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Toxicity potentials from waste cellular phones, and a waste management policy integrating consumer, corporate, and government responsibilities

Seong-Rin Lim, Julie M. Schoenung *

Department of Chemical Engineering and Materials Science, University of California, Davis, CA 95616, USA

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ABSTRACT

Cellular phones have high environmental impact potentials because of their heavy metal content and current consumer attitudes toward purchasing new phones with higher functionality and neglecting to return waste phones into proper take-back systems. This study evaluates human health and ecological toxicity potentials from waste cellular phones; highlights consumer, corporate, and government responsibilities for effective waste management; and identifies key elements needed for an effective waste management strategy. The toxicity potentials are evaluated by using heavy metal content, respective characterization factors, and a pathway and impact model for heavy metals that considers end-of-life disposal in landfills or by incineration. Cancer potentials derive primarily from Pb and As; non-cancer potentials primarily from Cu and Pb; and ecotoxicity potentials primarily from Cu and Hg. These results are not completely in agreement with previous work in which leachability thresholds were the metric used to establish priority, thereby indicating the need for multiple or revised metrics. The triple bottom line of consumer, corporate, and government responsibilities is emphasized in terms of consumer attitudes, design for environment (DfE), and establishment and implementation of waste management systems including recycling streams, respectively. The key strategic elements for effective waste management include environmental taxation and a deposit-refund system to motivate consumer responsibility, which is linked and integrated with corporate and government responsibilities. The results of this study can contribute to DfE and waste management policy for cellular phones.

1. Introduction

Cellular phones have the potential to generate significant environmental impact because cellular phones contain toxic and rare substances and because of the rapid rate of technological change in their design, which leads to a large quantity of waste cellular phones. State-of-the-art functionality and aesthetic design are constantly changing, prompting consumers to purchase new phones more frequently. Fig. 1 shows the sales volume over time of cellular phones in the United States (US EPA, 2008a). Cellular phones are essential tools for telecommunication and information technology and are also regarded as fashion icons to identify and express personal character. Therefore, people continuously desire new and fashionable cellular phones with higher functionality. This consumer attitude has effectively shortened the useful life span of cellular phones, and is causing accelerated resource consumption due to the high content of rare and precious minerals in cellular phones and increased environmental impact from waste cellular phones (Frey et al., 2006; Osibanjo and Nnorom, 2008; Geyer and Doctori Blass, 2010).

The potential for environmental impact from cellular phones has been previously studied by others from various viewpoints. From the life cycle perspective, ecological footprint analysis and life cycle energy modeling have shown that the raw material acquisition and the manufacturing stages require the most land area and energy (Frey et al., 2006; McLaren et al., 1999). Leachability tests have been performed to assess the content and leachability potential for the heavy metals and organic compounds contained in cellular phones (Lincoln et al., 2007). Characterization of heavy metals in the plastics from waste cellular phones has been demonstrated to generate environmental pollution when a large quantity of waste cellular phones are disposed of by open burning, such as has taken place in developing countries (Nnorom and Osibanjo, 2009). Human health impacts from toxic materials contained in cellular phones have been qualitatively investigated (Osibanjo and Nnorom, 2008). These studies have not, however, quantitatively evaluated human health and ecological toxicity potentials from waste cellular phones with respect to the fate, exposure, and effects of toxic heavy metals.

Waste management policy for cellular phones needs to motivate environmentally responsible behavior from both consumers and manufacturers. We draw from the field of sustainability within which the phrase 'triple bottom line' represents the need to balance

* Corresponding author. Tel.: +1 530 752 5840; fax: +1 530 752 9554.
E-mail address: jmschoenung@ucdavis.edu (J.M. Schoenung).

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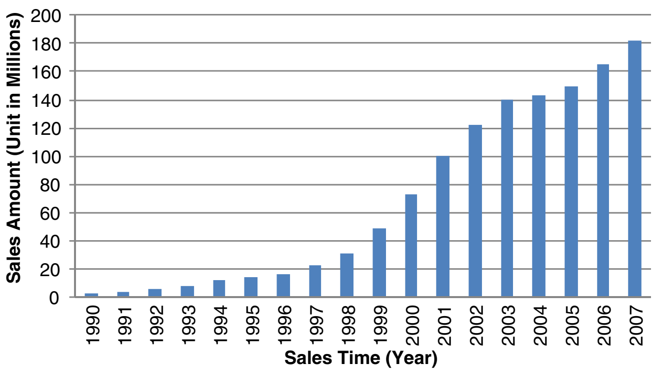

Fig. 1. Sales volume of cellular phones in the United States. Source: US EPA (2008a).

economic, environmental and societal imperatives (Pope et al., 2004); here, we incorporate the phrase with a slightly modified meaning: the need to engage consumers, manufacturers and government in environmental responsibility. At present, many existing electronic waste (e-waste) policies have been based mainly on extended producer responsibility (EPR) to motivate design for environment (DfE) and to promote recycling (Mayers et al., 2005; Kahhat et al., 2008; Widmer et al., 2005). For instance, the European Union (EU)-Waste Electronic and Electric Equipment (WEEE) Directive regulates manufacturers and distributors to take-back end-of-life (EOL) products and to meet a target for recycling and recovery (European Commission-WEEE Directive, 2003). This type of legislation attempts to motivate manufacturers to improve product recyclability by employing DfE (Nnorom and Osibanjo, 2008), but does not take into account consumer responsibility related to their consumption and disposal attitudes. In other cases, e-waste regulations are designed to motivate consumer responsibility. Japan, for instance, has established a take-back system in which consumers pay fees to dispose of e-waste (Nakano et al., 2007), and the State of California charges consumers advanced recycling fees (ARFs) for display devices at the purchase point (California State Board of Equalization, 2007). These policies exclude EPR for manufacturers, which thereby exclude motivation for manufacturers to develop products that are more environmentally responsible and recyclable. Specifically for waste cellular phones, current waste management depends on both voluntary and mandatory efforts by manufacturers and retailers to implement take-back systems and on market-driven reuse and refurbishment businesses to export EOL phones to developing countries (Geyer and Doctori Blass, 2010). Therefore, effective waste management policy for cellular phones is required to provide motivation for appropriate consumer attitudes toward consumption and disposal of these devices and for manufacturers to implement DfE in their product design.

The objectives of this study are: (i) to evaluate the human health (cancer and non-cancer) and ecological toxicity (ecotoxicity) potentials from heavy metals in waste cellular phones, which will provide manufacturers with valuable information to support their DfE goals; (ii) to highlight consumer, corporate, and government responsibilities for effective waste management; and (iii) to identify key elements necessary in an effective waste cellular phone management strategy. The toxicity potentials are evaluated from the heavy metal content in waste cellular phones, the respective toxicity potential characterization factors, and the pathway and impact model for heavy metals. The sources of heavy metals with high toxicity potentials are identified for DfE. The consumer, corporate, and government responsibilities are emphasized in terms of consumers' behaviors toward the purchase of new phones and the return of EOL phones, manufacturers' efforts to implement DfE, and government's role in establishing and implementing an appropriate waste management system and in coordinating among relevant stakeholders associated with cellular phones. The key strategic elements for effective waste management include two economic instruments, i.e., environmental taxation and a deposit-refund system, to motivate consumer responsibility, which is linked and integrated with corporate and government responsibilities. The results of this study can contribute to DfE and waste management policy for cellular phones.

2. Methods for toxicity potential evaluation

Human health toxicity (cancer and non-cancer) and ecotoxicity potentials from cellular phones were evaluated on the basis of a pathway and impact model, coupled with data on heavy metal content and respective toxicity potential characterization factors. As shown in Fig. 2, the model represents the air and water pathways of heavy metals in e-waste by considering disposal through incineration and landfill and the thermodynamic characteristics of heavy metals, i.e., lithophilic or volatile (Lim and Schoenung, 2010). Important assumptions within this model include: (i) the heavy metals in flue gas from the incineration process impact human health and ecosystems through the air because bottom ash and fly ash are landfilled (each heavy metal from e-waste exhibits a unique distribution among bottom ash, fly ash, and flue gas because of its thermodynamic properties, i.e., lithophilic, or volatile), and (ii) the heavy metals in landfilled cellular phones leach into the ground water and impact human health and ecosystems through the water. This landfill assumption is based on a worst-case scenario to avoid uncertainty related with complex and diverse reactions and transformations in landfill facilities and on the egalitarian perspective to take into account long-term impacts over the functional life span of the landfill liner (Lim and Schoenung, 2010). This model is used to evaluate toxicity potentials from a waste cellular phone flowing into incineration and landfill facilities, which are the primary disposal methods used in countries with low recycling rates such as in the United States (US EPA, 2008b). Recycling is not directly considered in the analysis, but is motivated by the results.

The formulae used to evaluate average toxicity potentials per unit are provided below:

$$TP^w = \sum_{i=1}^{n} (C_i \cdot W \cdot CF_i^w)$$

$$TP^a = \sum_{i=1}^{n} (C_i \cdot W \cdot \alpha_i \cdot CF_i^a)$$

where TP^w and TP^a are the average toxicity potentials from a cellular phone for water and air, respectively; C_i is the average content of heavy metal i in a cellular phone; W is the average weight of a cellular phone; α_i is the distribution ratio to flue gas for heavy metal i; and CF_i^w and CF_i^a are the toxicity potential characterization factors for heavy metal i for water and air, respectively. The heavy metal

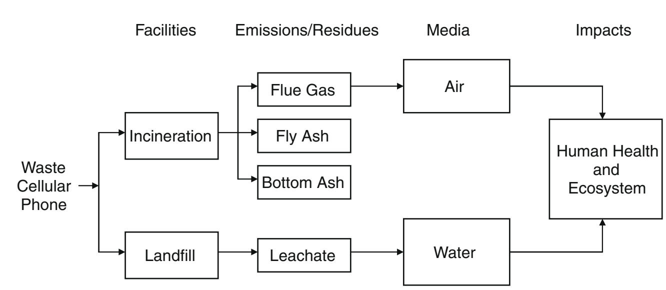

Fig. 2. Pathway and impact model for heavy metals in waste cellular phones. Modified from the model in Lim and Schoenung (2010).