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# A novel recycling approach for transforming waste printed circuit boards into a material resource

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**Abstract**

The recovery of materials from urban waste has become progressively more important with wastes providing a variety of resources. This study focuses on the recycling of electronic printed circuit boards (PCBs) from mobile phones, computers, TVs, white goods, and micro-processors etc. that contain significant amounts of hazardous/toxic components along with a variety of metals, ceramics and polymers. Both formal and informal sectors are engaged worldwide in recycling such e-waste to recover precious and other metals (upto 40-70% of value). However poor recycling techniques, especially in developing countries, generate high levels of environmental pollution that affects both the ecosystems and the people living within or near the main recycling areas. Various e-waste recycling methods used in the informal sector include manual dismantling, open burning of PCBs, plastic chipping and melting, burning wires to recover copper, acid & cyanide salt leaching, and inadequate metallurgical treatments. These activities release dust particles loaded with heavy metals and flame retardants into the atmosphere that may re-deposit near the emission site, or be transported over long distances depending on their size. Significant levels of environmental pollution are thus associated with recycling e-waste.

This study presents an environmentally sustainable solution to e-waste management and reducing associated pollution during recycling. In this study, waste PCBs were heat treated in the temperature range 1150-1350°C for periods of up to 20 minutes in an Argon atmosphere. Key metallic constituents namely Cu, Sn and Pb showed a tendency to segregate out in the form of copper rich and Sn rich metallic balls. Minor elements such as Al, Fe, Mg, Ni, Pd, Pt and Zn segregated along with metallic droplets. Such high temperatures led to the removal of hazardous lead and the recovery of highly concentrated copper alloys and precious metals. Pyrolysis of PCBs also generated a carbon rich residue containing traces of Sn and very low levels of copper. Various ceramic impurities present precipitated out as slag and did not interfere with metal recovery.



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## 1. Introduction

Electronic waste, commonly termed 'e-waste' are end-of-life electric and electronic equipment considered obsolete by their users[1, 2]. Increasing consumption and short lifespan of electronic devices has become a waste management and urban pollution issue in recent years. The obsolescence of electronics has resulted in millions of tons of waste being discarded and landfilled. Between 20 to 50 million tonnes of e-waste are being generated each year worldwide[3], increasing by 3 to 5% every year[4]. There are several difficulties with recycling e-waste. Various components of e-waste are a heterogeneous mixture of materials of varying composition, sizes and shapes; this complex waste is made up of metals, ceramics and plastics that may be valuable and/or hazardous in nature. There is no average composition of electronic wastes, as manufacturers are continuously changing components and applications[5].

A number of valuable materials are also present in electronic waste. Copper and precious metals can amount from 40 to 70% of the total value in different types of e-wastes, making recycling attractive from an economical point of view[5]. For instance, one ton of waste mobile phones after battery removal contains up to 130 kg of copper, 3.5 kg of silver, 340 g of gold and 140 g of palladium that can be recycled and reused[6]. If all end-of-life mobile phones discarded in 2008 were recycled, 1250 ton Cu, 13 ton Ag, 3 ton Au and 2 ton Pd would be available for reuse, valued at US $105 million[7]. Due to the wide range of electrical and electronic equipment available on the market, the European Union has divided e-waste types into ten categories (Table 1)[8].

Table 1. E-waste categories[8].

| No. | Category | Label | Major electric and electronic equipment |
|---|---|---|---|
| 1 | Large household appliances | Large HH | Refrigerators, washing and cooking machines, electric fans, air conditioners. |
| 2 | Small household appliances | Small HH | Vacuum cleaners, irons, toasters, grinders, coffee machines, electric knives, hair-cutting, tooth brushes, clocks, watches, scales. |
| 3 | IT and telecommunications equipment | ICT | Mainframes, data processing, personal computers, laptops, notepads, calculators, printers, copying equipment, facsimile, telephones. |
| 4 | Consumer equipment | CE | Television and radio sets, video cameras, recorders, amplifiers. |
| 5 | Light equipment | Lighting | Luminaires for fluorescent lamps, straight or compact fluorescent lamps High-intensity discharge lamps, low-pressure sodium lamps. |
| 6 | Electrical and electronic tools | E&E tools | Drills, saws, sewing machines. |
| 7 | Toys, leisure, and sports equipment | Toys | Electric trains or car racing sets, video games, computers for biking, running, etc., coin slot machines. |
| 8 | Medical devices | Medical equipment | Radiotherapy, cardiology and dialysis equipment, pulmonary ventilators. |
| 9 | Monitoring and control instruments | M&C | Smoke detectors, heating regulators, thermostats. |
| 10 | Automatic dispensers | Dispensers | Automatic dispensers for hot or cold drinks, solid products, etc. |

However, there are several issues and limitations associated with current practices of e-waste management and recycling. An informal sector has risen due to the opportunity for recovering valuable metals at low costs and has increased significantly in recent years due to the illegal exports of discarded electronics to developing and emerging economies. The informal sector generally uses poor recycling techniques, causing high levels of pollution and can cause severe damage to the environment and human health. Environmental pollution is caused by inappropriate recycling techniques by the release of hazardous components in e-waste after landfilling/treatment, agents, by-products and compounds in well-established recycling processes and by-products left after these processes.

This paper first presents an overview of the environmental pollution being caused by the current approaches being used to recycle e-waste. Key factors causing environmental damage have been identified. Details are then presented on a novel high temperature pyrolysis approach for recycling waste printed circuit boards (PCBs) that can be used to recover a wide variety of materials in an environmentally sustainable manner. This technique was used for producing various metallic and nonmetallic phases that could be used as material resource in a wide range of applications.