Green Manufacturing: A Key to Innovation Economy

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Abstract This thematic section focuses on different aspects of transformations of ‘e-waste’ into value-added materials and the associated developments. The papers selected demonstrate how innovative scientific research and development is delivering economically viable, real-world solutions for industry by reimagining waste as a resource for the future. These three papers cover analysing above ground resources, simple technique for measuring the elements inside the waste and high temperature transformation of waste.

Introduction

Electronic waste, or e-waste, is one of the fastest growing and most challenging waste streams worldwide. With high consumer demand, increasingly short production cycles and the early obsolescence of products in both affluent and developing country markets, the manufacturing and sales of equipment in the global electronic industry is now worth some ~US\$1 trillion annually, yielding some 30–50 million tons of obsolete equipment worldwide each year [1]. The US Environmental Protection Agency (US EPA) estimates the average American household alone uses some 28 devices [1]. Discarded electronic devices represent a

crisis of both quantity and toxicity; e-waste poses serious health and environmental dangers both in landfill, due to leaching, and to the many informal sector workers and their communities in developing nations who strip out valuable elements in unregulated, manual recycling processes.

It is well recognized that embedded within e-waste are many valuable materials with a positive market value for recovery and resale such as precious metals, including gold, silver, platinum, palladium and copper; and strategic metals, like rare earth metals and other non-ferrous metals, as well as plastics [2]. Printed circuit boards (PCBs), for example, contain some 10–20 % of copper by weight, compared to the 1 % of copper within the newly mined ore [3], and some 10 kg of gold can be extracted from 25 tonnes of used mobile phones. However, e-waste also contains a range of hazardous substances and contaminants. PCBs contain arsenic, cadmium, mercury and bromides. Old cathode ray tube (CRT) televisions contain lead and phosphorus pentachloride, and flat-screen televisions (LCDs) contain mercury.

While safe resource recovery from e-waste is technically possible, it is expensive and currently relies largely on access to large scale, high tech furnaces, mostly located in Europe. Many nations, including Australia, have few or no viable resource recovery processes for e-waste. Consequently, some 90 % of e-waste from industrialized nations is exported. Instead of being properly processed, much of it is reclassified as second-hand goods and dumped in landfill, where it poses both an environmental and health risks to the surrounding regions. Increasing volumes of e-waste are, however, also diverted to developing nations where informal e-waste processing exposes poor communities to serious health hazards, and their local environments to contaminants. A 2015 report by the United Nations Environment Program estimated some 42 million tonnes of

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electronic waste was thrown away worldwide in 2014. As it is impossible to determine what proportion of this waste was illegally recycled, the cost to the global economy, in terms of lost embedded resources, could be as much as USD52 billion [4]. In Australia, only about 10 % of e-waste is recovered and processed. In the United States, less than 20 % of e-waste is recycled, and large stockpiles of unused devices are being amassed as technologies advance, such as the estimated 99 million unused TVs in America's homes and sheds [5], representing a significant loss of potentially valuable resources.

The solution to our growing e-waste mountains is the development of new processes that overcome current cost barriers and other disincentives such as the need for large, industrial scale facilities and furnaces, and for the expensive transport of large volumes of e-waste over long distances to centralized processing facilities. While science and technology can solve many problems, real-world solutions must be framed by the circumstances that will drive their uptake. Worldwide, electronic devices are now virtually ubiquitous, and their use will continue to expand. This means cost-effective, local solutions must also be accessible to as many communities as possible, anywhere in the world. We need small-scale processes that can safely and effectively transform e-waste into valuable resources for re-use.

This thematic section focuses on different aspects of transformations of 'e-waste' into value-added materials and the associated developments. The papers selected demonstrate how innovative scientific research and development is delivering economically viable, real-world solutions for industry by reimagining waste as a resource for the future. These three papers cover analysing above ground resources, simple technique for measuring the elements inside the waste and high temperature transformation of waste.

Above-Ground Resource Analysis

Urban mining, a term increasingly used by authorities and scholars, is the act of recovering resources from wastes generated by urban environments. The major difference between urban mining and conventional mining is the source of raw material for the mining process [6]. Urban mining is increasingly becoming an important focus of the resource industry as a result of two major points of view, the first being environmental protection concerns as natural resources are becoming increasingly scarce, and secondly, the value of the urban wastes material content [7]. Urban mines are rich sources of different materials and elements in their pure and processed forms. These include solid, liquid and gaseous wastes in biodegradable or non-

biodegradable forms [6]. Most of the environmental management agencies have adapted the US EPA's classification of the urban wastes which comes in three different categories: construction and demolition materials, municipal solid waste—tires, and electronics (E-waste) [6].

The focus of this research was on understanding the above-ground resources from its quantity to where they stocks and finding how their distribution is important for evaluation of economic values for wastes. This information is critical in order to understand the social and environmental impacts of mining these resources and effectiveness of collection systems. This paper “first discusses the value of location in policy and decision making about above ground resource use and management, reviews the top-down and bottom-up methods for above ground resource analysis, then presents a geographical information systems (GIS) approach to above ground resource analysis, and finally implements the approach to the construction of a spatially enabled database of above ground in-use copper, zinc and steel stocks at various levels of geographical regions in Australia.”

Measurement of Elements

Reuse, and metal recovery from electronics waste, is a new opportunity for downstream industries as that could lead to generation of value-added materials. A comparison between metallic contents of PCBs and the metallic contents of each of these metals natural ore reveals that there is great opportunity in recycling these wastes [3]. Reusing these elements instead of mining can reduce the greenhouse gases, reduce the energy and also eliminate the environmental impact of e-waste. A comparison clearly indicates huge energy saving for recycling metals compared to their extraction from their natural ores. As an example, the savings account for 95 % for aluminum, 85 % for copper, 60 % for steel, 75 % for zinc, and 90 % for nickel [8]. Current practice for reusing e-waste is focussed on using e-waste as input in already existing processes for processing ores and producing elements in their pure form, which transfer these pure elements to oxide or sulfite form and again produce pure form of those elements. For this purpose, a new technique is required to analyze the elements exist in different e-waste stream and identify the best processing option for that particular waste stream.

This paper reviews the recent development by CSIRO on gamma-activation analysis (GAA) for rapid and non-destructive analysis of different metals in ores and waste materials. This paper has “demonstrated that gamma activation analysis provides a powerful tool for analyzing both valuable and hazardous elements in waste materials. The

advantages of GAA include: true, bulk analysis of large and heterogeneous samples; rapid measurement, with no sample preparation required and results available in a few minutes; and excellent sensitivity for economically and environmentally important elements, including gold, silver, copper, tin, bromine and lead.”

High-Temperature Recovery of Rare Earth

Recently high-temperature processing of e-waste has attracted a lot of attention for processing e-waste stream. In pyrometallurgy, crushed scrap is introduced into a molten bath in which plastic will be degraded as source of energy, and refractories are removed in the form of slag. This slag is then further processed to recover base or precious metals like Cu, Ag, Au, and Pt [9]. A hydrometallurgical process [10] is more predictable and controllable, but the presence of chlorides and cyanides is still hazardous. A hydrometallurgical process is also very costly in terms of recovering waste liquids and making new solutions.

This paper “presents a systematic review of previous studies on the high temperature (pyrometallurgical) recovery of rare earths from magnets. The features and conditions at which the recycling processes had been studied are mapped and evaluated technically. The review also highlights the reaction mechanisms, behaviors of the rare earth elements and the formation of intermediate compounds in high temperature recycling processes. Recommendations for further scientific research to enable the development of recovery of rare earth and magnet recycling are also presented.”

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