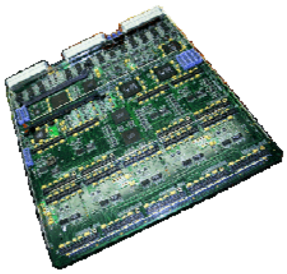
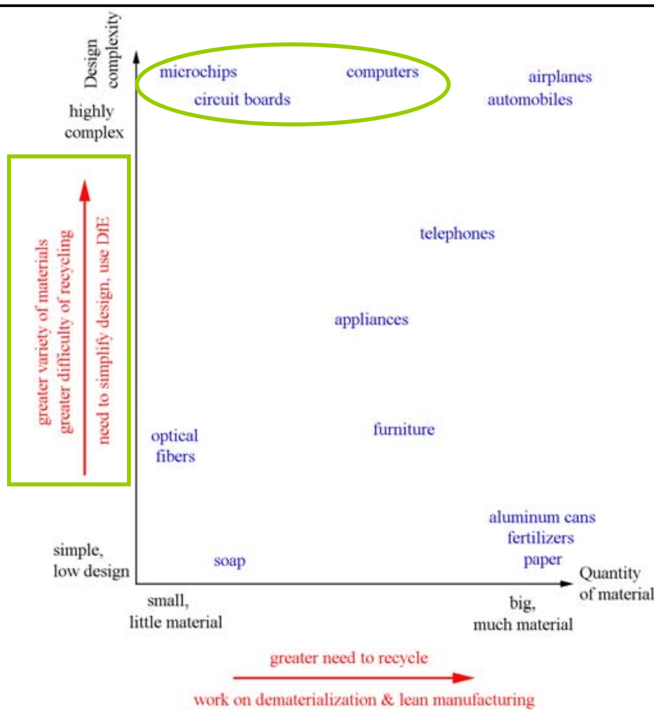
Environmental Issues in the Electronics Industry



A young and highly competitive industry
for which technical performance rules, and
environmental concerns have not yet been a priority.



Environmental Impacts of Computer Use

Direct *versus* Indirect

DIRECT

- Environmental impacts in manufacturing
  - energy consumption, many chemicals
  - workers' exposure
  - upstream impacts of making chemicals
- Energy consumption during use
- Environmental impacts at disposal
  - difficult disassembly, hazardous materials

INDIRECT

- Health effects on users
  - damage to wrists, eyes, spinal column
  - lack of physical exercise – obesity
  - addiction to computer games – poor tests scores
- Impacts on industrial activities
  - …
- Impact on consumer purchases
  - manner of purchasing, not quantity
- So-called "3rd-order effect", rebound effect
  - transportation of goods
  - land use ("de-malling"), cell-phone towers
  - consumption patterns, paper consumption

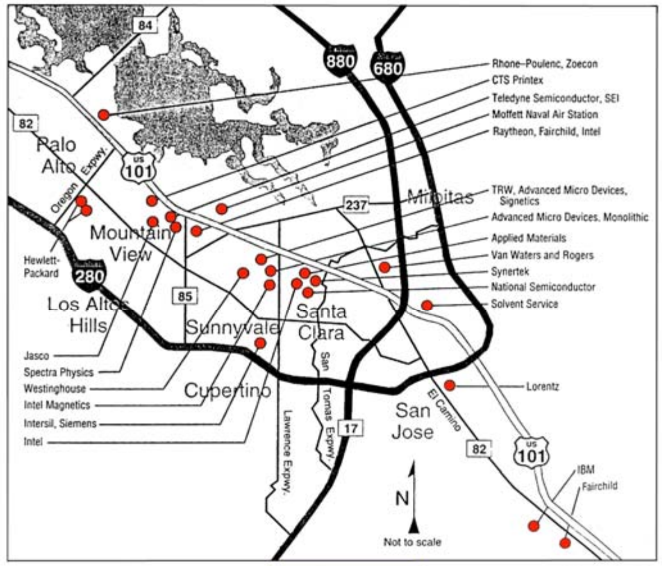
<u>Chief issues concerning microchips, printed circuit boards and computers:</u>

1. During manufacturing:
   - Use of many nasty chemicals
   - Human exposure
2. During use:
   - Energy consumption to power the devices
3. End of life:
   - Proliferation of electronics in waste stream
   - Complex disassembly
   - Dumping in poor countries
   - Toxics

1. Impact during manufacturing

National need (they said!) to be globally competitive in the face of a rapidly changing technology.

No wonder, we got this! The highest concentration of superfund sites is in Silicon Valley.



[5] California's Silicon Valley has more Federal Superfund sites than any other area of its size in the nation, plus many other toxic sites that are being monitored by state and regional agencies.

Environ. Sci. Technol. **2002**, *36*, 5504–5510

The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices

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The scale of environmental impacts associated with the manufacture of microchips is characterized through analysis of material and energy inputs into processes in the production chain. The total weight of secondary fossil fuel and chemical inputs to produce and use a single 2-gram 32MB DRAM chip are estimated at 1600 g and 72 g, respectively. Use of water and elemental gases (mainly N_2) in the fabrication stage are 32 000 and 700 g per chip, respectively. The production chain yielding silicon wafers from quartz uses 160 times the energy required for typical silicon, indicating that purification to semiconductor grade materials is energy intensive. Due to its extremely low-entropy, organized structure, the materials intensity of a microchip is orders of magnitude higher than that of "traditional" goods. Future analysis of semiconductor and other low entropy high-tech goods needs to include the use of secondary materials, especially for purification.

1. Introduction

We live in the semiconductor age. Microchips have become part of everyday life, playing essential roles in ubiquitous devices such as computers, cell phones and even automobiles. A global semiconductor industry has arisen to meet the demand for microchips, a business that has grown in leaps and bounds the past few decades. Estimates place the overall economic scale of the semiconductor at $140 billion in 2000 with an average 16% growth per year over the past few decades (*1*).

The environmental implications of this new industry are a matter of potential concern, especially given its substantial economic scale and high rate of growth. Microchips themselves are small, valuable and have a wide variety of applications, which naively suggests that they deliver large benefits to society with negligible environmental impact. On the other hand, the semiconductor industry uses hundreds, even thousands of chemicals, many in significant quantities and many of them toxic. Emissions of these chemicals have potential impacts on air, water and soil systems and potentially pose an occupational risk for line workers. Historical incidents of environmental impacts on soil and water systems are discussed by Mazurek (*2*), and LaDou and Rohm review occupational hazards in the industry (*3*). Also, the industry is well-known to be intensive in its use of energy, water and materials.

It is safe to assert that there is little consensus regarding impacts of the industry. While individual firms presumably understand their own practices fairly well, publicly available environmental data and analyses of the sector are scarce. Given rapid process change and evident effort the industry is making toward environmental protection (e.g. ref *4*), it is plausible to believe claims that emissions issues have been largely addressed. However, little real evidence exists to support or refute this. Also, semiconductor firms are unlikely to have a complete picture of impacts associated with the supply chain for raw materials, which could be significant. It is thus appropriate that civil society, in particular academia and NGOs, put forth a community to work toward a wider understanding of and response to the industry's environmental issues.

Materials flow analysis of the semiconductor production chain could make a valuable contribution to identifying the scale of environmental impacts and directions for further work. Materials flow analysis utilizes process material input-output data to characterize the use and emissions of materials within and between processes (*5, 6*). Materials flow analysis designed to characterize material use and/or environmental impacts associated a particular product or service is called life cycle assessment (*7, 8*). Starting with an earlier study (*9*), in this article we undertake materials flow analysis of the semiconductor production chain as well as a life cycle assessment of a computer memory chip.

There is a limited body of publicly available literature relevant to materials analysis of the semiconductor industry. In its life cycle assessment of a workstation, the Microelectronics and Computer Technology Corporation (MCC) published results for electricity use, water consumption and aggregate chemical wastes for production of a complete set of microchips in a computer (*10*). The Electronics Industry Association of Japan (EIAJ) has carried out extensive work to characterize emissions trends in the Japanese semiconductor industry and also has reviewed inputs and waste management issues (*11, 12*). Their yearly waste surveys cover 98% of domestic capacity and report tonnage of emissions in the aggregate categories of sludge, oil, acids, alkali, plastic, metal, ceramics and glass (*12*). As part of the Toxics Release Inventory (TRI) program, the U.S. Environmental Protection Agency (EPA) surveys U.S. firms annually for emission quantities of around 650 different substances, reported when the facility's annual throughput of that chemical exceeds a threshold level of 11.3 metric tons (*13*). This information is published along with an environmental review of process technology and pollution prevention issues for the industry (*14*). The United Nations Environment Program (UNEP) and the United Nations Industrial Development Organizations (UNIDO) jointly published a report on the semiconductor industry surveying waste management issues, which included detailed data on materials inputs for "generic" integrated circuit fabrication process on a 4-in. diameter wafer (*15*). One would hope that data from environmental reports of semiconductor manufacturers could be useful in this context. However, publicly reported data on materials and energy use is only at the level of the entire firm (or regional division), which cannot be converted to the process level without additional information.

There are many gaps in the literature; we highlight three outstanding ones. One is a lack of process data describing

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10.1021/es025643o CCC: $22.00

For its fabrication, a 2-gram microchip necessitates
1600 grams of petroleum,
72 grams of chemicals,
32,000 grams of water,
700 grams of elemental gases.

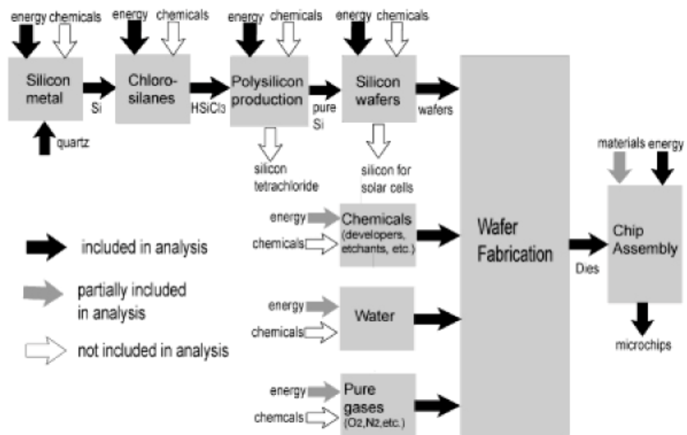


FIGURE 1. Production chain for semiconductor devices.

Williams, Ayres & Heller, *Environ. Sci & Tech*., 2002.

Preparation of the silicon wafer

(http://www.sumitomometals.co.jp/e/business/silicon.html)

- Ingot growth
  to make crystal
  doping, hi-temperature furnace

- Ingot blasting & cleaning
  to remove oxides and surface contaminants
  calcined alumina, silicon carbide, alcohol rinse

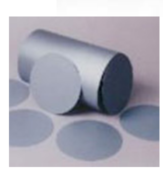
(http://www.risoe.dk/rd/ntd/sil_ntd_uk.htm)

- Wafer slicing
  to cut thin wafers
  diamond saw, coolants

- Wafer washing
  cleaning step
  soap solution (NaOH), H_2O_2, H_2SO_4, alcohol

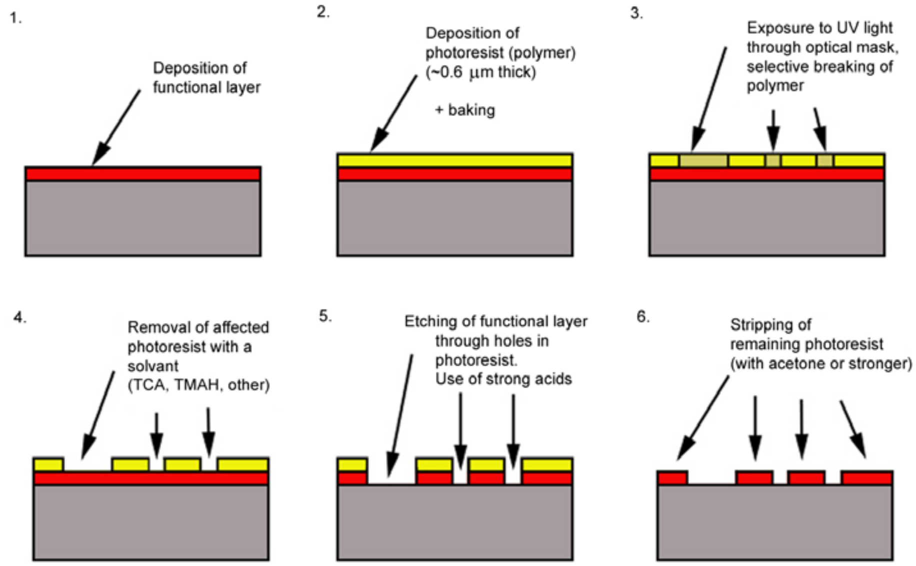
- Wafer lapping, etching & polishing
  to provide a very smooth surface
  acids (hydrofluoric, nitric, acetic)
  sodium hydroxide (NaOH)
  colloidal silica

- Silicon epitaxy
  to make a protective film
  chemical vapor deposition with intermediate rinses



(http://www.sliceofsiliconvalley.com/story.html)

The engraving of a microchip, layer by layer



... and this is only one layer among very many !

TABLE 1. Firm Data on Chemical Inputs to Semiconductor Fabrication per Square Centimeter of Input Wafer (*16*)

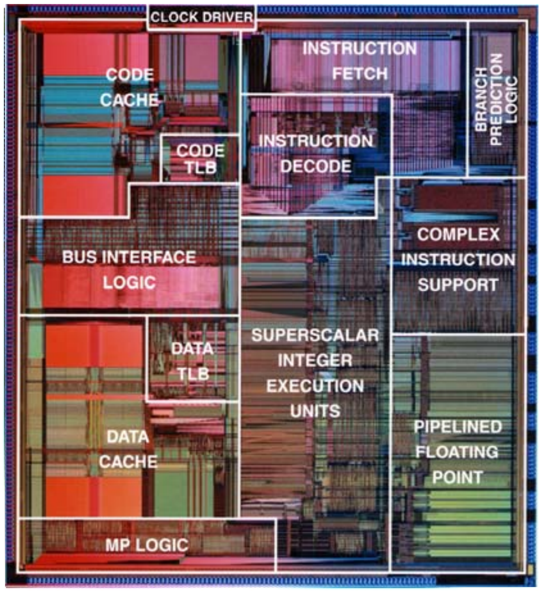
category	substance	input per wafer area (g/cm^2)
elemental gas	He	1.7E−01
	N_2	4.4E+02
	O_2	3.0E+00
	Ar	1.7E+00
	H_2	4.6E−02
	subtotal gas:	4.5E+02
deposition/dopant gases	silane (SiH_4)	7.8E−03
	phosphine (PH_3)	1.7E−05
	arsine (AsH_3)	4.3E−06
	diborane (B_2H_6)	4.3E−06
	dichlorosilane (SiH_2Cl_2)	1.4E−03
	subtotal deposition/dopants:	9.3E−03
etchants	ammonia (NH_3)	1.2E−02
	N_2O	7.2E−02
	Cl_2	4.8E−03
	BCl_3	8.7E−03
	BF_3	3.5E−05
	HBr	2.2E−03
	HCl	5.0E−03
	HF	9.5E−04
	NF_3	2.3E−03
	WF_6	4.3E−04
	SF_6	6.5E−03
	C_2F_6	5.0E−02
	CHF_3	3.1E−02
	CF_4	3.0E−02
	subtotal etchants	2.3E−01

category	substance	input per wafer area (g/cm^2)
acids/bases	HF 1 vol + NH4 30 vol mixture	2.84E+00
	phosphoric acid H_3PO_4 86%	2.41E+00
	hydrofluoric acid 0.5%	3.42E+00
	hydrofluoric acid 5%	4.55E−01
	hydrofluoric acid 50%	2.52E−01
	nitric acid 70%	1.19E+00
	sulfuric acid 96%	7.85E+00
	hydrochloric acid 30%	2.52E+00
	ammonia 28%	7.76E−01
	slurry	2.86E−01
	HCl 30%	5.06E−01
	NaOH 50%	6.51E−01
	subtotal acids/bases:	2.32E+01
photolithographic chemicals	hydrogen peroxide 30%	4.43E+00
	isopropyl alcohol	2.02E+00
	tetramethylammonium hydroxide	4.31E+00
	methyl-3-methoxypropionate	1.48E+00
	acetone	5.54E−01
	hexamethyldisilazane	2.20E−02
	hydroxyl monoethanolamine	1.42E+00
	subtotal photolithographic chemicals	1.42E+01
	NaOH for neutralizing wastewater	7.60E+00
	total chemical input:	45.2 g/cm^2

TABLE 2. Aggregate Chemical Use/Emissions for Wafer Fabrication (*10–16*)

Williams, Ayres & Heller, *Environ. Sci. & Tech.*, 2002.

After a very large number of layers, one gets something like this

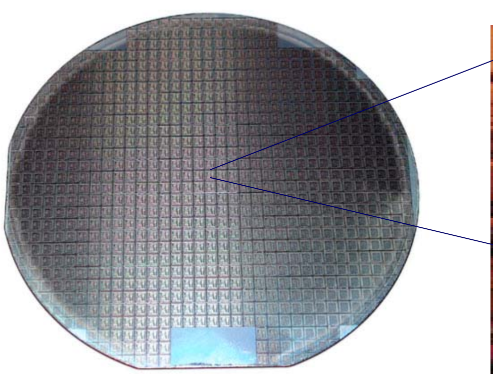


Intel Pentium processor

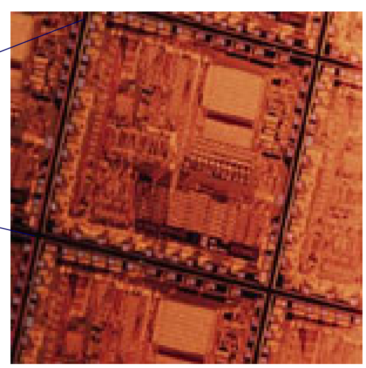
By 2004, Intel processor chips had more than 100 million transistors per chip.

(http://www.optics.rochester.edu/workgroups/cml/opt307/spr06/alex/index.htm)

Several hundred microchips are engraved simultaneously on the same wafer, which is then snapped into little rectangular fragments, one chip on each.

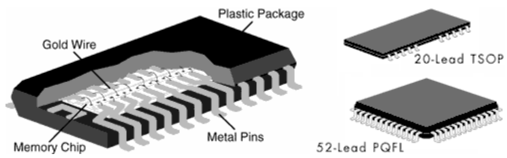


(http://www.electronetwork.org/education/ic/)

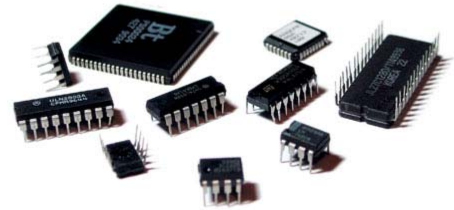


(http://www.sliceofsiliconvalley.com/story.html)

Terminals are then added, and each chip is packaged under a protective cover.



(http://www.micron.com/k12/semiconductors/assembly)



(http://www.electronetwork.org/education/ic/)

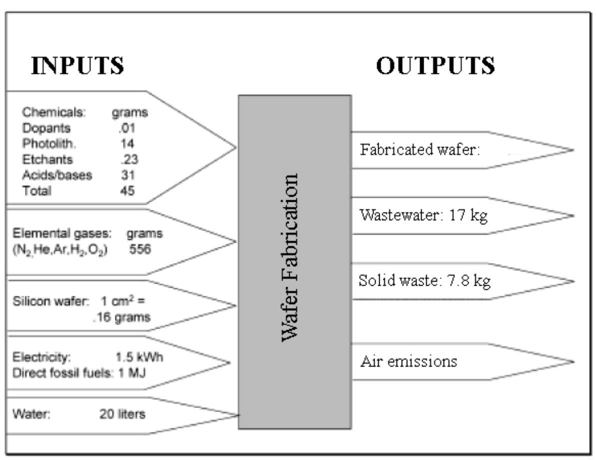
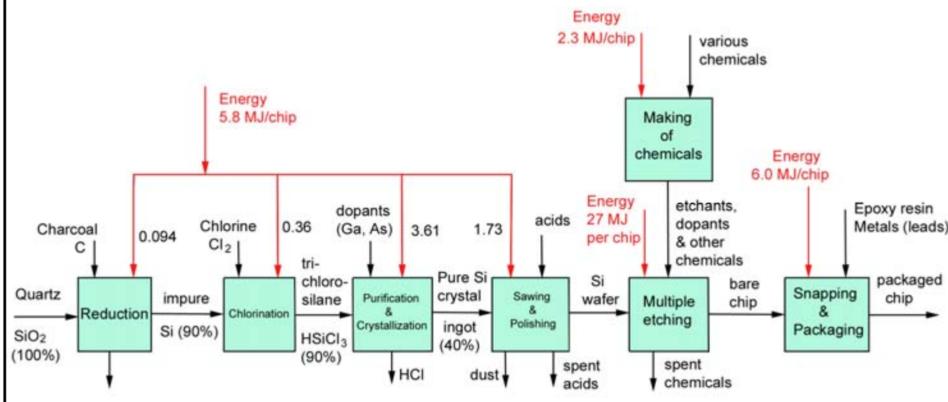


FIGURE 2. Summary input/output table for wafer fabrication

Williams, Ayres & Heller, *Environ. Sci. & Tech.*, 2002.

Amounts of energy and chemicals used in the production of a memory chip



ENERGY CONSUMPTION
in production and use of a 32MB DRAM chip

Fabrication of the chip:

5.8 MJ in production of silicon wafer
2.3 MJ in production of etching chemicals
27.0 MJ in fabrication of chip
5.8 MJ in assembly process
0.17 MJ in production of assembly materials

TOTAL for fabrication: 41 MJ per chip manufactured

Use of the chip:

15 MJ electrical consumption during lifetime

TOTAL for both fabrication and use: 56 MJ per chip

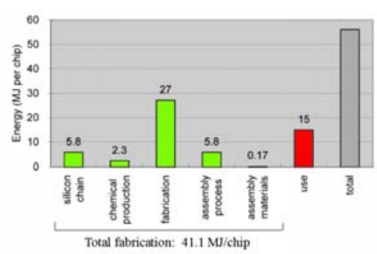


FIGURE 3. Energy consumption in production and use of a 32MB DRAM chip.

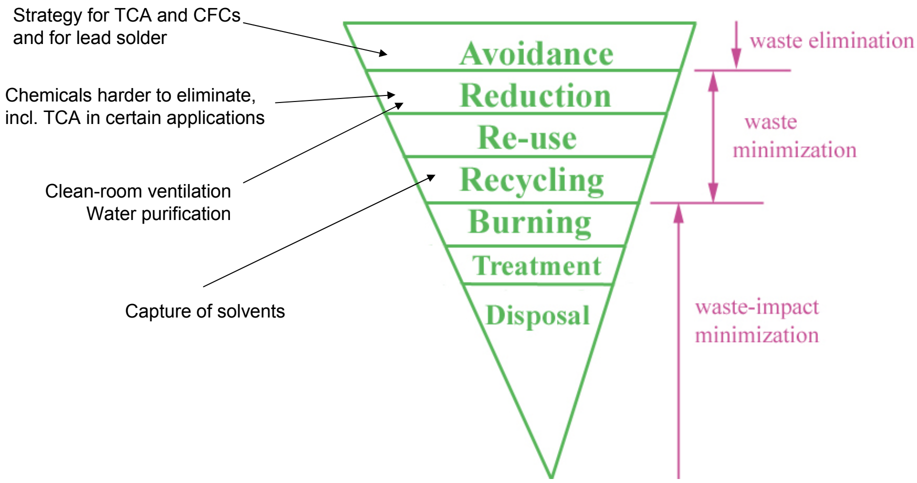
(www.ce.cmu.edu/~hsm/NATO-ARW/pres/EricWilliams.ppt)

Breakdown of energy consumption during manufacture per type of activity:

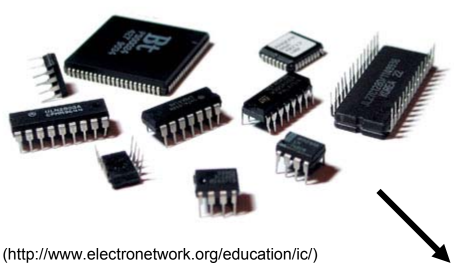
46% clean-room ventilation and air conditioning
35% wafer and chip actual fabrication
7% making liquid nitrogen
7% manufacturing assortment of chemicals
5% water purification

100%

What can be done to clean the chip manufacturing process?



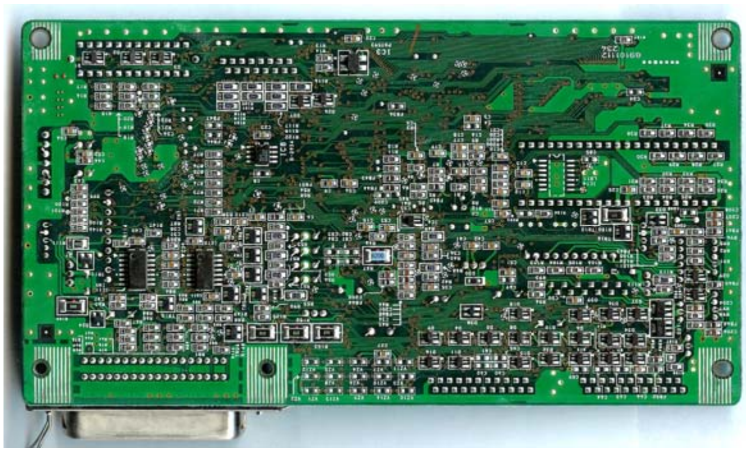
Packaged chips now placed on circuit boards



(http://www.electronetwork.org/education/ic/)

(http://www.deskpicture.com/DPs/Technology/CircuitBoard_3.html)

Besides a few additional components (resistors and capacitors),
the circuit board includes a base, some wiring, gold plating on leads,
and lead-tin solder.



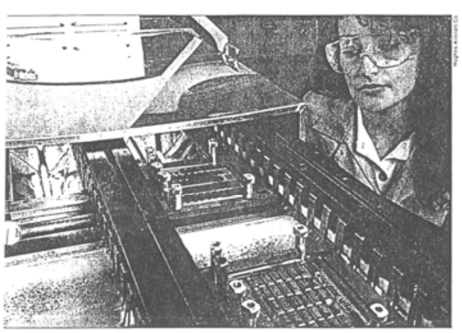
By far, the dirtiest step is soldering, with a mix of lead and tin.
This alloy is particularly advantageous because it melts in the range of 183°C (361°F).

Steps in applying solder:

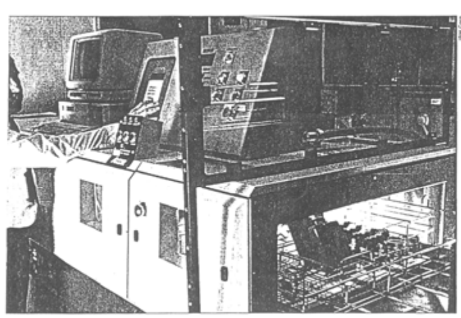
1. Application of a “flux” (resin-based material) to provide adequate adhesion

2. Soldering proper
   use of lead-tin alloy; still no economically safer alternative

3. Removal of extra flux with solvent
   used to be TCE, then CFCs or TCA, now something less harmful



At Hughes Aircraft Co., electronic circuit cards pass through a new lemon-juice-based foaming flux solution, called HF-1189, that can be cleaned off with water instead of ozone-depleting chlorofluorocarbons.



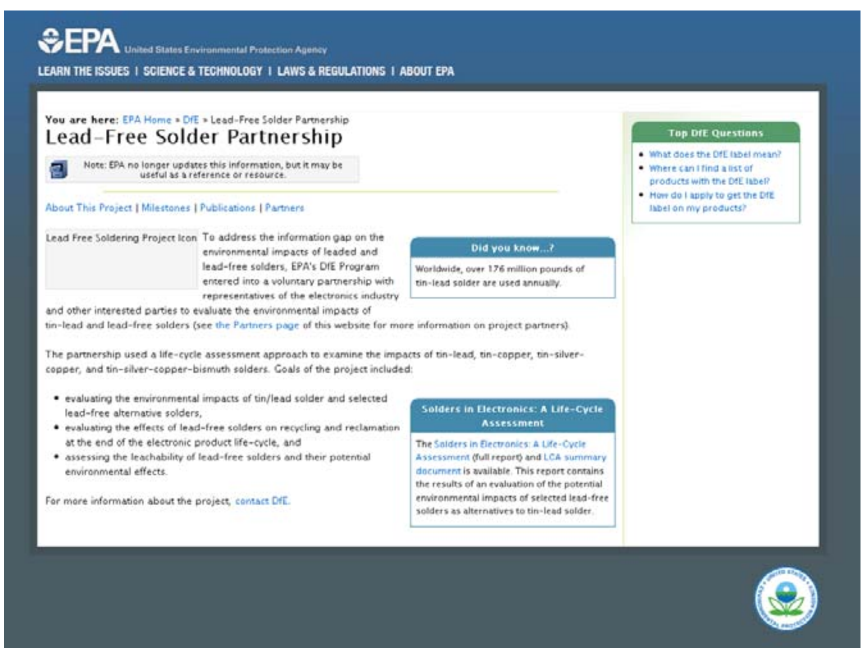
At IBM Corp., assembled circuit boards go through a water cleaning process in a machine that behaves like a powerful dishwasher.

The European directives on Waste of Electrical and Electronic Equipment (**WEEE**) and Restriction of Hazardous Substances (**RoHS**) strongly suggest that lead-free electronic assemblies will be mandatory in Europe starting in the next few years.

An adequate substitute for lead solder must be:
- melting a low temperature
- electrically conductive
- safe for workers
- not toxic
- economically feasible
- hopefully recyclable, too.

There is no viable alternative at this time, but several potential candidates are:
- 95.5% tin, 3.9% silver, and 0.6% copper;
- 57.0% bismuth, 42.0% tin, and 1.0% silver;
- 96.0% tin, 2.5% silver, 1.0% bismuth, and 0.5% copper; and
- 99.2% tin and 0.8% copper;
- Electrically conductive adhesives (polymers containing tiny metallic flakes) are seen as another possibility.

Lead-free soldering – The search is on.



2. Impacts during use

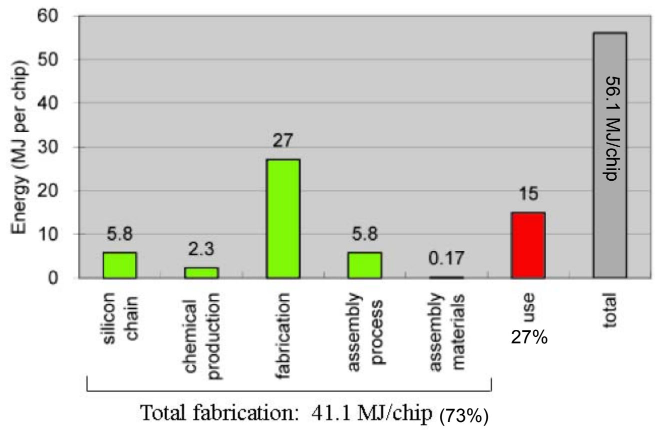
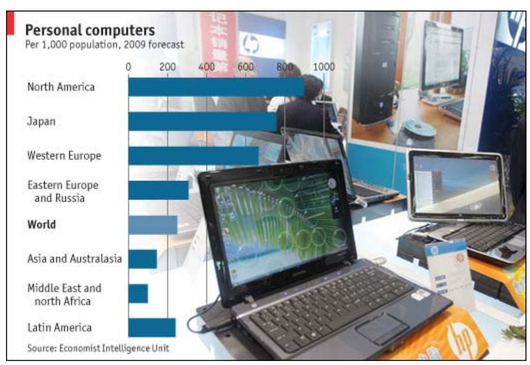


FIGURE 3. Energy consumption in production and use of a 32MB DRAM chip.

In the United States, there are over 800 computers per 1000 people, and there are over 900 computers per 1000 employees in office buildings.

We are well on our way to one computer per person in the nation.

It could even go above one as people may own more than one computer.



It is estimated (2007) that electricity consumption for the internet alone amounts to 9.4% of the total electricity consumption in the USA or 868 billion kWh per year.

April 2011 estimate: 2% of global energy demand, growing about 12% a year.

EPA's Energy Star program

Home > Products > Office Equipment > **Computers**

Computers

An ENERGY STAR qualified computer uses 70% less electricity than computers without enabled power management features.

Earning the ENERGY STAR

- If left inactive, ENERGY STAR qualified computers enter a low-power mode and use 15 watts or less. New chip technologies make power management features more reliable, dependable, and user-friendly than even just a few years ago.
- Spending a large portion of time in low-power mode not only saves energy, but helps equipment run cooler and last longer.
- Businesses that use ENERGY STAR enabled office equipment may realize additional savings on air conditioning and maintenance.
- Over its lifetime, ENERGY STAR qualified equipment in a single home office (e.g., computer, monitor, printer, and fax) can save enough electricity to light an entire home for more than 4 years.
- The ENERGY STAR specification for computers, game consoles, and other hardware was revised on October 20, 2006 and is effective starting July 20, 2007. More about the specification.

8 Ways to Easily Reduce the Energy Consumption of Your Computer – and Save Big Money

(http://www.thesimpledollar.com/2008/04/16/8-ways-to-easily-reduce-the-energy-consumption-of-your-computer-and-save-big-money/)

1. **Plug all equipment into a SmartStrip.** 
2. **Set up Windows so that it automatically shuts down every night.**
3. **Tinker with your computer's energy settings.**
4. **Use an efficient uninterruptible power supply, especially for computers you don't turn off.**
5. **Remove all unnecessary peripherals from home servers.**
6. **Put your laptop charger (and other chargers) on a timer.**
7. **"Green" your equipment when you replace it – go for EnergyStar 4.0 compliant.**
8. **Adjust your monitor's brightness.**

ENVIRONMENTAL IMPACTS OF COMPUTER USE:

Direct versus Indirect:

Direct:

Energy consumption
CDs, paper, *etc*.

Indirect:

Health effects on user
- Damage to wrists, eyes, spinal column
- Lack of physical exercise

Impact on industrial activities, business activities
Impact on consumer purchases (manner, not quantity)

"*3rd-order effect*", so-called rebound effects

Shifts in consumption patterns, transportation, land use, *etc*.

Some indirect effects of computer usage are beneficial.

- Computer simulations → Forecasts (ex. hurricane, flooding) → prevention
  → saving lives and protecting the environment
- Quicker reactions and better organization following environmental accidents
  → reduced environmental damage
- Spreading news on web sites and blogs → increased environmental awareness
- Computer-aided design (CAD) → reduced need for prototypes → less material
  + possibility to add LCA and demanufacture design
- Digital photography → avoidance of photochemicals
- Computers in health care → computer-aided surgery
  → digital X-ray pictures (avoidance of chemicals)

It is very possible (but impossible to tell for sure) that more environmental gain can be achieved by using computers toward green activities than by improving computers themselves. This is because computers play such a major role in our lives.

3. Recycling of computer equipment

http://www.philosophyofinformation.net/blog/archive/2006_04_01_archive.html

Where does this all go? What happens to it at its destination?
What is the impact on people and the environment there?

And, it is getting increasingly more acute because:

- More people own computers (since invention of personal computers in the mid 1980s) and an increasing number of people now have more than one computer (since the advent of laptops).

- The lifetime of a computer is getting increasingly shorter:
  - 10 years in the 1960s
  - 4.3 years by 1998
  - less than 2 years by 2000.

"Between 1997 and 2007, nearly 500 million personal computers became obsolete. Almost two computers for each person in the U.S. Some studies predict that a large number of televisions will be disposed when high definition television becomes widely available.
(*Source*: National Recycling Coalition).“

"Nearly two million tons of used electronics, including computers and televisions, are discarded each year. In addition, an estimated 128 million cell phones are retired from use annually. " (*Source*: EPA)

The rate at which computers are being disposed of is skyrocketing.

http://www.techeblog.com/?cat=11&paged=5

Innovative approaches to computer recycling !

But mere cascading and very limited outlets…

Any forethought?

It is one thing to design a performing system and to make computers and personal electronics available to nearly all people.

But, how does it affect electronics recycling?

(http://www.cs.cmu.edu/pics/campus/images/servers.jpg)

It does not seem that anyone plans for recycling at the time of acquiring computer equipment.

But, some early efforts are being made at the level of manufacturing.

In the early days of computing, the problem was virtually inexistent. Obsolete computers were simply stashed under the staircase. But, constant upgrading of computers did not make that last long…

Maine is first state to require computer and television manufacturers to pay for recycling and disposal.

Already more than 60 million computers in landfills!

Up to 80% is exported to places such as Nigeria and China.

THE NEW YORK TIMES OP-ED FRIDAY, JANUARY 27, 2006

E-Waste@Large

By Elizabeth Royte

LAST week, Maine became the first state to require manufacturers of computer monitors and televisions to pay for their recycling and disposal. Washington, with a pending bill, may be next. That's progress, right?

Computer recycling sounds like an unmitigated good: it keeps hazardous components out of incinerators and landfills, which researchers at Carnegie Mellon University estimate already hold more than 60 million computers. And by reusing glass, plastic, aluminum and heavy metals (like lead, copper and mercury), recycling averts the energy use and pollution linked with mining and drilling for new materials.

But because recycling in the United States is expensive, hazardous and encumbered with environmental and safety regulations, many companies that collect e-waste simply ship it to underdeveloped nations. According to the Silicon Valley Toxics Coalition and the Basel Action Network, up to 80 percent of the material dropped off by well-meaning Americans at community recycling events ends up bundled for export.

Most of the stuff that goes overseas can't or won't be fixed and sold. Computer dealers in Lagos, Nigeria, for example, complain that up to 75 percent of the 400,000 units they receive each month from recyclers are junk. A 2002 documentary showed Chinese workers, including children, using hammers and chisels to pry copper and aluminum from computers, burning PVC-coated wires to get at copper and swirling acids in buckets to extract gold.

After stripping what they can, workers dump the computer carcasses and waste sludge in nearby fields or streams. Soil and water tests in the e-waste processing town of Guiyu, China, for instance, revealed levels of chromium, tin and barium hundreds of times higher than allowable in the United States.

It's easy to find American companies that call themselves computer recyclers, but it's hard to trace what they actually do. The government doesn't regulate these businesses, and the Environmental Protection Agency has no certification process for recyclers.

There are dozens of e-waste bills being considered across the country, including one in New York City. Five states and 15 counties ban computer and television monitors from landfills. California, Maine, Maryland and Massachusetts have e-waste recycling programs in place, all financed by different mechanisms.

Even the electronics industry doesn't like this patchwork approach, but so far, no one has come up with anything better. Four e-waste bills are floating around the House and Senate: the biggest difference between them is whether consumers or manufacturers would pay for the programs. A strong argument holds that when producers must manage their own discards, they have a strong incentive to design equipment that's nontoxic and easy to recycle.

The sooner Congress gets it together, the better. Electronic waste is now considered the fastest-growing segment of the municipal waste stream in the United States. The National Safety Council estimated in 2004 that by 2009, 250 million computers will have become obsolete. As awareness of the hazards of e-waste rises, more states will ban it from landfills. But keeping toxic trash from our dumps won't mean a thing if we don't forbid the export of hazardous material to countries without enforceable environmental regulations.

To halt this environmental injustice, in which we're all complicit, the federal government needs to restrict the use of hazardous materials in computers, require manufacturers to put in place recycling programs (it will be a lot cheaper and safer to recycle this stuff once the toxics are out) and ban hazardous waste exports. That may sound like a tall order, but that's no reason not to proceed: the European Union has already passed every one of these laws. □

Leif Parsons

Don't export toxic computer trash.

Elizabeth Royte is the author, most recently, of "Garbage Land: On the Secret Trail of Trash."

Videos online (among many others)

Computer Recycling - Intercon Solutions

http://www.youtube.com/watch?v=4n0wOnLNXwc

Recycling of defective wafers at IBM, Burlington (Vermont, USA):

http://www.youtube.com/watch?v=ooMmwSqr9XY

Are we still operating with the slogan “out of sight out of mind”?


Shipment to and dumping in poor countries violates the 1989 Basel Convention on hazardous waste (which came into force in 1992).

Steps and issues in computer recycling

- Collection
  Some is still kept under staircases, in closets and attics.
  Some people still throw computers in the trash.
- Transportation to collection center, sorting
- Preliminary disassembly, destruction of hard-disk data
- Capture and recycling of precious metals (gold and silver)
- Shipment to another place (where labor is cheap) for further disassembly or shredding
- Recycling/resale or disposal of separated materials.

A case study

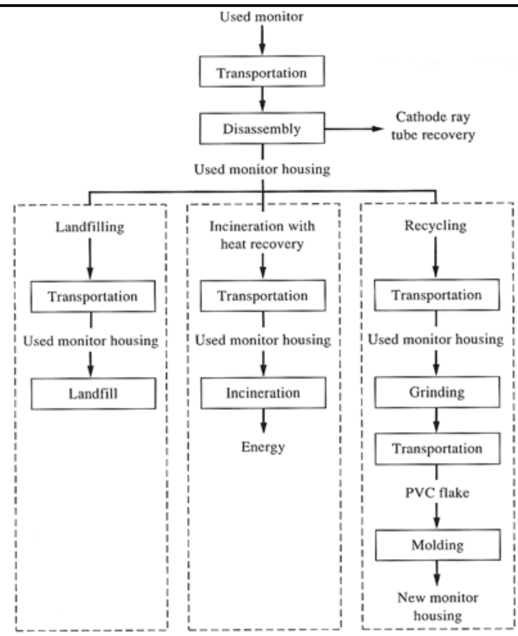


FIGURE 6.11
Functional analysis of the three PVC monitor housing disposal options by IBM.
(Adapted from Besnainou and Coulon, 1996)

Life-cycle inventory analysis results for the three disposal options

	Unit	Landfilling	Incineration	Recycling
Raw materials				
Crude oil	kg	0.036	0.025	−1.07
Coal	kg	0.0002	−0.67	−0.44
Natural gas	kg	0.0001	0.004	−1.28
Limestone	kg		1.50	−0.004
NaCl	kg			−1.5
Water	L	0.007	−0.008	−4.2
Air emissions				
Particulate matter	g	0.15	33	−8.3
CO_2	g	115.	2400	−4000
CO	g	0.41	1.07	−5.3
SO_x	g	0.16	−13.0	−27
NO_x	g	1.17	−4.17	−33
NH_3	g	0.0007	0.0143	0.0011
Cl_2	g			−0.004
HCl	g		300	−0.48
Hydrocarbons	g	0.31	−13.70	−42.6
Other organics	g	0.00	−0.02	−1.60
Water effluents				
Biochemical oxygen demand (BOD_5)	g	0.0002	0.0002	−0.18
Chemical oxygen demand (COD)	g	0.0006	0.0007	−2.46
Chlorides	g			−89.4
Dissolved solids	g	0.42	0.48	−2.6
Suspended solids	g	0.0002	−0.004	−5.3
Oil	g	0.005	0.007	−0.10
Sulfates	g			−9.6
Nitrates	g		−0.0004	0.00004
Nitrogen-TKN	g			−0.01
Sodium ions	g			−5.1
Metals	g			−0.45
Solid wastes				
Hazardous chemicals	g			−0.003
Landfilled PVC	g	2.2	0	0.02
Slags and ash	g		1.7	−0.10
Other	g	0.00005	−0.44	−0.14
Energy				
Total primary energy	MJ	42		−103
Electricity	kWh	0.0012	−2.1	−2.3

Source: Besnainou and Conlon, 1996.

The intuitive answer is the correct one: Recycling is the best option.

That is, from an environmental point of view. What about the economic point of view?

Situation in the European Union

Considerations range the gamut of environmental, social, economic & cultural dimensions.

ENVIRONMENTAL:

Running out of landfill space.
Pollution and "green issues" get press.

SOCIAL:

People, or at least governments, want to be proactive.

ECONOMIC:

High taxation enables more draconian action.

CULTURAL:

Who pays for human health problems and environmental impacts?

(slide adapted from Ron Lasky)

Situation in the European Union (cont'd)

Packaging

1994 Directive (paper, plastics and metals)

Automotive

End of Life Vehicles (ELV, 2000, 2003)
Ban on lead, mercury, cadmium, and hexavalent chromium

Batteries

1991 Directive 91/157/EEC

Electronics

- Waste Electrical and Electronic Equipment (**WEEE**, 2003)
  Objectives: Prevention, reuse, recycling and recovery of WEEE
  At its core: WEEE directive sets a minimum recycling rate.
- Restriction of Hazardous Substances in Electrical and Electronic Equipment (**RoHS**, 2003)
  Objective: Assist recycling efforts set forth by WEEE
  At its core: RoHS sets out maximum enforceable requirements (expressed as max % of substance per "homogeneous material").

Same substance bans as for automobile industry, except that lead is still tolerated for electrical soldering.

Positive side effect of European legislation

American, Japanese and Chinese manufacturers cannot afford to overlook the European market. They therefore need to comply. This makes their products more benign and easier to recycle, not only in Europe but also across the world.

Situation in the United States

Among several other activities, there exists the National Center for Electronics Recycling (NCER)

NATIONAL CENTER FOR ELECTRONICS RECYCLING

http://www.electronicsrecycling.org/

The NCER has a created an electronics recycling index, known as the Per-Capita Collection Index (PCCI) designed to measure changes in the amount of used electronic equipment, such as computers, televisions and monitors collected in representative programs across the United States.

$$PCCI = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + P_6}{6}$$

P_1 through P_6 are the pounds per capita values of the six collection programs noted below. The index is stated in lbs collected per capita and is re-calculated every year.

Program	collection total	population of area served	lbs per Capita 2009	lbs per Capita 2008	lbs per Capita 2007	lbs per Capita 2006
California	162,004,676	36,961,664	4.4	5.9	5.0	3.5
Maine	7,912,292	1,318,301	6.0	4.0	3.5	3.0
Delaware	3,999,184	885,122	4.5	4.1	3.7	3.3
Hennepin County	5,735,624	1,156,212	5.0	4.7	4.8	4.0
Brandford, CT	152,009	28,969	5.2	5.0	4.4	4.8
Frederick County, VA	512,872	115,882	4.4	3.6	3.8	3.5
	180,316,657	40,466,150	**4.9**	**4.5**	**4.2**	**3.7**

The CCPI collection index has increased 32% in 3 years

Company by company

Most major computer companies run their own national mailback programs. Usually for a fee, but sometimes free, these companies will send you a pre-paid mailing label, or let you print the label using their website. You then package your unwanted computer equipment and send them along, or arrange a pickup. Some companies, such as Sony, operate their own take-back programs and will take their own branded products back for free at certain pre-identified locations around the country.
Below is a list of consumer take-back programs:

HP: Mail-back program with home/office pickup for $13-34 depending on the type and quantity of hardware to be returned. Any HP or non-HP brands of personal/office computer equipment or peripherals are accepted. This program does not accept monitors with broken glass or other types of consumer electronic equipment such as VCRs, DVDs, televisions.

IBM: As part of its product end-of-life management (PELM) activities, IBM began offering product take-back programs in Europe in 1989 and has extended and enhanced them over the years. IBM's Global Asset Recovery Services organization now offers Asset Recovery Solutions to commercial customers in 21 countries worldwide, and continues its efforts to extend them further.
Also, the IBM PC Recycling Service allows consumers and businesses to recycle any manufacturer's PCs, including system units, monitors, printers and optional attachments for $30, shipping included.

Intel: Intel offers a mail-back program for any Intel branded product sold to individual consumers, such as Intel boxed processors, Intel boxed motherboards and Intel brand network cards. Historical items such as Intel brand PC cameras, Intel brand PC microscopes, Intel brand keyboards, *etc*. are also appropriate for recycling. Packaging and shipping are the responsibility of the individual.

http://www.electronicsrecycling.org/ContentPage.aspx?pageid=87

Apple: US customers who buy a new Mac through the Apple Store or Apple’s retail stores receive free shipping and environmentally friendly disposal of their old computer.

Dell: Dell offers free PC recycling at any time for Dell-brand products. Dell also offers free recycling when purchasing a new Dell product. Packaging and shipping are the responsibility of the individual.

Canon: Canon offers a mail-back program that accepts CANON brand of consumer binoculars, camcorders, cameras (digital & film), fax machines, ImageCLASS products, PC copiers, printers, projectors or other video equipment, and scanners.

Epson: Epson offers a mail-back program that accepts EPSON printer, scanner, digital camera, laptop, computer or projector. The fee for this service is only $10 per item which includes shipping and recycling costs. Users of the service also receive a $5 coupon per item returned, for use at the Epson Store.

Sony: The Sony Take-Back Program gives Sony customers a free and convenient way to recycle up to five Sony products per day by dropping them off at designated Waste Management eCycling Drop-Off Centers throughout the country.

Gateway: Gateway offers a trade-in program and a recycling program available to customers who have made a recent Gateway purchase. In order to verify your eligibility, you need to provide a valid serial number and proof of purchase of your new Gateway or eMachines product. The cost of the recycling program is a function of weight.

Toshiba: Toshiba offers a trade-in program.

Lexmark: Lexmark offers a mail back program called the Lexmark Equipment Collection Program. Through this program, customers may return any end-of-life Lexmark branded products (inkjet and laser printers, all-in-one products and multifunction products), and Lexmark will recycle the equipment for free.

http://www.crserecycling.com/main.php?p=technology

Creative Recycling Systems introduces revolutionary electronics recycling system

CRS has introduced a new state-of-the-art electronics recycling system at the company's headquarters in Tampa, Fla. The revolutionary structure allows for the recycling of electronic components in a single computerized process. In addition to computer monitors and TV's, the system will economically process CPU's, consumer electronics, office equipment, telecommunications equipment and the whole range of E-Scrap without any need to pre-sort.

Acquired by Creative Recycling to meet the growing demands of the electronics recycling business, the innovative system dissects up to 24,000 pounds of recyclables per hour – the equivalent of 800 monitors – in an extremely worker-friendly and environmentally safe manner. It takes less than five minutes for a single item to complete the recycling process.

The system integrates components from leading manufacturers of shredding, pulverizing and separation equipment. Maximum output is achieved through video monitors, scales and computerized logic controllers. Pulverizing takes place in a controlled atmosphere enclosure with negative air pressure. A complete dust collection and control system attached to a high efficiency particulate air (HEPA) filter ensure a pristine atmosphere.

System outputs include glass, plastics, ferrous and non-ferrous metals.
This equipment is part of a multi-million dollar investment the company has made in expanding its capacity. It further distinguishes CRS as an industry leader in electronics recycling with the most cost-effective and best environmental solution.

See videos at http://www.crserecycling.com/main.php?p=technology