3 The Toxic Content of Cell Phones and Other Electronic Devices

Cell phones and other small electronic devices contain a large number of hazardous substances. Some of these, such as cadmium, have long been known to have serious impacts on the environment and public health. This chapter will focus on two substances at the center of the current policy debate on the hazardous content of electronic products, brominated flame retardants and lead solder, as well as on several less well-known materials found in these products.

It should be noted that these substances are not known to pose threats to the environment or public health while the devices are being used. Rather, their hazardous effects occur upstream — during materials extraction and processing — and at end of life, when cell phones and other wireless products are incinerated or disposed of in landfills, and during recycling processes such as shredding, grinding, melting, plastics extrusion, and metals processing.[1] This chapter will focus on cell phones, but the toxic materials discussed are contained in components of wireless devices in general.

Persistent, Bioaccumulative Toxins: A US EPA Target

Many of the substances discussed in this chapter are on the US Environmental Protection Agency's "Draft RCRA Waste Minimization List of Persistent, Bioaccumulative, and Toxic Chemicals" (PBTs). This list (see Appendix A), published in November 1998, comprises the "priority" PBTs that may be found in hazardous wastes regulated under the Resource Conservation and Recovery Act of 1976. US EPA has set a national goal of reducing the quantity of these PBTs present in waste by at least half by 2005.[2]

The EPA's PBT list is a product of politics as well as science. There has been intense lobbying over what substances should be included, with some being omitted because their impacts have not yet been thoroughly documented. Nevertheless, the list is a good starting point for gaining insight into the problems posed by the toxic content of cell phones and other wireless electronic products. Finally, the hazard ratings referred to in this chapter are from a slightly earlier version of the EPA's PBT list;[3] the final list did not rank the chemicals as to degree of hazard.

Dangers of PBTs

PBTs are persistent in that they linger in the environment for a long time without degrading, increasing the risk of exposure to human beings. They can also spread over large areas, moving easily between air, water, and soil, and have been found far from the areas in which they were generated. PBTs accumulate in the fatty tissues of human beings and other animals, increasing in concentration as they move up the food chain. As a result, they can reach toxic levels over time, even when released in very small quantities.[4]

According to the EPA, "PBTs are associated with a range of adverse human health effects, including damage to the nervous system, reproductive and developmental problems, cancer and genetic impacts."[5] Children are particularly susceptible because they weigh less than adults and their immune systems are less developed. Some PBT-containing products, such as lead-based paints, have been banned in the US, but many PBTs continue to be used in electronic products.

PBTs found in cell phones include arsenic, antimony, beryllium, cadmium, copper, lead, nickel, and zinc. (Cell phones also contain toxic substances not included on the EPA's list of PBTs, such as brominated flame retardants.) The amount of PBTs contained in a single cell phone or similar product is small, but the number of such devices entering the waste stream is increasing rapidly. Indeed, the small size of these products increases the likelihood that they will be thrown in the trash and sent to incinerators and landfills, where environmental contamination can occur from combustion and leaching into soil and groundwater. For this reason, reducing the PBT content of cell phones and other electronic products, and managing them properly at end of life, are essential to preventing damage to the environment and public health.

Toxic Substances Targeted by Companies

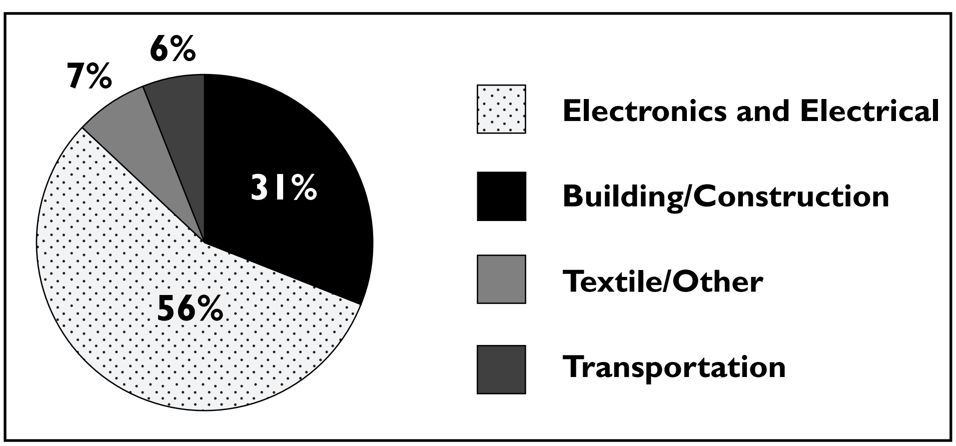
In Scandinavia, two companies have compiled lists of toxic substances of concern in cell phones and other electronic devices.

Denmark S/D, the country's largest telecommunications service provider, has undertaken a project that aims to develop "green" procurement guidelines for manufacturers of cell phones and other telecommunications products, and a system for providing product information to consumers. A questionnaire developed by the company for its vendors (see Appendix B) indicates the materials of concern and the components that need to be easily separated for disposal. Almost all the chemicals included in this questionnaire are on the EPA's PBT list.

In Sweden, the large cell phone producer Ericsson has posted on its website a list of substances that are restricted or banned from its products and from products it purchases from other suppliers (see Appendix C). While lead solder is merely restricted and not banned at present, Ericsson expects 80 percent of its new products to be lead-free, 80 percent of its printed wiring boards to be halogen-free, and all of its products to be beryllium-free by 2002.[6] Two categories of brominated flame retardants, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs), are already on Ericsson's list of banned substances.

Brominated Flame Retardants

Figure 3.1 Uses of Brominated Flame Retardants

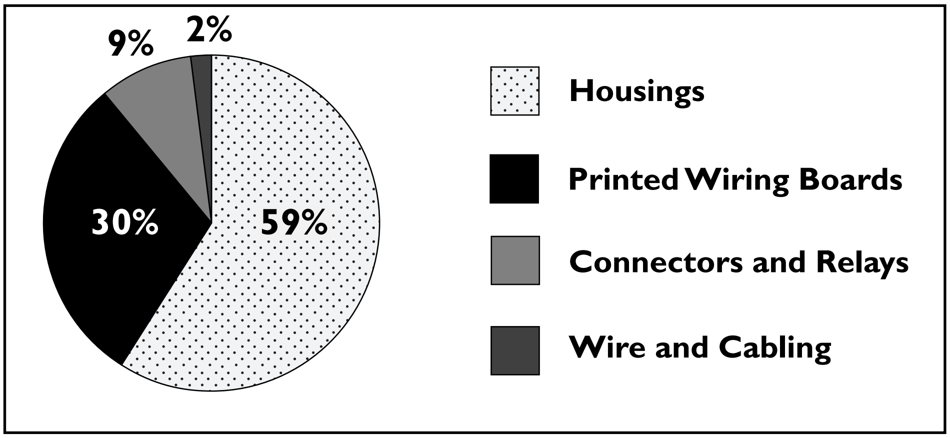


Source: Bromine Science and Environmental Forum

In electronic products such as cell phones, plastics are used in the printed wiring board and in cables, housings, and connectors. Because plastics are highly flammable, a flame retardant is typically added to reduce the risk of fire. According to the Bromine Science and Environmental Forum (BSEF), an industry trade association, 39 percent of all flame retardants are brominated.[7] Others are based on chlorine, phosphorous, nitrogen, or inorganic materials.

Figure 3.1 shows the various uses of brominated flame retardants. Electrical and electronic products are by far the largest application, at 56 percent.[8] In the past, electrical and electronic products contained either chlorinated or brominated flame retardants, both of which are known as halogenated flame retardants.* When they were found to have damaging effects on the environment, chlorinated retardants were replaced by the brominated variety.

Figure 3.2 Consumption of Brominated Flame Retardants in Electronic and Electrical Products



Source: Bromine Science and Environmental Forum

Environmental and Health Impacts

Brominated flame retardants in electrical and electronic products are primarily used in printed wiring boards and plastic housings (Figure 3.2).[9] There are a number of different types of brominated flame retardants (see box), some of which are clearly damaging to the environment and human health; the impacts of others are still being evaluated. Research indicates that brominated flame retardants can be persistent, bioaccumulative, and toxic, and that they can leach into soil and groundwater from landfills.[10] The presence of copper, widely used in printed wiring boards, increases the risk that brominated flame retardants will form dioxins and furans during incineration. (Dioxins and furans are polychlorinated organic compounds, some of which are known to be highly toxic to animals.) This risk is further exacerbated by incomplete combustion when incinerators operate at too-low temperatures.[11]

Brominated Flame Retardants

Hexabromocyclododecane (HBCD)
Polybrominated biphenyls (PBBs)
Polybrominated diphenyl ethers (PBDEs)

- Decabromodiphenyl ether (Deca-BDE)
- Octabromodiphenyl ether (Octa-BDE)
- Pentabromodiphenyl ether (Penta-BDE)

Tetrabromobisphenol (TBBP-A)

Source: Bromine Science and Environmental Forum, "An Introduction to Brominated Flame Retardants," October 19, 2000, 4.

Brominated flame retardants can also generate dioxins and furans during recycling and smelting, thereby creating an obstacle to the recycling of plastics from electronic products. According to a study published by Environment Canada, most recyclers do not process plastics from electronic equipment, because they are unable to determine which ones contain brominated flame retardants.[12]

* The word halogenated derives from the Greek for "salt former." These substances commonly react in nature with metals to form salts.

Table 3.1 Total Market Demand for the Major Brominated Flame Retardants, 1999 (metric tons)

Type of Brominated Flame Retardant	Europe	Americas	Asia	Total
Tetrabromobisphenol (TBBP-A)	13,000	21,600	85,900	121,300
Hexabromocyclododecane (HBCD)	8900	3100	3900	15,900
Decabromodiphenyl ether (Deca-BDE)	7500	24,300	23,000	54,800
Octabromodiphenyl ether (Octa-BDE)	450	1375	2000	3825
Pentabromodiphenyl ether (Penta-BDE)	210	8290	--	8500
Total	30,860	58,665	114,000	204,325
	15.1%	28.7%	56.2%	100%

Source: Bromine Science and Environmental Forum, July 2000.

Polybrominated biphenyls. PBBs are persistent and insoluble in water. They can enter aquatic systems from manufacturing facilities and landfills, spread widely, and become a part of the food chain after consumption by fish (they have been found in the Arctic in the tissues of seals). PBBs can form dioxins and furans during recycling or incineration, and are associated with increased risk of cancer, disruption of the endocrine system, and illnesses of the digestive and lymphatic systems.[13]

Production of PBBs has been banned in the US since 1977. According to BSEF, PBBs are no longer produced anywhere in the world and there is no market for them.[14] They are still a concern, however, because of their presence in old electronic products, which will continue to enter the waste stream for many years. In addition, the possibility exists that production of these substances could resume in the future.

Polybrominated diphenyl ethers. PBDEs are associated with cancer, liver damage, neurological and immune system problems, thyroid dysfunction, and endocrine disruption.[15] Like PBBs, they can create dioxins and furans when burned or during recycling.[16]

Concern over PBDEs is on the rise, particularly since Swedish studies found a 50-fold increase in their concentration in human breast milk between 1972 and 1997. PBDEs have also been found in the blood of workers at a Swedish electronics recycling facility and in breast milk and fish in Japan.[17] In 2001, high levels of PBDEs were found in salmon in Lake Michigan, prompting a new study of the impacts of these chemicals.[18] They have also been found in fish in Virginia.[19] A study released in December 2001 by Environment Canada found extremely high levels of PBDEs in the breast milk of North American women — 40 times higher than the highest levels found in Sweden.[20]

Regulating the Use of Brominated Flame Retardants

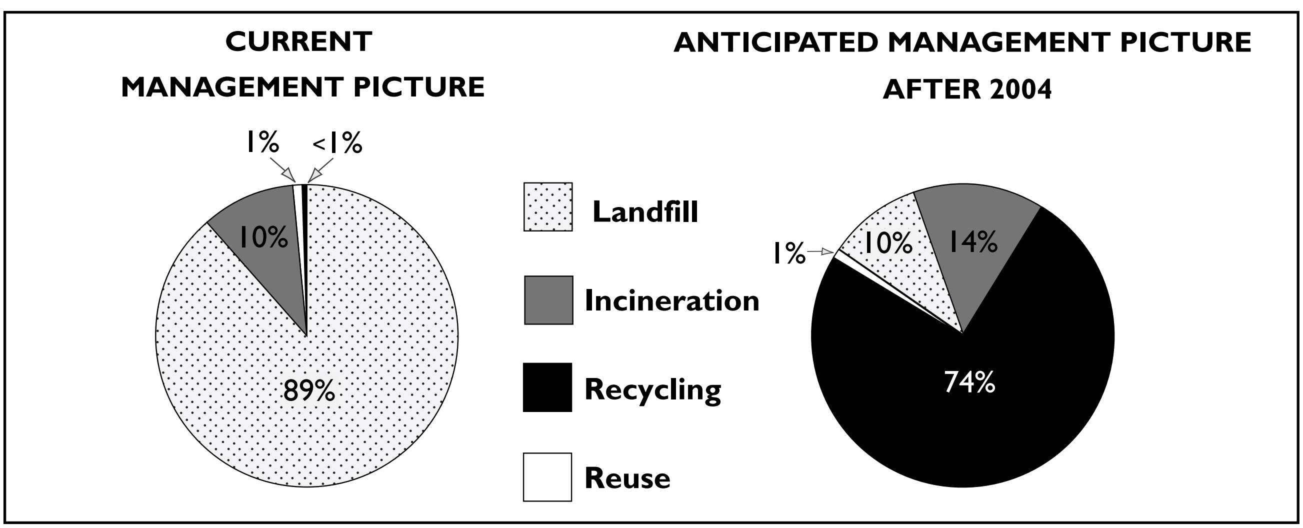
Certification programs. In Europe, popular eco-labeling programs such as the German Blue Angel and the Scandinavian White Swan do not award their labels to products that contain PBBs or PBDEs. In Sweden, the TCO eco-label program has established specific criteria for cell phones covering a broad range of issues, from ergonomics to electromagnetic fields. Cell phones receiving this label may not contain any chlorinated or brominated flame retardants in plastic components weighing over 10 grams or in plastic laminates.[21]

Companies that obtain certification of their products by an eco-label program do so voluntarily. Thus, these programs do not carry the same weight as regulations that impose outright bans or limitations on the use of brominated flame retardants and other hazardous substances.

Government regulations. There have been moves to phase out or limit the use of PBDEs in a number of European countries, including Germany, the Netherlands, and Sweden. In 1995, the Organisation for Economic Cooperation and Development (OECD) reached a voluntary agreement with industry to reduce the use of PBBs and PBDEs. In September 2001, the European Parliament took a tough stance on PBDEs, voting to phase out penta-, octa-, and deca-PBDEs in electrical and electronic products as part of the European Union's (EU's) forthcoming *Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment*, or RoHS directive (discussed in chapter 5). This decision was strongly opposed by industry and was made despite the fact that risk assessments being conducted by the EU were not yet complete.[22] The RoHS directive, along with the EU's forthcoming *Directive on Waste Electrical and Electronic Equipment*, or WEEE directive (also discussed in chapter 5), are expected to have a major effect on the design, production, and end-of-life management of electronic products.

Figure 3.3 looks at the ways in which plastic wastes containing brominated flame retardants are currently managed in Europe versus their anticipated management after the WEEE and RoHS directives take effect. Recycling of these plastics is expected to increase from less than 1 percent to 74 percent,* while landfilling is expected to

Figure 3.3 Management of Plastic Wastes Containing Brominated Flame Retardants in Europe



Source: INFORM, Inc., based on data from Bromine Science and Environmental Forum.

* Energy recovery is expected to account for 4 percent of this recycling.

drop from 89 percent to 10 percent and incineration is expected to increase from 10 percent to 14 percent. Reuse is expected to remain at 1 percent. After 2004, however, BSEF expects less than 25 percent of plastic wastes containing brominated flame retardants to end up in disposal facilities — a dramatic change in these materials' end-of-life management.[23]

Industry opposition. The bromine industry vigorously opposes a blanket ban on brominated flame retardants. The Bromine Science and Environmental Forum claims that bromine is not a toxic substance — that in fact it is used in cough medicine. It argues that flame retardants based on bromine are the most effective type with respect to both performance and cost because they provide the highest level of fire protection for the smallest quantity used. BSEF also says it is not clear that alternatives to brominated flame retardants are less harmful to the environment and human health. Consistent with this position, the bromine industry is studying the feasibility of recovering bromine from waste plastics for use in a "closed-loop" system of bromine manufacture.[24]

With respect to specific types of brominated flame retardants, BSEF claims that octa- and deca-BDE are not dangerous and do not bioaccumulate. Contrary to the view of many government officials and environmentalists, the trade group insists that the PBDEs found in breast milk and in the blood of electronics recycling workers present no health risks.[25] BSEF also claims that dioxins and furans are not a concern with new incinerator technologies, that brominated flame retardants do not hamper the recycling of plastics, and that waste-to-energy conversion of plastics containing these substances is safe (in waste-to-energy conversion, materials are burned to recover energy). Further, the group claims that the trend toward increased quantities of PBDEs in breast milk, evident since the early '70s, has been reversed, with concentrations dropping 30 percent from 1997 to 2000.[26]

The issue of tetrabromobisphenol (TBBP-A). A ban on all brominated flame retardants would also include TBBP-A, which is used in 96 percent of printed wiring boards and accounts for over half the total market volume of brominated flame retardants. While there are suspicions that TBBP-A has damaging environmental effects similar to those of PBBs and PBDEs, this has not been demonstrated. Its phaseout under the EU's forthcoming regulations is under debate.

In a publication on brominated flame retardants, BSEF cites a World Health Organization assessment that TBBP-A has little potential to bioaccumulate and that "the risk for the general population is considered to be insignificant."[27] US EPA, however, recently added TBBP-A to its Toxics Release Inventory,* citing the chemical's properties of persistence, bioaccumulation, and toxicity.[28] Finally, an Environment Canada study states that TBBP-A is persistent, highly toxic to aquatic life, and suspected to bioaccumulate.[29]

Industry Efforts to Eliminate Brominated Flame Retardants

Leadership in eliminating brominated flame retardants is coming from companies in Europe and Japan. The Swedish phone giant Ericsson backs the bromine-free lobby and plans to eliminate bromine from 80 percent of the printed wiring boards in new products.[30] Sony's Green Management Plan calls for the elimination of brominated flame retardants from its products by 2003.[31] Other major electronics producers, such as Phillips and NEC, are also working to replace brominated flame retardants in their products. The majority of these efforts involve the use of flame retardants based on phosphorus, which does not contribute to the creation of dioxins and furans when products are incinerated or recycled.

* The federal Toxics Release Inventory (TRI) program collects data on the quantities of nearly 650 toxic chemicals released by industrial plants into the air and water, and incinerated, recycled, treated, and disposed of on-site and elsewhere.

US companies are also developing alternatives to brominated flame retardants, but they are moving more slowly and have not made any explicit commitments to eliminate specific amounts from their products. Rather, they are including reduction of hazardous substances as a general goal in their environmental programs and are eliminating brominated flame retardants from selected products. For example, one of Motorola's phones is now free of brominated flame retardants. Intel, a major supplier of integrated circuits and printed wiring boards, reports that most plastics in its products no longer contain brominated flame retardants, and none have PBBs or PBDEs.[32] On the other hand, the American Electronics Association has joined the bromine industry in opposing restrictions on brominated flame retardants.

Other Efforts

An alternative to finding substitutes for flame retardants is to redesign products so that flame retardants are not required. Researchers at Delft University of Technology in the Netherlands have found that the environmental impacts of printed wiring boards could be substantially reduced if brominated flame retardants were eliminated. They suggest using printed wiring boards on a base of polyimide (plastic) foil, which would have such a high flaming point that no retardants would be needed. Moreover, these components would be no more expensive than the currently used boards made of fiberglass and epoxy resins.[33]

Elimination of brominated flame retardants from electrical and electronic equipment is a goal of a number of environmental groups in the US and abroad. Michael Bender, a consultant to the Silicon Valley Toxics Coalition, has circulated a resolution calling on the US Congress to expand monitoring of brominated flame retardants in human beings, require their phaseout by 2006, and, in the interim, require labeling of products containing these substances.[34] Friends of the Earth, based in Europe, has launched a campaign to boycott products containing brominated flame retardants. In 2002, US EPA, Region IX (in California), will convene a multi-stakeholder roundtable focused on brominated flame retardants and their alternatives in electronic products. One issue to be addressed is whether PBDEs should be included on the EPA's list of persistent, bioaccumulative, and toxic chemicals targeted for waste minimization.

Lead

As noted earlier, US EPA's original list of persistent, bioaccumulative toxins ranked these chemicals as to degree of hazard. On this list, lead was ranked number one.

Lead is ubiquitous in electronic products, including cell phones, and is used in various components and coatings. An important application is in tin-lead solder — the primary means of attaching electronic components to each other and to the printed wiring board. An estimated 100,000 to 125,000 tons of lead solder are produced globally for the electronics industry each year.[35]

Lead in Municipal Solid Waste

In a study performed for US EPA in 1988, 40 percent of the lead in US landfills was found to be from discarded electrical and electronic products, principally the picture tubes of TVs. Apart from TVs, electrical and electronic products accounted for 4.4 percent of the lead found in municipal solid waste.[36]

Like brominated flame retardants, the quantity of lead contained in small electronic devices such as cell phones is small. Compared to a single TV picture tube, which may contain 4 to 8 pounds of lead, the printed wiring board of a cell phone contains about 50 grams per square meter,[37]or about .01 ounce of lead. However, the short life of cell phones means that large numbers are discarded each year, and because they are small, they are more likely than larger devices to be thrown in the trash and sent to incinerators and landfills, where environmental contamination can occur from combustion and leaching into soil and groundwater. Lead can also be released into the environment during recycling.

In the US, the lead solder contained in the printed wiring boards of the 130 million cell phones estimated to be retired in 2005 (see chapter 2) will generate approximately 1.3 million ounces, or 81,250 pounds, of lead waste. And printed wiring boards contained in the estimated stockpile of 500 million retired cell phones, once discarded, will put 312,500 pounds of lead into the environment.

Environmental and Health Impacts

A heavy metal found in food, soil, and dust, lead enters the food chain through atmospheric deposits on plants and absorption from the soil. It can also contaminate drinking water by leaching into groundwater from sources such as landfills. Lead is suspected of being carcinogenic, has adverse impacts on the central nervous system, the immune system, and the kidneys, and has been linked to developmental abnormalities. Lead poisoning in children can lead to impaired intelligence, hyperactivity, and aggressiveness.

Lead is regarded as a problem material throughout the world. According to the United Nations Environment Programme, it is "a substance that requires regulation on a global level with binding conventions."[38] The forthcoming EU directive on electrical and electronic waste, which requires the phaseout of lead solder, states that lead "accumulates in the environment and has acute chronic toxic effects on plants, animals, and microorganisms."[39] In the US, the EPA has slashed the threshold reporting levels for lead under the Toxics Release Inventory from 25,000 to 100 pounds per year because of concern over its environmental and health impacts.

Replacing the Lead in Solder

Replacing the lead in solder can be complicated and costly. Among the metals being considered are various combinations of tin, copper, silver, bismuth, antimony, indium, germanium, and zinc. Different materials are being used in different applications, but the most frequently used substitute is a tin-silver-copper alloy.[40] Almost all these alternatives have significantly higher melting temperatures than lead, requiring higher processing temperatures during manufacturing (Table 3.2). This, in turn, may mean that printed wiring boards will have to be redesigned so that the materials they contain can withstand higher temperatures.

Table 3.2 Melting Temperature of Different Types of Solder

Alloy	Melting Point (° C)
Tin-Lead	183
Tin-Bismuth	138
Tin-Zinc	198.5
Tin-Copper	227
Tin-Silver	221
Tin-Silver-Copper	217
Tin-Silver-Copper-Antimony	213–218
Tin-Silver-Bismuth	205–210
Tin-Silver-Bismuth-Copper	217–218
Tin-Silver-Bismuth-Copper-Germanium	210–217
Tin-Silver-Indium	179–218

Source: Adapted from Laura J. Turbini *et al.*, "Examining the Environmental Impacts of Lead-Free Soldering Alternatives," *Proceedings of the 2000 IEEE International Symposium on Electronics and the Environment*, 48.

There are questions as to whether lead-free solders will compromise the performance of electronic components. They may also have the effect of reducing the recycling value of cell phones and other devices if the high temperatures involved in separating the components cause some to be destroyed in the process. Another trade-off is energy use: higher melting points mean more energy used in manufacturing, which increases costs and is detrimental to the environment. Despite these concerns, however, there is strong momentum around the world toward a transition to lead-free solder. (An interesting alternative to finding substitutes to lead in solder is eliminating solders from printed wiring boards altogether, and replacing them with adhesives.[41])

Industry Efforts to Eliminate Lead from Solder

The three largest semiconductor manufacturers in Europe — Philips (Netherlands), Infineon (Germany), and ST Microelectronics (Switzerland) — have called for international standards for eliminating lead from solder. Noting that lead is found in nature with other metals and not all traces can be removed, they have agreed to define "lead-free" as less than 0.1 percent of a single material.[42] In the US, the world's largest semiconductor manufacturer, Intel, defines a lead-free product as one "to which lead or lead compounds have not been intentionally added."[43] Clearly, there is a need for a uniform, global definition of lead-free.

Japan. The Japanese electronics industry is the world leader in the use of alternatives to lead in solder. A requirement to phase out lead in electronic products is expected soon,[44] and a mandate from the Ministry of Economy, Trade, and Industry (METI, which was formerly the Ministry of International Trade and Industry, or MITI) requires that manufacturers recycle lead-containing appliances and document their lead content.[45] Market pressures, too, have generated competition among the large electronics manufacturers to introduce lead-free products as soon as possible. Sony has actually been able to increase its market share in Japan by offering such products.[46]

Meanwhile, Fujitsu has announced plans to eliminate lead solder from all its printed wiring boards by December 2002.[47] Other leading companies, including Sony, Panasonic, Hitachi, Mitsubishi, Toshiba, NEC, Sharp, and Seiko Epson, have plans to produce lead-free products within the next two years for the Japanese market and ultimately worldwide.[48]

Europe. Additional pressure to eliminate lead is coming from Europe, where the focus has been on regulation. The EU's forthcoming RoHS directive will require elimination of lead from electrical and electronic products sometime between 2006 and 2008 (the date is still under discussion).

Philips, Infineon, and ST Microelectronics are working together to set the ground rules for lead-free solder (including a consistent definition of lead-free). These companies anticipate introducing their lead-free products well in advance of the EU deadline.[49] The Global Environment Coordination Initiative (GECI), an alliance of electronics assembly firms formed in Brussels in July 2001, also says it can convert to lead-free solder long before the EU deadline. It targeted the end of 2001 for consumer electronics and cell phones, 2002 for laptop computers, and 2003 for desktop computers.[50]

In Sweden, the TCO eco-labeling program requires that, in cell phones, "the batteries, paint, lacquer and plastic components...shall not contain any lead."[51] This means that a product with lead solder can still receive the TCO label, although the organization expects to add lead-free solder to its labeling requirements in the next few years.[52] Both Nokia (Finland) and Ericsson (Sweden), two of the world's top five cell phone producers, plan to eliminate lead from their products by 2002.[53]

North America. In Canada, Nortel has developed a lead-free phone that it claims performs better than those made with lead-based solder.[54] In the US, Motorola has developed a phone with 95 percent less lead than its conventional phones but has not yet marketed it.[55]

The electronics industry in the US is moving much more slowly than industry in Europe and Japan, although developments abroad are having a significant impact. Since most electronic products are globally designed — that is, if they have to be lead-free in Europe and Japan, they will probably be made lead-free throughout the world — US companies are making substantial investments in research on substitutes for lead.

A major concern of the US electronics industry is the business risk involved in offering lead-free products when the replacement materials may themselves turn out to have detrimental health and environmental impacts. The Electronics Industry Alliance (EIA) — a major US trade association — opposes the forthcoming lead ban in Europe, but acknowledges that lead is damaging to the environment and public health. However, the group claims that "there has never been a scientific study to assess the environmental risks posed by the various lead-free solders under consideration and study as substitutes for lead solder."[56] The EIA is participating in a partnership with the EPA to perform life-cycle analyses of lead-based solder and its alternatives.

A recent report from Hewlett-Packard provides some insight into the views of an important US electronics manufacturer on this issue. HP acknowledges that its efforts to phase out lead have been driven by the EU's forthcoming directives and by market forces in Japan. It describes removing lead as a "daunting challenge" similar to the hypothetical task of changing a person's blood type. This is because lead solder is such an important factor in the design and manufacture of electronics products and the entire electronics supply chain.[57]

HP is concerned about the effects on costs and product performance of the high melting temperatures of lead-free solders. It notes that silver (a component of many potential substitutes) is toxic, has an exposure limit only three times greater than that of lead, and can more readily enter the water supply — all of which raise questions about its suitability as a substitute. (Silver was originally on the EPA's list of persistent, bioaccumulative, and toxic chemicals but was removed because of incomplete information.) HP is particularly interested in an alloy of tin, bismuth, and copper that has a lower melting point than tin-lead solder. The company cautions, however, that the supply of bismuth is limited, which could pose problems if its use in solders became widespread.* (It should also be noted that copper is on the EPA's Draft RCRA list of PBTs.)

HP believes there is "a shortage of compelling and credible scientific evidence that alternatives to lead in solder for electronics are better for the environment than the original tin-lead solder."[58] It is especially concerned about the possibility that replacements for lead could themselves be banned in the future. HP is urging the industry to work together on the issue and find a standardized solution that minimizes costs and keeps manufacturing complexity to a minimum. While a single substitute for lead may not be found for all products, the company believes that a small number of alternatives (preferably two) may be feasible.[59]

Intel, meanwhile, describes the transition to lead-free electronic products as "a massive undertaking." The company is particularly concerned about the impacts that lead-free solder may have on the compatibility of

* Other concerns about bismuth relate to its incompatibility with lead, which is likely to continue being used in coatings for several years. Also, the recycling process for bismuth is incompatible with the processes used for other metals, making it difficult to recover. See Cynthia Murphy and Gregory Pitts, "Survey of Alternatives to Tin-Lead Solder and Brominated Flame Retardants," *Proceedings of the 2001 IEEE International Symposium on Electronics and the Environment*, Institute of Electrical and Electronics Engineers, New York, 2001.

manufacturing processes across the supply chain, and is emphasizing the importance of establishing standards, identifying compatible technologies, and developing a conversion timetable. Intel also notes that the reliability of plastic components is affected by the high processing temperatures required by most lead-free solders, and that the costs of the replacement materials are higher than those of lead (Table 3.3).[60] On its website, Intel cites estimates that the material costs of eliminating lead in the US will be $140 to $900 million, with total supply chain costs likely to reach tens of billions of dollars.[61]

Debate Continues on Lead-Free Solder

Many US companies continue to oppose lead-free requirements through their trade associations. As already noted, the Electronics Industry Alliance opposes the EU's prospective ban but acknowledges that lead is a problem material. Another group, the Surface Mount Council, has argued that lead-free solders are no more friendly to the environment than lead, and that the focus should be on recovery and recycling rather than eliminating lead from products.[62] The US Chamber of Commerce has been pressing the European Parliament for exemptions to the EU's forthcoming ban.[63]

Table 3.3 Relative Costs of Lead Substitutes in Solder

Replacement Material	Relative Cost
Lead	1
Zinc	1.3
Antimony	2.2
Copper	2.5
Tin	6.4
Bismuth	7.1
Indium	194
Silver	212

Source: Todd A. Brady *et al.*, "Product Ecology at Intel," *Proceedings of the 2001 IEEE International Symposium on Electronics and the Environment.*

The industry's opposition to shifting to lead-free solder centers on three generic arguments often raised in connection with requirements to replace specific materials in products: 1) the change is too costly; 2) product performance will suffer; 3) the substitutes may be more damaging to the environment and public health than the original material.

Some researchers have rejected these arguments. For example, in a paper presented in 2001 at the Institute of Electrical and Electronics Engineers' annual symposium on electronics and the environment, researchers from the University of Tokyo and the Fraunhofer Institute in Berlin argued that eliminating lead, while posing some problems, will improve the environmental performance of electronic products. The researchers used "eco-indicator" systems developed in the Netherlands and Switzerland to compare lead and lead-free solders. They found that the substitute materials require increases in energy use of 15 to 50 percent, but saw the decreased toxicity benefits of the alternative materials as outweighing their negative energy impacts.

The University of Tokyo/Fraunhofer study also found that new production equipment can substantially reduce energy use, and that switching to alternative materials will lead to more new equipment being used. The researchers noted that eliminating lead from electronics products will increase their recycling value, since lead is a major contaminant and substitutes such as silver have considerable value. Despite the higher costs of the alternatives, they claimed that switching to lead-free solder will not increase the cost of printed wiring boards, because solder accounts for such a small percentage of total costs. Finally, the study pointed to one potential problem: switching to silver solders could consume 6 to 9 percent of the world's total output of silver, putting pressure on silver supplies. The researchers recommended the use of silver but emphasized the need for high rates of take-back and recycling.[64]

Other Hazardous Materials

Cell phones and other wireless electronic devices also contain cadmium and hexavalent chromium. It is well known that these substances — soon to be banned under the EU's forthcoming directives — are toxic and can have seriously harmful effects on public health. Cell phones also contain valuable materials such as gold, silver, palladium, and platinum, which should be recovered, reused, or recycled.

Other materials present in cell phones that pose threats to human health and the environment include beryllium, tantalum, arsenic, and copper.

Beryllium

In beryllium-copper alloys, the metal beryllium contributes hardness, strength, conductivity, and corrosion resistance. Beryllium-copper alloys usually contain about 2 percent beryllium.[65] In cell phones, they are used in springs and contacts that need to expand and contract.

Beryllium-copper has a worldwide market of 50 million pounds per year, with cell phones accounting for the largest share, at 15 million pounds. The US is the largest producer, processor, and consumer of beryllium. With the increased popularity of cell phones, production has soared.[66]

Beryllium can be a serious health hazard in manufacturing and recycling facilities. In the form of dust or fumes, it is one of the most toxic metals to inhale. Small particles of the metal can break off when products are shredded or heated and spread through the air. Workers who become sensitized to beryllium can suffer irreversible and sometimes fatal scarring of the lungs.[67]

Because of the serious dangers it poses to workers, the presence of beryllium in cell phones can be a significant barrier to recycling. For example, at Noranda Inc., a large Canadian metals producer that also recycles electronic products, a number of workers were diagnosed with chronic beryllium disease. As a result, the company has set a beryllium limit on used electronic products entering its recycling facilities. The limit is 200 parts per million in solid scrap and 50 parts per million in powdered scrap. Loads that exceed these limits are rejected.[68]

Tantalum

The precious metal tantalum has been a key factor in reducing the size of cell phones and other small electronic devices. Highly resistant to heat and corrosion, it is used in capacitors that control the flow of current inside small circuit boards. About 35 percent of the tantalum capacitors produced are used in cell phones. With cell phone use soaring, the price of tantalum rose from $20 per pound in the early 1990s to about $350 per pound in January 2001.[69]

The health effects of tantalum are not known, because little toxicity testing has been done. However, Malaysia's Environment Ministry has found tantalum dumps to be radioactive and has voiced concern that miners could suffer lung disease from exposure to the metal.[70] Recently, some impacts were documented in an article in *The New York Times Magazine*, which described how tantalum mining in Congo has overrun a national park and devastated its population of wildlife.[71] The article also cited a United Nations claim that tantalum mining is perpetuating Congo's civil war, with factions battling over control of this valuable metal.[72] To mitigate devastating environmental and social effects such as these in the future, reusing and recycling hazardous materials such as tantalum are essential.

Arsenic

Arsenic can cause damage to the nerves, skin, and digestive system, and can even cause death when ingested at high levels.[73]

The average cell phone contains five gallium-arsenic semiconductors, which are superior to silicon chips in these devices because of their ability to reduce static. These chips are harmless during use but create a toxic compound when cell phones are incinerated. In Japan, where an estimated 610 million cell phones will be disposed of by the end of 2010, there is some concern over the 93 kilograms (205 pounds) of potentially toxic arsenic contained in this waste.[74] In the US, the 500 million retired cell phones estimated to be stockpiled by 2005 will put 169 pounds of arsenic into the environment once discarded.

Copper

On the EPA's original list of persistent, bioaccumulative toxins, copper was ranked 41. Copper is used as an herbicide to kill algae in swimming pools and lakes. It is toxic to fish and bioaccumulates in marine organisms. Ingestion by humans can cause diarrhea, liver damage, and death. It is used extensively in cell phones and causes dioxins and furans to form when materials containing brominated flame retardants (such as printed wiring boards) are incinerated.