Product Disposal and Re-use Issues for Portable Computer Design

C. Hendrickson, L. Lave, F. McMlchael, D. Slewiorek, A. Smailagic, T. Wu

EDRC 12-64-94

Product Disposal and Re-Use Issues for Portable Computer Design

by Chris Hendrickson,[1] Lester Lave,[2] Francis McMkhael[3] Danid Siewiorek,[4]
Asim Smailagic[5] and Tse-Sung Wu,[6]

Abstract

Portable computers including laptops, notebooks, sub-notebooks and potable digital assistants are a rapidly growing segment of the computer market. Manufacturers of portable computers have an opportunity to win public piaise and to avoid censure and liability by embracing green design and sensible product disposal systems. This paper analyzes the environmental issues associated with disposal, re-use and recycling of these machines, focusing on potential design changes to alleviate environmental burtfens. Portable computers can replace larger machines, resulting in lower energy use and lower overall material demand Since the number of portable computers purchased may be as many as 100 million over the next decade, environmental concerns become increasingly important Portable computers use batteries with toxic components, so there are disposal or recycling problems. Another significant issue in assessment of disposal and recycling processes is the expected life time of portable computers. Machine design with capability for easy upgrade can be expected to have a longer useful life. The *paper* uses experience gained in several generations of wearable computer designs at Carnegie Mellon University for illustration.

1.Introduction

Manufacturers of portable computers have an opportunity to win public piaise and to avoid censure and liability. During the next decade, manufacturers are likely to make and sell over 100 million portable computers. Although portable machines don't contain the same toxic materials as desktop computers (leaded glass, etc.)* they have their unique challenges for health and the environment All of these machines are battery powered, and the batteries generally contain highly toxic materials. Designers can gain a great deal by attending now, before the bulk of the machines are produced* to making poraWe copyutcirs greener. We consider hoe iapt of material use W re-use) and energy consumption. Issues of manufacturing process design, radiation and other health effects are not discussed.

Thane is likely to be expb»vc fpwrth in the use of personal "portable computers" in the next decade. In this category, we [illegible], portable digital assistants, [illegible], enhanced cellular telephones [illegible] systems (as in Fig. 1), but we [illegible] and microprocessors embedded in other devkfep. b many cases, portable computers will have telecoiwtfMrtc<itoa^bili^ for digital data exchange and personal coftvenations. BIS Strategic Decisions [13] estimate* a 1903 installed base of 400,000 wireless equipped *L&jjpmuh* and personal digital assistants, with growth to 7 npon by 1998. Saks and Marketing [illegible]J [illegible] estimates annual worldwide sales of [illegible] coqygtto to be 7 milBoo in 1991, with [illegible]. [illegible] Inc. [9] estimates [illegible]I of portable computers *m* 5 million, but [illegible]. The *are<rfpoctaWe computers in the [illegible] of *ptmml* computers is also [illegible] i a 5* stare i* 199Q[taving increased to a 15% *w in 1994. [5]. Owafufldecadcbasesatesof 5 to 7 mflBon «j AM growth would rcsrit to sales of weU over 100 million units. These numbers do not count computers embedded in poitable electro-mechanical devices such as automobiles. By way of comparison, a 1992 study [1] estimated a *wqdi* wide population of 115 million personal computers, or one for every 44 persons. In 1990, the number of worldwide motor vehicles was 600 million, or one vehicle for every 9 people, while sales were 48 million. [8] Thus, the numbers of unit sales for portable computers may be

[1]Assoc. Dean, Carnegie bstittfe of Technology and Prof., Dept. of Civil Engineering, Carnegie Mellon University, Pittsburgh, PA 15213. Phone: 412-268-2948, intone* <àn4#cnme4i

[2]Higgiiis Professor of Economics and University Professor, Carnegie Mellon University, Pittsburgh, PA 15213. Phone: 412-268-8837

tyaker Bknko *ST.* Professor of Environmental Engineering, Carnegie Mellon University, Pittsbofgh, PA 15213.

[4]PitrfessOTofO>mpulerSck«K»ai^ Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

[5]Visiting Research Scientist, Engineering Design Reseaich Center, Carnegie Mellon Uiiivei^, Pittsboi^ PA 15213.

Research Assistant, Engmccring Design Research Center, Carnegie Mellon University, Pittsburgh, PA 15213

roughly comparable to that of the 1990 computer industry, but smaller than the international motor vehicle industry.

Figure 1: VuMan H, a modular wearable computer with head mounted display intended for information and blueprint display f11]

2. Material Use

Portable computeis must be light but the sheer number of machines means that the overall material demand is considerable. Table 1 reports the weight and general material composition of some existing poitable computer configurations. With sales of 10 million units per year (see above) and uniform purchases among the different types of devices shown in Table 1, the annual output of poitable computers would be roughly 25,000 tons per year without including packaging materials, replacement batteries, manuals or waste during manufacture.

	Laptop	Wearable Computer	Wearable Computer	Personal Digital Assistant
Type	Dell 320SH	Navigator	VuMan n	HP100LX
WeightOb)	4	10	3	0.7
Battery Life (hrs)	3	2-4	3	8
Power (W)	24	19	1	NA
Battery WeightOb)!		13	1	0.1
Battery Type	NiCAD	NiCAD/ Alk.	NiCAD/ Alt	NiCAD/ Alk.

Source: Author's Measurements and [10].

Table 1: Characteristics of Four Portable Computer Types

To the extent that lighter portable computers replace larger machines on a one-to-one basis, then overall material requirements are reduced. Portions of larger machines may also be eliminated; as with the use of external displays and keyboards for portable computers. However, only a fraction of portable computers' are likely to be replacements for existing machines; as with the introduction of personal computers, there will be an overall increase in die number of existing computers.

Excluding batteries, portable computeis have only small amounts of toxic materials. Unlike personal computers with leaded glass in CRT displays, toxic materials are limited to trace elements in plastics, electronic components and connections, such as lead-based in solder.

Packaging and wastes during manufacture also impose material demands associated with portable computers. For example, the waste material associated with semiconductor devices used in a typical workstation has been estimated to be 90 lbs. for a negligible final product weight [7]. Similarly, the waste material in manufacturing printed wiring boards and computer assemblies for a workstation was estijjuied to be tun tiroes the fiqal average weight of 4 lbs [7]. Pack*§»g and typical peripherals for poraftge computers also can hare rignififiaitf nuiwini danandsi die packaging, manuals and whaler for a Toshiba laptop computer weighed roughly 30 lb*, or fire timeMbe weight of the portable computer itself. With »fcs of 10 million uaits or rougWy 25,000 tons of portable computer hardware, wastes and ptykagtug might be over a billion tons of material.

3. Battery and Energy Use

A distinguishing feature of portable computing is the importance of batteries as a power source. Batteries represent roughly 23 % of the weight of a typical laptop computer (a Compaq LTE), 13 % of the volume, and 6 % of the material cost of a laptop machijie [6). Due to their toxic content, batteries can have significant environmental impacts in manufacture and disposal. They also impose an environmental burden due to energy production for recharging.

The primary types of batteries used or considered for portable computing are shown in Table 2. This table includes a theoretical maximum value for specific energy (as measured in Watt hours per kilogram of battery) and die actual attained value of specific energy. The theoretical maximum value is based on the chemical properties of the active battery materials without considering casings or electrodes, so the theoretical maximum is unattainable. Nevertheless, one can expect improvements in performance over time; [9] notes that th* energy capacity of the nickel-cadmium battery used in various Powerbook™ notebooks increased 20% over a few years.

Each of the battery types listed in Table 2 have a high proportion of toxic materials and *represent* hazardous materials disposal problem, although the relevant regulations differ substantially among the different battery types. For example, jeaa**acKi Daturas arc restricted trom disposal in municipal solid waste, whereas nickel-cadmium batteries are routinely discarded by consumers.

There are a variety of factors that would lead a designer to choose one battery type over another, including safety considerations, the gravimetric and volumetric energy densities, the temperature range for operations, the self-discharge rate, etc. Apple Computer emphasizes high cycle life and long life expectancy in selecting batteries [9] and employs nickel-cadmium and nickel-metal hydride batteries.

Disposal and recycling of batteries used in portable computing can be a significant envirronmetual problem. With annual sales of 10 million portable computers, roughly IS million new battery packs would be purchased (since many customers' require a backup battery pack), representing roughly 7300 tons per year of batteries. Replacement batteries would also be required. Phillips et aL [9] estimate a two year service life in the field for metal hydride batteries used in certain types of Macintosh Powerbook™ machines; with a five year lifetime, two sets of replacement batteries would be purchased. Thus, battery disposal from portable computers might represent roughly 35 million units per year, or 17,500 tons per year. While this large an amount of toxic material is a disposal problem, it represents only a small fraction of the total volume of battery sales and of US hazardous waste. The worldwide battery market is roughly 3 billion units, so portable computing might represent only 1 % of the total. Nevertheless, a waste stream of 17300 tons of toxic material per year in a single location would trigger close monitoring under the federal clean air act (10 tons/year) and Superfund Amendments and Reauthorization Act (5 tons/year) regulations; the dispersed disposal associated with batteries could easily be more harmful to the environment than a single toxic discharge source considered by these regulations.

CettType	Specie EM*8r(Wb/Kf)	
	Theoretical	*Actual*
Lead/Add	170	40
Seated Le«d/Acid	170	50
Nickel/Iron	270	50
NicW/Cadmium	210	40
Nickel/Zinc	350	70
Nickel/Hydrogen	360	50
Silver/Iran	360	50
Zinc/bromine	430	70
Zinc/Chlorine	650	70
Sodium/Sulphur	76ft	140
Utfakm/ Chalcogenide	85-1470	90-450
Lithium/ *Pdtytner*	870	200

Note: specific energies reported to ...

Table 2: Theoretical and Actual Specific Energies for Various Battery Types *[6]*

Disposal of batteries *cm* be costly, depending upon die applicable regulations and collection mode. Municipal solid waste *s&ii* to landfills costs roughly $ 100 per ton, including collection and tipping fees [3]. Due to small volumes (with consequent higher collection fees) and more stringent regulation/special collections far household hazardous waste cost as much as $ 10,000 per ton. Currently, bulk disposal of rechargeable batteries costs the Department of Defense $ 2,000 per ton. Returning individual batteries to the manufacturer might cost S 2 per pound in shipping and handling plus a bulk disposal fee, so the cost per toil would be S 5,000. With 17,500 tons of toxic material, disposal costs would be somewhere between $ 2 million (with disposal as municipal solid waste), $ 70 million (with product return and bulk disposal) and S 175 million (with treatment as household hazardous waste and special collection).

The scale of toxic materials associated with portable computing suggests that some form of recycling or regulation is desirable. Some companies already take back batteries and recycling operations exist The tipping fee at a municipal solid waste landfill is typically S 35 per ton, [31. In 1992, a recycler of nickel-cadmium batteries (Inmetco, Ellwood City, PA) charged S 460 per ton to take discarded batteries. Tipping fees at hazardous waste landfills are comparable.

While we focus here on product re-use and discard issues, it is worth noting that battery use also represents environmental costs in manufacture and indirectly through demands for recharging electricity. Portable computer designers should be (and are) given significant incentives to reduce electrical demand. Programs such as the Energy Star certification process suggest that low power technology may play a significant role in the personal computer market as well.

4. Design for Disassembly and Re-Use

Much of die knowledge already available for environmentally conscious electronic design can and should be directly applied to the design of portable computers [4,7]. For example, snap fits, eliminating metal inserts and restricting die different types of plastic used can make assembly, disassembly, maintenance and re-use easier.

Figure 2 illustrates the disassembly tree for the central unit of the VuMan II wearable computer. For this machine, parts are held together by snap fits that can be readily separated.

While designs having easier disassembly may have multiple benefits, other design decisions may make recycling more difficult Composites may be introduced for extra strength and lightness, but composite material of multiple material types typk^yrtiAc nxycling irore difficult Deposition of circuits may reduce weight and assembly cost, but can make removal of tract metal elements difficult As in many design problems, tradeoffs between different functional requirements must be made. Nevertheless, explicit consideration of recycling opportunities may improve decision making. Various kinds of computer aids may be useful in this regard [2].

5. Desi&i for Longevity

Will design of portable computers for greater longevity yield significant environmental benefits? By extending the life of portable computers, the demand for input materials and disposal is correspondingly reduced.

Greater longevity could be achieved by a variety of design changes, such as explicit consideration of operational stresses and repair possibilities. In the rapidly evolving technology of portable computing, however, a crucial issue in extending the effective life of devices is to insure an easy means of upgrading devices for new software and chip generations. For example, pottable computers can be designed with die possibility for new flash card inserts or cpu chip replacement in a similar fashion to desktop machines.

Explicit design for longevity and upgrade paths may make good economic sense. There may be more profit potential in marketing new software and card inserts while selling the basic portable computing box at a relative low price. This is the strategy which has proven successful for razorblades and the video game marketplace, and it is beginning to appear in the desktop machine market

The environmental gains from increased longevity stem from reduced material use and manufacturing process waste. The material used in actual machines is relatively small, whereas savings in manufacturing wastes and packaging could be substantial as noted above.

Battery use might decrease slightly (since fewer machines would be discarded with remaining battery life), but decrease in demand for batteries in new machines would be largely offset by demand for replacement batteries.

6. Policy Implications

Our analysis of environmental effects associated with portable computers has led to the following coiiclusions for policy implications:

1. Manufacturing and packaging waste streams may be substantial and could be reduced by increasing the effective life of machines and process changes in the manufacturing industry.

2. Given the possibility of uncontrolled disposal of batteries, corporate programs including incentives for safe disposal of batteries may be good investments. Retailers might voluntarily accept batteries back for recycling or make prepaid mailers available to customers. We estimate a cost of $ 5,000 per ion of batteries for such a program. Voluntary agreements of this type are common in Western Europe and are becoming more prevalent in the US.

3. Battery recycling requirements are likely. Without action on the part of system manufacturers, we predict that some form of regulation in this regard will be imposed either piecemeal (which may be quite expensive to companies and consumers) or through international agreement

4. Product takeback may also be a desirable strategy for manufacturers to pursue. Material weights of actual products are relatively small, so collection costs are also small. Concentrating products may be sufficient to allow cost effective recycling efforts.

S.Use of portable computers may have indirect environmental benefits, such as reducing travel and consequent demands on materials and energy. The low power technology developed initially for portable computers offers a good model for larger, more power intensive applications.

7. References

[1] Anzovin, S.
The Green PC.
Windcrest/McGraw Hill 1993.

[2] Diaz-Calderone,A.,S.Fenves,J.Garrcttand C. Hendrickson.
Computer-Based Advisors for Environmentally ^onscious, oreen xroauct Design.
In First Congress on Computing. American Society of Civil Engineers, June, 1994.

[3] Hendrickson, C, L. Lave and F. McMichaeL
System Design for Municipal Solid Waste Recycling.
Technical Report, Carnegie Mellon University, February, 1994.

[4] Kirby,JJLandI.Wadehra.
Design Business Machines for Disassembly and Recycling.
In *Intl. Sym. on Electronics and the Environment,* pages 32-36. IEEE, May, 1993.

[5] Lohr,sJ
Dell's Second Stab at Portables.
NewYork Turns :C1, February 22,1994.

[6] MacKay, Colin and Bert Haskell.
The Role of Batteries in Portable Electronics.
Proc National Electronic Packaging and Proudction Conference: 1621-1633,1992.

[7] Cartron, D., R. Ferrone, B. Kushnerand G. Pitts.
EnvironmentalConsciousness:AStrategic Competitiveness Issuefor the Electronics and ComputerIndustry.
Technical Report, Microelectronics and Computer Technology Corporation (MCC), March, 1993.

[8] Motor Vehicle Manufacturer's Association.
1992 WorldMotor Vehicle Yearbook
MVMA,1992.

[9} Phillips, J., J. Chan, and N. Szasz.
Power Sources and Portable Computers.
IEEE AES Systems Magazine:35-37,May, 1993.

[10] Smailagic, A. and D. Siewiorek.
A Case Study in Embedded-System Design: The VuMan 2 Wearable Computer.
IEEEPesign & Test of Computers :S6-67, September, 1993.

[11] Smailagic, A. and DP. Siewiorek.
The CMU Mobile Computers: A New Generation of Computer Systems.
Proc. WEE COMPCON 94, February, 1994.

[12] Taylor, T.C.
Sales Force Automation.
Sales & Marketing Management :47-60, Jan, 1992.

[13] Anonymous.
Special Section on Wireless Technology.
Wall Street Journal :R5, February 11,1994.

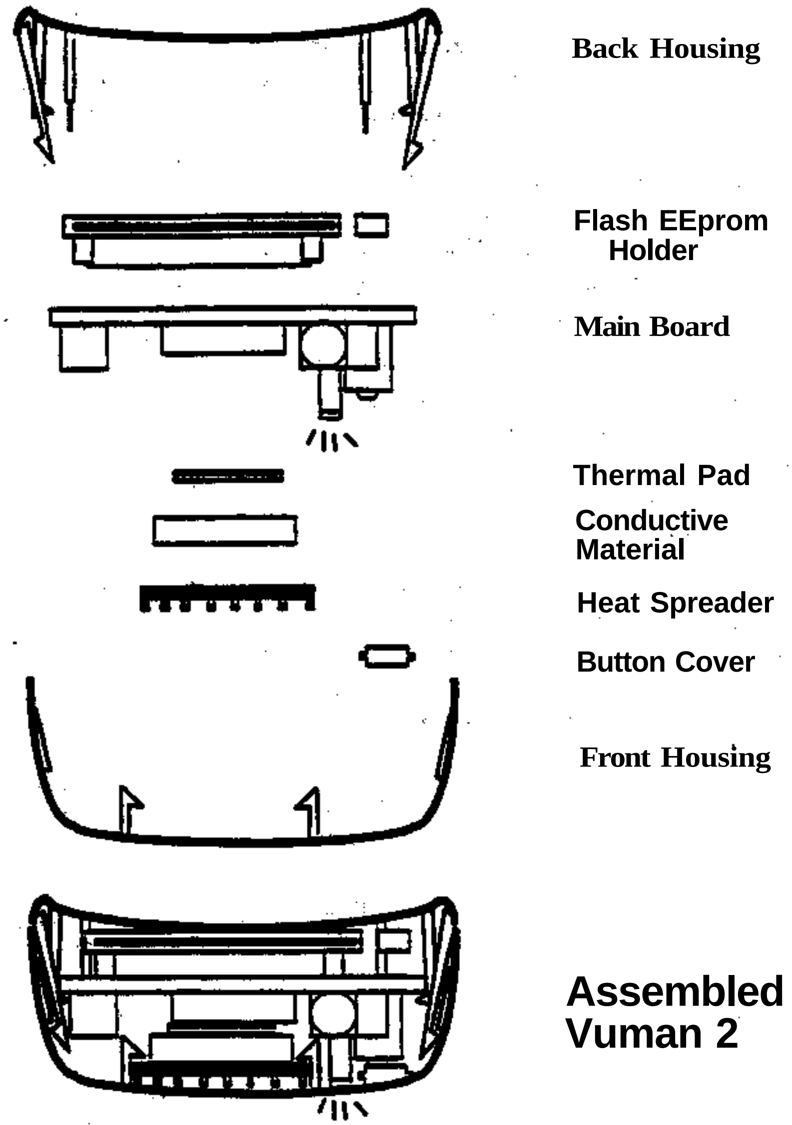

Figure 2: Pam of the VuManll Wearable **Computer** Processing Unit