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Electronic Waste Recycling can be a Sustainable Enterprise

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Abstract

The regulatory status and the fiscal responsibility of disposing of electronic waste (e-waste) has been a well-debated point recently. The primary concern has been centering on lead in the Cathode Ray Tube (CRT) and heavy metals in the circuit boards. Primarily, are the heavy metal levels over the toxicity characteristic leaching procedure (TCLP) limits? If the e-waste is not a hazardous waste by definition, why not send it directly to the local landfill?

The debate continues into the proper techniques for representative sampling of a very non-homogeneous waste stream. The best method for the representative sampling of the e-waste was found to be a random/systematic approach. A CRT screen, a CRT funnel, and circuit boards were randomly selected from each individual monitor systematically selected for analysis. The screens, funnels and circuit boards were crushed and a sample of each waste stream was removed for analysis. Standard EPA test methods were employed for the TCLP and total priority pollutant metal analysis. The analytical results from the representative sampling showed both the funnel and screen portions of the CRT to far exceed TCLP limits.

The administrations at most colleges and universities are principally concerned with the bottom line - financial sustainability of any proposed project. Environmental Health and Safety Offices, chiefly concerned with the regulatory status, will need to demonstrate to the administrations that the gains associated with recycling e-waste outweigh the costs. In regards to e-waste, the units are a virtual plethora of valuable resources. These resources can easily be separated and recycled. In our current operations at Utah State University (USU) we recycle 98 percent, by mass of the monitors that we receive. At 4,000 monitors per year, averaging 29 pounds and 2 cubic feet, we have saved USU $25,000 in the last fiscal year.

Introduction

In recent years we have heard the catch term "Sustainability". Sustainability is defined as the management of an exploited system such that no additional damage is caused to that system or surrounding systems. Caution must be used when defining a system for evaluation. Too close and the surrounding systems are not taken into account, too far away and everything looks good. In the case of electronic-waste (e-waste) the system entails the landfill, air, and water. The surrounding system is comprised entirely of our budgets. The ultimate goal of sustainability is "nothing in and nothing out", though the first law of thermodynamics (dU=dq+dw) states that this is impossible. The achievable goal of sustainability is to require less input and generate less output than the current activity.

Sustainable Electronic Waste Recycling

It has been estimated by the Calvert Foundation[i], that by the year 2010 the world will dispose of 200 million computers every year. This study stated that the average $3,000 computer system would depreciate to a value of less than $100 within four years. This equates to a $2,900 profit to computer manufactures every four years for every computer sold. Though people are willing to write off this depreciation they are wont to give additional money to have the worthless equipment properly disposed or recycled. Currently there is a wide discrepancy in the costs of recycling e-waste. At the high end you have the computers vendors that are offering recycling services for $25 per unit, or $75 per computer system. These high-end recyclers are primarily interested in remarketing any saleable units. Any unsaleable items are scrapped and the components recycled or discarded, with the ultimate disposition location undeclared. At the low end you can have the waste removed for the cost of shipping. Low-end recyclers tend to "High-Grade" the waste (skim the more valuable components off the top for sale) and then send the remaining portion to Asia for recycling. Some facilities and recyclers were found that legitimately recycle e-waste in the United States. These facilities are averaging $0.25 per pound for recycling fees plus the cost of transportation. An average weight of 60 pounds per unit and 200 million units per year multiplies out to $3 billion dollars per year for recycling e-waste. That figure hardly sounds sustainable.

Legally, it is acceptable to discard all e-waste, excluding CRT glass, in a landfill or ship overseas to China. Land filling would not be sustainable due to the loss of natural resources found in the e-waste and the vast volume added to the nations landfills. Due to the lack of worker protection and environmental regulations in China, exportation would be ethically or environmentally unacceptable. The Basel Action Network[ii] reported that e-waste arriving at the Nanhai port in the Guangdong Province was separated into high value materials (memory chips, high metal circuit boards, copper, aluminum) and low value materials (Low metal circuit boards, CRTs with yokes, plastics, power sources). The high value materials were sent to facilities where they were processed into raw materials with no procedures in place for worker or environmental protection. These facilities produce large amounts of air and water pollution. The low value materials were discarded. Local residents will scrounge through these discard piles and remove materials that they can process themselves. Circuit boards are taken home where the precious metals are extracted from the fiberglass and plastics by acid digestion (water pollution) or burned off (air pollution). CRTs are taken and smashed to remove the high copper content yokes and the high nickel content ferrous metal masts. The glass is discarded into an irrigation ditch. It has been documented that the lead levels in the water downstream from Guiyu, Guangdong, China were 2,400 times (48ppm) the US safe Drinking Water Standards of 20 ppb.

Electronic Waste Composition
Cathode Ray Tubes (CRT)

The CRTs found in monitors contain lead. Lead levels vary dramatically depending upon the age and manufacture of the CRT, but is present in all. The best sampling protocol, given the extreme heterogeneity of the waste, was "Random Systematic". Two Thousand monitors ware systematically separated into four general categories: Newer 17+ inch monitors, Newer <17 inch monitors, Older >15 inch monitors, and Older <15 inch monitors. One monitor from each category was randomly selected. The four monitors were:

Silicon Graphics HL 79 65KW – SG by Mitsubishi NEC JC-1403HMA by NEC
Apple Audio Vision 14" by Sony Trinitron IBM 67X0150 by Clinton

The CRTs were removed from the monitors, separated into panel and funnel glassand crushed to a uniform sieve size (<0.5mm). The eight samples were sent to a certified laboratory for total and TCLP lead analysis. A composite sample was analyzed for all eight-priority metals.

Table I – CRT Lead Concentration[iii]

Monitor		Weight	% of Waste stream	Funnel		Panel		Composite
Catagory	Sample			Total Pb mg/Kg	TCLP Pb mg/L	Total Pb mg/Kg	TCLP Pb mg/L	TCLP Mg/L
New >17"	Silicon Graphics	75 lbs	10	230	12	1,100	74	As - <0.1 Ba – 4.7
New <17"	Apple Audiovision	32 lbs	30	73	10	160	28	Cd-<0.001 Cr - <0.02
Old >15"	NEC	26 lbs	40	1,000	21	2,100	16	Hg-<0.002 Se - <0.1
Old <15"	IBM	16 lbs	20	370	21	35,000	280	Ag - <0.01
Average		30 lbs		418	16	9,590	99	

The results determined that regardless of the type of monitor both the funnel and screen portions were all determined to be a characteristic hazardous waste D009[iv]. As such, when a monitor is determined to no longer be functional or usable as a monitor it will be hazardous waste. The cost for stabilization and landfill of a D009 characteristic hazardous waste is $0.63/ pound[v].

The environmentally friendly option for CRT disposal is recycling. Both the glass and the lead are recyclable natural resources. Unfortunately, There are many brokers that are currently running shell games with the waste and the CRTs are ending up in landfills or China. Many of the current attributes of e-waste recycling are reminiscent of hazardous waste in the 1980's (A lot of fly by night operations out for a quick buck and then leave the waste in a swamp, a few years later we all get an invitation from the EPA to come help pay for the clean up). There are currently two companies in the US that actually recycle leaded glass. Doe Run in Missouri and Dlubak in Ohio and Arizona.

> The Doe Run smelter will take the glass if the masts, bands and guns have been removed. The glass is placed in their lead smelter were the lead is extracted and the glass is discarded in the slag.
>
> Dlubak Glass will take the monitors whole and de-manufacture (usually with prison labor) down to the glass. The panel glass is separated from the funnel glass. Both grades if glass are pulverized to an acceptable mesh size and sent to glass manufactures for smelting. Currently the leaded glass is going to Techna Glass here in the US, L.G. Phillips in Brazil to make television tubes, or to Torreone Mexico for new CRTs.

At Utah State University, we determined that Dlubak Glass in Yuma, Arizona was our best option based on transportation costs. Recycling fees were $0.10/lb and transportation of a hazardous waste cost $0.40. An average monitor weighs 30 pounds for a total cost of $15.00 per monitor. Proper containerization of the hazardous waste for shipment was determined to be lined Gaylord boxes at $27 per box. The one cubic yard boxes could only fit nine monitors, or an additional cost of $3 per monitor. In Utah monitors must be shipped on a manifest, but in Arizona monitors and CRTs are a recyclable material and can be shipped on a bill of lading. We send our CRTs to ONYX Specialty Services, a Part-B permitted facility, on a manifest were it is terminated and the monitors become "Recyclable Material" proceeding to Dlubak on a bill of lading.

At the annual rate of 2,000 monitors, direct monitor recycling would have cost USU $36,000 annually. Under the principle of sustainability we needed to reduce the financial input. This was easily accomplished by separating the CRT from the monitor. The average CRT weighs 15.5 pounds and 30 CRTs can be placed in a single Gaylord box. Thus, lowering recycling, packaging and shipping costs to $8.75 per monitor. Labor costs have averaged two minutes per monitor for the CRT extraction giving a total cost of disposal at $9.15 per monitor. Yearly cost of monitor disposal is currently $18,300.

Monitors

The CRT removal and packaging took one person 2 hours per week. This produced one well-packaged box of CRTs ready for shipment. Unfortunately, this also left a pile of trash 60 cubic feet in size and weighing 450 pounds. This is a lot of garbage and most of it is recyclable, made up of six basic components; aluminum, copper wire, ferrous metals, plastics, circuit boards and miscellaneous.

Table 2 – Monitor Natural Resources

Material	Aluminum	Copper (wire)	Ferrous	Plastics	Circuit Boards	Misc.
Average Amount	0.5	2	0.5	6	4	1.5
Priced Per Pound	0.30	0.15	0.02	0.05	0.00	0.00
Value per monitor	0.15	0.30	0.01	0.30	0.00	0.00

Ferrous metals, copper wire and aluminum cases/cooling towers were all easily recycled through a local scrap yard. It took an additional two minutes per monitor to separate out these materials. The income from the easily recyclable materials was $0.46 per monitor. With the additional labor costs of $0.40 per monitor this provided a profit of $0.06 per monitor ($1.80 per week). This fit into the principle of sustainability under both clauses. It reduced the amount of waste going to a landfill by 90 pounds per week as well as reducing input of money ($1.80 income and $4.00 savings from lower landfill tipping fees).

Plastics and circuit boards have a market, but not any that are readily accessible. One of the main ridged plastics secondary refinery is located in Salt Lake City, Recovery Plastics International. They take all grades of ridged plastic and separate it into various compositions by grinding and floating. The separated plastics are sent to primary refineries to be reprocessed back into consumer products. The current market price for mixed ridged plastics is $0.05/lb. The biggest benefit from recycling plastics is the savings in landfill space. An average monitor consists of 6 pounds of plastic and takes up an average of two cubic feet (uncrushed). The weekly savings totals 180 pounds and 60 cubic feet. The cost of shipping totally offset the income from the recycling fees so that the only true financial savings for sustainability is the $2.43 per week savings on tipping fees.

Circuit boards have proven to be the most difficult market to tap into. Though circuit boards from computers are valued up to $0.50 per pound, mainly for the memory chips, the boards from monitors are low grade and as such have little value. The cost to grind and smelt the monitor circuit boards is roughly equal to the value of the recovered metals. Transportation costs to secondary refineries range from $0.10 to $0.15 per pound. With no income from the sale of the boards this is a direct money outlay. From a sustainability perspective the four pounds of landfill savings does not offset the $0.40 cost per monitor. If shipping costs were less than $0.10 per monitor recycling of the circuit boards would be feasible.

Central Processing Units (CPU)

The future at USU is the on-site de-manufacturing and off-site recycling of CPUs. Central processing units are rich in natural resources. Dr. Martin Goosey has determined the following component concentrations in an average CPU:

Table 3- Materials Found in a Desktop Computer Weighing – 60 lbs.[vi]

Name	**Content Of Total**		**Weight (lbs)**	**Recycling Efficiency**	**Use / Location**
	%	ppm *(TCLP)*			
Silica	24.8803		15	0%	Glass, solid state devices / CRT
Plastics	22.9907		13.8	20%	Includes organics, oxides
Iron	20.4712		12.3	80%	Structural, magnetivity (steel) PWB
Aluminum	14.1723		8.5	80%	Structural, conductivity / housing connectors
Copper	6.9287		4.2	90%	Conductivity/CRT, PWB
Lead	6.2988	<3,150	3.8	5%	Metal joining, radiation shield
Zinc	2.2046		1.32	60%	Battery, phosphor emitter / PWB
Tin	1.0078		0.6	70%	Metal joining/PWB, CRT
Gold	0.0016		<0.1	99%	Connectivity, conductivity
Silver	0.0189	<9.45	<0.1	98%	Conductivity / PWB connectors
Palladium	0.0003		<0.1	95%	Connectivity, conductivity
Platinum	0			95%	Thick film conductor / PWB
Cobalt	0.0157		>0.1	85%	Structural, magnetivity /(steel) PWB
Nickel	0.8503		0.51	80%	Structural, magnetivity/ (steel) PWB
Ruthenium	0.0016		<0.1	80%	Resistive circuit / PWB
Selenium	0.0016	<0.8	0.00096	70%	Rectifiers / PWB
Indium	0.0016		<0.1	60%	Transistor, rectifiers / PWB
Rhodium	0			50%	Thick film conductor / PWB
Barium	0.0315	<15.75	<0.1	0%	In vacuum tube/CRT
Manganese	0.0315		<0.1	0%	Structural, magnetivity /(steel) PWB
Beryllium	0.0157		<0.1	0%	Thermal conductivity / PWB
Tantalum	0.0157		<.1	0%	Capacitors / PWB power supply
Titanium	0.0157		<0.1	0%	Pigment, alloying agent
Antinomy	0.0094		<0.1	0%	Diodes / housing PWB, CRT
Cadmium	0.0094	<4.7	<0.1	0%	Battery, glu-green phosphor, PWB,CRT
Chromium	0.0063	<3.15	<0.1	0%	Decorative, hardener, steel
Bismuth	0.0063		<0.1	0%	Wetting agent in thick film
Mercury	0.0022	<1.1	<0.1	0%	Batteries, switches / housing
Germanium	0.0016		<0.1	0%	Semiconductor/PWB
Arsenic	0.0013	<0.65	<0.1	0%	Doping agents in transistors
Gallium	0.0013		<0.1	0%	Semiconductor/PWB
Europium	0.0002		<0.1	0%	Phosphor activator / PWB
Niobium	0.0002		<0.1	0%	Welding, allow/housing
Vanadium	0.0002		<0.1	0%	Red phosphor activator
Yttrium	0.0002		<0.1	0%	Red phosphor emitter / CRT
Terbium	0		0	0%	Green phosphor activator

Based on this information it was determined that the value of the natural resources, market values from June 2002, to be $20.42/CPU[vii]. We have estimated 10 minutes per CPU to dismantle the units to Plastic, Ferrous Metals, Aluminum, Copper Wire, Circuit Boards, Hard Drives, and Memory Chips. Thus, the total estimated costs for de-manufacture and transportation is $4.16 for an average CPU. The theoretical profit from recycling CPUS is $16.26. With the 30 pounds of savings from reduced landfill disposal this appears to be more sustainable than monitor recycling.

If all of the silver, cadmium, or mercury in a CU were soluble, it is feasible that a computer could be considered a D011, D006, or D009 (respectively) characteristic criteria hazardous waste. The chance of these priority pollutant metals being sufficiently soluble are remote, but warrants further investigation.

Summary

On-site de-manufacturing and off site recycling of monitors is a sustainable activity. The average cost to the environment for disposal of one computer monitor is 30 pounds and two cubic feet of waste with 0.16 pounds of lead. The financial cost for disposal as a hazardous waste is $23.10 per monitor or off-site de-manufacture and recycling is $18.00 per monitor. The practice of on-site de-manufacturing can lower the costs to the environment to 5.5 pounds and 0.1 cubic feet per monitor with dramatically reduced contamination of heavy metals. The financial costs for recycling, including de-manufacturing labor, are $9.15 per monitor, a saving of $8.85 per monitor over the direct recycle option.

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[i] Blackwood, Jonathan; **The Greening of HP**; Calvert Foundation, 2004

[ii] Jim Puckett, The Basel Action Network (BAN), Leslie Byster, Silicon Valley Toxics Coilition (SVTC), Sarah Westervelt, BAN, Richard Gutierrez, BAN, Sheila Davis, MFF, Asma Hussain, SCOPE, Madhumitta Dutta, Toxics Link India; **Exporting Harm**; 2/25/02

[iii] ChemTech-Ford, Analytical Laboratories; Project USUJB, 65347

[iv] 40 CFR 261.24 (b), Table 1

[v] ONYX Environmental Services, Enviro Safe Services of Idaho

[vi] Microelectronics and Computer Technology Corporation (MCC), 1996 Electronics Industry Environmental Roadmap, Austin, TX MCC

[vii] Goosey, Martin; Keller, Rod**: A Scoping Study, End of Life Printed Circuit Boards**; June 2002