e-JUNK EXPLOSION

Do you have an old computer in your closet at home? Odds are the answer is yes. Of course, it's covered in dust, the keyboard is grimy, and you haven't even turned it on for years. You'd like to get rid of it, but you don't know how or where. But rest assured—you're not alone. Obsolete computers and other kinds of electronic junk are piling up everywhere, creating what some experts predict will be the largest toxic waste problem of the 21st century.

Matt Ray/EHP

What's in our PCs? Materials of health concern in a typical desktop computer.

Name	Use/Location	Health Effects
Plastics*	Includes organics and oxides (other than silica)	PBDE–endocrine disruption and affects on fetal development; PBBs–increased risk of cancers of the digestive and lymph systems
Lead	Metal joining, radiation shield/CRT, PWB (printed wiring board)	Damage to central and peripheral nervous system, circulatory system, and kidneys; effects on endocrine system, serious adverse effects on brain development
Aluminum	Structural, conductivity/housing, CRT, PWB, connectors	Skin rashes, skeletal problems, and respiratory problems including asthma; linked to Alzheimer's Disease
Gallium	Semiconductor/PWB	Clear evidence of carcinogenesis in experimental animals
Nickel	Structural, magnetivity/(steel) housing, CRT, PWB	Allergic reactions, asthma, chronic bronchitis, impaired lung function; reasonably anticipated to be a human carcinogen
Vanadium	Red phosphor emitter/CRT	Lung and throat irritation
Beryllium	Thermal conductivity/PWB, connectors	Lung damage, allergic reactions, chronic beryllium disease; reasonably anticipated to be a human carcinogen
Chromium	Decorative, hardener/(steel) housing	Ulcers, convulsions, liver and kidney damage, strong allergic reactions, asthmatic bronchitis, may cause DNA damage; a known human carcinogen
Cadmium	Battery, blue-green phosphor emitter/housing, PWB, CRT	Pulmonary damage, kidney disease, bone fragility; reasonably anticipated to be a human carcinogen
Mercury	Batteries, switches/housing, PWB	Chronic brain, kidney, lung, and fetal damage; increases in blood pressure and heart rate, allergic reactions, effects on brain function and memory; a possible human carcinogen
Arsenic	Doping agents in transistors/PWB	Allergic reactions, nausea, vomiting, decreased red and white blood cell production, abnormal heart rhythm; inorganic arsenic is a known human carcinogen
Silica	Glass, solid state devices/CRT, PWB	Respirable-size crystalline silica can cause silicosis, emphysema, obstructive airway disease, and lymph node fibrosis; a known human carcinogen

Sources: Microelectronics and Computer Technology Corporation (MCC), 1996; Electronics Industry Environmental Roadmap, Austin, TX (MSS); *Poison PCs/Toxic TVs*, Silicon Valley Toxics Coalition, 2001; ATSDR ToxFAQs, 1995-2001; National Toxicology Program *9th Report on Carcinogens*, 2001

*Plastics contain polybrominated flame retardants, and hundreds of additives and stabilizers not listed separately.

PhotoDisc

If that sounds excessive, consider the following: the glass cathode ray tubes (CRTs) found in televisions and computer display monitors each contain an average of 4 pounds of lead. Multiply that by the 315 million computers expected to become obsolete in the United States by 2004, and there is 1.2 billion pounds of lead to worry about. The color monitors of most computers contain a CRT that fails federal toxicity criteria for lead and is classified as hazardous waste by the U.S. Environmental Protection Agency (EPA). Circuit boards and batteries are also full of lead, in addition to smaller amounts of mercury and hexavalent chromium. Plastics used in electronic equipment pose a hazard because they may contain polyvinyl chloride, which produces dioxins when burned. Many other plastics and some circuit boards contain brominated flame retardants (BFRs), several of which are suspected endocrine disruptors that also bioaccumlate in animal and fish tissues. A recent study by the California Department of Health published in the February 2002 issue of *Chemosphere* found very high levels of BFRs in the blubber of Harbor Seals as well as in the breast milk of nursing mothers in California's bay area.

Most experts believe the full environmental impact of e-waste is just beginning to be fully realized. Thanks to Moore's Law—the 1965 observation of Intel cofounder Gordon Moore that computer processing power was doubling every 18 months and could continue into the foreseeable future—the shiny new computer bought today is virtually obsolete by the time it's plugged into the wall at home. Most of the now-obsolete machines tossed out in the relentless push towards the technologic future are still in storage, according to the Silicon Valley Toxics Coalition (SVTC), an environmental group based in San Jose, California. But as consumers upgrade their computers for the third and fourth time, these older relics are increasingly finding their way into municipal waste streams. And the problem goes way beyond computers. Other obsolete electronic products are also adding to the growing waste problem. With the emergence of DVD players, high-resolution television, and digital flat-screen monitors, traditional television sets and VHS players are also beginning to clutter up landfills, contaminating incinerator feedstocks and adding to waste exports to developing countries, where environmental recycling and disposal standards are often non-existent or ignored. Sales of consumer electronics goods from manufacturers to dealers are expected to surpass $95.7 billion in 2002, according to the Consumer Electronics Association. That figure represents a vast amount of technology—technology that will undoubtedly some day become obsolete. The question is, when it does, what will we do with it all?

Clogging the Waste Stream

e-Waste is the fastest growing component of municipal trash by a factor of three, according to the European Commission. According to the SVTC, consumer electronics in the United States already account for 70% of the heavy metals, including 40% of the lead, found in landfills. Getting all this toxic e-junk out of the waste stream is an environmental priority. "I wouldn't say we're facing a crisis now," says James Doucett, deputy director of the Massachusetts Bureau of Waste Prevention's Business Compliance Division. "But we're expecting a major problem, driven largely by new television technology and high turnover in computer equipment."

The goal for Massachusetts officials—indeed for stakeholders everywhere—is to reuse or safely recycle as much electronic waste as possible. But in the United States, the electronics recycling industry is ill-equipped for the task. "The birth of electronic recycling in this country only dates back to around 1994," says Lauren Roman, vice president for marketing at United Recycling Industries, an electronics recycler based in West Chicago, Illinois. "The volume is still low. We only recycle a small percentage of what's out there." According to the National Safety Council's (NSC) May 1999 *Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States*, the most widely referenced (and most current) source of e-waste statistics, only 11% of the 20 million computers that became obsolete in the United States in 1998 were recycled. (There are no comparable figures for other types of electronic equipment.) Roman suspects that even this number is overstated. A large percentage of the computers described as recycled by the NSC were probably exported overseas, she says. "There aren't any definitive standards for recyclers in the United States," says Roman. "You could call yourself a recycler when in reality you're a broker who fills containers with electronic waste and ships them to China."

The fate of most of the e-waste produced in the United States remains a mystery. Experts assume the majority is landfilled, incinerated, exported, or just abandoned in storage. Even the recycled minority is hard to track. This is partly because the recycling industry is composed of a veritable jungle of overlapping specialists: primary recyclers that refurbish products for resale; secondary recyclers that "demanufacture" equipment to extract raw materials such as metals, plastic, and glass; smelters that use CRT glass as inputs to produce raw metals; and so-called "third party" resellers—typically nonprofit organizations—that sort and repair obsolete products for resale or donation. These terms are used interchangeably in different contexts, and there aren't any standardized methods to account for product flows from one sector to the next. As a result, end-of-life data for recycled electronics in the United States are virtually nonexistent.

What is certain is that volumes passing through the recycling pipeline are much lower than they could be. Residential electronics, for example, are almost never recycled. Why? Because state and local collection programs are rare and sporadic and because the vast majority of Americans have no idea what do with their old computers, three-quarters of which are sitting in closets at home. Furthermore, residential waste tends to be old, with little or no resale value. The typical consumer buys a television set and then watches it for 15 years. By the time it's ready for retirement, it's almost completely worthless. The same goes for old computers. "The value of the metal, the circuit board, and the power supply combined from [certain outdated] machines might come in at around a dollar," says Peter Bennison, vice president of Waste Management and Recycling Products, Inc., in Schenectady, New York.

Recycling of electronics from business sources is also minimal. The Resource Conservation and Recovery Act (RCRA) makes it illegal for companies to throw many waste electronic components in the trash. But some recyclers who accept the material as a paid service will often ship it overseas for as little as a penny a pound because the domestic profit margin is just too low. Among the chief costs is transportation: relative to its value, electronic equipment is heavy, bulky, and expensive to move. Loading it onto cargo ships bound for distant lands is often cheaper than trucking the material to a specialty shop such as Envirocycle Inc. in Hallstead, Pennsylvania, a massive 190,000 square foot recycling processor of CRT glass. "We're only running at 20–25% of our capacity," says Envirocycle's vice president, Gregory Voorhees. "If you're not running at 100%, you need to make up for that loss, which typically means you have to charge more for the service."

Like many other large recycling firms, Envirocycle stays in business by contracting with local, corporate sources of e-waste that provide a steady supply of relatively new and uniform material. This arrangement typifies the current norm for the industry, which is heavily concentrated among a handful of key players. In 1998, the most recent NSC data available, the top 10 firms processed an estimated 75% of electronics recycled in the United States.

By far, the most challenging electronic component to recycle is the plastic. Unlike plastics used in food packaging, those harvested from waste electronics aren't typically marked or identified, which makes visual distinction extremely challenging. Unfortunately, buyers of waste plastic almost always want pure, uniform materials they can reprocess to form new parts. But depending on the application, even a small amount of incompatible plastic can contaminate an entire load of otherwise pure material and render it nearly worthless.

Overcoming these problems is a goal that drives Patricia Dillon, a research associate with the Gordon Institute of Tuft's University in Medford, Massachusetts. Dillon is a program manager with the aptly named Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment, a group of representatives from 70 organizations throughout the plastics supply chain. Recently, the group produced draft guidelines describing how a few simple steps can help purify plastic waste streams during disassembly, including presorting by product, for example television sets versus computers, which typically use different types of plastic.

Dillon's group is also working with industry to develop new markets for mixed plastics, for instance, using them as roadbed paving material or concrete aggregates. But these emerging markets are just getting off the ground, she concedes, and the last stops for most electronics plastic are still export, landfilling, and incineration in waste-to-energy plants.

e-Waste and Environmental Health

According to the SVTC, a lack of data complicates our understanding of the potential health effects from exposure to e-wastes. Ultimately, e-waste poses the most direct health risks when it degrades and the internal chemicals are released to the environment. Lead and mercury are highly potent neurotoxins, particularly among children, who can suffer IQ deficits and developmental abnormalities at very low levels of exposure. Cadmium, a toxic metal found in circuit boards, is listed by the EPA as a "probable human carcinogen," and also produces pulmonary damage when burned and inhaled. Hexavalent chromium, also used in circuit boards, has been found to produce lung and sinus tumors when inhaled at high doses.

In addition to metals in electronics, many environmentalists worry that the BFRs in plastic pose health risks. BFRs are among a group of bad actors known as persistent organic pollutants—specifically, chemicals with a high affinity for fats that travel the world and accumulate in human, animal, and fish tissues. Animal experiments have shown that a number of these chemicals affect thyroid function, have estrogenic effects, and act through the same receptor-mediated pathways as does dioxin, which is among the most potent animal carcinogens known. Further, environmentalists charge, electronics recyclers have not really come to grips with the special environmental problems that they say are inherent in the prolific use of BFRs in e-waste plastics. "There have been almost no studies on the ultimate fate of BFRs when they are melted or burned in recycling or incineration applications," says Jim Puckett, coordinator for the Seattle, Washington–based Basel Action Network (BAN) that serves as a watchdog on issues of "toxic trade."

Making a dent in the piles. Recyclers sort through old electronic components collected through a local curbside program. Experts estimate that only a very small percentage of electronics are being refurbished and resold due to high costs and lack of consumer incentives.

Arnold Greenwell/EHP

Regulating e-Waste

In the United States, reactions to the problems of e-waste are varied, creating a patchwork of inconsistent regulations that suggest the need for a unified strategy, experts say. Nebraska, for instance, has introduced legislation that would impose an advance disposal fee on the sale of CRTs, whereas Massachusetts and California have banned them from disposal altogether. Within 2 years, the European Union nations will adopt the Directive on Waste Electrical and Electronic Equipment, a controversial piece of legislation that saddles electronics manufacturers with financial responsibility for product disposal. A companion measure called the Restriction on Hazardous Substances (ROHS) also bans the use of certain hazardous chemicals in electronics production.

Much of the answer to the question of how to regulate e-waste in the United States hinges on the debate over the extent to which environmental releases occur at disposal facilities. Linking environmental levels of toxic contaminants to e-waste in landfills or incinerators is a nearly impossible task. For policy makers, the issue boils down to whether disposal facilities can capture the chemicals before they're released to the environment, a question that often degenerates into bitter scientific debate. Industry sources insist that pollution controls in both landfills and waste-to-energy incinerators are sufficiently protective. Environmental activists, on the other hand, insist the opposite is true.

At present, the EPA characterizes waste hazards from landfills using a test called the toxicity characteristic leaching procedure (TCLP). This test involves soaking

Technology wasteland. (left) Women in Guiyu, China strip miles of waste cables to recover the copper wire inside. (right) A child plays barefoot on a pile of deconstructed computers.

Basel Action Network

a ground-up mixture of the material of interest in an acidic mixture akin to vinegar and then analyzing the liquid for levels of hazardous chemicals. If the levels are higher than a particular standard, the material fails the test and is designated hazardous waste under RCRA.

Few people know more about the TCLP as it relates to electronic waste than Timothy Townsend, an assistant professor of environmental engineering sciences at the University of Florida in Gainesville. Townsend spends much of his time grinding computer parts up into homogeneous mashes that he subjects to the TCLP in his laboratory. The results of his work were used to classify color CRTs as hazardous waste by the EPA. He's currently working on ways to run the TCLP on a whole computer, which will entail crushing the machine and soaking it in enough TCLP fluid to fill a 55-gallon drum. He expects that the computer will fail the test. "There's a lot of [toxic] lead solder in the circuit boards," Townsend explains. "We expect to have results this summer. We're also looking at other things like cell phones, VCRs, personal electronics, and laptops. Anything with a circuit board and lead solder has the potential to fail the TCLP." The California EPA's Department of Toxic Substances is also running additional TCLP tests on a variety of electronics components and their results are expected this spring.

Industry critics often complain that the TCLP bears no resemblance to a real landfill and that just because test leachates have high metal concentrations doesn't mean that landfill leachates will. Townsend recognizes that comparability with actual field conditions is a challenging issue. But he counters that acidic and even highly basic conditions that enhance metal leaching in landfills aren't rare, and that in any case, the TCLP is—"like it or not"—the only regulatory test available for such purposes. "It's a question that needs more investigation," he says.

In characteristic fashion, the European response to this charged and uncertain question has been to err on the side of caution. Included in the ROHS directive is a requirement that electronics manufacturers find substitutes for two BFRs—polybrominated diphenyl ether and polybrominated biphenyl—by 1 January 2008. In addition to flame retardants, the requirement targets heavy metals, including lead, mercury, cadmium, and hexavalent chromium. Exemptions are allowed if alternates for these chemicals aren't available.

Also characteristically, U.S. companies have attacked the European Commission's precautionary approach. According to Holly Evans, director of environmental affairs with the Electronic Industries Alliance (EIA), a trade group based in Arlington, Virginia, that represents more than 80% of the $550 billion electronics industry, U.S. companies resent the policy because it's not directly based on risk assessment evidence that links chemicals in electronics equipment to environmental harm.

The China Connection

Stakeholders who debate the risk of e-waste in the developed world do so in countries where technical and regulatory environmental controls are sophisticated relative to developing countries. For years, environmental groups such as Greenpeace have warned of outdoor electronics burning en masse in Asian countries from China to Pakistan. To document this activity, representatives from BAN recently went to China to investigate. "We'd heard anecdotal information about export from recycling industry dialogues but realized that nobody really knew what was going on in Asia," says Puckett. "We asked government and industry and nobody knew, and it was clear that few cared to know. It was a clear case of blissful ignorance, so we decided to go and see it for ourselves."

Acting on a tip from an e-mail from a Chinese mainlander who had read a story in the local Chinese press, Puckett and his colleagues were directed toward the town of Guiyu, located in Guangdong province just 4 hours' drive northeast of Hong Kong. The team made a 3-day trip in early January 2002. What they saw there astounded them.

According to Puckett, the villages in and around Guiyu have been on the front lines of the international e-waste trade for 7 years. Most of the waste is trucked to Guiyu from the port town of Nanhai near Hong Kong, where container ships brokered by Hong Kong and Taiwanese kingpins arrive daily from the United States, Canada, and Japan. “The turnover is amazing,” Puckett says. “The sheer number of trucks, the number of people involved, a constant flow of smashed computers. None of it is refurbished: the goal is to get as much steel, plastic, copper, and gold as you can. We never saw leaded glass of the CRTs being recycled: the CRTs were simply being dumped after the copper coil was pulled off. This was formerly a rice-growing area. Now the irrigation ditches are all massive dumps full of unusable CRT glass and other computer waste.”

Environmental health threats to the local community abound. According to Puckett’s observations, unprotected workers – many of them children – spend their days heating circuit boards in shallow woks to melt the lead solder so that they can pull the computer chips off for resale or for acid stripping to recover gold. As the lead and plastic burn, they release to the air toxic fumes that can be inhaled, ingested, and absorbed through the skin. The molten lead residue is simply poured onto the ground. Puckett took soil, sediment, and water samples in the river area and found levels hundreds of times those deemed safe in developed countries.

Another common practice is to dissolve computer chips in pits full of a primitive mixture called “aqua regia,” composed of 75% hydrochloric acid and 25% nitric acid. “The smoke and fumes from the acid pits could be seen from miles away,” Puckett recalls. “We’d get to these acid-stripping areas simply by walking toward the smoke along the river levees.” Once used, the acids and sludges from the process are simply dumped into the local river. “The river banks were covered in this stuff,” Puckett says. We tested the soils and water and they came up near zero pH. The ground there is so saturated in acid.”

The activities of yet another village near Guiyu appeared to be wholly devoted to burning plastic wire casings in open pits, mainly at night because the practice is frowned upon by local authorities, likely due to the massive black smoke plumes that result from such burning. These materials contain polyvinyl chloride and BFRs, which both produce dioxins when burned at low temperatures. Puckett describes the village as “completely blackened” with the toxic soot.

The Ban team’s findings are described in a report titled *Exporting Harm: The High-Tech Trashing of Asia*, coauthored with the SVTC, that was released on 25 February 2002. In its official response to the report, the EIA states: “Internationally, EIA is working with governments through the Organization for Economic Cooperation and Development (OECD) to develop internationally recognized guidelines for the environmentally sound management of scrap PCs. We hope this initiative will help governments ensure that recycling facilities operating within their borders are properly regulated and held to high environmental, health and safety standards.”

The Legal Environment

In all likelihood, Puckett says, the activities at Guiyu simply represent the tip of the iceberg when it comes to dangerous handling of computer waste in developing countries. Hard figures are impossible to come by, but anecdotal numbers cited by BAN suggest that 80% of the electronics from the United States that are listed as “recycled” are actually exported, mainly to Asia. “Companies goodheartedly send their stuff to recyclers and everyone feels all warm and fuzzy and green,” says Roman. “But many of the smaller companies don’t audit the recyclers, and therefore they have no way of knowing what actually happens to their machines once they’re gone.”

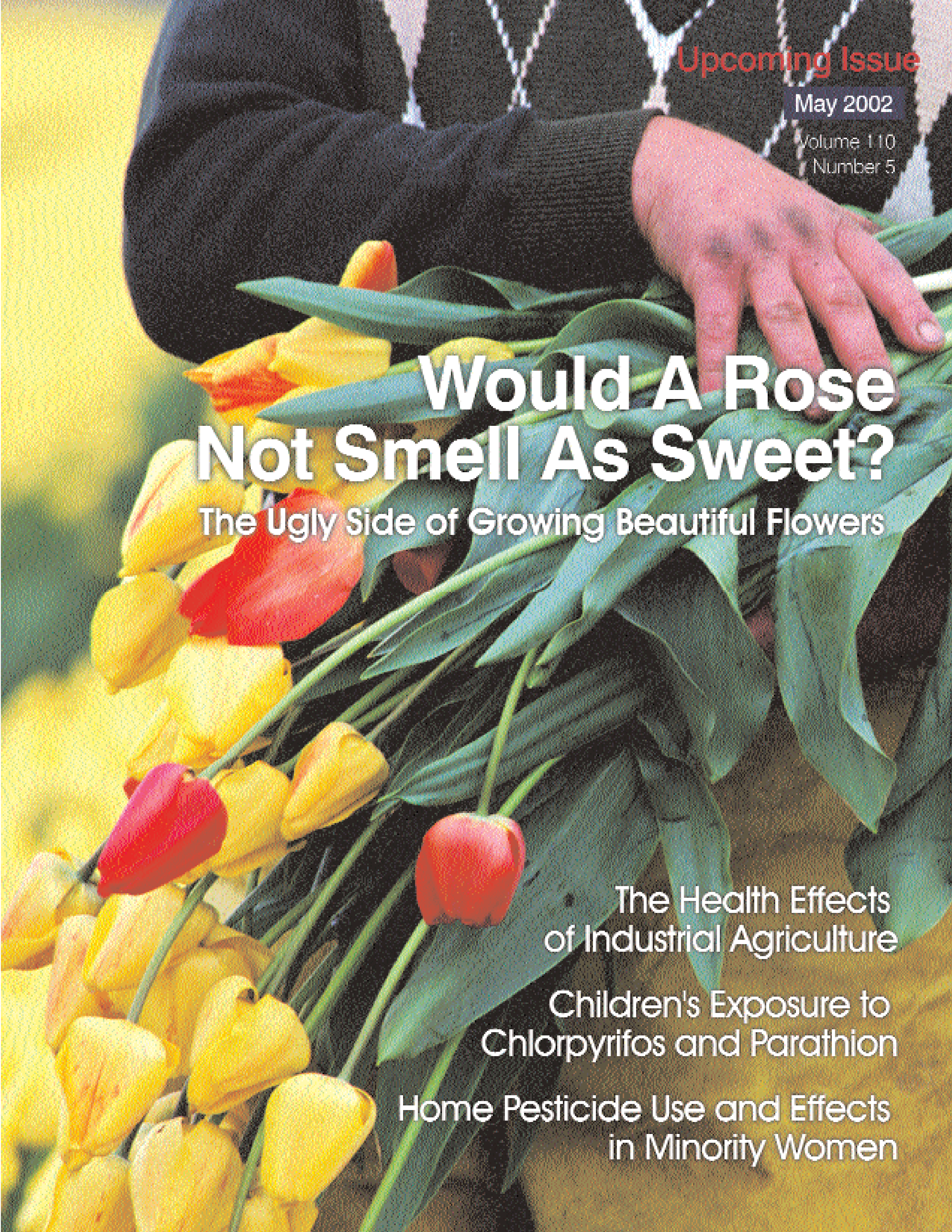
Even though U.S. companies are prohibited by RCRA from throwing their old electronics away, the “recyclers” that pick them up aren’t bound by any mandated certification program. That means the donor company can absolve itself of liability simply by giving the material to any organization that calls itself a recycler. Sometimes, the donor will get a “certificate of recycling” from the collector, but these certificates aren’t subject to any legally binding approval process. Robert Tonetti, senior environmental scientist with the EPA’s Office of Solid Waste in Washington, D.C., acknowledges that the lack of recycler accreditation creates a gap in the system. “But I’m not sure I’d call it a regulatory gap,” he says. “Certainly the nongovernmental organizations would say it is. The business community would disagree.” Currently, the International Association of Electronics Recyclers (IAER), based in Albany, New York, is developing a voluntary certification program designed to ensure that recyclers adhere to best management practices for environmental management and safety.

Tonetti says that export markets for obsolete electronics are a critical necessity, not only for U.S. industry but also for poorer countries where old computers are refurbished for continued use. Furthermore, in a *New York Times* article published on 25 February 2002, the day the BAN report was released, Tonetti said that a contributing factor in the growth of obsolete electronics exports was a trend towards closing U.S. metals smelters used for recycling, frequently because of environmental regulations. But he concedes that even those recyclers certified by the IAER could have a hard time monitoring the environmental management of exported material. “Are they going to require certification from all their distribution outlets overseas?” he asks. “It’s an expensive proposition. Eventually, recycler certification should be based on international standards, but it will probably be years before we see this.”

Meanwhile, it’s perfectly legal under U.S. law to export all forms of electronic waste, including color CRTs which are listed as hazardous waste by the EPA, as long as recycling, and not disposal, is the objective. The legality of these waste exports is somewhat murky in the context of an international agreement called the Basel Convention, whose aim is to limit the international spread of hazardous waste, particularly to the developing world. The convention was brokered by the United Nations Environment Program in Basel, Switzerland, in 1989. [See *EHP* 107(8) 410-3, 1999.] Of the countries that originally signed the convention indicating their intent to ratify, only the United States, Haiti, and Afghanistan have failed to do so. Parties to the convention agree to manage those wastes defined by the Basel Convention that are transferred among themselves using a set of evolving criteria that constitute “environmentally sound management.” (The Basel Convention has its own list of hazardous wastes, some of which overlap RCRA [e.g., color CRTs], and some of which do not.) Nonparties have no such legally binding obligation. This means that the United States is free to export color CRTs to China—which has banned imports of such items—without incurring liability for the environmental management of its exports typified by recycling in Guiyu. “Our only responsibility is to remind [parties to the convention] of their Basel obligations,” says Tonetti. “But these are sovereign nations and they will do with the waste what they want.”

As the controversy over electronics recycling heats up, stakeholders across the various sectors are diligently looking for solutions. Currently, a number of different paradigms including local, state, and federally funded recycling programs, as well as manufacturer buy-back programs and point-of-sale disposal taxes, are being considered to fund electronics recycling in the United States [see Spheres of Influence, p. A196]. But a coherent strategy has yet to emerge. In the meantime, as the world remains ever poised to latch onto the “next big thing” in electronics technology, basements, attics, and developing countries will remain the repositories of the last next big thing.

Charles W. Schmidt



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