International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Pretreatment Methods and Pyrolysis techniques in the Recycling of Electronic waste: A Review

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A B S T R A C T

The increase in the production of newer models of electronics has made the older ones obsolete; hence, resulting in the generation of huge amount of electronic waste (e-waste). Reuse and recycling of non-reusable e-waste have been implored to reduce the amount of e-waste that go into farmland and landfills, which are detrimental to man and his environment. The recycling of the e-waste has led to the recovery of valuable metals and energy from e-waste such as such as mobile phones, laptops and refrigerators, printer and photocopiers, etc. However, improper storage and handling, ineffective and inefficient pretreatment methods and environmental unfriendly recycling methods have caused environmental and health risk to e-waste worker. This review considered pretreatment method, which is the bedrock of appropriate recovery of material from e-waste, for effective and efficient recycling that promotes eco-friendliness. Pyrolysis recycling techniques was also review. Satisfactory effectiveness in recovery and recycling of e-waste will be achieve with robust understanding on the pretreatment methods and pyrolysis techniques.

Keywords: *E-waste, manual treatment, mechanical treatment, pretreatment of e-waste, pyrolysis,*

1. INTRODUCTION

E-wastes are exported to developing countries from developed countries due to high influx of the market with new electronics (Hsu *et al*. (2019). Different categories of e-waste include (Khaliq et al., 2014 and EU (2012) : Large household appliances, Small household appliances, IT and telecommunications equipment, Consumer equipment, Lighting equipment, Electrical and electronic tools (with the exceptions of large-scale stationary industrial tools), Toys, leisure and sport equipment, Medical devices (with the exception of all implanted and infected products), Monitoring and control instruments, Automatic dispensers

Most of the e-waste cannot be reused but can be recycled. The existence of metals, plastics, etc. in e-waste make its recycling beneficial and economical (Das et al., 2021, Khaliq *et al*., 2014). E-wastes contain so many metals including precious metals (Au, Ag, Cu, Pt, Pd, Ru, Rh, Ir and Os); platinum group metals (platinum, tantalum, gallium, tellurium, germanium, selenium and palladium) critical metals (Co, Pd, In, Ge, Bi and Sb) and non-critical metals, such as Al and Fe (Forti et al., 2020). Thus e-waste recycling serve as a secondary source of these precious metals (Zeng et al., 2018; Awasthi et al., 2019), since their primary sources are been depleted (Ghosh *et al*., 2015). The amount of gold recovered from one ton of e-waste from personal computers is more than that recovered from 17 ton of gold ore and the processes for recovering precious metals from e-waste are easier than their primary ores (Khaliq et al., 2014 Rankin, 2011). In terms of strategic importance, availability and rate of depletion, critical metals are scarce and greatly used with high depletion rate while non-critical metals have abundant stocks (Supanchaiyamat and Hunt, 2019 and Das et al., 2020). These metals are the components e-waste such as printed circuit boards, liquid crystal displays, cathode ray tubes, fluorescent lamps, hard disk drives, light emitting diodes and batteries high depletion rate while non-critical metals have abundant stocks (Supanchaiyamat and Hunt, 2019 and Das et al., 2020). These metals are the components e-waste such as printed circuit boards, liquid crystal displays, cathode ray tubes, fluorescent lamps, hard disk drives, light emitting diodes and batteries (Natarajan *et al*., 2015, Askari, *et al*., 2014, Khaliq *et al*., 2014, Willner and Fornalczyk, 2013). LCDs contains Indium-tin oxide (ITO), for indium (In), europium is a primary element for phosphors production while printed circuit boards and chip-on-board LEDs are made with gold (Sethurajan *et al*., 2019), gold is recovered from waste LED (Murakami *et al.* (2015). PCBs in e-waste contain plastics and polymers that are made from polyethylene, polypropylene, epoxies and polyesters (Khaliq et al., 2014) and non-metallic, consisting of Pb/Sn and BFRs, which are mostly toxic (Ghosh et al., 2015).

In developing countries such as Nigeria, India, China, Indonesia, etc., they lack eco-friendly managerial skills and knowledge of green recycle methods of e-waste. Thus, these e-wastes are indiscriminately disposal in agricultural farmlands and landfill, where they are burnt openly and leached with acid that deteriorate the environment via the emission and release of toxic gases into the atmosphere and contamination of rivers and underground water (Khaliq *et al*., 2014). These cause environmental pollution and health risk to the e-waste worker and scavengers in recycling yards (Malliari and Kalantzi, 2017; Li *et al*., 2018).

To minimize emissions of hazardous compounds during e-waste recycling and management, some measures on pollution-control such as: safe storage, negative pressure to control dismantling dust, and closed mechanical dismantling (Ghimire and Ariya, 2020) and environmentally friendly methods are implored. Pretreatment is one of the most important steps and it can be done via physical, mechanical, thermal and chemical routes for the separation of nonmetallic and metallic fractions. Pretreatment of WPCBs plays a key role for isolating the valuable metals from the raw materials and this may reduce the cost of metal production from the secondary resources. This review considered pretreatment method, which is the bedrock of appropriate recovery of material from e-waste, for effective and efficient recycling that promotes eco-friendliness. Pyrolysis recycling techniques, which involves thermal decomposition, was also reviewed.

2. E-WASTE PRE-TREATMENT MANAGEMENT TECHNIQUE

Electronic waste is complex and heterogeneous in nature due to the varying metal and material it has, thus making its recycling difficult (Sethurajan, *et al.*, 2019 and Yazıcı, et al (2015). Pretreatment is the first step to the recovery of critical and precious metals from e-waste prior to metallurlogical processes. During pretreatments, precious and critical elements may be lost and end up as dusts or fine particles (Namias et al., 2013 & Marra et al., 2018). It involves mainly three steps which include manually disassembly/dismantling, mechanically processing and dust extraction (Ottiger, et al., 2019, Lenz et al. (2019).

2.1 Manual dismantling

Manual dismantling allows selective recovery of reusable and valuable components of the e-waste according to priority while ensuring that hazardous parts of the waste are detached appropriately (Vermesan et al., 2020; Sethurajan, et al., 2019). The dismantling process of the parts of e-wastes is done manually, been laborious, although automated methods are underway for specific devices (Park et al., 2015; Kopacek, 2016) and is carried out using hand tools, such as hammer, screw drivers, pliers, industrial scissors, side cutter etc (Kumar et al., 2017 and Hubau et al., 2019). It involves sorting, separation, cleaning, emptying, dismantling and segregation (Ottiger, et al., 2019). Hence, the e-waste-worker must always be kitted-up with personal protective wears such as gloves, goggles, dust mask, overall cloth and protective shoes to minimize exposure to contaminants from the e-waste (Lenz et al. (2019). E-waste parts and devices that can be dismantled include: capacitors, screen and monitors, batteries, PCB, central processing unit (CPU), random access memory (RAM), floppy-disk, hard drives, etc.

Sorting of e-waste components eases handling, transportation and processing. The e-waste parts are sorted into small equipment and large equipment, lamps, batteries, screen and monitors, wires, printed circuit boards (PCB), etc. After sorting, the e-waste components are separated using either non-destructive, semi-destructive or destructive methods (Ottiger, et al., 2019). Non-destructive methods include dismantling, taking off, taking apart and taking out, uncoupling, unlocking, unsoldering, disengaging, demoulding, unfastening, unclamping. While semi-destructive method include: fragmenting, dissecting, splitting, tearing and breaking, melting, ablating; destructive separation methods, involve shredding, dissecting, melting, milling, tearing, shearing, breaking, mashing. The Cleaning process is to avoid pollution in the separated material fractions and must be done before the mechanical processing.

Next is to empty devices such as lamps and cathode ray tube, which contain hazardous gases (Lenz et al., 2019) to avoid exposure and contamination, which may cause serious health risk to the e-waste worker. In manual dismantling, the e-waste device cases are removed, harmful components are identified and removed without spreading and releasing any trace of the gas, and then the remaining fractions separated and sorted. Thereafter, the devices are segregation into their varying fractions such as glass, capacitors, motors, plastics, coils, cables, screws, led diode, batteries, ferrous metals, lamp tubes, magnetic deflectors, electron gun, etc. (Lenz et al. (2019).

2.2 Mechanical Treatment Processes

Mechanical processes are the center of recycling of e-waste (Das et al., 2020), in which recyclable e-waste components such as plastics, are set aside for reuse in the production of secondary product such as plastic water-bottles, waste-baskets, plastic buckets, baskets and cup, and filaments for 3D printers (Gaikwad et al., 2018). It involves mainly concentration and selective treatment. The concentration of dismantled components of e-waste involves crushing, sizing, sorting and removal of dust (Ottiger et al., 2019), which is based on their physical properties such as size, shape, density, and electrical and magnetic characteristics (de Oliveira et al., 2012).

2.2.1 Crushing

Crushing is done by shredding and milling, to expose the inner part of the separated devices by using rotary cutters, alligator shears, cutting mills, impact mills, hammer-mill crushers or shredders (Das et al, 2020, Ottiger et al., 2019, Kaya, **2016**). In a recent study, Electro Dynamic Fragmentation of PCB was demonstrated as an unconventional method for size reduction and liberation of components (Martino et al., **2017**).

2.2.2 Sizing involves the separation of the crushed materials based on dimension of the particles and is done via sieving and screening.

2.2.3 Sorting

Sorting of mixtures of crushed e-waste components is the key to the mechanical processing since the mixture contains different metals and nonmetals (Huang et al., 2021). Sorting is a physical separation based on differences in physical properties including specific gravity, conductivity, magnetic susceptibility, flotation, electrostatic forces, and optical properties (Meng et al., 2019, Moroni, et al., 2018, Meng et al., 2017, and Wills & Finch, 2015).

2.2.3.1 Sensor-based sorting

Sensor-based sorting, parameters such as colour, type of polymer material or conductivity are considered. Coloured cameras are used to detect colours and shapes of mostly non-ferrous materials. Whereas, infrared sensor scanning is used to identify plastics, via irradiation with infrared light while glass is detected by optical sensor scanning (Kellner et al., 2009).

2.2.3.2 Sorting based on density

Sorting of heavy waste components of e-waste from light ones can be done depending on their differences in density (Vermesan, et al., 2020) and relies on the behaviours of the crushed particles to force of gravity, air and water resistances. Such separators of density include air tables, air cyclones, and centrifugal, shaking tables, heavy media separation, jigging and sink–float separators (Álvarez et al., 2017; de Oliveira et al., 2012, Pongstabodee et al., 2008). This can be achieved by jigging, whereby, the sortable components are loaded on a tray where a fluid is pumped in through the apertures and flows up and down periodically (Tsunekawa et al., 2012), leading to the layering of the substances according to their densities. Another sorting via density is the liquid floatation (Jeon et al., 2018) or sink-float methods, in which separating media such as water, saline or dense media are used to separate metals from plastics (Waseem, et al., 2022; Bauer et al., 2018, Wang, et al., 2015) and plastics and resins (Vermesan et al., 2020, Moyo et al., 2020). Wastewater and sludge, which contains heavy metals, are generated after liquid floatation process and leads to environmental and health issues if disposed untreated (He and Duan, 2017).

2.2.3.3 Sorting based on eddy current

Crushed e-wastes contain complex structures of mixture with different shapes and properties, the non-ferrous metal crushed particles are preferably separated from other particles using eddy current technology (Huang et al., 2021). Eddy current separation (ECS) technology is a clean, safe and eco-friendly technology used to separate nonferrous metals from nonmetal components of e-wastes (Huang et al., 2021; Ruan, et al., 2016a). The separation occurs when eddy current is induced in nonferrous metal of the e-waste, while interacting with different magnetic field, which alters the curve path along which the nonferrous metal moves and thus separates them from ferrous metals and nonmetals (Smith, et al., 2019; Ruan et al., 2014). Non-ferrous metals are metals, which do not contain iron but have low weight and are non-magnetic, such metals include aluminum, copper, zinc, lead, tin, gold, silver, platinum, indium, gallium, mercury, cadmium, lithium, etc (Foulke, (2008). ECS is an eco-friendly method in which the generation of solid waste, wastewater, air pollution is minimal or totally absent (Ruan et al., 2014). High feeding speed of the crushed particle into the separator reduces the efficiency of the separation technique (Ruan, et al., 2016a). Crushed particles with very low electrical conductivity/density ratio such as stainless steel, glass, and plastic cannot be separated using ECS, but Al and Cu with high electrical conductivity/density ratio, of $13.1 \times 10^3 m^2/\Omega{\cdot}Kg$ and $6.6 \times 10^3 m^2/\Omega{\cdot}Kg$ respectively can be separated from other particles via ECS (Vermesan, et al., 2020 and Kellner et al., 2009). More so, it can also be used to separate nonferrous metals of size < 5mm (Vermesan et al., 2020, Moyo et al., 2020; Habib Al Razi, 2016). Electrostatic separation separates metal conductors from non-conductors.

2.2.3.4 Magnetic sorting

Magnetic separation is done with low intensity magnetic drum separators for the separation of ferrous metals as magnetic fraction (Qiu et al., 2021, Vermesan et al., 2020, Zhang et al. (2017); Yazici and Deveci (2015); Tuncuk et al., 2012) from less or non-magnetic materials in the shredded mixture (Sethurajan et al., 2019, Zhu et al., 2019). Electromagnetic cross-belt separators are used to recover iron, galvanized steel, and tin-coated steel, and magnetic materials such as electrical transformers and chip coils (IMT, 2024).

2.2.3.5 Sorting based Electric field

Electric field separation is a method that involves the use of electrical separator to separate e-waste particles based on their electrical properties in high-voltage electric fields and may involve electrostatic sorting, high voltage sorting, and eddy current sorting (Tao, Z. et al, 2023). Coarse and fine particles of crushed e-waste can be charged via different mechanism such as mechanical triboelectrification, fluidization triboelectrification, electrification in a stream of electrons and ions created by the corona discharge, electrification by induction, or electrification occurring in an electrostatic field (Lyskawinski et al., 2021, Lesprit, et al., 2021, Younes et al., 2017).

2.2.3.6 Sorting via Electrostatic separation

Electrostatic separation (ES) is a common technology for separating metals and particles with size less than 0.1 mm (Ruan et al., 2016a) that is based on the conductivity of the components of the e-waste, which could be conductors, semiconductors, and nonconductors (Xue et al., (2012). These are separated in electric field through electrostatic separation (Barakat and Mayer-Laigle, 2017). Electrostatic separation method involves particle charging, separation at the grounded surface, and separation caused by the trajectory of the particles (Kelly, 2003). The particle charging could be via contacting of dissimilar materials, ion bombardment and induction (Kelly, 2003).

2.2.3.7 Triboelectrostatic separation

Triboelectrostatic separation also known as Frictional electrification (Benabboun et al., 2014) based on selective sorting of a material under an electric field depending on the characteristic charge or polarity of their surfaces and is particularly appropriate for granular plastic waste obtained from printed circuit boards (Wu et al., 2013). Triboelectric charging or contact charging, involves the contact between solid surfaces of the crushed e-waste particles by collisions and frictions on one another, leading to the generation and accumulation of high electrostatic charge, causing electrical discharge, wall adhesion and/or changes in surface properties (Lesprit, et al., 2021, Iuga, et al., 2015). The particles must have the ability to accumulate electrostatic charge on their surface when rubbed against another material (Lyskawinski et al., 2021). This contact electrification or triboelectric effect works with electric field forces to drive the negatively and positively charged particles to move to different plates, thereby separating the particle of the crushed e-waste of similar size, density, magnetic properties, and electric conductivities (Iuga, et al., 2015). The final separation is via free-fall separators or separators with rotating cylindrical electrodes (Piotr et al., 2018 and Lyskawinski et al., 2021). In conclusion, to separate crushed e-waste particles using trielectric separation, the e-waste particle are triboelectrically charged, fed into an electric field separator, then, particle trajectories are deflected in the electric field based on their polarity and amount of charge thereafter, are separated (Achouri, et al., 2017, Iuga et al., 2015, Benabboun et al., 2014). The benefits of triboelectrostatic separation methods include it simplicity, low cost, high efficiency of separation, consumption of less energy (Achouri, et al., 2017, Li et al., 2015).

PVC and rubber which are non-conductive can be recovered from scrap cables composed of Al and Cu, that are conductive, via triboelectrostatic separation (Dascalescu et al., 2016, Zelmat et al., 2017, Li et al., 2017). The technique applies to polymers, like high-impact polystyrene (HIPS), Polyvinyl chloride (PVC), High-density polyethylene (HDPE), polycarbonate (PC), Polyamide (PA) and acrylonitrile butadiene styrene (ABS), polylactide (PLA), polyethylene terephthalate (PET) and polyethylene high-density polyethylene (PE-HD) plastics (Lyskawinski, et al, 2021; Messafeur, et al. (2018), Boukhoulda, et al., 2017, Younes, et al., 2017). Thus, PVC in printed circuit boards, which are weak in carbon, can be separated from the pure PVC using this technique. (Li et al., 2015, Miloudi et al., 2015). Particle size, relative humidity and temperature of the particles affect the charging properties of the waste plastic granules while the influence of time and air expenditure in the tribocharging process affect the charge on the surface of the ground plastics ((Vermesan, et al., 2020, Lyskawinski et al., 2021). Messafeur et al. (2018) investigated the separation of a quaternary mixture comprising of PA, PC, high impact polystyrene, and polyvinyl chloride granules via sliding mode tribocharging with a metal wall.

2.3 Removal of dust particles

The concentration process generates dust that should be removed appropriately to ensure good working conditions, efficiency of the machines (VDI, 2012) and prevent respiratory tracts health risk to the e-waste workers. Dust fractions are unavoidably produced during size reduction method and processes such as magnetic, eddy-current or electrostatic separation cannot efficiently take care of them (Yazıcı & Deveci, 2015, Sethurajan, *et al.*, 2019), thus leading to high metal losses of up to 10–35 %. Marra et al. (2018) verified that about 80% of rare earth metals were trapped up in dusts due to conventional pre-treatment processes. However, flotation and centrifugal gravity separation can be utilized to recovery metals from dust and fine size fractions (Veit *et a*l., 2014). All the separated parts are cleaned of dust before processing via suction from the source of production (VDI, 2012)**.**

3. PYROLYSIS

Pyrolysis is the thermal degradation of solid waste at different high temperatures between 300– 900◦C, in the absence of oxygen or in an atmosphere of inert gases, to produced solid, liquid oil and gas (Rehan *et al.*, 2017). Here, organic materials are decomposed thermochemically with lower emissions of air pollutants such as polybrominated diphenylethers (PBDEs) (Czajczynska *et al*., 2017). In pyrolysis process, the higher molecular chain polymers are broken down into monomers using either heat, a catalyst or hydrogen gas and the efficiency of process is affected by factors such as mixing feed materials, residence time, pressure, type of reactor, temperature and cooling mechanisms (Chiwara *et al*., 2017). During the pyrolysis of e-waste some toxic compounds are emitted, including PAHs, VOCs, particulate matter with semi-volatile organic products, and the remaining ash contains leachable pollutants (Sahle-Demessie et al. (2021).

In developing countries, plastics are managed via open or landfill disposal (Gandidi et al., 2018), thus, insects and rodents are provided habitat for their multiplication and this leads to the spreading of diseases caused by these animals (Alexandra, 2012). E-waste components such as the PCBs plastics epoxy resin and metals used to reinforce their glass fiber (Hsu et al., 2019). Plastics products contain petrochemical and additives such as flame-retardants, stabilizer, and oxidants that make biodegradation process very complicated (Ma *et al.*, 2017). Techniques used to process plastics waste include gasification, hydrogenation, biodegradation and pyrolysis (Marshall and Farahbakhsh, 2013). The different pyrolysis method include flash pyrolysis, gasification, fast pyrolysis and slow pyrolysis (Kuppusamy *et al*., 2016 & Inyang and Dickenson, 2015). A mixture of gasoline, diesel and heavy oil are obtained at fast pyrolysis using high temperatures of 500-800 ℃ while wax and char are the major product left in the reactor, including minor fractions of paraffin oil and gas, after imploring slow pyrolysis of plastic e-waste at lower temperatures of (Ndirangu et al (2019), Irawan, et al., 2018). Plastic e-wastes are converted to energy, as solid, liquid and gaseous fuels ((Sahle-Demessie et al. (2021) under thermal degradation of low temperature (<400 ℃), moderate temperature (400-600 ℃) and high temperature (>600 ℃) (Irawan, et al., 2018). The use of pyrolysis as a recovery technique for valuable materials and energy from different components of e-waste, limits their disposal on landfills, achieving a circular economy (Sahle-Demessie et al. (2021). Pyrolysis is not used for the recycling of substances that cannot decompose thermally at 600 C, explosives and liquids with high oxidizing properties at increased temperature Ndirangu et al (2019).

Plastics extracted from e-waste can be converted to energy and other products via pyrolysis to attain highest economic gain and green environment process ((Sahle-Demessie et al. (2021 and Ndirangu et al (2019). Applications of catalysts in pyrolysis is to target specific reaction, reduce temperature and time taken to complete the process and to enhance process efficiency (Serrano *et al.*, 2012; Ratnasari *et al.*, 2017). Catalyst such as ZSM-5, zeolite, Y-zeolite, FCC, and MCM-41 can be used in pyrolysis (Ratnasari et al., 2017) for cracking, oligomerization, cyclization, aromatization and isomerization reactions (Serrano et al., 2012). Natural zeolite can be used as a catalysis in pyrolysis after modifying and activating it thermally at 550 C and with trioxonitrate (V) acid to give higher liquid oil that contains mixture of aromatics, aliphatic and other hydrocarbon compounds (Miandad *et al.*, 2019).

The type of feedstock, level of contamination of the feedstock and conditions of the entire pyrolysis process determine the toxicity level of the bio-char that is produce after pyrolysis (Ndirangu et al (2019). The control of hazardous emission during pyrolysis of e-waste management makes the process efficient and eco-friendly (Khaliq et al., 2014). Char produced at a higher temperature of 700 °C are alkaline, thus are used agriculturally to neutralize acidic soils, and improved soil fertility while biochar produced at lower temperatures of 300°C are acidic and are used to correct alkaline soils (Hossain et al., 2011). Limitations of pyrolysis are high cost, high energy requirements, non-selectivity and losses of rare earth elements (REE) ((Sethurajan et al., 2019, Tunsu & Retegan, 2017). More so, the liquid fraction of pyrolysis residue may contain heavy metals and PAHs, which can cause water and soil pollution if disposed without separation.

4. PRINTED CIRCUIT BOARDS (PCBS) AND RECYCLING TECHNIQUES OF WASTE PRINTED CIRCUIT BOARDS WPCBS

Metal contained in PCBs are gold, palladium, paltinium, silica, aluminum, calcium, iron, potassium, magnesium, manganese, sodium, phosphorus, titanium, antimony, barium, lead, boron, cadmium, cobalt, copper, chromium, mercury, molybdenium, nickel, tin, vanadium, zince and silver **(**Vermesan *et al.*, 2020, Awasthi, *et al.*, 2019, Verma,et al., 2017), Evangelopoulos, (2014)). Hanafi, et al., (2012). Hence, printed circuit boards (PCBs) in e-waste are considered as secondary sources of valuable and hazardous materials (Isıldara, *et al.*, 2019, Fang, et al., 2013). Apart from metals, PCBs is composed of a polymer (epoxy resin or fiberglass fiberglass-based) and ceramic materials (Kumar et al., 2018), plastic materials, which contain fire retardant substances for fireproofing the board. Thus, WPCBs should be properly disposed of and recycled because of their pollutant content such as brominated flame retardants, polybrominated dibenzo-p-dioxin and dibenzofurans, chlorinated dioxin, and polycyclic aromatics (Evangelopoulos, 2014); and secondly due to sustainable management of resources and environmental protection considering the large amounts of metals and nonmetals. The PCB recycling process can be divided into three main phases—disassembly, treatment and refinement ((Hsu *et al*., 2019, Hadi *et al.*, 2015). In disassembling or dismantling, metals and plastics; valuable products such as microprocessors and memories; and dangerous product such as aluminum radiators, capacitors, batteries, etc. (D'Adamo et al., 2019) are removed to avoid contamination during the recycling processes. The dismantled PCBs are broken down into micro parts, using shredders and grinders into a uniform powder, which are separated further into metals and nonmetals by manipulating their different physical concepts (e.g., thickness, magnetism, or density conductivity). Thereafter, Pyrometallurgy, hydrometallurgy, or a combination of both methods are implored to refine the metal powder into pure raw material (Hsu *et al*. (2019, Ferella et al., 2015).

5. CONCLUSION

The generation and indiscriminate dumping of huge amount of e-waste in farmland and landfill and use of crude methods in the management of e-waste have caused damaging problems to man and his environment. Reuse and recycling of non-reusable e-waste using eco-friendly processes reduces to the lowest minimum the health risk caused by using crude methods in recycling. The pretreatment of e-waste components via modernized and environmentally friendly methods before recycling process will produces recyclates that are void of contaminants with hazards in e-wastes and minimizes the amount of pollutants released into the environment.

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