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An industrial ecology teaching exercise on cycling e-waste

Patrick Kangas, Gary E. Seibel*

Environmental Science and Technology Department, University of Maryland College Park, MD 20742, United States

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ABSTRACT

We describe an Industrial Ecology teaching exercise on the recycling of discarded consumer electronics ("e-waste"), using a computer as an example. In the exercise students, working in groups, disassemble a used computer into component parts. The parts are classified and inventoried in terms of mass. Then, using available information on the prices of materials that can be readily recycled, an economic assessment of the recycled computer is made. We provide a sample data set from the lab for a computer hard-drive that was disassembled into 12 categories of components with a recycling value of 2.58$ US. The students enjoy the hands-on experience of disassembly as an exercise in "creative destruction" and they are encouraged to discuss ways that computers might be better designed for disassembly and recycling based on their experience in the lab. An energy circuit diagram of material cycling in consumer electronics is presented to provide a systems context for the overall teaching exercise.

1. Introduction

Industrial Ecology is a relatively new synthesis of human interaction with the environment (Graedel and Allenby, 2003). One version of the field has the goal to make industrial systems more like natural ecosystems in terms of cycling and recycling of products made and used by humans. The view of the founding industrial engineers was that natural ecosystems completely cycle materials, such as plant nutrients, and that this level of cycling performance should be a goal of industrial production. According to the editor of the Journal of Industrial Ecology (Brattebo, 2002), "IE is not an academic discipline. It is a scientific concept, or some would say a scientific field, that is working across established disciplines. It is also a way of thinking and a strategy that may be applied at different scales in society, and is founded on a set of theories and methods. IE is therefore oriented toward describing, analyzing, understanding, and improving systems."

A conceptual advancement of the field was to consider that man-made products have a life-cycle, like living organisms. This thinking has led to life cycle assessment which is a major new accounting approach for material balances, energy efficiency and environmental impact. In the ecosystem at the end-of-life, organisms die but the elements they are composed of recycle back to support the next generation of organisms. Much of Ecology deals with studying how elements cycle, which requires a system approach of pathways and rates of movement of elements through the network of living and non-living components of the ecosystem. In contrast to natural ecosystems in the industrial systems at the end-of-life, human-made products are typically disposed of in landfills as waste. The elements in the products are lost and cannot be used to support the next generation of the human-made products. McDonough and Braungart (2002) coined the metaphor "cradle to grave" to describe the one-way, linear dynamics of industrial systems and "cradle to cradle" to describe the cycling dynamics of natural ecosystems. In this paper we describe a teaching exercise in which students disassemble a used computer for hands-on experience on material cycling in consumer electronics. Most discussions of Industrial Ecology education involve the design of multi-course curricula (Marstrander et al., 2000; Ning et al., 2007; Geng et al., 2009; Shi, 2016) or broad concepts such as life cycle assessment (Cooper and Fava, 2000; Hawkins and Matthews, 2009). This type of literature takes an overall top-down approach to the issue of Industrial Ecology education. In this paper we use a bottom-up approach of describing a single laboratory exercise in a university Industrial Ecology course that has been successful at engaging students.

2. Teaching exercise

We have developed several lab exercises as part of a class on Industrial Ecology for advanced undergraduates and graduate students at the University of Maryland. The labs are meant to support lecture topics and to provide active experiences for learning. The lab exercise described here is intended to cover the cycling of materials that occurs when items of consumer electronics reach their

* Corresponding author.
E-mail address: gseibel@umd.edu (G.E. Seibel).

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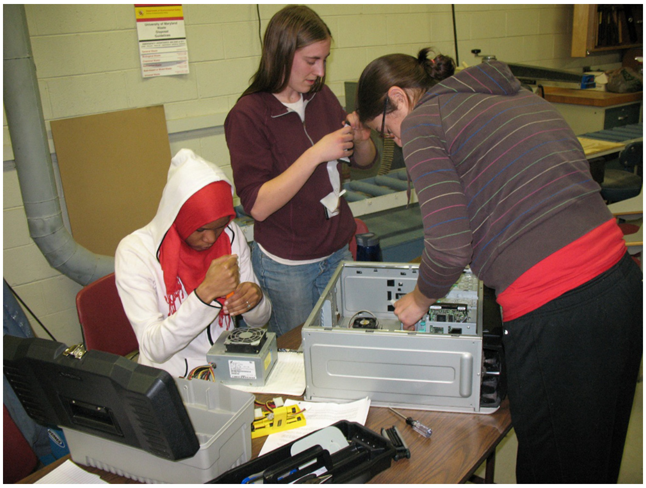

Fig. 1. Students disassembling a computer in the Industrial Ecology class at University of Maryland.

end-of-life. The analogy with this exercise is that a used, discarded computer is like a tree leaf that falls to the forest floor at the end of the growing season and the disassembly of the computer is similar to decomposition that occurs when the leaf reaches the forest litter layer and is broken down by physical processes, microbes and invertebrate animals.

This example of a human product was chosen because of interesting aspects of rare materials needed to make the electronics and because of critical environmental issues with the disposal of the electronics at the end of their useful life. The term "e-waste" has been used to describe consumer electronics when they reach the end of their useful life. Certain materials in the e-waste can cause toxic pollution (such as mercury). Other materials in the e-waste are valuable and in short supply (such as gold and copper) and can be lost if not cycled back to the production of useful products. The challenge of e-waste is that the different elements occur in complex combinations of hazardous and valuable materials that are difficult to separate and ultimately only 10–25% of end-of-life consumer electronics are recycled (Wilshire et al., 2008; Leonard, 2010). E-waste is a global issue with significant potential environmental impacts (Carroll and Essick, 2008; Grossman, 2006; Robinson, 2009). As an indication of the issue, Leonard (2010) states "....e-waste is a global nightmare, with between 5 and 7 million tons of electronics becoming obsolete each year, their trashed toxic components poisoning the land, air, water, and all of the earth's inhabitants." In the U. S. the disposal and recycling of electronics are strongly regulated, but this is not the case in Africa and Asia where laws are not as strict. Recycling of e-waste in lesser-developed countries can be more like a salvage operation with open air burning of wire to recover copper and open acid baths for separating metals such as lead, silver and gold. These kinds of recycling operations can create toxic conditions for the workers and pollution for the environment (Stone, 2009). Various issues about the consumer electronics industry and e-waste are discussed in lecture which compliments the laboratory session.

The hands-on lab exercise involves the disassembly of examples of used consumer electronics that we collect prior to the class. We have most commonly used computers that have been discarded but other items have been tried as well (Fig. 1).

To begin the exercise students are divided into groups of 4–5 individuals and each group is given the computer. An effort is made to provide similar machines to each group in the class so that the results of the exercise are comparable between groups and can be used for statistical analysis.

Table 1
Characteristics of component part categories from disassembly of a computer hard drive from a sample student group. Numbers in parentheses are percentages of the total mass.

Component	mass, grams	potential recyclability
Ferrous metals	8,529.0 (46.5)	yes
Circuit boards	4,126.7 (22.5)	yes
Hard plastic	4,016.70	yes
Wire	594.7 (3.2)	yes
Stainless steel	564.7 (3.1)	yes
Capacitors	142.1 (0.8)	no
Aluminum	129.2 (0.7)	yes
Magnets	77.7 (0.4)	no
Screws (ferrous)	65.8 (0.4)	yes
Copper	55.3 (0.3)	yes
Miscellaneous plastic	38.3 (0.2)	yes
Batteries	2.8 (<0.1)	no
TOTAL	18,343.00	

Table 2
Potential value of disassembled components. Unit value prices of recycled component parts were found on-line (see text for web site addresses).

Component	mass (grams)	unit value	value
Ferrous metal	8,529.00	0.06	0.51
Wire	594.7	1.98	1.18
Stainless steel	564.7	1.1	0.62
Aluminum	129.2	0.44	0.06
Copper	55.3	3.74	0.21
TOTAL	9,872.90		2.58

Each group is given a tool kit containing tools necessary for electronics disassembly. These tool kits include a magnet for separating ferrous versus non-ferrous metals, screwdrivers, pliers, small wrench and socket sets, wire cutters and prying tools. A larger tool box containing more specialized tools is also available in the laboratory for shared use by students in the disassembly project. This box contains bits and drivers for removing tamper-proof and security fasteners, a drill and drill bit set, miniature screwdrivers and extraction tools. Each student is provided with a set of cotton gloves and safety glasses. The students are given general safety instructions along with specific instructions relevant to the particular item being disassembled. This could include techniques for discharging capacitors and batteries, removing glass fuses, handling laser cut metal components, etc. Tool use instruction is also included. We usually allow two, 3-h lab sessions for the exercise. This time commitment allows for disassembly, an inventory of disassembled parts, class discussion and lab clean-up. At the conclusion of the lab, students recycle the disassembled component parts in the university's recycling facilities.

As an example of the results of the exercise, Table 1 shows the inventory of disassembled component parts for a computer hard drive from one student group. Twelve component parts are shown according to mass and their potential recyclability. Ferrous metals, circuit boards and hard plastic make up more than 90% of the total mass of the disassembled hard drive. Most of the components are disassembled into uniform categories as shown in Table 1. However, the circuit boards remain mostly intact since it is not possible to break them down further in the time alloted and with the techniques available to the class. In terms of recycling, circuit boards are typically soaked in an acid-bath to remove the attached parts and that process was not feasible to perform in the lab exercise. Nine of the 12 component parts are listed as being potentially recyclable for typical recycling programs. Table 2 lists those components that have market values that are easily accessible by checking commodity web sites, such as https://rockawayrecycling.com/scrap-metal-prices/

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