high investment. The disadvantages of this method are the challenges of cutting and restoring thicker glass after using a laser beam.
9-	Water Jet Separation	High-pressure water containing abrasives is sprayed into a jet through a nozzle along the line of the cathode ray tube frit. This method is simple and affordable, but usually the presence of abrasives contributes to sewage which is a major concern [[95]] .
10-	Acid Melting	The acid melt injects the hot nitric acid and the hot acid bath to melt the interface joining the plate and the cathode ray tube funnel. The main challenges in using this technology are the need to dispose of a large amount of wastewater and liquid generated through this method [[96]] and thus, this method is not suitable or recommended due to its negative environmental impact.

The above-mentioned methods used to separate funnel glass are not taken into account if fluorescent colors are present in the coatings. These coatings are a concern due to the different metals that can be removed with the following techniques as shown in the following table:

Table 22: Available technology for removing paint

Technology	Brief description	References
Wet-scrubbing method	Water and coatings scrubbed off from disintegrated cathode-ray tube glass positioned in a tumbling mill	Lee et al. (2004)
Ultrasonic method	Disintegrated cathode-ray tube glass is submerged into acid and water and immersed in an ultrasonic device for a certain time	Ezrat and Zhang (2014)
Sandblasting method	Air jet under high pressure ensures blasting of small steel balls onto the glass surface	Heart (2008)
Vacuum-suction method	Slack finishes from the panel glass are sucked using surface vacuum-suction device	Heart (2008)

12- Conclusion

It is clear that the rising volume and flow of e-waste from electronic display equipment can lead to dire environmental and human consequences, if not addressed in the near future. As more and more display board vehicles are filled with earth, easily minable items may be lost. Thus, increased production may lead to a rise in their prices first, and secondly, the depletion of precious and precious metals, and currently the processing of electronic display panels is not sustainable - or of great feasibility in developing countries. Therefore, there is an urgent need for new environmentally friendly approaches to recycling and recovering valuable components from waste display board vehicles. e .

The processing and recycling of electronic display panels is a multifaceted challenge, as evidenced by the detailed analysis of different processing methods. Each individual process is just as deterministic as the collective one, starting with electronic scrap collection and ending with recovering the metals for reuse. The heterogeneity in the chemical composition of the display boards, their attachments, and the toxicity of the materials contained in them present important challenges to the recycling methodology.

Dismantling waste electronic display panels, and separating particularly hazardous components from non-hazardous materials, is a critical step in reducing toxicity concerns during processing. When dismantling the display panels, physical techniques are used to separate the nonmetals from the metals found in electronic display panels and printed circuits. Reducing display panels, printed circuits, and enclosures to fine particle sizes of less than 150 µm is the first step in physical separation. Density separation is the most popular option for physical separation of plastics and other minerals.

Electrostatic separation (coron and eddy current) and magnetic separation are also used to separate materials based on differences in electrical conductivity and magnetism (ferrous versus non-ferrous). Non-metallic parts (NMF) can often be recycled for reuse in fillers and composites.

Any hole in the ship of the international community could drown everyone without exception. In order to spare people in developing countries more economic, living and energy crises, everyone should show a sense of responsibility towards these countries and their citizens by reaching broad outlines of the priority areas proposed to be undertaken in the field of recycling and recovering metals from electronic screen equipment. The study recommends that researchers do a lot of studies in the same study to explain and complete

[93] Yu M, Liua L, Li J (2016) .
[94] Yu M, Liua L, Li J (2016) An overall solution to cathode-ray tube (CRT) glass recycling. Procedia Environ Sci 31:887–896. https://doi.org/10.1016/j.proenv.2016.02.106.
[95] (Heart 2008).
[96] Yu M, Liua L, Li J (2016) .

what should be mentioned and clarified in various electronic display equipment.

References

1. Ardente & Mathieux (2012): Application of the project's methods to three product groups.
2. Behnamfard A., Salarirad M.M. and Veglio F., "Process Development for Recovery of Copper and Precious Metals from Waste Printed Circuit Boards with Emphasize on Palladium and Gold Leaching and Precipitation," Waste Management, 33, (2013), 2354-2363 (Oxford).
3. Birloaga I., De Michelis I., Ferella F., Bazatu M. And Veglio F., "Study on the Influence of Various Factors in the Hydrometallurgical Processing of Waste Printed Circuit Boards for Copper and Gold Recovery," Waste Management, 33, (2013), 935-941. htpp://dx.doi.org/10.1016/j.wasman.2013.01.003.
4. Böni. H.; Widmer, R.: Disposal of Flat Panel Display Monitors in Switzerland. EMPA, St. Gallen, 2011.
5. 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).
6. Circuit Boards recycling: An extensive assessment of current status. J. Clean. Prod. 94, 5– 19.
7. Dang, M.T., Brunner, P.-L.M., Wuest, J.D., 2014. A green approach to organic thin-film electronic devices: Recycling electrodes composed of Indium Tin Oxide (ITO). Sustain. Chem. Eng. 2, 2715–2721. doi:10.1021/sc500456p.
8. Display Search (2008), 'Total flat panel display shipments will grow 5% per year through 2015; consumer and industrial applications driving growth', Press Release, 5 February, http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/flat_panel_displays_more_t han_99_percent_of_display_sales.asp.
9. E. Ma, and Z. Xu, J. Hazard. Mater., DOI 10.1016/j.jhazmat.2013.10.020 (2013).
10. Ebin, B., Isik, M.I., 2016. Pyrometallurgical processes for the recovery of metals from WEEE, in: Chagnes, A., Cote, G., Ekberg, C., Nilsson, M., Retegan, T. (Eds.), WEEE Recycling. Elsevier Inc, pp. 107–138.
11. Ertug B, Unlu N (2012) An evaluation study: recent developments and processing of glass scrap recycling. Epd Congress:381–388. https://doi.org/10.1002/9781118359341.
12. Fan, S.K.S., Fan, C., Yang, J.H., Liu, K.F.R., 2013. Disassembly and recycling cost analysis of waste notebook and the efficiency improvement by re-design process. J. Clean. Prod. 39, 209–219. doi:10.1016/j.jclepro.2012.08.014.
13. Ficeriova J., Bal A.Z.P., Dutkova E. and Gock E., "Leaching of Gold and Silver from Crushed Au-Ag Wastes.," Open Chem. J., 2, (2008), 6-9.
14. Ghosh, B., Ghosh, M.K., Parhi, P ., Mukherjee, P.S., Mishra, B.K., 2015. Waste Printed Circuit Boards recycling: An extensive assessment of current status. J. Clean. Prod. 94, 5–19. doi:10.1016/j.jclepro.2015.02.024.
15. Götze & Rotter (2012): Challenges for the recovery of critical metals from waste electronic equipment - A case study of indium in LCD panels.
16. Götze, in: Proceedings of the conference Electronics Goes Green 2012+ (EGG), Berlin, Germany, 2012, pp. 1-8.
17. Graedel, T. E.; Reck, B.; Buchert, M.; Hagelüken C. et al. "Recycling rates of metals", United Nations Environment Programme, (UNEP edits.) 2011.
18. Graedel, T.E., 2011. Metal Stocks & Recycling Rates, Recycling Rates of Metals: A
19. Guidelines and Certification Schemes for E-waste Recyclers - Recommendation ITU-T L.1032 2019
20. Ha V.H., Lee J., Jeong J., Haia H.T. and Jha M.K., "Thiosulfate Leaching of Gold from Waste Mobile Phones." Journal of Hazardous Materials, 178 (1–3), (2010), 1115–1119.
21. Hafiz Zaid Ahmad,others,2015, Extraction of Metals from Electronic Waste,Department of Chemical Engineering,-COMSATS Institute of Information Technology, Defense.
22. Hall, W.J., Williams, P.T., 2007. Separation and recovery of materials from scrap printed circuit boards. Resour. Conserv. Recycl. 51, 691–709.doi:10.1016/j.resconrec.2006.11.010.
23. Havlik, T., Orac, D., Petranikova, M., Miskufova, A., Kukurugya, F., Takacova, Z.,2010 Leaching of copper and tin from used printed circuit boards after thermal treatment. J. Hazard. Mater. 183, 866–873. doi:10.1016/j.jhazmat.2010.07.107.
24. Heart S (2008) Recycling of cathode ray tubes (CRTs) in electronic waste. Clean Soil Air Wat 36:19–24. https://doi.org/10.1002/clen.200700082.
25. HIWA SALIMI,2017,Extraction and Recovery of Gold from both Primary and Secondary Sources by Employing A Simultaneous Leaching and Solvent Extraction Technique and Gold Leaching In Acidified Organic Solvents -Department of Chemistry-University of Saskatchewan. Saskatchewan S7N 5C9 Canada.
26. Hsiang J, Díaz E (2011) Lead and developmental neurotoxicity of the central nervous system. Curr Neurobiol 2(1):35–42. https://pdfs.semanticscholar.org/ed4e/57f3e2f3c3f7231af00427ab5271 907cdfa0.pdf
27. http://www.idtechex.com/products/en/articles/00000934.asp
28. Hu B, Hui W (2018) Lead recovery from waste CRT funnel glass by high-temperature melting process. J Hazard Mater 343(5):220–226. https://doi.org/10.1016/j.jhazmat.2017.09.034.
29. Initial evaluation of the Minamat agreement in Yemen - March 2019
30. K. S. Park, W. Sato, G. Grause, T. Kameda, and T. Yoshioka, Thermochim. Acta, DOI 10.1016/j.tca.2009.03.003 (2009).
31. 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).
32. Kasper, A.C., Berselli, G.B.T., Freitas, B.D., Tenório, J.A.S., Bernardes, A.M., Veit, H.M., 2011. Printed wiring boards for mobile phones: Characterization and recycling of copper. Waste Manag. 31, 2536–2545. doi:10.1016/j.wasman.2011.08.013.
33. Kissling et al. (2012): Definition of generic re-use operating models for electrical and electronic equipment.
34. Kopacek (2008): ReLCD: Recycling and re-use of LCD-panels.
35. Kumar, M., Lee, J., Kim, M., Jeong, J., Yoo, K., 2012. Leaching of metals from waste printed circuit boards (WPCBs) using sulfuric acid and nitric acid. Environ. Eng. Manag. J. 3613.
36. Lairaksa N, Moon AR, Makul N (2013) Utilization of cathode ray tube waste: encapsulation of PbO-containing funnel glass in Portland cement clinker. J Environ Manag 117:180–186. https://doi.org/10.1016/j.jenvman.2012.12.014
37. Lee CH, Chang CT, Fan KS, Chang TC (2004) An overview of recycling and treatment of scrap computers. J Hazard Mater 114:93–100. https://doi.org/10.1016/j.jhazmat.2004.07.013.
38. Lee J-S, Cho S-J, Han B-H, Seo Y-C, Kim B-S, Heo SP (2012) Recycling of TV CRT panel glass by incorporating to cement and clay bricks as aggregates. Adv Biomed Eng 7:257.
39. Leonard SS, Harris GK, Shi X (2004) Metal-induced oxidative stress and signal transduction. Free Radic Biol Med 37:1921–1942. doi: 10.1016/j.freeradbiomed.2004.09.010
40. M. Alfantazi, and R. R. Moskalyk, Miner. Eng., DOI 10.1016/S0892-6875(03)00168-7 (2003).
41. Manhart, A.; Griesshammer, R.: Soziale Auswirkungen der Produktion von Notebooks [Social impacts of the production of notebook PCs]. Oeko-Institut e.V., Freiburg, 2006.
42. Martens, H.: Recyclingtechnik – Fachbuch für Lehre und Praxis [Recycling technology – a textbook of theory and practice]. Heidelberg, 2011.
43. Matthias Buchert, Andreas Manhart , Daniel Bleher, Detlef Pingel , Recycling critical raw materials from waste electronic equipment , 2012, Commissioned by the North Rhine Westphalia State Agency for Nature, Environment and Consumer Protection.
44. Mecucci A. and Scott K., "Leaching and Electrochemical Recovery of Copper, Lead and Tin from Scrap Printed Circuit Boards." Journal of Chemical Technology and Biotechnology, 77, (2002), 449–457.
45. Miyoshi H, Chen D, Akai T (2004) A novel process utilizing subcritical water to remove lead from wasted lead silicate glass. Chem Lett 33:956–957. https://doi.org/10.1246/cl.2004.956.
46. 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.
47. NGO Directory 2014
48. Oh C.J., Lee S.O., Yang H.S., Ha T.J. and Kim, M.J., "Selective Leaching of Valuable Metals from Waste Printed Circuit Boards." Air & Waste Management Association, 53, (2003), 897–902
49. Okada T, Yonezawa S (2013) Energy-effcient modifcation of reduction-melting for lead recovery from cathode ray tube funnel glass. Waste Manag 33:1758–1763. https://doi.org/10.1016/j. wasman.2013.04.009

50. Öztürk T (2015) Generation and management of electrical–electronic waste (e-waste) in Turkey. J Mat Cycles Waste Manag 17:411–421. https://doi.org/10.1007/s10163-014-0258-6
51. Partnership for Action on Computing Equipment - UNEP/CHW.10/20- 11 July 2011
52. Prakash, S.; Manhart, A.: Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana. Öko-Institut e.V., Freiburg, 2010
53. Preparatory studies for Eco-design Requirements of EuPs, Lot 3: Personal Computers (desktops and laptops) and Computer Monitors. Brussels, 2007.
54. Quinet P., Proost J. and Van Lierde A., "Recovery of Precious Metals from Electronic Scrap by Hydrometallurgical Processing Routes." Minerals Metallurgical Process, 22, (2005), 17–22.
55. Quinet P., Proost J. and Van Lierde A., "Recovery of Precious Metals from Electronic Scrap by Hydrometallurgical Processing Routes." Minerals Metallurgical Process, 22, (2005), 17–22.
56. recovery techniques from e-scrap: Hydrometallurgy in recycling. Miner. Eng. 25, 28–37
57. Rieger, R.: Die Verwendung von "seltenen Erdmetallen" in der Elektrogerät- und Fahrzeugproduktion und ihre Erfassungsmöglichkeit im Materialrecycling [The use of rare earths in the production of electronic equipment and vehicles and options for collection for materials recycling]. Diplomarbeit an der Technischen Universität Dresden [Dissertation for Dreseden University of Applied Sciences], Dresden, 2009.
58. Robinson, B., 2009. E-waste: an assessment of global production and environmental impacts. Sci. Total Environ. 408, 183–191. doi:10.1016/j.scitotenv.2009.09.044.
59. Rocchetti, L., Amato, A., Fonti, V., Ubaldini, S., De Michelis, I., Kopacek, B., Vegliò, F., Beolchini, F., 2015. Cross-current leaching of indium from end-of-life LCD panels. Waste Manag. 42, 180–187. doi:10.1016/j.wasman.2015.04.035.
60. Ross Young; "Global Manufacturing Trends: What Can We Learn from the HB LED Market Explosion?", in 2011 Solid-State Lighting Manufacturing R&D Workshop, Boston, MA, 2011-04-12.
61. Rotter, V.S., Ueberschaar, M., Chancerel, P., 2013. Rückgewinnung von Spurenmetallen aus Elektroaltgeräten, in: Proceedings of Berlin Recycling and Raw Materials Conference. Berlin, pp. 481–493.
62. 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.
63. Schlesinger, M.E., King, M.J., Sole, K.C., Davenport, W.G., 2011. Extractivemetallurgy of copper, 5th ed. Elsevier.
64. Schüler, D.; Buchert, M.; Liu, R.; Dittrich, S.; Merz, C.: Study on Rare Earths and Their Recycling. Öko-Institut, Darmstadt, 2011
65. Silvas F.P.C., Correa M.M.J., Caldes M.P.K., Moraes V.T., Espinosa D.C.R. and Tenorio J.A.S., "Printed Circuit Board Recycling; Physical Processing and Copper Extraction by Selective Leaching," Waste Management, 2015 (accepted).
66. Singh N, Li J, Zeng X (2016b) Solutions and challenges in recycling waste cathode-ray tubes. J Clean Prod 133:188–200. https://doi.org/10.1016/j.jclepro.2016.04.132
67. Singh N, Wang J, Li J (2016a) Waste cathode rays tube: an assessment of global demand for processing. Procedia Environ Sci 31:465–474. https://doi.org/10.1016/j.proenv.2016.02.050.
68. Status Report, UNDP.
69. Syed S., "A Green Technology for Recovery of Gold from Non-metallic Secondary Sources," Hydrometallurgy, 82, (2006), 48-53.
70. T. Minami, Thin Solid Films, DOI 10.1016/j.tsf.2007.03.082 (2008).
71. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012) Heavy Metal Toxicity and the Environment. In: Luch A. (eds) Molecular, Clinical and Environmental Toxicology. Experientia Supplementum, Springer, Basel. 101:133-164.
72. Tuncuk, A., Stazi, V., Akcil, A., Yazici, E.Y., Deveci, H., 2012. Aqueous metal
73. Tunsu, C., Petranikova, M., Gergorić, M., Ekberg, C., Retegan, T., 2015. Reclaiming rare earth elements from end-of-life products: A review of the perspectives for urban mining using hydrometallurgical unit operations. Hydrometallurgy 156, 239–258. doi:10.1016/j.hydromet.2015.06.007.
74. U.S. Department of Energy: Critical Materials Strategy. Washington D.C., 2010.
75. Xu Q., Chen D., Chen L. and Huang, M.H., "Gold leaching from waste printed circuit board by iodine process." Nonferrous Met., 62, (2010), 88-90.
76. Yamashita M, Wannagon A, Matsumoto S, Akai T, Sugita H, Imoto Y, Komai T, Sakanakura H (2010) Leaching behavior of CRT funnel glass. J Hazard Mater 184:58–64. https://doi.org/10.1016/j.jhazmat.2010.08.002.
77. Yedjou CG, Milner J, Howard C, Tchounwou PB (2010) Basic apoptotic mechanisms of lead toxicity in human leukemia (HL-60) cells. Intl J Environ Res Public Health 7(5):2008–2017. doi: 10.3390/ijerph7052008
78. Yot PG, Mear FO (2011) Characterization of lead, barium and strontium leach- ability from foam glasses elaborated using waste cathode ray-tube glasses. J Hazard Mater 185:236–241. https:// doi.org/10.1016/j.jhazmat.2010.09.023
79. Yu M, Liua L, Li J (2016) An overall solution to cathode-ray tube (CRT) glass recycling. Procedia Environ Sci 31:887–896. https://doi.org/10.1016/j.proenv.2016.02.106.
80. Zangl, S.; Brommer, E.; Grießhammer, R.; Gröger, J.: PROSA Fernsehgeräte [PROSA television sets]. Oeko-Institut e.V., Freiburg, 2009.
81. Zhang, K., Wu, Y., Wang, W., Li, B., Zhang, Y., Zuo, T ., 2015. Recycling indium from waste LCDs: A review. Resour. Conserv. Recycl. 104, 276–290. doi:10.1016/j.resconrec.2015.07.015