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Biodegradable Electronics for the Sustainable E-Waste Management: A Review

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Abstract

In the economically growing countries e-waste clearance is a priority at present, because improper waste disposal has negative effect on public health and environment, also leads to economic loss. The stress on e-waste management system is scaling up as the lifecycle of the electronic devices is getting shorter day by day. The aim of the present study is to understand the mechanism of e-waste management and evaluation of the household understanding about the e-waste management. Due to improper disposal of e-waste environmental problems can increase which ultimately leads to health consequences. Hence, a substitute to traditional electronics is needed. To solve the problem of e-waste, biodegradable electronics have been considered most viable replacement to save environment. Hence, present review will focus on many biodegradable organic materials that can provide the best replacement for various electronic devices components along with highlighting recent achievements and applications for the implementation of the bio-degradable devices.

Keywords: E-waste management, electronic devices, Environment, Bio-degradable devices.

Introduction

Globally, e-waste management problem is increasing day by day, leading to various health issues such as asthma, pneumonia and cardiovascular disorders. Due to deficit of an efficient and well-planned e-waste management scheme, environmental issues such as food and water contamination, air pollution and bioaccumulation has increased [1]. Different reports have articulated various concern associated with e-waste management, such as requirement of productive e-waste collection and proper discarding strategies. Nowadays the lifetime of electronics has shortened gradually reduced to few months [2]. Such factor also leads to the e-waste problems and highlight the need of the viable and sustainable e-waste management system. Figure 1 depict the life cycle of the electronic devices [3]. Around 53.6 million tons of the e-waste was generated all over the globe till 2020 [4]. According to Mishra et al, [5] there will be 4%-5% electronic waste annual increase globally. As reported by Wu et al, [6] it can increase 12.5 million tons annually by 2022.

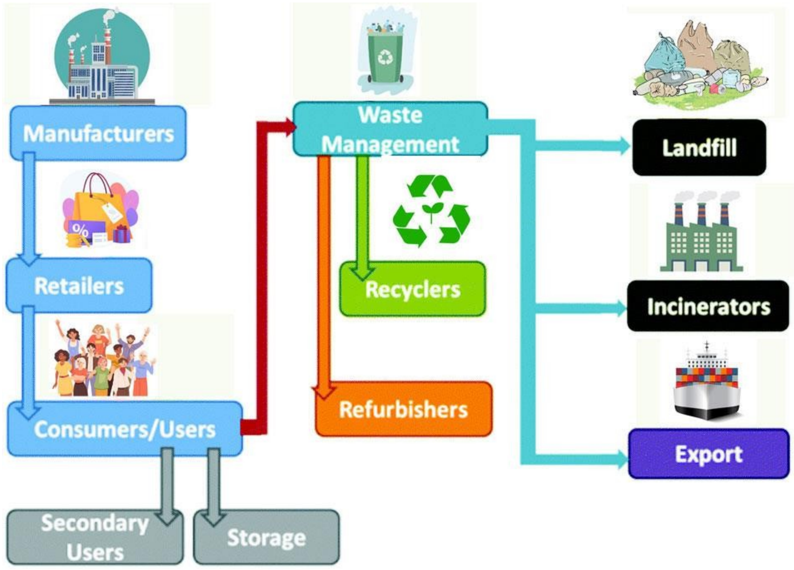

Figure 1: Lifecycle of the electronic devices along with e-waste management [3]

E-waste is defined as the equipment no longer considered useful and must be discarded, worldwide different types of e-waste are produced every day. E-waste includes all type of plastics, metals, heavy metals, precious metals like gold, silver and platinum as well as non- precious metals like aluminium and copper [7, 8, 9]. Researchers have suggested that there are 1000 different harmful pollutants present in the electronic waste, causing impairment to human health and habitat. All harmful pollutants from the e-waste contaminate soil and water. Due to all these consequences e-waste problem needs to be addressed. E-waste is increasing as a result of IT (Information technology) boom [10, 11]. For the management of the e-waste role of households also needs to be considered because all are the consumer of the electronic products. Although, due to lack of proper guidelines and negligence e-waste has become serious challenge for the populations all over the world [12, 13]. Traditional method of waste processing is land filling, but it can lead to leaching of lead and other heavy metals into the ground water. Other method is incineration, which emit toxic fumes into the air and causes air pollution [14].

These harmful metals such as lead, cadmium, chromium, polychlorinated biphenyls (PCBs) leech out into the environment and children are more sensitive to these pollutants because their systems and body is still developing, exposure to these harmful materials can cause irreversible damage [15, 16]. To solve the problem the investigation for the highly viable and less harmful forms of electronics has increased.

Sources and Classification of the E-Waste

E-waste term refers to any electrical and electronic equipment (EEE) and Information communication technology (ICT) such as tablets, phones, monitors, laptops abandoned by their owners with no bound of reuse [17, 18]. E-waste is not recycled or reused; it is simply junked for various grounds like damaged, becoming old or any technical problem [19-21].

E-waste is comprising appliances that utilize electric power and in 2022, Abdulaziz [22] illustrated major classes of the e-waste as given in Table 1.

Table 1: Classification of e-waste given by Abdulaziz, 2022 [22]

Serial Number	Classification Categories	**Description**
1	Heavy Equipment	Dish washers, washing machine, drier,photovoltaic cell, central heating
2	Portable Equipment	Cameras, speaker, microwave oven, speakers,vacuum cleaner
3	Lightening Equipment	Compact fluorescent lamp, light emittingdiode lamps
4	Screens and Monitors	Laptops, LED (Liquid crystal display), LCD,Cathode ray tube TVs
5	Small IT devices	Mobile phones, Cordless phones, desktop PCs
6	Temperature controlrelated equipment	Fridge, freezer, air conditioners, cooleddispenser

E-Waste Health Hazards

The E-waste recycling with minimal safety precautions and open burning restoration has made conditions very hazardous. The health status of the people handling e-waste is poor and infected with the acute diseases. E-waste equipment contains about 60% metals, 30% plastic and around 2,7% hazardous pollutants [23]. E-waste equipment recycling and reuse is 25% and rest 75% is waste all over the world [24]. The landfill is considered an excellent source of manure, thereby all are using it as manure in the vegetation. Thus, heavy metals enter human food chain quickly and causes neurological disorders. Recent reports have confirmed high amount of the heavy metals in the water, soil and air [25, 26]. E-waste components, and health effects are given in the Table 2 below.

Table 2: Health consequences of the E-waste components and Sources [27]

Sr. No.	E-waste Components	Health Hazards	Sources of Components
1	Lead	• Damage nervous system, kidney and blood systems •Effects child brain growth and damage	Present in printed circuit boards, glass panels and gasket in computer monitors.
2	Mercury	• Damage to the brain •Respiratory and skin disorders	Present in switches, relays and printed circuit boards.
3	Cadmium	• Irreversible toxic effects on human health • Damage kidney, liver and neural	Present in chip resistors and semiconductors.
4	Chromium	• It causes bronchitis	Present in decorator or hardener for steel housing and galvanized steel plates.
5	Barium phosphorus	• Causes muscle weakness and damage to heart, and liver	Present in CRTs front panel
6	Copper	• Causes stomach cramps, nausea, liver damage.	Present in copper wires
7	Nickel	• Causes dermatitis, skin allergy and asthma with lung allergy	Present in nickel-cadmium rechargeable batteries.
8	Berryllium	• Carcinogenic The inhalation of beryllium fumes and dust causes beryllicosis.	Present in motherboards
9	Lithium	• Pass into breast milk and harm nursing baby	Present in lithium-ion battery
10	PVC and Plastics	• When burnt generates dioxin that causes reproductive and developmental problems.	Present in computer body and cabling

Biodegradable Electronics

Bio-degradable electronics are green electronics being able to serve their function over recommended time frame and broke down into non-hazardous components by supporting environment safety and sustainability. The quality of biodegradability has been defined by EN13432 standard where 90% of the materials transformed to carbon dioxide, water and biomass beneath given temperature, oxygen and humidity with the help of the microorganisms [28]. Traditional electronic devices use inorganic material like ceramics and metals though bio- degradable devices use organic materials along with some metals. Various differences between traditional and bio-degradable electronic devices are described in Table 3.

Table 3: Various traditional and bio-degradable electronic devices properties [29]

Sr.No.	Properties	Traditional Electronic devices	Bio-degradable devices
1	Types of Materials	Metals • Gold • Silver •Chromium • Lead Inorganic Materials • Bulk Silicon • Silicon alloys	Metals • Gold • Silver • Magnesium • Iron • Molybdenum• Tungsten Organic Materials • Carbon-based (CNT,Carbon)
2	Methods of processing	Chemical Vapor Deposition • MOCVD • E-beam evaporation • Thermal evaporation Lithography	• Naturally occurring small molecules • Conjugated polymers Solution processing • Spin-coating • Screen printing • Ink-jet printing
3	Degradable	No	Yes, can be custom made by varying molecular weight,crystallinity of material
4	Environmental Effect	• Bad, various landfillscreated • Toxic chemicals leeching harmful to humans andanimals	• Neutral. Degradation by-products include H_2O, CO_2, biomass. • Generally benign toenvironment

Materials and Applications of the Bio-Degradable Electronics

Materials research and processing technological advances has enabled electronic devices to produce feature-rich devices for the consumers. A functional device prototype has been simplified into five basic components such as substrate, dielectric, active layer, electrodes and encapsulants. Substrate serve as foundation upon which semi-conductor, dielectric and metal layers are attached. Conventionally silicon, silicon dioxide, sapphire, germanium arsenide and indium phosphide is utilized as substrate. But these are non-biodegradable and disposal is difficult and expensive [30]. At present research interest have gradually shifted to biodegradable, ultra-thin substrate material such as polymer foils, polyethylene naphthalate, polyethylene terephthalate, polyimide is part of many electrinics from organic light emitting diode, organic photovoltaic to biomedical devices [31]. Nano-cellulose is another biodegradable material can serve as the purpose of substrate.

In a device active layer is the main part where electrical activity takes place, and material is usually semiconducting in nature to provide electronic control and resilience during operation. Silicon (Si) and metal oxides are traditional semi-conductor electronics, but discovery of semi-conducting polymers have determined a new class of cheaper organic materials [32]. There are more recent discoveries with respect to polymers like poly-aniline (PANI), poly-thiophene and poly ethylene dioxythiophene [33,34].

Electrodes in a device are utilized to commute charged carriers from devices to the external circuit. Organic polymer-based electrode materials are very popular nowadays due to good electronic conductivity after doping and ionic conduction.

Utilization of the graphite and carbon nanotubes (CNTs) as organic-based electrode for various biosensors is very prominent nowadays as it is eco-friendly [35]. Dielectric material is an electrical insulator that can be polarized by applying electric field. Biomolecules such as adenine, guanine, thymine, cytosine, different sugars such as lactose, glucose and sucrose can make best dielectrics due to low dielectric losses and high breakdown strength [36]. As devices are multi-layered sandwich structure, hence layers adhesion can be achieved by biomolecules like starch and carbohydrate- based sugars natural adhesives [37].

Conclusion and Future Aspects

E-waste management shall commence now before it becomes an irreversible pollution difficulty of the environment. Along with recycling, awareness among consumers and finding alternate to conventional electronics will be a stable solution for the sustainable development. Bio-degradable electronic devices are principally best preference as the discard of damaged devices will not pollute precious landfill areas and will not pollute soil and water. Currently biomedical devices have been manufactured by using biodegradable devices; other sectors need to adapt it for sustainability. Biodegradable electronics is certainly a great step towards a greener and highly sustainable environment for human being and other living organisms. The future of biodegradable devices will be looking into the use of biology and bio-based material to generate other suitable organic and biocompatible electronics.

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