Dēmos

Tackling High-Tech Trash:

THE E-WASTE EXPLOSION & WHAT WE CAN DO ABOUT IT

Elizabeth Grossman

About Dēmos

Dēmos is a non-partisan public policy research and advocacy organization. Headquartered in New York City, Dēmos works with advocates and policymakers around the country in pursuit of four overarching goals: a more equitable economy; a vibrant and inclusive democracy; an empowered public sector that works for the common good; and responsible U.S. engagement in an interdependent world.

Dēmos was founded in 2000

About Dēmos' Sustainable Progress Initiative

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The profound environmental and social challenges of our time demand creative public policies, new values and habits of thought, and on-the-ground models of a new economy where the priority is to sustain human and natural communities. Most fundamentally, a sustainable, just, and democratic future requires rethinking American capitalism as it exists today as a system of political economy. If we are going to care for people and the planet, large-scale changes are needed in how Americans consume and live, how the United States structures economic activity and measures progress, and how we engage in the global economy. Demos' Sustainable Progress Initiative facilitates creative new research, policy development, and strategic planning for advancing these sustainability goals.

About the Author

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Executive Summary

"The world's fastest growing and potentially most dangerous waste problem."

--The Wall Street Journal

In the United States and much of the world, computers, cell phones, and other high-tech electronics have become virtual necessities for everyday life. From routine office tasks, to complicated data management, to information sharing, to entertainment, high-tech electronics are the new engines of progress just as mechanical machines and assembly lines drove the industrial economy of the previous century. Whether in the home or the office, moreover, remarkable technological developments in electronics have driven down prices while increasing functionality and capacity, enabling rapid gains in utility and efficiency at relatively low upfront cost to consumers. The resulting benefits have created the most positive economic storyline of the past 15 years.

Yet, amid all the headlines about technological marvels and high-tech business icons, far less attention has been paid to the huge volumes of waste generated by skyrocketing sales and rapid turnover in high-tech electronics. Driving a market worth about $233 billion in 2010, Americans now own about 3 billion electronic products, with a turnover rate of about 400 million units annually. These sales volumes and rapid turnover rates are creating the fastest growing waste stream in the world: in the U.S. alone, the Environmental Protection Agency estimates that over 372 million electronic units weighing 3.16 million tons entered the waste stream in 2007 and 2008. Less than 14 percent was recycled, while the rest went into dumps and incinerators. Much of what is recycled, moreover, is handled unsafely in developing countries, posing serious health and environmental risks.

In contrast to other waste streams such as industrial effluents and air pollution, the rapidly growing electonic waste (e-waste) stream is largely uncontrolled and lightly regulated, relying on a patchwork of corporate "take-back" initiatives, state and local recycling programs, and a handful of (mainly European) e-waste policy directives. With projections of 4 to 5 billion units entering the e-waste stream from the United States alone over the next 10 years, we urgently need to develop a more comprehensive and coordinated policy framework to restrict hazardous dumping and recycling while also regulating and incentivizing design innovations that extend product life-spans and reduce overall toxicity in electronics.

This report assesses the scope of electronics consumption and resulting e-waste, the unique challenges policymakers face in handling this kind of waste, and steps we must take to gain control of the problem. Key aspects of the problem examined in this report include:

- Short product life-spans—the commercial and technological origins of rapid turnover in consumer electronics.
- The mounting scope of electronic waste—the downside of the surging worldwide electronics market.
- The major challenges of e-waste, including design and materials complexity, global supply chains, and unregulated recycling and e-scrap markets.
- The adverse health and environmental impacts of unregulated e-waste disposal, materials salvage, and recycling-for-reuse.
- Recent developments in e-waste export rules, private and public recycling initiatives, and green design and materials regulation to extend product life-spans and reduce overall toxicity.
- Assessing challenges to a more integrated life-cycle approach to electronics design, production, and recycling, with recommendations for specific policies to push for in the near term.

I. E-waste: What's the Problem?

Three billion and counting

Thanks to our appetite for gadgets, convenience, and innovation—and the current globalized economy that makes high tech electronics more and more affordable—Americans now own about 3 billion electronics products,[1] up from a total of about 2 billion only three years ago. With as many as 15 to 24 per household,[2] these digital devices include computers, cell phones, televisions, printers, audio and video players, cameras, fax machines, scanners, and entertainment systems. Rapid technological advances, aggressive marketing, and enthusiastic adoption of new products have spurred tremendous sales growth in consumer electronics. These trends have also resulted in rapid rates of obsolescence. This rapid turnover—about 400 million units of product annually or more than one piece of e-waste for every person in the United States—has made electronic waste, or "e-waste," the fastest growing part of the U.S. municipal waste stream.

In our rush to pursue and adopt the latest technologies, we have generally ignored the environmental and health impacts of the production, use, and disposal of electronics. This falls into a familiar pattern. Historically, the United States, like other industrial societies, has tended to "externalize" many costs associated with hazardous materials and waste, expecting these costs to be borne, not by manufacturers or consumers, but by communities and the environment. Until passage of clean air, clean water, and occupational health laws, industry could dump its effluent and use hazardous materials without expecting to be responsible for the consequences. While high-tech electronics is indeed a manufacturing industry, its public profile is very different from that of older industries. These digital, information-age devices, with their compact designs, are more efficient and less obviously polluting than older mechanical technologies like car engines and factory machines and so seem less material and less threatening to the environment. At the same time, public discussion of high-tech electronics has emphasized their ability to create "virtual worlds" and to overcome obstacles of geography, space, and time. As technology zoomed ahead, we paid more and more attention to what the gigabytes could deliver in the way of information, communications, and entertainment, while ignoring the material impacts: the real mountains of plastics, metals, leaded glass, and toxic chemicals that grew higher and higher each time we upgraded our hardware.

Continuing neglect of the material origins and waste surrounding consumer electronics has enormous consequences. In 2008 (the year of the U.S. Environmental Protection Agency's (EPA) most recent data), the United States generated more than 3 million tons of e-waste. About 85 percent of this equipment ended up in landfills.[3] Only about 18 percent of the year's discarded computers and televisions—and only 10 percent of used cell phones—were recycled. What happened to all the printers, fax machines, accessories and other defunct digital devices discarded over the same period is not fully accounted for. Meanwhile, over 230 million units of used and obsolete computer and television equipment, along with unknown numbers of used cell phones and other electronics, are now held in storage in the United States. Much of this leftover equipment will, at some point, join the waste stream.

Because electronics are complex in both design and material composition, and because they contain many potentially hazardous materials, e-waste is much more problematic than waste from other types of manufactured products. Most consumer electronics contain dozens of materials, many of which are toxic. If disposed of or handled improperly, as they often have been, used electronics can create hazards to human health and the environment. Many of these materials also pose occupational health hazards for those working in electronics manufacturing and recycling. Some of the most hazardous include metals (among them cadmium, lead, and mercury) and plastics made of numerous synthetic chemicals, including many persistent and bioaccumulative pollutants. Some of these plastics, if burned, as they often are in incinerators or dumps in developing countries, can release carcinogens. In 2001, an EPA report found that discarded electronics accounted for approximately 70 percent of the heavy metals and 40 percent of the lead found in U.S. landfills.[4] Given their metal and synthetic chemical contents, a dumpster full of discarded computers or televisions is considered hazardous waste. Yet in most states in the U.S. it is still perfectly legal to put a computer or television in the trash.[5]

With their compact construction and with dozens of materials packed together, electronics pose recycling challenges. They can be time-consuming and labor intensive to disassemble. Consequently, vast quantities of e-waste have been exported to countries around the world where labor is cheap and enforcement of environmental regulations lax. In Africa, China, India, and other places, huge quantities of e-waste are exported for inexpensive recycling that often takes place in rudimentary backyard workshops. Toxics emanating from e-waste have poisoned water and soil, created serious air pollution problems, and sickened workers, their families, and others in these communities.

Toxics released from improper disposal and recycling of electronics have entered the global environment and have been found in Arctic animals, far from where this equipment was ever used or dumped. Chemicals used in electronics have entered the food web[6] and are being found consistently in biomonitoring studies conducted by the U.S. Centers for Disease Control.[7] Lead from e-waste has been found in children's jewelry sold in the U.S. Contaminants from e-waste, among them heavy metals and plastic dust, also pose a hazard to recycling workers, including in the U.S., which is currently the only industrialized nation that uses prison labor for electronics recycling.

With the aim of encouraging recycling, U.S. solid waste regulations have minimized the instances in which used electronics and components are classified as hazardous. Parts, including circuit boards and cathode ray tubes, if destined for recycling, are not considered hazardous waste. Nor are small quantities of electronics disposed of by households or small businesses. In the absence of adequately effective take-back and recycling programs, and continued gaps in public education and awareness of e-waste hazards, however, the upshot has been continued dumping of electronics both at home and abroad.

But improved environmental health is not the only reason to recycle e-waste. Many electronics comtain valuable and precious materials (copper, silver, gold, platinum, and increasingly important so-called rare earth minerals, among them),which are inherently reusable and provide a powerful incentive to recycle this equipment for materials recovery. The U.S. Geological Survey has calculated that more gold could be extracted from a metric ton of used circuit boards than could be extracted from 17 metric tons of gold ore.[8] According to the EPA, one metric ton of circuit boards contains 30-40 times the copper found in the same amount of ore mined in the U.S.[9]

Despite the unique challenges posed by e-waste and the rapidly growing quantities, until recently electronics were not classified or counted as a discrete type of solid waste. Previously, electronics were classified with "durable goods" like refrigerators and washing machines, expected to last five years or more. This may seem like an arcane detail, but as one observer has remarked, "What you measure, you manage."[10] And until very recently, we have neither been measuring nor managing electronic waste.

What we've done about e-waste so far and why we need to do more

Since 2003, when California enacted the nation's first electronics recycling bill, 23 states have passed e-waste recycling laws. Most of these programs are just getting underway, with start dates in 2009, 2010 and 2011. Virtually all major electronics manufacturers and cell phone service providers now have voluntary take-back programs. But these programs are limited in scope and do not cover all the electronics we're discarding. And, most significantly, the United States—unlike the European Union, Australia, Japan, South Korea or Taiwan, where electronics recycling is mandatory—lacks any national requirements or systems for electronics recycling or end-of-life product management.

In addition to lacking any comprehensive e-waste recycling requirements, the U.S. is also one of the few countries that have not ratified the Basel Convention, the international agreement that regulates trade in hazardous waste. The U.S has also not yet signed or ratified the Basel Convention amendment known as the Basel Ban, which is designed to curtail the export of hazardous waste, including e-waste, from wealthy to less well-off nations.[11]

Consequently, an estimated 50 to 80 percent of the e-waste that's sent for recycling in the U.S. is exported to Asia, Africa, and other developing economies, where it is dismantled for materials recovery under environmentally unsafe and socially irresponsible conditions.[12] In China, India, and other places where dedicated, if often informal, materials recovery takes place, what can't be easily recycled or reused is frequently dumped. These dumps are often unregulated, uncontained, and located within residential communities. The same is true in West African countries that lack sufficient infrastructure for electronic materials recovery but receive used electronics destined for repair and reuse– shipments that include large quantities of equipment that cannot be repaired or is too old to be reused. The result is seriously contaminated air, soil, and water, contamination of local fresh food supplies, and related adverse health impacts, including impacts on children.

While a growing number of electronics recyclers have pledged not to export e-waste, with the exception of cathode ray tubes (CRTs) that fall under the EPA's CRT rule,[13] which requires prior informed consent from the country receiving equipment for recycling, there is currently no federal law that bars this export if the scrapped or discarded electronics are ostensibly destined for recycling. There is also little, if any, formal oversight of trade in used computer equipment, much of which ends up in these scrap markets. There are now voluntary electronics recycler certification and standards programs ("e-Stewards" and "R2"[14]), but only e-Stewards prohibits exporting e-waste to developing nations. Both programs are fairly new, so most recyclers are not yet certified and few customers have the capacity to research and verify a recycler's certification status or how a recycler disposes of equipment, parts, and materials. This lack of regulation and consistent oversight has resulted in government, corporate, institutional, and personal computers ending up in overseas dumps and being found for sale in export markets complete with intact—and readable—hard drives.

There have been improvements in electronics design over the past four to five years, many responding to European Union legislation, effective in 2006, that restricts the use of certain hazardous materials in electronics—including lead, mercury, cadmium, hexavalent chromium, and several brominated flame retardants.[15] Emerging research into the environmental health effects of synthetic chemical constituents of plastics commonly used in electronics has prompted additional changes in product design. These materials improvements, however, do not apply to the vast majority of electronics now entering or poised to enter the waste stream, nor do they remove all hazards from e-waste. There have also been design improvements aimed at easing disassembly for recycling—for example, increases in modular design, fewer fasteners, and reducing the number of different plastics used in a single machine. But to date, however beneficial, such changes have done little to reduce the overall volume of U.S. e-waste.

U.S. efforts to grapple with problems posed by e-waste have been ongoing for about a decade. Despite the initiation of numerous take-back and recycling programs, however, since about 2003, U.S. electronics recycling rates increased no more than 3 percent, even as the volume of computers discarded more than doubled.[16]

EPA Administrator Lisa P. Jackson recently announced that cleaning up e-waste is among the EPA's top international priorities.[17] Over the past several years, e-waste bills have been introduced in both the House and Senate. The most recent of these include H.R. 6252, the Responsible Electronics Recycling Act, which would prohibit export of scrap and non-working electronics from the U.S. to developing countries. Other bills include H.R. 1580, the Electronic Waste Research and Development Act, and its companion S. 1397, which would authorize the EPA to award grants for electronic waste reduction, research, development and demonstration projects; there is also H.Res. 938, a non-binding resolution that encourages Congress to develop a plan to recycle its own e-waste responsibly, using recyclers certified to the e-Stewards standard. None of these, however, is expected to pass in the 111th Congress.

Given the enormous number of electronics products sold and the rapid turnover of these products, and the extremely low recycling rates that persist despite the growing number of mandatory state programs and manufacturers' voluntary programs, it's clear that stronger, more comprehensive measures are needed to ensure environmentally safe and socially responsible handling of used and obsolete electronics. To stem the ongoing flood of e-waste effectively, we need to do more. Among other reform ideas that we will discuss in more detail later in the report, the following are key priorities:

» Expanding existing take-back and recycling programs to cover a greater scope of products and making these programs easier and more convenient to use.

» Expanding "extended producer responsibility" for electronics products, requiring manufacturers to "internalize" the full life-cycle costs of their products.

» Ending the export of hazardous e-waste for environmentally unsound and socially irresponsible materials recovery, processing, and disposal.

» Requiring improvements in both hardware and software design that would ease reuse and recycling, reduce overall environmental health hazards associated with electronics (from manufacture through end-of-product-life), and ultimately extend the life of products.

II. The Economics of E-Waste

Creating the modern consumer

Today's $233 billion U.S. market[18] for consumer electronics is, in a number of ways, simply the latest chapter in the history of technological consumerism—the selling to Americans of the next new thing, from motor vehicles, to athletic shoes, to cosmetics, to processed food. Convenience, speed, personal transformation and achievement have been the promise. Whether or not we actually need the latest iteration of a specific product, these new products have been marketed as necessary both for improving our personal standard of living and for helping to grow the American economy.

Where electronics fit into this story is complicated by the fact that the rapid rate at which we've acquired these products over the past 30 years is a result of both real technological advances in computing and telecommunications, and, at the same time, our marketing-driven perceptions of these products' utility and desirability. Writing in his 1960 book *The Waste Makers*, journalist and social critic Vance Packard, known for his trenchant commentary on consumer culture, traced the origins of America's trademark mass- consumerism to the advertising strategies developed after World War II. Their aim was to boost rates of consumption so they would keep up with the high production rates of the early post-war years.

Coming out of the war years, the average American was consuming twice as much in the way of manufactured goods as the average citizen had before the war, Packard observed.[19] At the same time, new automated processes made it possible to churn out more goods than ever before, putting an ever-growing number of new products on the market. Americans were buying more products than ever, but production outpaced even the increased rate of consumption. "Some marketing experts have been announcing that the average citizen will have to step up his buying by nearly 50 percent in the next dozen years or the economy will sicken," wrote Packard. "The other factor," he commented," is the great expansion of United States productive facilities based on the conviction in executive suites that the public can be induced to consume more each year."[20]

Thus, the marketing and sales teams of the late 1950s and 1960s devised advertising campaigns designed to convince Americans to buy products simply because these items were new. The concept of "progressive obsolescence," first coined in the advertising literature of the late 1920s, helped to define a strategy of using marketing campaigns to habituate people to buying new products

Planned Obsolescence: What Were They Thinking?

In the 1930s an enterprising engineer working for General Electric proposed increasing sales of flashlight lamps by increasing their efficiency and shortening their life. Instead of lasting through three batteries he suggested that each lamp last only as long as one battery. In 1934 speakers at the Society of Automotive Engineers meetings proposed limiting the life of automobiles. These examples and others are cited in Vance Packard's classic book The Waste Makers.

By the 1950s planned obsolescence had become routine and engineers worried over the ethics of deliberately designing products of inferior quality. The conflict between profits and engineering objectives were apparent. The fear of market saturation seemed to require such methods to ensure a prosperous economy, yet the consumer was being sold inferior products that could have been made more durable for little extra cost.

In an editorial in Design News toward the end of the fifties, E. S. Safford asked whether engineers should resist the philosophy of planned obsolescence if their management commissioned a 'short-term product' and argued that they should not: "Planned existence spans of product may well become one of the greatest economic boosts to the American economy since the origination of time payments." What was required, he argued was "a new look at old engineering ethics". Instead of trying to build the best, the lightest, the fastest and the cheapest, engineers should be able to apply their skills to building shoddy articles that would fall apart after a short amount of time, all in the interests of the market.

The editorial prompted a wide response. Several engineers wrote in to add their agreement. According to Packard, "the majority of engineers and executives reacting to the editorial, however, seemed angry and bewildered. They appeared to have little enthusiasm for the 'new ethics' they were being invited to explore." They objected because planned obsolescence gave engineering a bad name, because it cheated customers who were not informed of the death-date of the product, and because it directed creative engineering energies toward short-term market ends rather than more lofty and ambitious engineering goals.

Today when protecting the environment is such a priority goal, the question of product life and durability is again a critical question. Clearly the rate at which modern societies turn over equipment, automobiles, white goods and other items has a cost both in terms of resource use as well as waste and pollution. Yet our economic systems still seem to rely on the consumption that this constant turnover requires.

Excerpt from Sharon Beder, "Is planned obsolescence socially responsible?", *Engineers Australia*, November 1998, p. 52.

"on the basis of obsolescence in efficiency, economy, style or taste."[21] Using the example of a portable radio apparently designed to last no more than three years, Packard documented the kind of commercial thinking that would come to be epitomized in high-tech electronics three and four decades later. He recounts that this radio's designer defended the short-lived product by saying, "if portable radios typically lasted ten years, the market might be saturated long before repeat sales could support continued volume manufacturing…; second, the user would be denied benefits of accelerated progress if long life is a product characteristic."[22]

So, by the time personal computers, cell phones, portable CD players and then MP3 players arrived on the scene, Americans were already well in the habit of eagerly acquiring the next new thing. By then Americans were also accustomed to accepting short product life, whether as a result of "progressive" or "planned" obsolescence (see below), which also has a long history in the United States. High tech complicates this scenario with the fact that the aggressive marketing of high-volume production goods has been accompanied by new generations of products that do indeed have different capabilities, not merely new styles or colors.

Also among the likely reasons we've not only bought consumer electronics at enormous volume but also let the e-waste accumulate relatively unchecked is our now decades-long history of "planned obsolescence"—manufactured products with intentionally short life-spans. Some of these were designed as outright disposables or literally made-to-break in order to generate sales: razor blades, stockings, wristwatches, and toys among them. Others have been designed in ways that make them easier to replace than repair; still others designed in ways that make repair impossible. These products, some dating back to the turn of the twentieth century and earlier, have helped lay the groundwork for our acceptance of short-lived digital devices and, however tacitly, their waste stream.

More so than in the earlier phases of consumerism, however, the speed of real and perceived obsolescence in consumer electronics is fueled by powerful technological forces, such as "Moore's Law." This is the accurate prediction, first made by Intel founder Gordon Moore, that the computing capacity of semiconductor chips could be made to double every 18 to 24 months. As this has played out over the past three decades, we've also seen a nearly wholesale shift from mechanical machines and analogue devices—typewriters, stereo systems with turntables, adding machines, etc.—to digital technology: PCs, MP3 players, cell phones, webcasting, and streaming video. One can argue the varying merits of LPs, CDs, and digital audio files or debate whether or not each of the 50 million-plus Americans who now own a "smart phone" actually needs one, but like it or not, computers and internet access are now essential tools of contemporary life. So in our eagerness to adopt these information-age tools, we have focused on the apparent miracles of microprocessors and what the expanding megahertz and gigabytes can deliver, while paying scant attention to the material impacts of our digital consumerism.

In addition to the rapid rate of technological change, another unique problem with high-tech electronics is their complexity of design and assembly. Unlike previous generations of mechanical and electrical devices, today's devices are far too complicated for the average consumer to understand or tinker with. You can't just throw open the hood or tighten a few screws. For the most part, we have to rely on what the packages deliver and accept them as they come. Not until a manufacturer has to share in the responsibility for a used or obsolete product—or take responsibility for the environmental and health impacts of their manufacturing process—does this equation really begin to shift.

Who foots the bill?

E-waste is one of the most complex, bulky, and non-biodegradable forms of trash ever created. This makes dealing with it equally complex, and makes handling it in an environmentally sound way potentially expensive. In the United States, garbage—both trash and recycling—is typically managed by local governments and financed by those governments and/or resident taxpayers. But the high price of processing e-waste, and its environmental impacts (as well as its data security liabilities), are prompting local governments, many institutions and businesses, as well as consumers and environmental advocates to question this status quo. Fundamental to this discussion is the idea that end-of-life product costs, currently borne by the community and the environment, should be shared by or shifted to the products' manufacturers.

This concept, whereby companies that manufacture products retain physical or fiscal responsibility for their products when they become waste, is known in much of the world as extended producer responsibility. It is fundamental to the way in which the EU has established its electronics recycling programs. But the idea is relatively new to Americans. When first proposed as a way to manage and finance e-waste recycling in the U.S., it was met with a mixture of skepticism and hostility by many in the business community. U.S electronics manufacturers, all of whom operate internationally, lobbied against the EU's regulations when they were proposed, arguing that they could lead to trade barriers, have significant adverse financial impacts, and potentially encourage the use of materials more environmentally harmful than those already employed.

But in the five years since the EU's directives mandating electronics recycling and restricting hazardous materials in electronics have been in effect, the industry has not experienced any resulting trade barriers and, as the sales figures attest, it is not suffering financially. The industry is thriving even as manufacturers, in proportion to their market share, are now involved in financing and managing electronics recycling programs across the EU. Manufacturers are now working in comparable programs in all but one of the U.S. states that have passed electronics recycling laws (the exception being California), also without apparent adverse impacts on sales.

Still, in the U.S. we are only recycling between 15 and 20 percent of the approximately 3 million tons of e-waste we discard annually. Local communities continue to bear most of the financial costs of e-waste, and the environmental impacts remain largely uncontrolled. All of these costs are high. An assessment done by the Computer Take-Back Campaign in 2003 and 2004, when state legislatures were first beginning to grapple with e-waste, found that the cost of handling and processing e-waste in the next ten years could exceed $10 billion. Numbers like those caught the attention of local law makers. So did the environmental liabilities—including the consequences of allowing toxic heavy metals to build up in local landfills. Also prompting action on the local level was potential cost to local governments' reputations. Much negative publicity has been generated by pictures from Chinese e-waste dumps showing equipment bearing ID-tags from local government agencies and school districts in the U.S. These shocking photos, which included pictures of children sitting atop mounds of e-waste and playing near smoldering e-waste plastics, prompted many local policymakers to begin addressing e-waste issues at home.

Why is e-waste piling up?

In many ways the high-tech electronics industry is no different from any other. For most industries, where the garbage goes, and how the environment absorbs and responds to waste, are costs outside the scope of traditional balance sheets. At the same time, as Bill McKibben has noted, we've been told that "some force like evolution drives us on to More and Faster and Bigger."[23] We live in a culture that discourages the idea of limits and resists regulation. The idea of a "new start"—whether it's a new career or a new computer—is engrained in the American dream. Combine this with the powerful consumer incentive of falling prices for more functionality and capacity per digital device, and the result is a growing mountain of e-waste.

Thus, in electronics we have a kind of perfect storm for vast consumer waste—with the American penchant for innovation and our history as a consumer culture combined with a product stream driven forward by apparent "laws" of technological development. Almost mundanely, the assumption has been that computers and other consumer electronics needn't be designed for an extended life span because the next generation of products will always be close on the heels of the one preceding it.

Historically, there has been no incentive for the types of modular, repairable, easily upgraded design that would extend the life of electronics. At the same time, many of the most successful technological advances—like the shift from cathode-ray-tube televisions and monitors to flatscreens—entailed entirely new designs. And again, what makes used electronics so problematic to deal with is that, unlike a pile of discarded paper cups, water bottles, or soda cans, each piece of equipment contains scores of different materials, many of them hazardous to the environment and human health, all packed together tightly in ways that, particularly in the case of handheld devices, can make assembly and disassembly, whether for repair, upgrades, or recycling, very difficult. Unlike other mass-produced manufactured products, moreover, each individual piece of high-tech electronics typically requires multiple accessories: chargers, remote controls, ink and toner cartridges, batteries, memory cards, to name but a few. Few of these accessories are broadly transferable between brands and product lines, yet all have to go somewhere when their (often short) useful lives are over.

III. The E-Waste Landscape

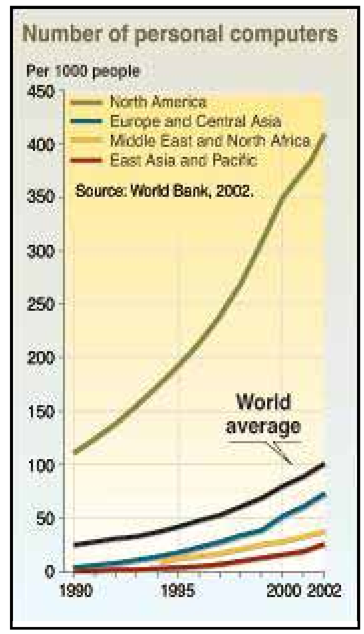
How much electronics are we consuming?

Despite financial hard times worldwide, in 2009 and 2010 the volume of electronics sold has continued to grow. The growth has been steady over the past twenty years, punctuated by large spikes following the introduction of new products. For example, between 1992 and 2002—the time period in which many homes and offices acquired their first personal computers—overall U.S. sales of consumer electronics quadrupled.[24] When DVD players were introduced in 1997, the year's sales were about 1 million worldwide; by 2004 that number had reached 25 million. Between 2005 and 2006, world sales of MP3 players more than tripled, growing from 10 to 34 million. In one quarter of 2010, one manufacturer sold some 20 million such devices. Meanwhile, in 2010 there are now some 3 billion more cell phones owned worldwide than there were three years ago; nearly 300 million of these are in the U.S.

Overall, according to the Consumer Electronics Association, in 2009 the average U.S. household spent approximately $1,380 on consumer electronics, $151 more than in 2008.[25] This spending includes:

Computers

In 2009, the number of computers sold worldwide grew by more than 5 percent to a reported 306 million units.[26] There are now over 1 billion computers in use worldwide—approximately one computer for every six people on the planet. Of these about 96 million were sold in the U.S.[27] Nearly 120 million are projected to be sold here in 2010.[28] And in April 2010, the research firm Gartner reported that PC shipments for the year's first quarter had increased by 27.4 percent over the first quarter in 2009. Over half of these are now mobile PCs—laptops and other kinds of notebook or tablet computers. Gartner's projection for worldwide computer sales in 2010 is valued at $245 billion, with approximately a third of total computer sales (lap- and desktop) expected to be in the U.S. Currently about 86 percent of all U.S. households own at least one computer.[29]



Cell phones

In 2009 some 1.2 billion cell phones were sold worldwide,[30] and by February 2010[31] the number of world cell phone subscribers reached 4.6 billion. More than 285 million of those are now owned in the U.S.[32] A reported 135 million "handsets" were sold in 2009, sales worth $24 billion and up some 3 percent from 2008. About a third of all cell phones sold are now "smart phones."[33]

Televisions

About 211 million televisions were sold worldwide in 2009. By the third quarter of 2010, the year's projected sales worldwide were expected to reach $243 billion. Digital TV sales alone are now in excess of $25 billion.

Americans have purchased so many televisions that in the U.S there are now, on average, nearly 3 TVs per household and a total of 114 million households with at least one TV—numbers that do not reflect TVs in public and commercial places (hotels, restaurants, hospitals, gyms, airports, etc.) And despite the financial downturn, the number of digital TVs purchased in the U.S. between 2008 and 2009 grew by nearly 8 million. This has been accompanied by a 50 percent jump in sales of HD TVs that are now in 65 percent of U.S. households.[34]

Altogether, Americans now own well over 200 million computers, more than 200 million cell phones, and more than 200 million televisions. In addition, an array of newer devices are all gaining sizeable markets:

MP3/MP4 players: Apple alone sold about 20 million iPods in just the first quarter of 2010.[35] In all of 2006, an estimated total of all MP3 players sold was 34 million.

Video players: 2009 saw a 150 percent increase in sales of Blu-ray video players, selling approximately 7 million units worth about $1 billion, a number that does not include all DVD players.

eBook readers: In 2009, more than 2 million eBook readers were sold, with over $1 billion in sales. This number does not include those sold in 2010, or an estimated 8.25 million iPads sold in the six months since their introduction.[36]

And there's more: GPS devices, data back-up and storage devices, digital cameras, audio recorders, printers, and game players—all selling in the tens of millions or more annually.

Semiconductors, the essential material component in all of these devices and others, have seen correspondingly huge volume increases in sales in recent years. According to the Semiconductor Industry Association, $25.7 billion worth of semiconductors were sold worldwide in August 2010, an increase of 32.6 percent since the same time in 2009. This brings semiconductor sales for the first eight months of 2010 to $194.6 billion, an increase of 44 percent since 2009.[37] And in the midst of continuing economic hard times, in April 2010, Intel, the world's largest semiconductor manufacturer, reported its highest ever first-quarter sales ($10.3 billion) and profits ($2.4 billion).[38]

So it is something of an understatement to say that the consumer electronics industry is generating huge revenues. Profits of course vary by company but many are also staggeringly high. In March 2010, the *McClatchy Tribune* reported that Intel's profit for the fourth quarter of 2009 had jumped 875 percent over the same time in 2008.[39] The company reported 2010 third quarter profits up 59 percent.[40] Meanwhile, profits for major electronics manufacturers in the first three quarters of 2010 also grew, from 17 percent on the low end to the astounding 508 percent reported by Panasonic.[41] Needless to say, these rates of profit do not depend simply on steady growth of the industry's already enormous sales volumes. This growth is also generated in part by new technologies and the acquisition of brand new devices (eBook readers, "smart phones," HD-TVs, Blu-ray video players, etc.), and it is also propelled by the short life-span of many of the most popular devices.

Thus the question arises: What has contributed to the rapid turnover of so many electronics, creating what one electronics recycling professional has described as a "skyrocketing rate of obsolescence."[42] And more to the point, are there design or other innovations that could help reduce the volume of e-waste by extending product life? Before examining the latter question more closely in Section IV of this report, we need to understand why, in fact, consumer electronics do not last very long.

Why doesn't this stuff last longer?

The scenario is familiar. The day comes when the computer that boasted the latest operating system and the biggest hard drive on the planet has become a dinosaur. The electronics merchant that once touted that machine's efficiency now explains in tones of pity and derision just how far from the cutting edge of new technology you are. With the purchase of a new computer, you also can buy, for well under $100, a brand new printer with far more bells-and-whistles than the one you already have, which apparently is not compatible with the new computer in any case. Or, you see an advertisement from your "wireless service provider" announcing a new bargain calling plan, available only with the purchase of a new phone, which thanks to rebates and discounts will cost you next to nothing. So, although your current cell phone works perfectly well, you get a new one.

Essentially, then, rapid turnover in electronics involves a combination of hardware failures, new software requirements that require more computing capacity, designs that encourage replacement rather than repair or upgrade of existing devices, and marketing that encourages rapid replacement of devices with the new and better ones.

However essential they may be to keeping toxics out of the environment, reducing occupational health hazards, and reclaiming materials for reuse, recycling programs alone will not decrease the amount of old, obsolete, and discarded electronics we're now contending with. To do so will require design changes in hardware—and likely software—that will enable substantial extension of product life.

To understand the challenges involved, one must first consider what the expected life-span is for the primary categories of electronics. Also important, when assessing electronics' life-spans from an e-waste perspective, is the fact that whole categories of consumer electronics have been superseded by newer technologies, among them: VCR players, portable cassette and CD players, cathode ray tube (CRT) monitors and TVs. (How many people still have a "walkman" in a closet? What about a zip-drive and a pile of zip disks?) At the same time, although some technological advances are designed, at least in theory, to reduce the overall number of devices needed to perform a particular task (all-in-one printer/scanner/fax machines and "smart phones" that are also MP3 players, GPS devices, and personal-data-assistants), the overall number of products sold keeps growing. Meanwhile, product life-span has not changed significantly in the course of the past ten years.

Here are some of the factors and challenges involved in considering how to curtail the rapid rate of obsolescence in specific areas:

Computers

Historically, the average lifespan of a computer is considered to be about three to five years. Many people do keep them longer and many go on to have a second user, but an average of three to five years has been the length of time on which both computer manufacturers and electronics recyclers have based their projections of volume.

Technological advances, including those in software, have undoubtedly been a major contributor to this short life-span, both in terms of computing capacity and other factors, including operating and maintenance costs. Some of these advances have been accompanied by manufacturing and design changes that may increase the resource efficiency of products on a per unit basis or reduce the use of certain hazardous substances. But, they have also meant the disposal of equipment perceived to be obsolete while still in working condition. Overall, over the past decade, the environmental profile of many consumer electronics has improved, yet we're consuming and disposing of more than ever.

The switch from CRT to flat screen monitors (in computers and televisions) is one such example. In 2004 the sales of CRT monitors and LCD or flat-panel computer displays were about evenly matched. By 2010, flat-panel sales surpassed those of CRT models both in the U.S. and worldwide. This transition in technology coincided with the conversion to digital TV in the United States (affecting an estimated 40 million televisions in U.S. households) as well as the increased availability of programs broadcast in high definition digital signal (HDTV). Data is not yet available on how many TVs may have been discarded as a result, but the Electronics TakeBack Coalition estimates that number to be in the tens of millions. Meanwhile, acquisition of flat screen computer monitors and some users' transitions from desktop computers to mobile has meant that additional CPUs (and other accessories) may be discarded along with the old CRTs.

There is something of an upside to the demise of CRTs. Flat screens contain far less material than do CRTs, which contain between 2 and 4 pounds of copper per unit. CRTs can also contain as much as 8 pounds of lead distributed between the leaded glass screen (which also contains barium, cadmium, and phosphorus) and the unit behind the screen, in addition to other metals and plastic housings. Newer computers, since at least 2006, lack lead solder and, if flat screen, have no need of the bulky lead and copper connectors used in CRTs. On the other hand, LCD TVs contained mercury lamps until recently, when LEDs began to take their place. And to date, there's been little testing of all the materials involved in LED production.

Over the past five years, peripherals and accessories—cables, charging devices, printers and scanners—have become more universal between computer models, whereas before 2004 or 2005, reduced compatibility of these outside devices meant that a new computer almost always meant additional acquisitions and discards. But as we acquire more electronics per capita, the *overall* number of accessories also grows. In but one fraction of this market, "aftermarket mobile phone accessories," sales are currently estimated to be worth $26 billion worldwide and are projected to grow to $50 billion by 2015.[43]

While there are upsides to these product evolutions, especially regarding the overall quantity of material and the reduction of certain hazardous materials, other challenges persist and new ones arise as individual devices and product lines evolve. Computers, particularly the increasingly popular mobile notebook computers, are not designed to facilitate upgrades in computing capacity. While some manufacturers will, if pressed, explain how memory can be expanded and hard drive capacity increased with an existing computer, most of these changes require using third-party parts that are not covered by the existing computer's warranties. The cost of these upgrades (including labor) often approaches 50 percent of the cost of a new computer, and if there is no warranty to cover repairs on the upgraded machine, extending the life of an existing computer is further deterred.

Printers

Printers bring another set of problems. Because printers lack the high value circuit boards used in computers (which contain valuable metals), they have far less value to recyclers. Given the downward slope in the price of printers, the incentive to repair a broken printer, and hence available expertise in such repair, is low. So printers have become, from a consumer's perspective, highly disposable. Of the 23 states that now have required electronics recycling, only 5 include printers in their mandatory recycling programs.[44]

Here too there is an upside, however. Printers are becoming more compatible with a range of computers, so it is becoming less essential to acquire a new printer to match every new computer. Similarly, cables are becoming more compatible, and, increasingly, computers and printers (and other components) can communicate wirelessly, so fewer new accessories are needed.

But significant challenges remain with printers, particularly the rapid turnover of ink and toner cartridges, which contribute to the e-waste stream and are not widely covered in public recycling programs. Many commercial ink and toner cartridge recycling programs exist, but they are difficult to audit and it is unclear how much of the recovered material goes back into new cartridge production. In addition, the upfront cost of ink and toner can quickly exceed the price of the printer, contributing to the perception of printers as low-value. If producer responsibility were a necessary part of product design, this would be an area where significantly less waste would result.

Cell phones

The electronics industry has estimated that a cell phone's life span is about two years.

In a striking statistic, the EPA notes that in 2007 Americans discarded over 140.3 million cell phones, more than were reported sold in 2009. (An unknown number of used phones are in storage somewhere).

The challenges here are particularly daunting given the throw-away culture of cell-phone marketing strategies. Broadly, we need to increase reuse and recycling rates for cell phones to meet both the expanding market demand and recent rapid changes in technology (for example, the advent of "smart phones"). For the future, we need to establish new design standards for upgrading rather than replacing an existing "smart phone" and its key components (memory cards, batteries, SIM cards, etc.). In the shorter term, to directly reduce the volume ending up in the trash, we need to increase mandatory take-back and recycling programs, and to bar cell phones (and other handheld devices) from landfills and incinerators. Only two of the 23 U.S. states with electronics recycling programs include cell phones, and one of those two did so under a separate law.

Televisions

Historically, televisions have had the longest lifespan of the major consumer electronics products, lasting as long as 13 to 15 years. But in 2009, with the U.S. conversion to digital TV (other countries had previously made the change) and an estimated 40 million already-owned televisions affected by this change, a higher than average turnover of TVs was expected.

With the advent of flat screens, digital and HD-TV, and larger screen TVs, and the national transition to digital TV signals, the lifespan of many existing TVs has effectively been shortened over the past few years. At the same time, the incentives for and availability of TV repair have both plummeted.

The difficulties in this area are many and significant. Given the large number of TVs, their weight and variable design (running the gamut from the 14-inch portable to the large console model and now flat-screens), and the fragility and toxicity of the CRTs that comprise the bulk of TV monitors currently being discarded, the electronics recycling industry considers TVs to be among the most challenging of items to recycle. As televisions become increasingly digital, there may be more opportunities for designs that facilitate upgrades to accommodate changes in technology. Recycling programs are not yet universal or convenient enough to capture the huge volume of TVs being discarded. Not all of the state electronics recycling programs include televisions, most notably Texas's, in one of the biggest markets.

MP3 players

MP3 (and MP4) players have become exceptionally popular and profitable in just the last ten years. But given the rapid changes in technology in these products over this short period, hard numbers on life-spans are difficult to come by. While there are now manufacturers' and retailers' recycling programs available, MP3 players seem not to have been designed with an extended life-span in mind. For example, early in the life of the iPod product line, Apple came under fire from environmental advocates for producing a device that was not designed to accommodate battery replacement by the iPod owner and where initial battery replacement cost was high enough to be an incentive to replace the whole product (iPhones and other "smart" phones have a similarly non-DIY-friendly design).

The main challenge here is to rethink product design to accommodate software upgrades and battery replacement (including by the consumer), while increasing the profile and mandate of recycling programs. Currently only two state recycling programs include MP3 players, and existing retailer and manufacturer take-back programs need to be better publicized to capture more of the used product stream.

How much of an e-waste tsunami is there?

As noted earlier, U.S. accounting of e-waste as a discrete, stand-alone category of solid waste is a relatively recent development. As of the end of 2006, there was no central database for this information and no auditable numbers for the amount of e-waste being recycled. At that point, neither the federal government nor individual state governments had any comprehensive accounting for the volume of electronics being recycled or otherwise disposed. Estimates were—and largely continue to be—based on both sales figures and projected product life-spans, in combination with recycling numbers from various voluntary and pilot programs and events.

Since then, however, the EPA has begun compiling statistics on recycling for a limited number of electronics products. The most recent figures available come from 2007 and 2008. Over that period, between televisions, computer products, and cell phones, approximately 304 million units were disposed of, while only 68.5 million were recycled (see Table 1).[45] Summarized and updated by the EPA in 2008, these quantities equal approximately 3.16 million tons of e-waste generated nationwide, with approximately 13.6 percent of that going to recycling and the rest going to landfills or incinerators.[46]

Table 1: Units Discarded: Disposed or Recycled

	Units Discarded	Disposed	Recycled
Televisions:	26.9 million	20.6 million	6.3 million
Computer products (including monitors, CPUs, keyboards, mice and other peripherals)**:**	205.5 million	157.3 million	48.2 million
Cell phones:	140.3 million	126.3 million	14 million

Source: Environmental Protection Agency

Breaking down the U.S. numbers into shorter time-frames, the Electronics TakeBack Coalition calculated that, in 2007, some 112,000 computers were discarded in the U.S. each day; in 2004, the EPA reported that the U.S. government alone was disposing of approximately 10,000 computers every week—a number that did not include computers used by the military or U.S. Postal Service. While global numbers are much harder track, the United Nations Environment Programme estimates a range of 20 to 50 million metric tons of e-waste generated annually.[47]

At the same time, as noted earlier, an enormous amount of used and obsolete electronics remain stored, and at some point these stored electronics will enter the waste stream. According to the EPA's most recently available accounting, of the electronics sold between 1980 and 2007, approximately 235 million units were in storage, including 99.1 million televisions, 65.7 million desktop computers, and 42 million laptops.[48] The EPA does not have information on stored cell phones. But a survey done in 2004 by the Wireless Foundation and the Cellular Communications and Internet Association found that 60 percent of those surveyed had at least one old cell phone at home.

Some unused computer equipment remains in storage because of data security concerns. (Recycling and data security professionals often recommend hard drive removal and destruction, something not likely to be done by most non-professionals.) While many people now understand that computer equipment and televisions should not be tossed into the trash, most remain unsure of how to recycle their equipment. Many others keep old equipment as a backup if their new machines fail.

Given an opportunity to dispose of old electronics safely, people are often eager to do so. In 2003, Denver residents set a record for a one-day collection by delivering over two hundred tons of used electronics to a Dell take-back event. They even created a mile-long backup onto the interstate. But a 2004 cell phone collection event in New York's Westchester County—perhaps less well publicized than the Denver event—collected only 32 phones from a population of 900,000.

The EPA does not break down its stored electronics numbers by ownership, but it is becoming increasingly important to corporate and institutional owners (educational, government, healthcare) that used computer equipment be handled properly and safely. Improper disposal of large quantities of computer equipment poses serious liability issues in terms of environmental hazards as well as data security. So, increasingly, large-scale purchasers of computer equipment are asking for take-back services as part of purchasing agreements with electronics manufacturers, or they are working with recyclers who perform secure data destruction and can provide thorough documentation for all equipment, materials, and parts throughout the recycling and reuse process. Many large-scale purchasers (hospitals for example) are also increasingly demanding high environmental standards from the equipment itself.[49]

Where is the e-waste coming from?

Most of the used and obsolete computers and other electronics now being recycled in the United States come from corporations, institutions or government agencies that purchase large quantities of equipment, or from programs designed to collect specific components such as ink and toner cartridges or batteries. An early survey of electronics recycling, done in 1999 by the National Safety Council (NSC), found that more than 80 percent of recycled electronics in the United States came from original manufacturers of these products.

The other major source of electronics recycling at that time were large companies with more than 500 employees; more than 75 percent of the equipment received by companies that refurbish and resell electronics also came from large businesses. When the International Association of Electronics Recyclers (IAER) reviewed the 1999 NSC study in 2003, little had changed. At that time, the IAER also compared individual, small business and corporate or institutional recycling rates. In both 2003 and 2006, IAER found that the large-volume purchasers were recycling at about twice the rate of individuals and small businesses.

Why is e-waste especially hazardous?

High tech electronics, especially the older equipment now in the waste stream, contain a large number of hazardous and toxic materials.(See Table 2) Desktop monitors and older TV monitors have cathode ray tubes (CRTs), which contain cadmium, lead, and mercury among other hazardous materials. Lead and mercury are well recognized neurotoxins; cadmium is toxic to the kidneys and can build up in the human body. Lead and mercury can leach out of landfills and contaminate soil and groundwater. U.S. landfills, according to the EPA, are managed so that leaching of heavy metals does not pose a problem, but huge quantities of our used electronics end up exported to landfills and dumps in places where environmental management is lacking or inadequate.[50]

Electronics recycling workers have been exposed to lead, cadmium, brominated flame retardants, and other toxics while dismantling and handling damaged CRTs. Circuit boards made before 2005 and 2006 contain lead solder. Some have beryllium processors. If damaged, these processors can release beryllium dust that causes an incurable lung disease. Consequently, many recyclers do not allow beryllium processors in their shredding operations. In some electronics recycling facilities, these processors must be identified and removed by hand.

The plastics in electronics contain numerous hazardous chemicals, including brominated flame retardants (BFRs—among them polybrominated diphenylethers (PBDEs), tetrabromobisphenol A, and hexabromocyclododecane) and plasticizers. The BFRs can leach out of the plastics at any time during a product's life; landfills containing electronics have been identified as sources of BFRs entering the local and global environment. These chemicals are now recognized to be persistent and bioaccumulative pollutants as well as endocrine disruptors that can set the stage for numerous health disorders and can interfere with development, metabolism, and reproduction.[51]

Many electronics contain PVC (polyvinyl chloride), particularly in wire coatings and packaging. PVC is a plastic that can release carcinogenic and persistent dioxins and furans when burned—as is often the case in the primitive recycling facilities and dumps where many old devices and machines end up. Dioxins are a class of chemicals that include some PCBs (polychlorinated biphenyls) and Agent Orange. Some brominated flame retardants are considered dioxin-like. Dioxins have an enormous ability to interfere with hormonal activity. They are toxic to the liver and can impair the immune, nervous, and reproductive systems. One of the hallmarks of dioxins and dioxin-like chemicals is their persistence. In the human body, the half-life of dioxins is considered to be about 11 years. Once in the environment, these compounds last for years, even decades.

The plastics used in electronics can break down into or release numerous other hazardous synthetic chemicals that are both persistent and now pervasive. These chemicals include polycarbonate plastics that break down into bisphenol A; PVC that releases its plasticizers, a type of chemical compound called phthalates; and nonylphenol compounds used in circuit board production, among others. All of these add to the burden of chemical exposure that is now recognized by medical and scientific experts in the U.S. and around the world as a contributing factor in many chronic and widespread diseases and health disorders. (See Table 3; see also the President's Cancer Panel Report, 2008-2009,[52] the "Faroes Statement" on the human health effects of developmental exposure to chemicals in our environment,[53] and The Stockholm Convention[54]).

E-waste in the environment, what and where?

While some 3 million tons of e-waste are making their way to U.S landfills annually, about 430,000 tons are going to recyclers. But even in these relatively small numbers, sending a computer or TV off to a recycler doesn't guarantee that it will be handled properly. Electronics recycling is something of a system of triage. Any computer brought to a recycler, for example, will first be assessed for reuse. If it is working and can be refurbished, it will likely move into a resale market, either in the U.S. or internationally. If not, it may be dismantled for parts that again move into either domestic or international markets for circuit boards, hard drives, processors, etc. If not usable intact or for parts, the computer will be disassembled for materials recovery: metals, plastics, and in the case of CRTs, glass.

Depending on the size and capacity of the recycling operation, sometimes only sorting may be done on site, or sorting and disassembly—or, if the operation is large enough, plastics, metals, and circuit boards may be sent through sophisticated machinery that shreds the material and further sorts metals and plastics into various product streams, which then go to smelters or plastics recyclers. Both copper and CRT glass, among other materials, will almost always end up outside the U.S. for processing, as there are no primary copper smelters in the U.S. and the remaining glass furnace that processed leaded CRT glass in the U.S is due to close in 2013.[55] Part of the materials recovery process involves metals separation—copper, iron, and lead, for example—and extraction of precious metals, including gold. Some precious metals extraction is done in U.S. facilities.

But as part of this journey of disassembly, much e-waste is exported to developing countries for inexpensive, labor-intensive and environmentally unhealthy materials recovery. Vast quantities have been exported to communities in southern China, often ending up in small backyard workshops where plastics are burned over open flames and people work without any safety equipment, directly exposing themselves to toxic materials. In one such community, Guiyu, in Guandong province, electronics recycling has rendered the local water completely undrinkable. Tests of local water and soil found heavy metals and toxics associated with plastics at levels well above what international safety standards consider acceptable. Lead poisoning and high levels of endocrine disrupting chemicals have been found in children and others who live in such communities, while those who work in these primitive recycling workshops suffer skin, respiratory, gastrointestinal and other ailments related to chemical and dust exposure.[56]

Large quantities (one investigation found as much as 500 container loads a month) are also sent to places like the electronics markets outside of Lagos, Nigeria, ostensibly for reuse, but, because much of the equipment sent is beyond repair, often it is simply dumped. In many such places, once the valuable metals are removed (in some places even that is not done) and dumps become full, they are burned to reduce volume, which releases dangerous toxins into the local environment and eventually the global environment. Many of these dumps are located in or near residential communities and are accessible to domestic livestock, increasing the avenues for human exposure to the hazardous chemicals released by electronic trash.[57]

To date, there is still no U.S. government accounting for the total amount of e-waste exported. Estimates from electronics recyclers suggest that anywhere from 50 to 80 percent of what's sent for recycling ends up somewhere outside the U.S. EPA estimates, however, are extremely limited. They simply note: "The information available regarding the amount of used and scrap electronics exported for reuse or recycling is limited. To date, we have only examined export of CRTs. In 2005, approximately 61 percent (about 107,500 tons) of CRT monitors and TVs collected for recycling were exported for remanufacture or refurbishment."[58]

Tracking these exports precisely is challenging, as equipment and parts can change hands many times, in many stages, before they reach their destination. Because the U.S. has no enforceable standards or requirements specific to electronics recyclers, customers have had to do their own due diligence. There are now two voluntary certification programs for electronics recyclers, but customers must still read the fine print to determine the programs' policies and guidelines on e-waste exports.

Yet many recyclers do not reveal their business practices and often themselves do not know where the various materials, parts, and equipment they've collected are sent. In addition, large quantities of used electronics are bought at government and other institutional surplus outlets and put onto the scrap market for profit.

Table 2: Environmental and Occupational Impacts

Computer /E-Waste Component	Process Witnessed in Guiyu, China	Potential Occupational Hazard	Potential Environmental Hazard
Cathode ray tubes (CRTs)	Breaking, removal of copper yoke, and dumping	• Silicosis • Cuts from CRT glass in case of implosion • Inhalation or contact with phosphorcontaining cadmium or other metals	Lead, barium and other heavy metals leaching into groundwater, releaase of toxic phosphor
Printed circuit boards	De-soldering and removing computer chips	• Tin and lead inhalation • Possible brominated dioxin, beryllium,cadmium, mercury inhalation	Air emission of same substances
Dismantled printed circuit board processing	Open burning of waste boards that have had chips removed to remove final metals	• Toxicity to workers and nearby residentsfrom tin, lead, brominated dioxin, beryllium,cadmium, and mercury inhalation • Respiratory irritation	• Tin and lead contamination of immediate environment including surface and groundwaters. • Brominated dioxins, beryllium, cadmium, and mercury emissions
Chips and other gold plated components	Chemical stripping using nitric and hydrochloric acid along riverbanks	• Acid contact with eyes, skin may result inpermanent injury • Inhalation of mists and fumres of acids,chlorine and sulphur dioxide gases can causerespiratory irritation to severe effects includingpulmonary edema, circulatory failure, anddeath.	• Hydrocarbons, heavy metals, brominated substances, etc. discharged directly into river and banks. • Acidifies the river destroying fish and flora
Plastics from computer and peripherals, e.g. printers, keyboards, etc.	Shredding and low temperature melting to bereutilized in poor grade plastics	Probable hydrocarbon, brominated dioxin, andheavy metal exposures	Emissions of brominated dioxins and heavy metals andhydrocarbons
Computer wires	Open burning to recover copper	Brominated and chlorinated dioxin, polycyclicaromatic hydrocarbons (PAH) (carcinogenic)exposure to workers living in the burningworks area.	Hydrocarbon ashes including PAH's discharged to air, water, and soil
Miscellaneous computer parts encased in rubber or plastic, e.g. steel rollers	Open burning to recover steel and other metals	Hydrocarbon including PAHs and potentialdioxin exposure	Hydrocarbon ashes including PAH's discharged to air, water, and soil
Toner cartridges	Use of paintbrushes to recover toner without any protection	• Respiratory tract irritation • Carbon black possible human carcinogen • Cyan, yellow, and magenta toners unknowntoxicoity	Cyan, yellow, and magenta toners unknown toxicity
Secondary steel or copper and precious metal smelting	Furnace recovers steel or copper from waste including organics	Expoure to dioxins and heavy metals	Emissions of dioxins and heavy metals

Source: Basel Action Network and Silicon Valley Toxic Coalition, *Exporting Harm: The High Tech Trashing of Asia* (2002)

Table 3: Some of The Health Culprits in E-Waste

Cathode Ray Tubes (CRTs) 	Lead	The glass in computer screens and TVs contains lead and other heavy metals (typically cadmium and barium). When broken, the glass releases hazardous dust which can harm the **nervous and circulatory systems, and damage children's cognitive development.**
Liquid Crystal Displays (LCDs) 	Mercury	The elements that illuminate LCD flat screens of many mp3 players, cell phones and TVs can cause damage to the **brain, nervous and reproductive systems, the lungs, kidneys** and other organs, and are harmful to a developing fetus.
Computers 	Copper	Copper is found not only in computers but also in the circuit boards of nearly every electronic device. Mining and smelting copper generates waste that can cause **acid rain and release sulfur dioxide, nitrogen oxide, lead, arsenic, mercury and cadmium** into the environment.
Semiconductors 	Hundreds of chemicals used for microchip manufacture	The production of the microprocessors at the core of all high tech electronics is a chemical intensive process, and involves many acutely toxic compounds, including those known to damage the **nervous, respiratory, kidney, endocrine, reproductive and liver systems, as well as certain cancers**.
Plastics 	Plastics used in electronics often contain numerous hazardous chemicals, including brominated flame retardants, chemicals that make up polyvinyl chloride, and polycarbonate plastics.	Many chemicals that make up and are added to plastics used in consumer electronics are associated (at different stages of product life) with adverse impacts to **metabolic, reproductive, neurological, and immunological systems among other health problems and diseases including certain cancers.**

As noted earlier, part of what drives the far-flung market for e-waste is the value of metals, particularly precious metals contained in circuit boards. The magazine *E-Scrap News* has a monthly feature charting the value of used circuit boards, which contain gold, silver, platinum, and palladium. More recently, rare-earth metals, also prevalent in electronics, have became a focus in recycling markets. Plastics, while of lesser value, are also recoverable from e-waste. A notable upside is that such recycling of metals, plastics, and glass from electronics reduces the resources that would otherwise be required to extract, refine, or process those elements from raw materials. According to the EPA: "Recycling one million laptops saves the energy equivalent to the electricity used by 3,657 US homes in a year," and "One metric ton of circuit boards can contain 40 to 800 times the concentrations of gold ore mined in the US and 30-40 times the concentration of copper ore mined in the US."[59] The U.S. Geological Survey's 2001 estimate was that a desktop computer (with CRT) monitor could contain between two and four pounds of copper.[60]

As mentioned above, the current generation of U.S. landfills are managed to prevent direct leaching into adjacent soil and groundwater, but some leaching occurs nonetheless. While lead and other heavy metals are the materials of primary concern, some of the synthetic chemicals found in electronics can make their way into the environment solely through exposure to air and sunlight (brominated flame retardants for example[61]).

Regulating e-waste exports

There are two new voluntary certification programs for electronics recyclers, both recommended by the EPA. One, was developed by the Basel Action Network (BAN) in cooperation with the Electronics TakeBack Coalition and is called e-Stewards. The other, called "R2,"[62] was developed by the scrap metal industry and the Institute for Scrap Recycling Industries (ISRI). The Electronics TakeBack Coalition and the Basel Action Network (BAN), environmental advocacy groups that have been instrumental in exposing the export of e-waste and in promoting responsible and expanded electronics recycling, are critical of the R2 program because, in their view, it fails to adequately address e-waste exports, among other issues.[63] Supporters of the R2 standard say that no-export is not practical because there are not enough facilities to handle e-scrap domestically and a ban would discourage development of responsible recycling facilities in developing countries. ISRI says that their "responsible recycling" policy "bans the export of electronic equipment and components for land-filling or incineration for disposal, and requires that facilities outside the U.S. that recycle or refurbish electronics have a documented and verifiable environmental, health and worker safety system in place."[64]

The e-Stewards [65] certification program requires a pledge to honor Basel Convention principles (no export of hazardous waste from wealthy to poorer countries) and not to use prison labor. This standard is accredited through the American National Standards Institute and American Society for Quality (ANSI-ASQ) National Accreditation Board. Currently about 50 recyclers are in this program, including some with Fortune 500 company clients, with another 20 in the process of becoming certified.

Regulatory approaches, however, remain extremely limited. In general, exporting e-waste for reuse or recycling is not prohibited. (Criminal charges were recently brought against a San Jose-based recycler that had been shipping e-waste to China, but the charges are for fraudulently claiming to have recycled materials in California, not for exporting e-waste[66]). Local and state anti-dumping rules have begun to limit e-waste disposal in landfills and incinerators, but this patchwork of sub-national rules remains highly porous. Within the U.S., small quantities of electronics—including CRTs and circuit boards—can be sent to landfills or incinerators unless prohibited by local regulations. A dumpster full of old computers and TVs or CRTs does, however, qualify as hazardous waste; nevertheless, if the equipment is specifically destined for recycling, it is exempt from this classification.

Still, well over a dozen states have now banned CRTs and other computer equipment from local landfills. Some of these same states have also banned certain computer equipment from incinerators. But in the majority of states it continues to be legal to put electronics in the trash, and choosing a recycler remains challenging for many consumers.

IV. Reducing Electronic Waste: Policy Discussion

How do we tackle the ever-growing volume of e-waste?

It is implausible that e-waste will disappear, no matter what the next decades of high tech innovation bring. Neither will we see an end to the extensive use of synthetic chemicals and valuable natural elements in electronics manufacturing in the near term. Computers, cell phones, and the whole universe of digital devices will likely become smaller, more powerful, and more efficient, but there will also be more of them. Microchip circuitry may be as invisible as the network of nerves on a dragonfly's wings and whole libraries may appear on palm-sized screens apparently out of thin air, but unless some radical changes are made in the way we design and produce our Information Age electronics, their ecological footprint will continue to grow.

Some of these problems can be dealt with through straightforward regulation. For example, local governments can limit the materials they allow in their landfills and incinerators. Or, more broadly, governments can limit the use of hazardous materials in product manufacturing and consumer products, in order to protect worker, consumer, and environmental safety. Such regulation may not be simple to achieve, as evidenced by the lengthy and often contentious processes involved in regulating many currently restricted chemicals, but the goals of such an approach are clear.

Similarly, recycling of electronics can be mandated, as it is in Europe, Japan and other countries, and in a growing number of U.S. states. We can expand the scope of mandatory recycling (in the EU, electronics recycling regulations cover anything that runs on electricity, not just computer equipment), and we can develop statutory mechanisms to encourage participation. We can also make the need for recycling more explicit and convenient. It should be as easy to recycle used electronics as it is to buy new equipment. Electronics recycling should become nearly as routine as recycling bottles, cans, and paper.

Despite the growing numbers of manufacturers' recycling and take-back programs, consumers are not well-informed about such programs at any point of purchase—in retail outlets, on manufacturers' websites, or in packaging literature. Over the past five years, these programs have expanded considerably, and in states with strong recycling laws, recycling rates have increased notably. But given the relatively few such programs that are fully in effect, nationwide recycling rates have barely budged. Many devices and accessories in the e-waste stream also remain completely uncounted and unmanaged under existing recycling programs and laws. If electronics were completely barred from landfills and incinerators, pressure for better recycling would grow along with incentives for product designs that facilitate efficient and environmentally benign recycling. All of these measures would help us begin to close the electronics life-cycle loop.

What is more challenging, however, is how to stem the tide of e-waste altogether.

No one wants to stifle innovation or access to the products of that innovation. So the challenge is how to manage the growing ecological footprint of the products resulting from ongoing innovation—a challenge greatly heightened by the global nature of supply chains and markets, and by the demand for low upfront costs and high profits.

When the European directives mandating electronics recycling (the WEEE directive) and hazardous materials restrictions (the RoHS directive)[67] were initially proposed, they were met with resistance by manufacturers. But nearly five years after their enactment, more electronics are being sold than ever, and manufacturers' profits continue to grow. Clearly, requiring manufacturers to take an active role in recycling has not proven an impediment to business success. Similarly, restricting the use of hazardous materials from electronics has not stifled innovation. The challenge is how to build on these programs in ways that continue the progress already made in identifying and eliminating hazardous materials from both electronics production and finished products as well as in increasing the rates of collection and responsible recycling.

In the years since these directives were enacted, knowledge and awareness of the environmental health impacts of many of the materials used in electronics production has grown considerably. So has work in the fields of design-for-the-environment and green chemistry—both aimed at designing new materials and products that are environmentally benign and safe for human health, as well as resource efficient, at every stage of a given product's life. In the U.S., new chemicals policies, at both the federal and state level, increasingly include support for safe alternatives to materials being restricted. Expanded support for green chemistry and design-for-environment programs, particularly efforts that would facilitate a holistic consideration of product design from an environmental health perspective–combined with requirements for full disclosure of chemical constituents and strong testing for toxicological and environmental hazard traits–would be an important step forward in reducing the ecological footprint of consumer electronics.

Greener design standards, and public support for the requisite innovation, can establish a common market starting point for e-waste reduction, as we have begun to see in Europe. Achieving these goals, however, requires extensive cooperation and commitment on the part of manufacturers. The fact that electronics are produced globally, with most manufacturers using hundreds of different suppliers and production sites all around the world, significantly complicates the challenge. But the costs of failing to fully address these issues are increasingly apparent both in the U.S. and abroad. From the brownfields and Superfund sites left behind from the first decades of electronics manufacturing, to the e-waste dumps in developing countries, to the increasingly well-documented adverse health impacts of occupational and environmental exposure to hazardous chemicals and chemical interactions—the mounting toll of electronic waste and hazardous manufacturing processes can no longer be ignored.

If we accompany support for green innovation in product design with measures that compel innovation by forcing manufacturers to share in the costs of expanded recycling programs and other e-waste reduction strategies, we can begin to reduce the impacts of e-waste before a product enters the market, not simply by trying to intercept it before it reaches the trash bin. Accompanying such programs on the production side with purchasing policies that favor products with the lowest environmental impact would help shift the market. Some such programs exist along with those that rate or grade electronics on their environmental profile, but they need to be expanded and to become more proactive.

The biggest challenge: coping with the current e-waste explosion

While such efforts would improve the environmental profile of electronics for the future, they do not address the most challenging aspect of e-waste—its growing volume in the near term. There are numerous challenges in this arena, not least among them the backlog of used and obsolete electronics poised to enter the waste stream. But the biggest challenge is that the number of electronics being produced and sold continues to grow. The Computer Industry Almanac projects that by 2014, annual computer sales (desktop and laptops combined) will reach nearly 147 million, up from the 2010 figure of nearly 118 million.[68] Forrester Research projects combined U.S. computer sales between now and 2015 at "nearly half a billion."[69] World cell phone sales are expected to double in the same time period.[70]

While it may often be valid to question the need for the next new digital device, clearly this is not an effective strategy for reducing the volume of used electronics. Nevertheless, as the sales volumes grow, we can begin to craft policies that compel manufacturers to internalize the costs of e-waste and close the life-cycle and production loop in ways that extend product life-spans and reduce perceived disposability. Such measures might include common rules to improve product warranties, or manufacturers' programs dedicated to servicing and repair of existing equipment without the per-incident charges to the customer that deter repair; making repair manuals public and available could also be helpful. Some such programs already exist and are effective at extending product life-spans. We could think about extending such programs into newer problem areas such as battery replacement for handheld devices.

We need to make it easier and more convenient to recycle. There are already many voluntary models for this. For example, in April 2010—in honor of Earth Day—Target announced that it was putting recycling bins in front of many of its stores, including bins for MP3 players. Apple will take back an old iPod for recycling and give a customer 10 percent off the cost of many new iPods. The U.S. Postal Service introduced a program in the past year that provides envelopes for recycling small electronics. Many cell phone service providers have on-site phone recycling and mail-in take-back programs. But these programs are not widely publicized, and it is not sufficiently easy for individual consumers to remove personal data from their equipment—to name only two continuing barriers to the success of these voluntary recycling strategies. In addition, such public collection programs often do not disclose the recycling companies used, making it difficult to determine where the equipment is going.

We should also consider more direct recycling strategies, particularly those that expand extended producer responsibility. For example, we could require (or create incentives for) specific recycling between old and new devices: to purchase a new device, we would be encouraged to return an old device to its manufacturer for recycling or reuse and receive a new purchase discount.[71] This might go a long way toward getting stored obsolete electronics into the recycling and reuse stream—and, by increasing the volume of used equipment for which manufacturers had to take responsibility, it might motivate manufacturers to invest in design-for-environment efforts. Such a program could be crafted in a way that would not discriminate against those who were first-time electronics buyers, especially since that population is shrinking rapidly. Again, such expanded take-back programs do not guarantee that we'll produce and consume fewer devices overall, but they will help to close the loop of the overall e-waste stream.

Where we are and why we must take action

To recap: electronics recycling is now mandatory in the EU, Japan, Taiwan, Australia and South Korea. In the U.S., about two dozen states have now passed some kind of electronics recycling bill. The Electronics TakeBack Coalition estimates that about 61 percent of the U.S. population is now covered by a state recycling law. However, while these state programs include a variety of products, they still only cover a small range of products compared to recycling programs in other countries, and they do not include effective mechanisms to ensure that they will eventually result in the collection and responsible recycling of all older products. A number of states have also barred certain electronics (primarily CRTs) from local landfills and incinerators, but in the majority of states it is still permissible to toss consumer electronics in the trash. Most major electronics manufacturers now have take-back and recycling programs.

At the same time, there are now mandatory restrictions on using certain hazardous materials in electronics. While initiated in the EU, effectively these have become global standards. Additional restrictions on still other materials, primarily synthetic chemicals, have been enacted by individual countries and some U.S. States. Some such restrictions on chemicals used in electronics (on certain brominated flame retardants, for example) have prompted design changes in these products. Additionally, amid growing scientific, medical, and public concern about certain other chemicals that remain unrestricted, such as bisphenol A and phthalates from PVC, some manufacturers have begun to limit, or eliminate, their use of these compounds as well.

In the EU, it is illegal to export e-waste for any recycling that would take place under conditions less environmentally responsible than those operations would be in the country where that e-waste originated. The U.S. has no such policy and remains essentially the only industrialized nation that has not ratified the Basel Convention and its Basel Ban amendment that prohibits hazardous waste export from wealthy to less well-off countries. Enforcement of the EU export regulations is challenging, but it is taking place. In the U.S., opponents of e-waste export bans argue that such policies impede effective and efficient recycling. Proponents of such bans argue that their goal is to prevent shipments of obsolete equipment that cannot be repaired (and is essentially hazardous waste) to countries without proper recycling infrastructure.

Manufacturers and recyclers also caution that the current, often complex and confusing patchwork of take-back and recycling programs could be an impediment to expanded and improved recycling. But there are now dozens of successful and responsible electronics recycling businesses working with consumers on all scales—households, governments, institutions, and businesses of all sizes. They offer models to build on going forward. So, even as e-waste continues to grow, it is feasible to manage this waste without landfill and incineration, without relying on low-cost labor and environmentally harmful practices, and without insecurity of data and information.

Coordinating design innovation and recycling strategies

Most efforts in the overall strategy to curtail the dumping, landfilling, and incineration of electronics, and to compel more equipment into the responsible recycling and reuse stream, are currently aimed at the end of product life. The hazardous materials restrictions are also aimed at end-of-life impacts, but work as incentives to prompt changes at the design stage as well. We need to continue tackling the e-waste problems from both ends of the product life-cycle. We need to do so acknowledging that this is not a finite task but one of ongoing assessment of design to assure that new products meet, not only performance goals, but maximum resource efficiency and environmental health goals throughout a product's life.

In a number of ways, the high-tech electronics industry is being asked to go where no industry has gone on such a scale before. In Europe and Japan, producer responsibility has been applied to other products, such as packaging and cars, but no industry pushes products into the global market on the scale that high-tech electronics does. And no other industry employs a comparably complex global supply chain, both for manufacturing and for end-of-life materials recovery.

The idea of routinely thinking ahead to the end of a product's useful life at the initial stages of that product's design can seem antithetical to America's entrepreneurial culture, where putting the bottom line first, producing more and more, and seeking out speed, convenience, and the next new thing are dominant norms. Demanding environmental responsibility from high-tech industry challenges the very notion (and very American notion) of "business first"—succeeding not only by maximizing short-term profits but by beating competitors to market with the next new thing.

But increasingly, when it comes to hazardous e-waste, consumers and local governments are beginning to see the necessity of altering this equation. Many of the global electronics manufacturers are also beginning to understand and respond to this need. When synthetic chemicals that interfere with reproduction, development, metabolism, learning ability, and immune system health are turning up in newborns and toddlers, indeed in the vast majority of Americans tested by the Centers for Disease Control; and when toxic metals dumped overseas are coming back in toys that end up in our children's mouths; when communities all across the country are dealing with the economic and personal health impacts of local water and soil contaminated with carcinogenic chemicals left behind by earlier waves of electronics production—the case for change is increasingly self-evident.

If not addressed comprehensively, these problems will continue to accumulate. If left unchecked, it is not hyperbole to say that the environmental health impacts of e-waste, coupled with the companion costs of continually relying on new rather than recycled materials, pose significant, demonstrable risks for the environmental sustainability and social well-being of many communities worldwide. Without environmental sustainability and without safe and healthy workplaces and living conditions, social stability is undermined. Direct personal costs combined with the broader social costs of mitigating adverse impacts can weaken communities beyond repair.

We can't take back the millions of tons of electronics that have already gone to the world's landfills, but the same ingenuity and creative thinking we use to create digital products can be applied to the goal of reducing the waste they generate. We may not be able to recapture all of the heavy metals and the hazardous chemicals already at large in the environment, but we can push for policies and practices that will help us avoid a future where we compound such problems. Even if we have to pay a bit more for our cellphones and laptops and televisions, that increase will be a fraction of what it costs to clean a polluted aquifer or acres of contaminated soil, and to deal with the health care costs and other social costs related to these impacts. Perhaps we can consider slightly higher consumer prices as an insurance policy against future persistent, pervasive, and bioaccumulative toxic pollution.

V. Policy Recommendations

Here are six key approaches that will move us closer to reducing the ever-growing stream of e-waste:

» Expand existing extended producer responsibility take-back and recycling programs (voluntary and state-mandated) to cover a greater scope of products (from MP3 players and cell phones to computers and TVs, as well as peripherals, accessories, and batteries) and make these programs more obviously accessible and convenient to all consumers (from large business and institutional purchasers to individual households).

» End the export of hazardous e-waste for environmentally unsound and socially irresponsible materials recovery, processing, and disposal, following guidelines consistent with the Basel Convention and its Basel Ban amendment.

» Support research and development in green chemistry and engineering, around two goals: design-for-the-environment aimed at reducing use of hazardous chemicals and other materials in electronics production and finished products (from manufacture through end of product life); and design for materials recovery and reuse at the end of product life (in all categories of electronics).

» Expand the number of recyclers certified through the e-Stewards program and use of e-Stewards certified recyclers—including by large equipment purchasers and e-waste generators such as the U.S. government. This would ensure full downstream documentation of all electronics materials and data going into recycling, ensure that no equipment (whole or parts) can be exported for environmentally and socially irresponsible materials recovery and recycling, and that prison labor is not used for recycling. Working with existing requirements of the EU's WEEE directive,[72] require manufacturers to provide information on the full scope of potentially recoverable materials in products, including updates on new products or product models as they enter the market.

» Prohibit the deposit of any electronics or components (including batteries) in landfills or incinerators.

» To ensure safety for workers engaged in manufacturing, materials recovery, and recycling operations, as well as consumer and environmental health and safety, expand existing workplace "right-to-know" provisions to cover all facilities in a manufacturer's supply chain, so that workers are informed of the use of and potential exposure to any hazardous chemicals and materials. This documentation would require manufacturers to provide information on the full scope of materials in products and manufacturing processes, including updates on new products or product models as they enter the market. Only materials documented to be free of toxicological and environmental hazard traits would be free of such requirements (the preferred guidelines for identifying such hazards are outlined in a framework developed by the California Environmental Protection Agency's Office of Health Hazard Assessment–*Green Chemistry Hazard Traits, Endpoints and Other Relevant Data*, August 2010 draft).[73] Further, to better assess and prevent occupational illness in manufacturing and recycling, expand workplace monitoring requirements to provide routine monitoring of worker exposure to hazardous chemicals and materials, as well as routine health monitoring for the workers.

Conclusion

The big wake-up call on the impact of e-waste came to the U.S. almost ten years ago, when shocking pictures of electronics exported to primitive recycling workshops in China and India were brought to public attention in the 2002 film "Exporting Harm" and its companion report from the Basel Action Network and the Silicon Valley Toxics Coalition. Hundreds of reports and studies have followed, documenting the adverse environmental and social impacts of uncontrolled and improperly handled e-waste. Awareness of these issues has certainly grown.

Since 2002, hundreds and thousands of hours have gone into efforts at crafting programs and drafting legislation that would facilitate and mandate improved practices for recycling, reuse and product design. Twenty-three U.S. states have now passed an electronics recycling bill. Electronics manufacturers continue to expand their voluntary take-back and recycling programs. Federal bills aimed at tackling different aspects of the e-waste problem—export rules, government-owned equipment (in EPA-funded programs among others)—have been drafted. But all this work has made only a tiny dent in the e-waste problem. According to the EPA, the growth rate in recycling has only been about 3 percent over the last five years. Clearly we have to do better.

E-waste regulation has been a consistent issue for state and local policymakers since about 2002. The issue makes headlines when something goes wrong: discovery of used electronics being dumped outside of Lagos, Nigeria; a California recycler arrested for fraudulent documentation; a truck full of old TVs crashing on a Texas highway, leading to a nearly decade-long dispute over who's responsible for the hazardous waste. But for the most part, we, the broader public, continue buying new computers, the latest "smart" phones and e-book readers, and much more, without thinking much about the material impacts of our digital devices.

Back in 2004, the *Wall Street Journal* called e-waste "the world's fastest growing and potentially most dangerous waste problem."[74] The United Nations Environment Programme has said that "e-waste represents the biggest and fastest growing manufacturing waste."[75] EPA Administrator Lisa P. Jackson has called e-waste an "urgent concern" and says the EPA will work to improve electronics design, production, and end-of-life.[76] Many significant improvements have been made over the past six years to increase the per unit resource efficiency in semiconductor production and to reduce the hazardous waste associated with production of semiconductors, silicon wafers and other electronics components. At the same time, electronics manufacturers have complied with the RoHS directive and a number have taken additional voluntary steps to eliminate other chemicals of concern from their products.

Yet during this same time period, technology has continued to advance, and sales volumes have continued to skyrocket, presenting new and bigger e-waste challenges. A cell phone today can be more powerful than a computer considered state of the art just three years ago. Of course, the next new thing is far more exciting than thinking about the best way to sort and take out the trash. But to achieve these feats of apparent digital wizardry, the materials profile of the latest generation of many devices—particularly "smart phones"—has become even more complex. And in terms of sheer volume, the scope of electronics consumption overall is compounding at a startling rate.

In managing both the volume and complexity of our mounting e-waste, we are way behind the curve. But it is well within our means—our ingenuity and resources—to bring this problem under control. The more we delay, however, the higher the costs will be, making change less affordable and less likely in the future.

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