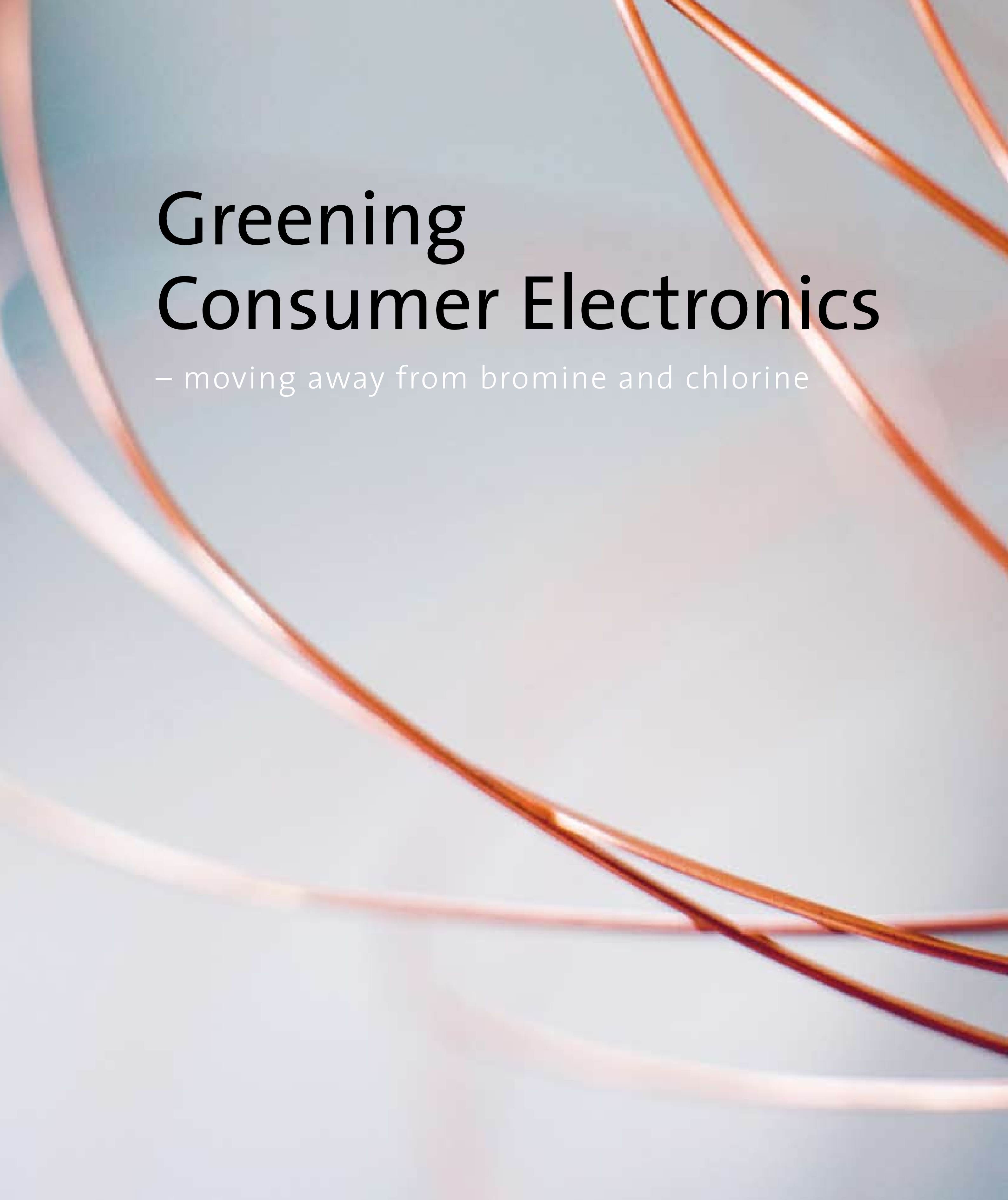
Greening Consumer Electronics

– moving away from bromine and chlorine



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CPA engages with businesses and NGO leaders to hasten the transition to an economy without harm. We coordinate the US-based Business NGO Working Group for Safer Chemicals and Sustainable Materials and we research and promote companies' efforts to transform the toxic chemical economy.

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Companies highlighted in this report have kindly contributed to the information provided in the substitution case studies. ChemSec and Clean Production Action are solely responsible for all other texts in this report.

Photo: Niklas Maupoix

PREFACE

Electronics manufacturers, standards bodies, and legislators have begun to take notice of the human health and environmental concerns associated with the use of brominated and chlorinated compounds in electronic products. An array of conflicting definitions and policies have emerged to address these concerns at various levels. This report is intended to show the feasibility of re-engineering consumer electronic products to avoid the use of these compounds and recommends a definition to address human health and environmental concerns that is implementable by industry.

CPA and ChemSec have compiled case studies that provide examples of seven companies that have removed most forms of bromine and chlorine from their product lines. The purpose of this report is to allow parties outside the industry to see the level of conformance that can be met today, as well as provide a tool for engineers designing the next generation of greener electronic devices.

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EXECUTIVE SUMMARY

THOUSANDS OF SUBSTANCES are used to meet the highly complex and technical performance requirements of today's electronic products. As growing volumes of consumer electronic products enter the waste and recycling streams, substances of high concern are unintentionally released into the environment. At present, the infrastructure to safely reuse and recycle obsolete equipment is insufficient. In addition, electronic waste, one of the fastest growing waste streams in the world, is increasingly exported to developing countries with even less capacity for appropriate waste management. In 2003, the European Union responded with two precedent-setting directives: WEEE, the Waste from Electronic and Electrical Equipment directive, which requires companies to take back and recycle their equipment; and RoHS, the Restriction of Hazardous Substances directive, which restricts the use of certain heavy metals and brominated flame retardants.

ROHS ESTABLISHED A DE FACTO GLOBAL ENVIRONMENTAL AND HUMAN HEALTH STANDARD that prompted companies to internally gain control over the chemicals used in their products. The directive required companies to better understand what chemicals are used in their products, how they are used, and to a lesser extent, what adverse effects they potentially have on human health and the environment. It also showed the importance of establishing chemical information systems throughout their supply-chains, as well as improving communication of these efforts and standards with customers, regulators, and consumers.

ENGINEERS THROUGHOUT THE ELECTRONIC SUPPLY CHAIN found ways to redesign products and develop new material streams to assure compliance with RoHS. Finding environmental solutions to RoHS restrictions did not curtail the continued development of reliable, new, and improved products with enhanced performance. Now many manufacturers are looking beyond RoHS and are restricting a more ambitious set of chemicals of high concern.

OF PARTICULAR CONCERN within the electronics sector is the widespread use of bromine- and chlorine-based compounds in many different electronic applications. High volume uses of bromine and chlorine in flame retardants and plastic resins like polyvinyl chloride (PVC) gained worldwide attention when scientific studies documented their link to the formation of dioxin, one of the most toxic chemicals synthesized. Dioxins and other harmful chemicals are released into the environment during the burning and smelting of electronic waste. Even the most sophisticated incineration facilities generate low levels of dioxin, but the most significant dioxin contribution occurs in developing countries whose facilities are not designed to handle toxic materials. Some of the unintentionally produced compounds are highly toxic, endocrine disrupting, and persistent, and are banned by the Stockholm Convention on Persistent Organic Pollutants (a treaty signed by 152 national governments).

THIS REPORT FEATURES seven electronics companies (two major consumer electronics companies, and five component suppliers) that have moved beyond compliance with regulatory mandates and engineered environmental solutions that negate the need for most – and in some cases all – uses of brominated and chlorinated chemicals. The case studies provide examples of how companies have addressed industry-wide technical performance challenges associated with this material change, while upholding quality, reliability, and product performance at an acceptable cost.

THIS MATERIAL conversion was initially led by electronics manufacturers, like Apple and Sony Ericsson (both featured in this report). Both companies are now offering consumers a wide range of products free of most uses of bromine and chlorine. Apple achieved this with all of its computer products, cell phones, and music devices. Sony Ericsson achieved this with all of its cell phone products.

APPLE AND SONY ERICSSON WORKED CLOSELY with their suppliers to develop new components that met the necessary technical and safety performance specifications, as well as material restrictions on bromine and chlorine use in products. This has led the largest disk drive manufacturer in the world, **SEAGATE**, to create new drives that no longer use chlorine- and bromine-based chemistries. This success was largely facilitated by the company's full material disclosure system, which allows its engineers to know the complete chemical content of their products. **DSM ENGINEERING PLASTICS**, a leading plastic material manufacturer, is among the first chemical companies to offer a complete portfolio of engineering plastics that are free of these substances. The company produced a brand new generic polyamide for connectors and sockets and a new thermoplastic copolyester that can be used as a replacement for PVC-based wires and cables. **NAN YA**, a major laminate manufacturer, and **INDIUM**, a high-end manufacturer of solder paste and flux, both overcame major technical challenges to produce bromine- and chlorine-free components for printed circuit boards that met the same reliability standards of their halogenated counterparts. And finally, **SILICON STORAGE TECHNOLOGY, Inc.** a semiconductor manufacturer, was the first in the industry to supply Apple and others with bromine-free chips.

WHILE THIS REPORT DOCUMENTS HOW FAR COMPANIES HAVE COME in addressing a major environmental and human health problem, many electronic manufacturers have yet to make the transition to bromine- and chlorine-free products. In certain situations, there is great potential to undermine the success that has been achieved by these companies. New standards and regulations will play a very important role in maintaining the momentum established by these companies and leveraging best industry practices in terms of defining and verifying products that are free of most bromine- and chlorine-based compounds.

IT IS ALSO IMPORTANT to note that concerns have been raised about the environmental and human health impact of alternatives to brominated and chlorinated compounds. This report provides references for NGO and government studies that assess the viability of safer alternatives. While some non-brominated and non-chlorinated chemicals are of equal risk to their brominated and chlorinated counterparts, there are many viable alternatives that have a less hazardous profile. For all companies making this material conversion, thorough hazard assessments of the alternatives is critical to ensuring that safer alternatives are being used to replace bromine and chlorine compounds.

TO MAINTAIN AND LEVERAGE THE MOMENTUM FOR GREENER ELECTRONIC PRODUCTS achieved by companies such as those featured in this report, widespread industry alignment will be needed to define technical specifications for bromine- and chlorine-free products. This will need to happen at a global level with stimulus from regulations like RoHS that influence worldwide chemical and material standards for the electronics sector. New supply chain specifications that employ a verifiable and implementable approach to removing these substances of concern from the electronics supply chain also have a critical role to play. And finally, new green procurement criteria defining toxic-free products need to be incorporated into standards differentiating environmentally preferred products in the marketplace like EPEAT (Electronic Product Environmental Assessment Tool). With the appropriate procurement, regulatory, and supply chain standards in place, it is more likely that the work started by companies such as the seven featured in this report will become mainstream in the consumer electronics sector.

1 BROMINE AND CHLORINE USE IN ELECTRONIC COMPONENTS

Bromine- and chlorine-based compounds are used ubiquitously in the production of today's modern electronic products as flame retardants, solvents, dyes, adhesives, and plastic resins. Up until recently, electronics manufacturers did not limit the concentrations of bromine and chlorine used in their products. But in response to the growing human health and environmental problems associated with the use of these compounds, leading manufacturers are now assessing the chemistry of their products and engineering solutions to avoid the use of brominated and chlorinated chemicals.

Chlorine (Cl) and bromine (Br) are elements classified as halogens, because of their position in group 17, or VII A, of the periodic table of chemical elements. The largest uses of compounds containing bromine and chlorine are brominated flame retardants (BFRs), added to plastics to inhibit fire, and polyvinyl chloride (PVC) plastics, an inherently flame-resistant plastic resin. BFRs and PVC, in addition to other brominated and chlorined compounds, are used extensively in the production of electronic products; refer to Table 1 for a list of potential components that may contain bromine and chlorine.

TABLE 1: Component or material types that may contain bromine or chlorine

- Printed circuit board laminates
- Flexible printed circuit boards
- Connectors
- Structural plastic parts
- Integrated circuits or other electrical components with plastic packages or coatings
- Cable insulators, over-molds, heat shrink tubes, and strain reliefs
- Fan impellers
- Optical films
- Gaskets
- Labels, insulators, and tapes
- Paints, inks, and coatings
- Adhesives
- Rubbers and elastomers
- Paper and corrugate
- Solder flux
- Glass

NOTE: This is not an exhaustive list of parts containing bromine and chlorine.

FLAME RETARDANTS AND PLASTICS

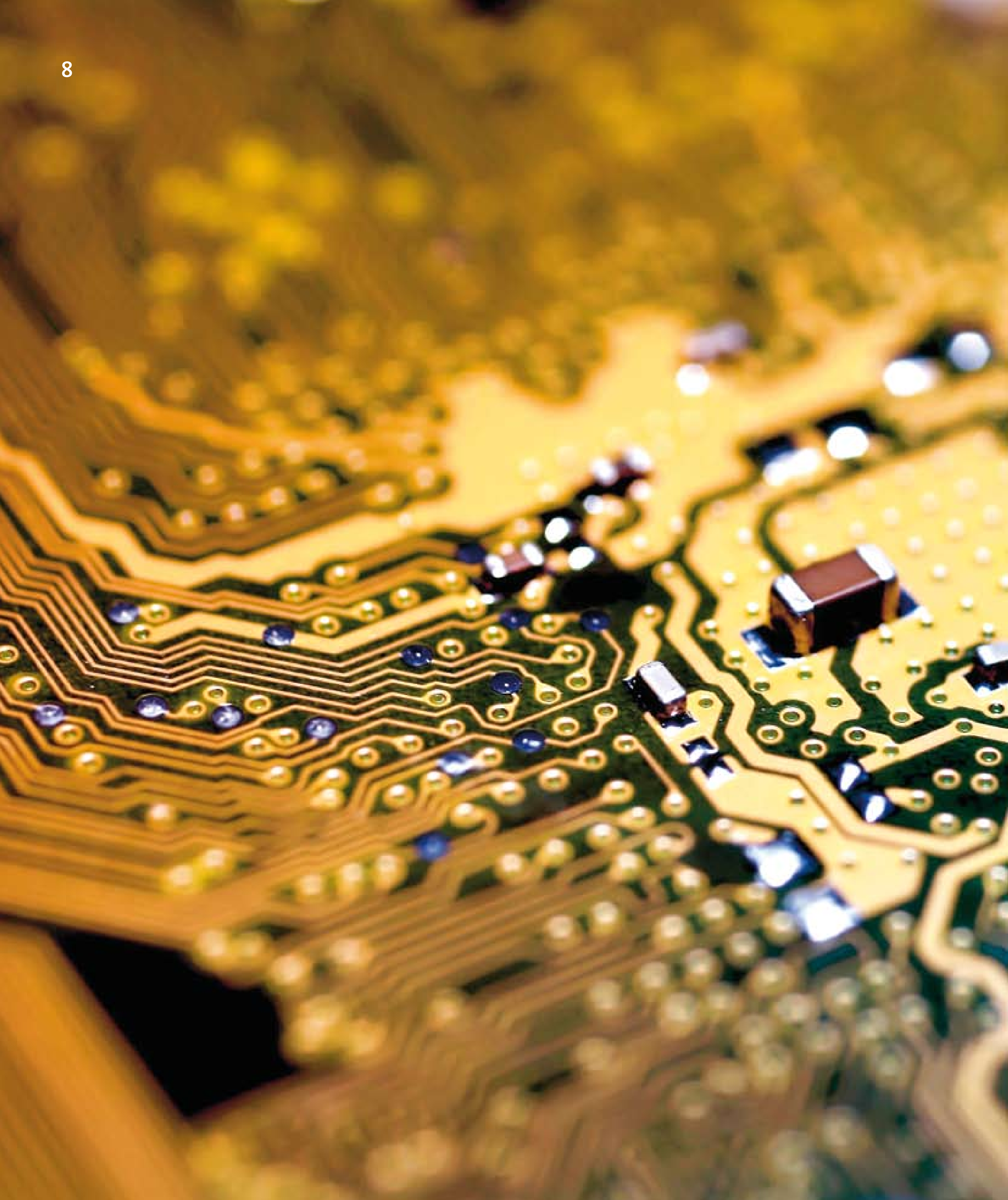
It is estimated that hundreds of different chlorinated and brominated flame retardants are currently on the market. The use of flame retardants is based on national fire safety standards, which vary from country to country. Many electronics manufacturers have opted for global compliance with fire safety standards set by the Underwriters Laboratories (UL), the world's largest, not-for-profit product safety testing and certification organization. To satisfy fire safety standards, very high concentrations – generally 50,000 to 300,000 parts per million (ppm) or 5% to 30% – of BFRs must be used in plastics to effectively impede fires. The most common brominated flame retardant used in components for electronic products, such as printed circuit boards (PCBs), is tetrabromobisphenol A (TBBPA). Prior to the implementation of the European Union's Restriction of Hazardous Substances (RoHS) directive, polybromodiphenyl ethers (PBDE s), and polybrominated biphenyls (PBBs) were sometimes used to flame retard electronics. New restrictions under Europe's chemical policy initiative, REACH (Registration, Evaluation, and Authorization of Chemicals), appear likely to be applied to a third flame retardant used in the electronics sector, hexabromocyclododecane (HBCD).

The predominant use of chlorine in electronics has been in PVC plastics. Most internal and external cables use PVC to insulate copper wires. Human health and environmental concerns about exposure to plastic additives used in PVC, such as lead, cadmium, and phthalates, as well as dioxin formation during the

Photo: StockExpert

ABSTRACT

Bromine- and chlorine- based compounds are used extensively in the production of today's modern electronic products as flame retardants, solvents, dyes, adhesives and plastic resins. The highest concentrations of bromine and chlorine are used in brominated and chlorinated flame retardants (BFRs and CFRs) and polyvinyl chloride (PVC). However, in response to growing awareness of the human health and environmental problems associated with the use of bromine and chorine, leading manufacturers have started to restrict the use of these chemicals. These manufacturers have also come to recognize that the wide variety of halogenated compounds used in the electronics supply chain makes it very difficult to certify that specific brominated or chlorinated compounds have successfully been removed from electronics products. Accordingly, some manufacturers have chosen to restrict the use of all substances containing these two elements, rather than contend with the difficulties involved in implementing and validating restrictions on specific, individual brominated and chlorinated substances. The method of focusing on chemicals on the group level rather than on individual compounds has come to be known as the elemental approach.



combustion of PVC components, triggered industry-wide efforts to replace PVC use in wire and cables. The major challenge has been developing alternative resins, that meet safety standards that in some instances were only written to specify PVC resins. To further complicate the situation, these safety standards vary geographically, forcing companies to use and get approval for multiple alternatives that comply with the different regional standards.

VARYING STANDARDS

Smaller concentrations of bromine and chlorine are used in a wide variety of applications other than flame retardants and PVC. Most manufacturers have focused on restricting the use of certain BFR applications and PVC, while others are restricting all uses of brominated and chlorinated substances. This has led to the development of standards that stipulate the requirements for officially defining components as "halogen-free," "low-halogen," "bromine-free," or "chlorine-free." Halogenated compounds are chemicals that contain a halogen element, such as bromine, chlorine, fluorine, or iodine. In this report, the term halogenated refers to compounds containing bromine or chlorine. Trade associations, such as the International Electrotechnical Commission (IEC) and the Japan Electronics Packaging and Circuits Association (JPCA), developed criteria for printed circuit boards to establish the requirements for the "bromine- and chlorine-free" standard, which requires that the circuit boards contain no more than 900 ppm bromine, 900 ppm chlorine, and 1,500 ppm of bromine and chlorine combined. Building on that standard, some electronics companies developed an analogous standard for all homogeneous materials that established the same limits for these elements in other parts of their products. This is sometimes referred to colloquially in the electronics industry as an "elemental" approach since limits are imposed based on the concentration of bromine and chlorine – not specific BFR or PVC compounds. While these products are not technically "free" of bromine or chlorine, only a very small concentration is permitted to account for impurities and the limitations of testing, and these are far below concentrations where intentional addition would impart any useful properties on the material.

The Association Connecting Electronics Industries (IPC) is currently in the process of developing another standard for all plastic resins. The current proposal (September 2009) applies the elemental standard to a subset of brominated and chlorinated compounds, namely BFRs, CFRs, PVC, and PVC congeners in plastic resins. This approach, however, is more difficult to verify through testing and some companies are calling for a more verifiable approach that would apply restrictions on all uses of bromine and chlorine.

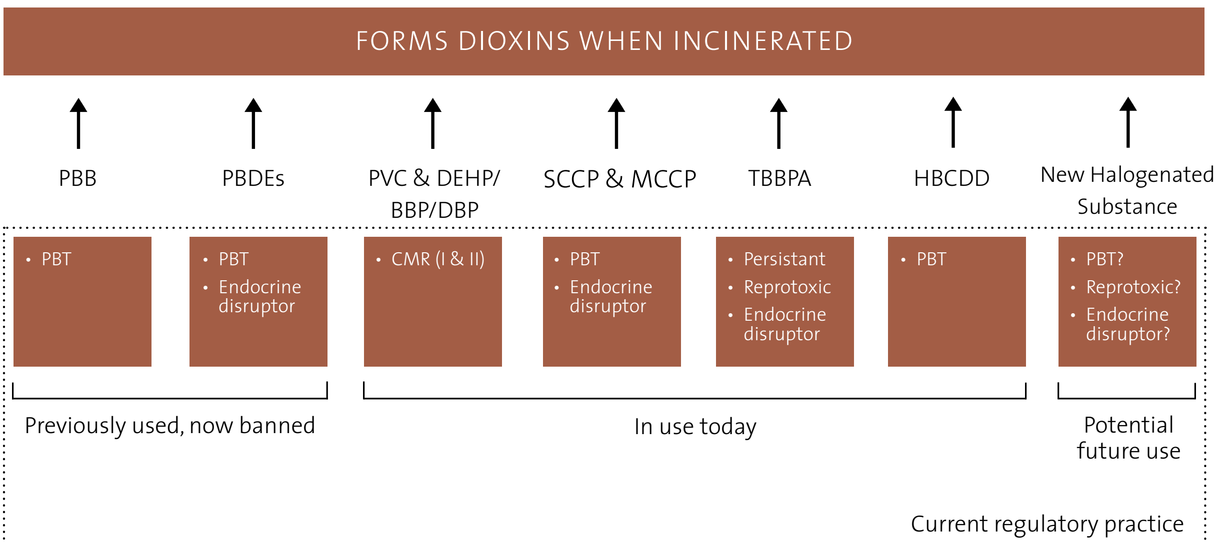
Photo: StockExpert

2 HUMAN HEALTH AND ENVIRONMENTAL CONCERNS

Compounds that contain organic bromine and chlorine tend to be particularly likely to bioaccumulate, be persistent and/or toxic – or to degrade in the environment into new brominated or chlorinated organic compounds with these characteristics.[1, 2, 3] As they accumulate over time, these organo-halogen compounds can become widespread pollutants in air, water, soil, and sediment, where they are increasingly ingested by humans and animals. It is also important to note that inorganic forms of these chemicals can lead to the formation of dioxin and other problematic chemicals, particularly when they are mixed with organic matter.

DIOXIN PRECURSORS

Of particular concern is the ability of halogenated organics to act as precursors for generating dioxin, a potent known human carcinogen[4] that is toxic at very low levels. Exposing halogenated organics such as the BFRs, CFRs, and PVC in electronics to incineration at insufficiently high temperatures or the uncontrolled burning practices commonly used in informal recycling in the developing world can generate dioxins, as well as furans, which can be equally toxic.[5, 6, 7]



Every organo-halogen compound used in electronics can produce dioxins and furans, particularly during the end-of-life treatment of obsolete equipment. This chart shows just a few of the bromine- and chlorine-containing compounds used in electronics products manufactured over the past few decades. In addition to well-known BFRs (HBCDD, PBB, PBDEs, and TBBPA), the chart mentions some phthalates used with PVC plastic (BBP and DBP), as well as other persistent and bioaccumulative substances used in electronics production, such as chlorinated paraffins (SCCP and MCCP). PBT is the acronym for persistent bioaccumulative and toxic substances.

ABSTRACT

Organic compounds containing bromine and chlorine have traditionally been used in electronics due to their ability to effectively impart flame retardance in a cost-effective manner. However, these compounds tend to bioaccumulate, be persistent, and/or toxic – or to degrade in the environment into new substances with these characteristics. Halogenated organics act also as precursors for generating dioxin, a potent known human carcinogen that is toxic at very low levels. This section focuses primarily on the environmental and human health impacts associated with the end-of-life management of products containing brominated and chlorinated compounds. The scope of this report does not include the studies that have documented bromine and chlorine contamination during production or use of electronics, but exposure to these compounds has been documented in the workplace and the home.

Chlorinated dioxins and furans can cause severe health problems[8], including:

- Cancer[4]
- Endocrine disruption[9]
- Endometriosis[10, 11]
- Neurological damage[12]
- Birth defects and impaired child development[13, 14]
- Reproductive system damage[15, 16]
- Immune system damage[17]

Because dioxins and furans break down slowly, they endure in the environment for long periods of time.[18,19] Like many organohalogens, they bioaccumulate in animals' fatty tissue. The highest concentrations are found in animals at the top of the food chain, including humans. Linda Birnbaum, a leading science expert on BFRs and dioxins, led the US EPA's 1994 dioxin assessment process, which concluded that for certain dioxins there was no safe level of exposure for humans.[20] Most of what we know about dioxins and furans is the result of the study of one particular dioxin: 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD), which is a developmental toxicant that causes skeletal deformities, kidney defects, and weakened immune responses in the offspring of animals exposed to it during pregnancy. The compound is also associated with some cancers and other health effects, including immune system alterations and skin lesions. Additionally, studies indicate many of the hundreds of other dioxins and furans are likely to cause similar health effects.[21]

Dioxins and furans concentrate in breast milk so that human infants now receive doses that are orders of magnitude greater than that endured by the average adult.[22] Such exposure to newborns is of great concern because it occurs at their most vulnerable stage of development. In Guiyu, China, an area infamous for its informal electronics recycling activities, the World Health Organization estimates that the daily intake of dioxins and furans by breast-fed infants exceeds guidelines by 11 to 25 times.[23] Other halogens used in electronics, such as the TBBPA and HBCD flame retardants, have also been shown to concentrate in breast milk[24], as well as in human and animal fat.[25]

In 2007, the highest levels of chlorinated dioxins and furans ever reported in the atmosphere were found in the air over Guiyu.[26] Dioxin production is a worldwide concern due to the persistent organic pollutants' ability to travel throughout the globe. In many cases polluted air travels towards the poles, but it is sometimes carried on the trade winds from Asia to North America.[27]

MIXED HALOGENATED DIOXINS AND FURANS

In addition to chlorinated dioxins and furans, two other forms of dioxins and furans can be formed from the combustion of electronics products: brominated and mixed chloro-bromo dioxins and furans.[28] Although neither of these other groups of halogenated dioxins and furans has been as well studied as their chlorinated analogs, studies indicate that both brominated and mixed halogenated dioxins and furans are at least of equal concern.[29]

It is now suspected that thousands of different mixed halogenated dioxin and furan compounds may be generated when electronics are burned. Some tests suggest that certain mixed halogenated dioxins and furans may be at least as toxic and perhaps even have greater toxicity than 2,3,7,8 TCDD, currently the most toxic chlorinated dioxin known. [30, 31, 32] Also of concern is the fact that more than a thousand different mixed halogenated dioxins and furans can be formed that have halogenated atoms in the same positions known to be involved with the high degree of binding to the aryl hydrocarbon (AH) receptor that is associated with 2,3,7,8 TCDD's toxicity.[33]

Although relatively few studies have looked for these mixed halogenated dioxins and furans in the environment, they have been reported in the Japanese atmosphere[34], as well as in Japanese rain, soil, and river sediments[35], and in marine sediments in Hong Kong and Korea.[36] In a study presented at the 2008 International Symposium on Halogenated Persistent Organic Pollutants (Dioxin) meeting, the concentrations of mixed halogenated dioxins and furans in the soil in Guiyu exceeded the total amounts of chlorinated and brominated dioxins and furans taken together.[37]

Once brominated and chlorinated compounds are widely dispersed in our indoor and outdoor environments, we cannot control human exposure to them. We also lack cost-effective technologies for remediating areas that are contaminated by these pollutants. Replacing these compounds with safer compounds that do not persist or accumulate in the environment will improve the environmental footprint of electronic products.

In 2007, the highest levels of chlorinated dioxins and furans ever reported in the atmosphere were found in the air over Guiyu (China), an area infamous for its informal electronics recycling activities[1] .

Photo: StockExpert

3 E-WASTE AND RECYCLING INFRASTRUCTURE

E-WASTE AND RECYCLING INFRASTRUCTURE

As new products with desirable new and improved features are introduced, the subsequent price drops in technologies that may only be a year or two old inevitably results in a steadily increasing stream of electronic waste (e-waste). Regulators in the EU and US are attempting to manage the growing volumes of e-waste produced in their respective jurisdictions. At present, the infrastructure to safely reuse and recycle obsolete equipment is insufficient and much of the waste is handled inappropriately in facilities that are not equipped to handle hazardous materials.

Properly handling halogen-containing electronic waste to avoid releasing toxic dioxins into the environment presents a real challenge even in countries with access to state-of-the-art technologies. The export of e-waste to developing countries with even less capacity for appropriate waste-management is also a critical issue.

ACCUMULATING ELECTRONIC WASTE

In 2008, the Consumer Electronics Association (CEA) predicted that worldwide revenues for consumer electronics would grow nearly 10 % in the next year, hitting the $700 billion mark in 2009.[1] CEA forecast that consumers would spend $42 billion more on consumer electronics products in 2009 over 2008. The organization expects that countries with fast-growing economies and large emerging middle classes, such as the BRIC countries (Brazil, Russia, India, and China) will continue to

Photo: Basel Action Network

purchase more and more electronics. This year, CEA anticipates that China will account for nearly 15 % of global electronics purchases, trailing only North America (22 %) and Western Europe (16 %).

E-waste is the fastest growing waste stream in the EU.[2] The EU produced between 8.3 and 9.1 million metric tonnes in 2005, based on the definitions set forth in its 2002 Waste Electrical and Electronic Equipment (WEEE) directive. The European Commission (EC) expects the annual e-waste volume to grow to 12.3 million metric tonnes by 2020.[3] In the US, e-waste is the fastest-growing category of municipal solid waste tracked by the federal Environmental Protection Agency (EPA).[4]

E-waste is the fastest growing waste stream in the EU.

The EU has a higher e-waste recycling rate than the US, but the two track electronics waste differently. The EU's WEEE legislation includes *"all electrical and electronic equipment used by consumers and.... intended for professional use."* In comparison, the US EPA tracks e-waste as *"select consumer electronics,"* a smaller category including TVs, VCRs, DVD players, video cameras, stereo systems, telephones, and computer equipment.

In 2005, the EU recycled 33 % of the electrical and electronic waste collected by its member states in authorized treatment facilities[3]. That equates to 2.7 million metric tonnes of waste. By comparison, in 2007 the U.S recycled a little over 37,000 metric tonnes, according to the US EPA[4]. This figure represents 13.6 % of the *"select consumer electronics"* waste disposed of by US consumers that year. In 2007, 18 %, by weight, of the 26.9 million TVs discarded in the US were recycled, according to the US EPA. Similarly, US consumers recycled 18 %, by weight, of the 205.5 million computer products (including CPUs, monitors, laptops, mice, keyboards, printers, faxes, and other computing

ABSTRACT

The rapid development of new products with desirable new and improved features, and the subsequent price drops in technologies that may only be a year or two old, inevitably results in a steadily increasing stream of electronic waste (e-waste). At present, the infrastructure to safely reuse and recycle obsolete equipment is insufficient, and much of the waste is handled inappropriately in facilities that are not equipped to handle hazardous materials. Even in the EU, which leads the world in effectively managing e-waste, as much as 41% of the union's annual waste volume – or 3.4 million metric tons – may be improperly treated. E-waste is often exported to developing countries with even less capacity for appropriate waste-management, where backyard burning can be the norm.

The widespread use of plastic in electronics, which is the main source of the bromine and chlorine, further compounds these problems. Somewhere between 25% and 30%, by weight, of the volume of electrical and electronic waste generated each year is composed of plastic, but less than 10% of this plastic is currently recycled. Many plastics cannot be recycled because they contain higher-than-allowable levels of restricted substances, such as certain brominated flame retardants; these plastics generally end up in a landfill or an incinerator, which can produce dioxins.

devices) deemed obsolete that year. In comparison, only 10 % (by weight) of the 140.3 million cell phones discarded in 2007 were recycled.

The EU's WEEE directive is aimed at eliminating the kind of informal recycling that pollutes the environment, but a European Commission (EC) report[3] estimates that 13 %, by weight, of the e-waste collected in 2005 in accordance with the WEEE legislation (equal to 1.1 million metric tonnes) was either not separated from domestic waste or was disposed of illegally. An additional 4.5 million metric tonnes – which equals 54 % of 2005's total e-waste volume – was collected but not accounted for. The EC report estimates that less than 2 % of this unaccounted for e-waste is reused, and it acknowledges, *"there is not sufficient information to make reliable estimates of what proportion... is illegally shipped out of the EU."* The EC report's worst-case scenario estimate of the volume of e-waste that may be improperly treated in or out of the EU could be as high as 41% of the union's annual e-waste volume, or 3.4 million metric tonnes.

The EU produced between 8.3 and 9.1 million metric tons in 2005, based on the definitions set forth in its 2002 Waste Electrical and Electronic Equipment (WEEE) directive.

Despite regulations, somewhere between 50 % and 80 % of the e-waste that is collected by recyclers in the US ends up in developing countries, including China, India, Pakistan, Vietnam, and the Philippines, according to the United Nations Environment Programme[5] and the Basel Action Network.[6] Most of the recycling in these countries is happening in substandard facilities not equipped to manage hazardous substances. High-value metals in electronics are removed and reclaimed, but most of the halogen-containing plastics are burned. The volume of informally and often illegally recycled electronics is unknown, but it is known that burning plastics containing bromine or chlorine at temperatures below 850° C will produce dioxins.[7] Such informal recycling operations generally take place outdoors, and plastic is burned at much lower temperatures unlikely to exceed 200° C. Experimental studies document that the total amount of dioxins and furans produced at lower temperatures is proportional to the material's halogen content.[8]

E-WASTE AND DIOXIN EMISSIONS

As noted in the previous chapter, the highest levels of chlorinated dioxins and furans ever reported in the atmosphere were found in the air over Guiyu, China, an area infamous for its informal electronics recycling activities.[9] Those emissions were the direct result of grossly inadequate handling of dioxin-laced emissions, but even modern facilities equipped with expensive technologies intended to reduce dioxin emissions must be operated and managed with extreme care to avoid releasing dioxins and furans into the environment if halogen-containing waste is incinerated. As the Stockholm Convention on Persistent Organic Pollutants[10] points out: *proper management of time, temperature and turbulence (the "3 Ts"), as well as oxygen (airflow), by means of incinerator design and operation will help to ensure that dioxins are not released into the environment*. This is important because research shows that even incinerators with modern flue gas treatment technologies operating at temperatures above the minimum 850° C temperature recommended in the guidelines can form dioxins when halogens are incinerated, particularly when the gases begin to cool. If the waste being incinerated contains high volumes of halogens, temperatures above 1100° C are required.[10]

Tests recently conducted at facilities using furnaces, energy recovery options, and flue gas treatment technologies representative of most of the incineration plants currently operating in

Photo: Basel Action Network

Europe documented that dioxins were detectable in the solid, liquid, and gaseous residues from every facility.[11] The furnace design, combustion operation, and flue gas treatments in use affected the levels of dioxin releases from these facilities, and the use of catalytic converters for flue gas treatment reduced dioxin emissions to outside air.

Other technologies used to capture dioxin emissions, such as activated carbon and scrubbers, produce dioxin-containing wastes that also must be managed with care to avoid accidentally releasing the dioxins into the environment. This includes the filters that capture dioxin-containing activated carbon and the sludge produced by scrubbers. The ash produced by incineration facilities also requires careful management. The heavier and larger bottom ash must be disposed of in a controlled landfill, for it can contain heavy metals, as well as banned substances, such as flame retardants PBDEs. The lighter fly ash captured by particulate removal devices also needs to be managed to avoid releases.

In summary, the incineration technologies and management practices required to avoid dioxin emissions are expensive and therefore not widely used.

RECYCLING PLASTICS

In the last several years, the infrastructure for collecting and recycling electronics has grown dramatically, mostly in Europe and parts of Asia, particularly, Japan, Korea, and Taiwan. At the same time, increasingly automated technologies for harvesting metals and plastics from electronics are being developed and deployed. In 2005, MBA Polymers opened the world's largest plant for recycling plastics harvested from electronics in Guangzhou, China. It has since opened up a facility in Kematen, Austria, and it is planning a third in the U.K. The company estimates that somewhere between 25 % and 30 %, by weight, of the volume of electrical and electronic waste generated each year is composed of plastic. Less than 10 % of this plastic is currently recycled.

The EU's Restriction of Hazardous Substances (RoHS) directive stipulates that only plastics containing less than 1,000 parts per million (ppm) of PBDEs, a group of banned flame retardants, can be reused in electronics. MBA Polymers is the only multinational company that currently recycles plastic harvested from electronics, and the company meets the requirements specified by RoHS by sorting out the majority of plastics containing brominated additives. One of the technologies for detecting bromine in electronics waste is x-ray fluorescence (XRF), which simply identifies the presence of the element itself, rather than the specific compounds (such as PBDEs) that contain bromine.

The options for electronics plastics that cannot be recycled because they contain higher-than-allowable levels of restricted substances are to dispose of them in a landfill or incinerator, or use "chemical recycling," which removes restricted substances. The disposal methods are widely available, but the chemical recycling option's ability to remove restricted flame retardants has been only demonstrated at the pilot level. Landfill disposal has been shown to emit banned BFRs, such as PBDEs, into the environment.[12] In the presence of sunlight, PBDEs in water can be photochemically transformed into brominated dioxins.[13]

Some developing countries, such as China, operate simple plastics recycling operations that use hazardous plastic materials harvested from electronics to produce lower quality plastics for consumer products such as coat hangers, plastic pots for plants, and cheap toys. Chinese researchers have also been investigating how plastic and other nonmetallic residuals from printed circuit board waste can be used to create "nonmetallic plate" materials[14] that can be used in applications such as sewer grates, park benches, and fences.

The European Commission (EC) expects the annual e-waste volume to grow to 12.3 million metric tons by 2020.

In the US, e-waste is the fastest-growing category of municipal solid waste tracked by the federal Environmental Protection Agency (EPA).

Photo: StockExpert

4 ESTABLISHING VERIFIABLE BROMINE AND CHLORINE RESTRICTIONS

The Restriction of Hazardous Substances (RoHS) has created an infrastructure for improving the management of chemical use in electronics products. This has enabled compliance with chemical restrictions in a sector that operates globally. In anticipation of future chemical regulations, many companies have moved beyond RoHS to develop material specifications that restrict the use of other chemicals and substances of high concern. Much of the prioritization for new restrictions has focused on the use of brominated and chlorinated substances in electronics products. Some product manufacturers are working toward this by targeting high-volume uses of brominated and chlorinated compounds through restrictions on brominated flame retardants (BFRs), chlorinated flame retardants (CFRs), and PVC plastic use in products. Others are going further by restricting nearly all uses of bromine and chlorine in electronic products in lieu of the substance-by-substance or compound-by-compound approach.

IDENTIFICATION CHALLENGES

The complex supply chain involved in the production of modern electronic products can include hundreds of companies producing thousands of different parts. Each part is made up of numerous substances, some of which are brominated and chlorinated compounds. Companies within the supply chain are generally aware of which types of parts are more likely to contain brominated or chlorinated compounds. However, the chemical makeup of parts is generally not published (e.g., due to intellectual property concerns) or known (e.g., due to a lack of communication through the supply chain). Furthermore, test methods do not exist for many brominated and chlorinated substances, preventing suppliers or electronics producers from using analytical laboratory testing to determine whether or not a component is free of specific BFRs and PVC. Without a means of independent verification, and because of the fact that suppliers are often unaware of the full chemical make-up of parts they sell, some electronics manufacturers are restricting nearly all uses of substances containing bromine and chlorine. This is often colloquially referred to as the "elemental approach," since restrictions are imposed on the elements themselves rather than on the compounds containing bromine and chlorine.

Laboratory tests to validate material restrictions of bromine and chlorine content are widely available and inexpensive. Companies that have chosen to eliminate bromine and chlorine from their products still allow trace amounts of the halogenated elements. Most companies limit the allowable amount of bromine and chlorine in their products to 900 ppm, or 0.09 %, by weight, per homogeneous material. This results in a miniscule amount of both elements, at most, in any "chlorine- and bromine-free" electronics product. More important, the achievement represents a huge reduction from the typical 50,000 to 300,000 ppm of bromine often used in flame retardant plastics, and >100,000 ppm chlorine used in PVC resins. The elemental restriction on bromine and chlorine closes the door on all BFR compounds and PVC resins. At such low concentrations of bromine and chlorine, BFRs are not effective and PVC resins could not be manufactured.

With the exception of a small number of consumer electronics companies restricting nearly all forms of bromine and chlorine in their products, most companies are restricting certain and in some cases all BFRs, CFRs, and PVC applications. While this is a critical step forward, it creates barriers to transparent, repeatable, reliable, and cost-effective compliance programs. A complete list for all BFRs and CFRs does not exist making it very difficult to provide analytical validation when components measure above the 900 ppm established for most bromine and chlorine restrictions. A paper trail from an upstream supplier is not sufficient for validation. For specific applications where a low-hazard chlorinated substance like sodium chloride (i.e., table salt) is needed in greater concentrations to meet performance specifications of a specific polymer, such as PPS (polyphenylene sulfide), an exemption can be made. This is clear and transparent, and the producer and customers can have confidence as to what is in their product.

Suppliers working to meet differing material specifications realized early on that harmonizing supply chain standards would increase efficiency and reduce costs. They also recognized the need for a common set of definitions for what it means for products to be sold as BFR-, CFR-, and PVC-free. For the past two years, IPC, a major electronics trade association, has spearheaded an initiative to define a commonly held standard that suppliers could work toward for many different original equipment manufacturers (OEM) customers. This work builds on previously developed standards such as IPC-4101B[1], which defines low-bromine and low-chlorine printed circuit board (PCB) laminates by establishing individual limits of 900 parts per million (ppm) (0.09 %) for bromine or chlorine, and a limit of 1,500 ppm (0.15 %) of the combined total of the two elements.

The IPC's proposed guideline for Defining "Low-Halogen" Electronic Products applies the thresholds established in IPC-4101 B to non-PCB based plastic components but allows higher concentrations for bromine and chlorine for all non BFR, CFR, and PVC applications. While this draft takes a critical step forward in acknowledging the need to establish thresholds for elemental bromine and chlorine for polymers, the unchecked allowance of higher concentrations of non-CFR, BFR, and PVC bromine and chlorine use creates a barrier to cost-effective and transparent verification programs. Since material tests do not exist for many specific compounds, it will be very difficult to obtain analytical tests that can differentiate BFRs and CFRs from other brominated and chlorinated compounds. It is also inconsistent with IPC-4101, which does not allow for these higher concentrations in printed circuit boards. In essence, the BFR /CFR- and PVC-free definition sets up conflicting measurement approaches, one for PCBs and one for all other plastic components used.

Creating a guideline that can be measured and tested repetitively with viable, cost-effective methods is essential to ensuring that the materials are removed from the product. For this to be used as a future reference point for regulations or other standards, regulators and customers will need clear verification that the products do not contain the targeted substances.

ABSTRACT

For electronics companies to ensure regulatory compliance, RoHS has contributed to the creation of an infrastructure for improving the management of chemical use in electronic products. In anticipation of future chemical regulations, companies have moved beyond RoHS to develop material specifications that restrict the use of other chemicals and substances of high concern. Much of the prioritization for new restrictions has focused on the use of brominated and chlorinated substances in electronic products. Some companies are working to eliminate high volume uses of bromine and chlorine by restricting certain halogenated flame retardants and polyvinyl chloride applications. While others – for reasons of cost-effectiveness, transparency, and viable laboratory testing methods – are restricting nearly all uses of brominated and chlorinated chemicals at the elemental level. This is often colloquially referred to as the "elemental approach," since restrictions are imposed on the elements themselves rather than on the compounds containing bromine and chlorine.

5 ALTERNATIVES TO BROMINE AND CHLORINE BASED COMPOUNDS

As the case studies highlighted in this report make clear, many suppliers are producing products that are bromine- and chlorine-free. To get to this point, both electronic manufacturers and suppliers have employed a range of green design strategies that include product redesign, increased use of inherently fire-resistant materials, such as metal enclosures, and the substitution of brominated and chlorined chemicals with safer alternatives. This has led to the development of new materials and chemicals that have a lower impact on human health and the environment.

There are a wide range of non-brominated and non-chlorined alternatives available for most electronics applications. Some of these alternatives have hazardous characteristics, while others are more benign. It is therefore critical that companies complete full hazard assessments of any alternatives they are evaluating to ensure that substitutes have improved environmental profiles. With the aid of toxicological assessments, some companies have been able to give preference to the use of certain alternatives such as metal hydroxides, an ingredient found in antacids.

ENVIRONMENTALLY PREFERABLE FLAME RETARDANTS

The chemical industry has responded to the demand for safer flame retardants through a new association called PINFA (Phosphorus, Inorganic, Nitrogen Flame Retardants Association), which is dedicated to producing flame retardants that have improved environmental and human health profiles. PINFA identifies flame retardants that do not persist and bioaccumulate in the environment and have lower toxicity. These chemicals have not undergone the same scrutiny as their brominated and chlorinated counterparts, but this is due in part to the fact that they do not make it onto priority lists for high-volume chemicals, which is what triggers risk assessments for chemicals used in Europe. However, these manufacturers do recognize that hazard data is needed to provide market assurance that these alternatives have better environmental and human health profiles.[1]

Governments have responded with evaluations of the alternatives. In Europe, the Danish EPA and the German UBA authorized major studies that assessed alternatives to halogenated flame retardants and concluded that safer alterna-

tives were available. The Öko Institut, in its report suggesting additions and revisions to RoHS, concluded that substitutes with "[fewer] potential adverse effects on environment and human health" are available for use in place of the halogen-containing substances it has recommended banning. This has been reaffirmed by U.S.-based NGO and government studies.[2,3,4,5,6] Clean Production Action's Green Screen for Safer Chemicals provides a hazard-based chemical categorization tool to evaluate and compare chemicals based on their environmental and human health properties. The state of Washington used this tool to conclude that safer alternatives can be used to replace PBDEs. Most of these alternatives can also replace other forms of BFRs. In addition, plastics manufacturers are creating new resin formulations to replace PVC used in electronic products. For example, less hazardous resins, such as thermoplastic copolyester, can now be used for wires and cables and new polyamide can be used to produce connectors and sockets.

Photo: Basel Action Network

ABSTRACT

Concerns have been raised about the environmental and human health impact of alternatives to brominated and chlorinated compounds. This report provides references for NGO and government studies that assess the viability of safer alternatives. While some non-brominated and non-chlorinated chemicals are of equal risk to their brominated and chlorinated counterparts, there are many viable alternatives that have a less hazardous profile. For all companies making this material conversion, thorough hazard assessments of the alternatives is critical to ensuring that safer alternatives are being used to replace bromine and chlorine compounds.

6 CASE STUDIES

This section profiles seven companies that have played key roles in changing the way brominated and chlorinated compounds are both viewed and used in the electronics industry. It not only features two prominent brand name companies, Apple and Sony Ericsson, but also critical suppliers that manufacture the components essential for the operating capacity of all electronic products. DSM Engineering Plastic, Seagate, Nan Ya, Indium, and Silicon Storage Technology, Inc. are leaders in their respective component sectors, which range from materials for printed circuit boards to the hard disk drives to the plastics that are used in connectors, sockets, cables, and wiring. These case studies demonstrate the level of conformance that can be met today without the use of brominated and chlorinated compounds. They also provide a tool for engineers working to overcome the technical challenges of designing products that do not contain these substances.

Restriction of Elemental Bromine and Chlorine to Achieve Elimination of BFRs and PVC in Consumer Electronics Products

COMPANY PROFILE

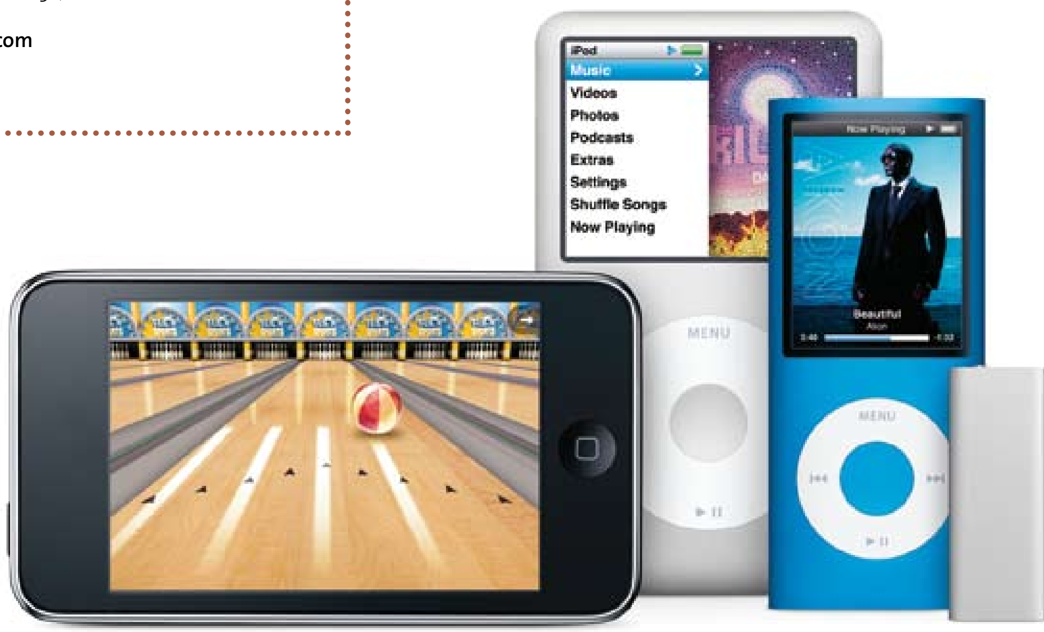
APPLE INC.

Consumer Electronics Manufacturer.

Apple Inc. is a world renowned manufacturer of various consumer electronics devices, including portable and desktop personal computing systems, as well as portable music devices and mobile communication devices.

Headquarters:	Cupertino, CA, USA
Design Center:	Cupertino, CA, USA
Sales:	$33 billion (US dollars, 2008)
Employees:	32,000 worldwide

www.apple.com



"Apple is committed to phase out the use of bromine (Br) and chlorine (Cl) in its products with the intent to minimize impact on the environment and human health during manufacturing, use, and disposal."

– Apple Specification on the Restriction of Bromine and Chlorine, 069-1857-D

ABSTRACT

Apple restricts nearly all uses of brominated and chlorinated compounds, at the elemental level, from its products. Customers can now purchase products like the iPod shuffle, nano, and touch, and the iPhone that are free of brominated flame retardants (BFRs) and polyvinyl chloride (PVC). Apple's iMac and Macbook products are free of all BFRs and PVC with the exception of PVC use in external wires. Apple had to work with suppliers to change the composition of hundreds of parts, including printed circuit boards (PCBs), connectors, fan impellers, cable insulators, adhesives, films, inks, dyes, flexible printed circuits, and enclosures. To implement its restrictions, Apple required its suppliers to establish strict compliance management programs.

Apple has a long history of working to improve the environmental footprint of the materials designed into its products. For the past decade, the company has worked to reduce the use of substances of concern. By embedding the concept of continuous improvement into its design strategy, the company has become an industry leader in providing customers with a wide range of electronic products that contain safer chemicals and more sustainable materials.

In accordance with its commitment to eliminate substances of high concern, Apple has spent the last several years investing in new designs, tools, and materials to provide customers with the world's first complete range of BFR-free notebook and desktop computers and handheld products. With the exception of external AC and DC cables, Apple also offers the world's first range of PVC-free products.

Apple also recognized that other substances beyond BFRs and PVC that contain bromine and chlorine are likely candidates for future regulatory restrictions in Europe and the U.S.A. Accordingly, the company imposed restrictions on all materials containing brominated and chlorinated compounds, not just BFRs and PVC. This was the first time that a manufacturer attempted to eliminate the use of nearly all brominated and chlorinated compounds in complex electronic equipment. The approach, colloquially referred to as the "elemental approach" because the restrictions are imposed on bromine and chlorine regardless of what compound may contain them, represents the most rigorous basis for restrictions on chlorine and bromine use in electronic products.

Apple's elemental approach helped simplify verification and testing of parts being qualified for new products. The company's extensive research showed that elimination of only specific BFR compounds, such as TBBPA, would be more difficult from a validation perspective since many BFRs are difficult to detect; moreover, testing for PVC can be challenging at low concentrations. In contrast, the methods for detecting bromine and chlorine were well-established and relatively inexpensive to carry out. By using these methods, the company was able to develop robust and transparent compliance programs for its suppliers.

APPLE PRODUCTS	ELIMINATING SUBSTANCES OF CONCERN
MacBook Air	Mercury-free LCD display Arsenic-free display glass BFR-free PVC-free internal cables
MacBook Pro	Mercury-free LCD display Arsenic-free display glass BFR-free PVC-free internal cables
iMac	Arsenic-free display glass BFR–free PVC-free internal cables
iPhone 3G and iPhone 3GS	Mercury-free LCD display Arsenic-free display glass BFR-free PVC-free
iPod touch	Mercury-free LCD display Arsenic-free display glass BFR-free PVC-free
iPod nano	Mercury-free LCD display Arsenic-free display glass BFR-free PVC-free
iPod shuffle	BFR-free PVC-free

The widespread use and complex nature of brominated and chlorinated compounds in BFRs and PVC required Apple to completely eliminate (rather than just reduce) these substances of concern from thousands of parts, including printed circuit boards (PCBs), connectors, fan impellers, cable insulators, adhesives, films, inks, dyes, flexible printed circuits, and enclosures. Apple's goal was to have all products compliant by the end of 2008. With the exception of PVC-free replacements for external wiring in some computers and displays, Apple has met its goal and now has many BFR- and PVC-free products available to consumers. Apple continues to work with suppliers to develop PVC-free alternatives that not only meet the necessary technical and safety specifications for external cables, but also meet Apple's stringent cosmetic requirements.

OVERCOMING TECHNICAL CHALLENGES

To provide clear guidance to its supply chain, Apple developed a new specification in 2006 that outlined the company's intention to eliminate bromine- and chlorine-based compounds in all homogeneous materials used in Apple products. When Apple initially released its 069-1857 specification, the company referenced and revised widely accepted standards such as the IEC 61249-2-21:2003 standard for low-bromine and low-chlorine printed circuit board laminates. Apple defined bromine- and chlorine-free by using the same limit established in these standards, namely that of 900 ppm (0.09 %) of bromine and chlorine, and 1500 ppm (0.15 %) of the combined total of the two elements. This threshold essentially closes the door on all intentionally added BFR compounds and PVC applications, because chlorine and bromine in BFR and PVC applications are not effective at such low concentrations. Bromine is typically used in concentrations above 50,000 ppm to flame retard plastics and the chlorine content in PVC is even higher.

New supply chain specification

SUBSTANCE	RESTRICTIONS FOR HOMOGENEOUS MATERIALS (SUBSTANCE CONCENTRATION LIMIT BY WEIGHT)
Bromine (Br)	≤ 900 ppm (0.09 %)
Chlorine (Cl)	≤ 900 ppm (0.09 %)
Total concentration of bromine (Br) + chlorine (Cl)	≤ 1500 ppm (0.15 %)

Unlike the IEC specification, which only applies to printed circuit board laminates, Apple's specification requires that its established thresholds be met for all homogeneous materials. This ensures that every material used in the company's products can be tested and verified with readily available and inexpensive test methods and procedures.

Apple's suppliers were required to establish strict compliance management programs, which included using certified laboratory testing to demonstrate that they were complying with the new requirements. This approach is analogous to that required by many electronics manufacturers to demonstrate RoHS compliance. Throughout the transition, Apple monitored its suppliers' compliance via internal audits, and the company repeatedly found instances where brominated or chlorinated materials were used in parts that suppliers claimed to be compliant with Apple's limits on bromine and chlorine. A transparent compliance program, which allows for quick and inexpensive material testing, enabled Apple to identify problems early on and take corrective action. This would not have been possible if Apple had relied solely on the paper trail of supply chain declarations – which is commonly used to demonstrate compliance by OEMs in the electronic sector – nor would it have been possible if Apple had only restricted BFRs and PVC because compliance tests for these substances are either more complex or do not exist. An extensive auditing program in a supply chain is critical to increasing compliance and ensuring full implementation of new material specifications, particularly during the early stages of the transition.

TECHNICAL CONFORMANCE AND RELIABILITY

An important aspect of Apple's achievement in eliminating bromine and chlorine was the company's success in ensuring that the new environmental specifications do not interfere with the strict quality, reliability, safety, and performance requirements that are critical to the dependability of its products.

Apple's conversion to BFR- and PVC-free products was not without cost, but the company's expenses were reduced by employing widely accepted strategies: implementing the transition in phases; leveraging new product development cycles to introduce new materials; and partnering with suppliers on new materials development and qualification. To minimize disruptions to production, Apple phased out the use of chlorine and bromine over four transition phases coinciding with new product releases (four phases listed below).This approach had the advantage of sharing the research and development costs of using alternative materials with the fixed cost of developing new products.

PHASE ONE >>>>
User-inaccessible (i.e. internal) cable jackets and internally-designed PCB laminates

PHASE TWO >>>>
Insulators, films, and enclosure plastic parts

PHASE THREE >>>>
User-accessible (i.e. external) cable jackets and externally-designed PCB laminates

PHASE FOUR >>>>
Connectors and electrical components soldered to printed circuit boards

Apple worked with suppliers to overcome manufacturing and design challenges that inhibited the replacement of BFRs and PVC. This partnership allowed the company's suppliers to manufacture parts that met its reliability, performance, and quality requirements. In many cases, bromine- and chlorine-free alternatives were not "drop-in" replacements and required process or design changes to accommodate their differing material characteristics:

- **Bromine- free laminates for printed circuit boards:** The electrical and mechanical characteristics of bromine- and chlorine-free PCB laminates, including the dielectric constant, peel strength, and glass transition temperature, differ from traditional BFR based laminates. Designers had to address these differences by designing PCBs specifically tailored for bromine- and chlorine-free materials. Extensive testing had to be conducted to ensure that signal integrity, reliability, electromagnetic compatibility, and manufacturability met internal standards.

- **Chlorine-free cables:** The transition to PVC alternatives for internal cables was not trivial. Many of the alternative materials for external cables that were available did not meet Apple's strict cosmetic and mechanical requirements. In some cases Apple was able to avoid the use of cables altogether by simplifying the internal design of its equipment. Such an approach allowed Apple to replace over six feet of cables in the Mac Pro with more material-efficient connectors that allow easy disassembly at end of life.

- **Bromine/chlorine-free solder paste and flux:** Apple conducted trials with several suppliers comparing traditional brominated fluxes with bromine-free alternatives to quantify changes in manufacturability. Process conditions had to be adjusted to determine the optimal soldering conditions for the solder paste and flux selected for Apple's manufacturing process.

During the initial phases of the transition, availability of bromine- and chlorine-free parts was an ongoing concern. The schedules of the company's supply chain partners had to be considered since it typically took several months for the suppliers to complete qualification testing and ramp-up volumes of new bromine- and chlorine-free materials. Suppliers subsequently used Apple products as a launch vehicle for offering new bromine-free and chlorine-free materials to other equipment manufacturers.

Technical challenges remain. For example, identifying suitable PVC alternatives for external AC and DC power cables has proven to be extremely difficult due to regional variations in external safety standards. The variance in international safety standards poses a major challenge to electronics manufacturers who support a worldwide customer base, and it can force the development of multiple alternatives to meet differing standards. Apple has been working with resin manufacturers and cable extruders to develop customized resins that meet its requirements. Apple has already shipped millions of products with PVC-free alternatives. For example, the company has been shipping PVC-free USB cables and headphone cables for iPod and iPhone products since the summer of 2008.

Apple has worked closely with suppliers to develop new alternatives for its desktop and notebook products and is in the final stages of developing and certifying PVC-free AC power cables.

USING SAFER CHEMICALS AND MORE SUSTAINABLE ALTERNATIVES

"Materials that adversely affect human health or the environment must not be substituted in place of bromine or chlorine."

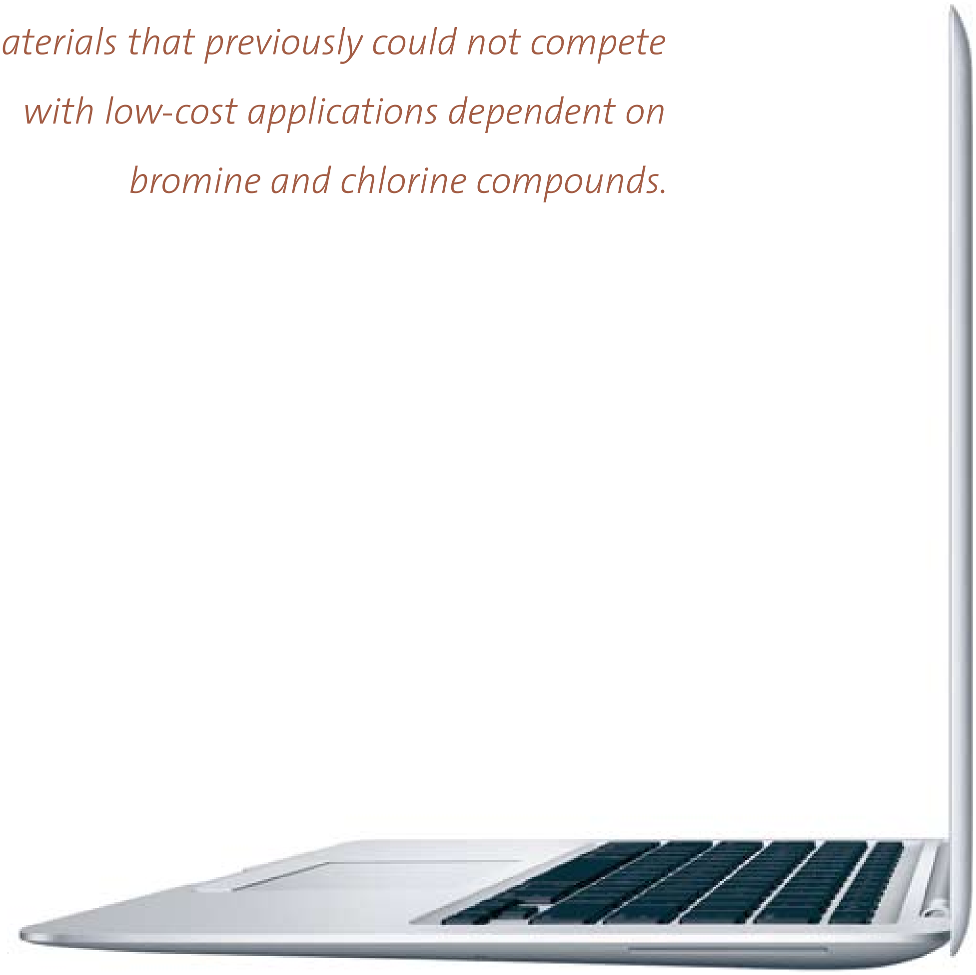
– Apple Specification on the Restriction of Bromine and Chlorine, 069-1857-D

Since 2001, Apple has led the industry in increasing the use of inherently fire-resistant metals for enclosures, such as titanium, steel, and aluminum, to avoid the use of any flame retardant. The company has also used new polymers that have higher inherent flame resistance and therefore reduce dependency on flame retardants.

Apple encouraged the use of environmentally benign, cost-effective, and widely available alternatives. The company continued its ban on potential flame retardant substitutes like antimony trioxide and red phosphorous because of their high environmental risk. Apple also conducted toxicity assessments on preferred alternatives to ensure that the company was moving toward safer substances. For example, components in Apple products use flame retardants such as ammonium polyphosphate (or APP, which is often used as a food additive), metal hydroxides (which are used in antacids), and other safer substitutes.

Apple's success in overcoming technical challenges is increasing the market viability of new chemicals and materials that previously could not compete with low-cost applications dependent on bromine and chlorine compounds. This ground-breaking work allows manufacturers to debut chemicals and materials that are designed to have a lower environmental impact yet perform well and meet critical reliability specifications.

Apple's success in overcoming technical challenges is increasing the market viability of new chemicals and materials that previously could not compete with low-cost applications dependent on bromine and chlorine compounds.



Bromine- and Chlorine-Free Mobile Phones

COMPANY PROFILE

SONY ERICSSON

Mobile Phone Manufacturer.

Sony Ericsson is a world-renown provider of mobile phones. The company is a 50:50 collaborative effort between Sony Corporation and Telefonaktiebolaget LM Ericsson.

Headquarters:	London, UK
Sales:	€1.736 billion (Euros, Q1 2009)
Employees:	9,400 worldwide

www.sonyericsson.com

The GreenHeart phones are bromine- and chlorine-free, and Sony Ericsson has pledged that the GreenHeart concept will be rolled out across its entire product portfolio in the coming years.

Sony Ericsson

Sony Ericsson has been working on sustainability issues since its October 2001 formation. Ericsson was a pioneer in this area and started researching halogen-free devices in 1999. Sony Ericsson's decision to cease using halogens in its phones was motivated by the fact that a large proportion of electronic waste is exported for inappropriate waste-management, in spite of ambitious regulations and product take-back systems developed by producers and operators.

In 2000, Ericsson released its first phone (T28) that did not use brominated flame retardants (BFRs) in the casing and the printed wiring board. However, at this time, BFRs were still used in other components of the phone. The first phone produced after the Ericsson and Sony handset divisions merged also avoided the use of BFRs in the same components. Since then, the joint company's continuous improvement programs have enabled it to extend this approach to all of the mobile phones it produces. In addition, BFRs and halogenated polymers have been removed from most of the components in the phones. The only remaining uses of BFRs are in small electrical components such as resistors and capacitors. Sony Ericsson's phones are now 99.9 % halogen-free, and all chargers exept one are free from PVC but the company plans to be totally PVC free by the end of 2009.

TIMELINE OF SUSTAINABLE PRODUCT DEVELOPMENT

1996	Phased out use of NiCd
1999	First BFR-free phone (Ericsson)
2002	First BFR-free phone as joint company
2004	First in the industry to introduce RoHS compliant phone
2009	Launch GreenHeart™ platform

ENVIRONMENTALLY CONSCIOUS DESIGN

Sony Ericsson employs a structured approach to creating sustainable designs. The company's design process starts with the consideration of customer requirements and regulatory demands, as well as business goals and targets. The product design cycle also includes a structured environmental compliance phase, where the environmental impact of new designs is reviewed. The items considered in such reviews include data from the company's "COMET" (Compliance on Materials and Environment) material declaration database and an evaluation

ABSTRACT

Sony Ericsson's phones are now 99.9 % bromine- and chlorine-free, and the company plans to end its use of PVC in external charging systems by the end of 2009. Sony Ericsson's decision to cease using halogens in its phones was motivated by the fact that a large proportion of electronic waste is exported for inappropriate waste-management, in spite of ambitious regulations and product take-back systems developed by producers and operators.

In May 2008, Sony Ericsson began implementing a materials declaration system, which requires its suppliers to disclose all the substances used in Sony Ericsson products.

Sony Ericsson... has now shipped over 350 million BFR-free phones, as well as accompanying chargers and other accessories.

of chemical analysis data to ensure that new products do not contain any chemicals on the company's lists of banned and restricted substances.

Sony Ericsson's banned substance list and its restricted substance list are both central to the company's sustainability work. Both are posted on the company's Web site for interested customers, suppliers, competitors, and consumers to view. The purpose of Sony Ericsson's lists is to prevent hazardous substances like certain halogenated compounds from entering the company's production system and products, as well as to publicly state its intention to phase-out or restrict the use of other substances that are already in the system or in existing products.

Sony Ericsson's initial criteria for determining whether or not a substance should be include global legislation, stakeholders' input, and market requirements. Sony Ericsson does not perform its own scientific studies on the human and environmental health effects of the chemicals it considers for inclusion in its banned or restricted substances lists. Instead, the company gathers information from a variety of sources, including NGOs, customers, governments, and other industry stakeholders. The first step for considering whether a substance should be included in the non-compliance lists requires Sony Ericsson to determine whether substitution with less-hazardous alternatives is feasible, either in the short or long term. For example, if Sony Ericsson finds out that it is using a possibly carcinogenic substance and that substance can be readily substituted or phased out, then Sony Ericsson will put the substance on one of its lists.

ADDRESSING DATA GAPS

While Material Safety Data Sheets (MSDSs) can provide some useful information, especially on "work environment" issues, Sony Ericsson has found that more information on material content is often needed. For instance, an MSDS may not indicate whether or not plastic parts are halogen-free. As is the case for many downstream users, Sony Ericsson can sometimes encounter difficulties in getting basic information about the content of different materials. This often happens simply because the supplier does not understand what the company is asking for. To be sure that there are no misunderstandings about such product content, Sony Ericsson sends its mobile phones out for external analysis of their chemical content to verify supplier information.

There are two possible methods for Sony Ericsson to ensure that the items produced by its suppliers do not contain hazardous substances. Historically, the company relied solely on suppliers to verify that their products did not contain the substances included on Sony Ericsson's banned or restricted substances lists. In recent years, however, it became apparent to the company that using a materials declaration system would allow it to take a more proactive strategy as new hazards become known. Such a system would also inform the company as to exactly what is in its products and also enable it to monitor for known hazards.

In May 2008, Sony Ericsson began implementing a materials declaration system, which had been in development for several years. The new system uses a standard industry format (IPC-1752) to collect information from suppliers. This means that Sony Ericsson wants full disclosure concerning all substances in Sony Ericsson products from all suppliers. The company estimates that it should have full disclosure on all components in its products by the end of 2010.

PROVEN RELIABILITY AND MATERIAL SUPPLY

Sony Ericsson has been working on reducing BFRs in its phones since 1999, and the company's products demonstrate that it is possible to manufacture halogen-free electronic devices that can withstand the extremely rigorous, industry-required physical reliability testing that is conducted prior to releasing a new product. Reliability testing of handsets often consists of harsh physical tests, such as a "drop test," in which an electronic device is tested to see how much force it can withstand, and a "shake test," in which engineers determine how well the electronic components fair after being literally shaken at a specified frequency and duration. These tests are conducted to simulate the rigors of the harsh conditions to which phones may be subjected to during daily use.

Sony Ericsson's engineers, in partnership with their suppliers, were able to resolve commonly known issues with halogen-free plastics, such as brittleness, and what was initially a limited supply of raw materials. The company has now shipped over 350 million BFR-free phones, as well as accompanying chargers and other accessories. The company was able to produce these devices without sacrificing their world-class reputation for selling reliable products. Sony Ericsson's leadership role in producing halogen-free devices provided incentive to their suppliers to develop reliable alternatives. As a result, there is now a reasonably large supply of alternatives available for a variety of plastic-based components, including BFR-free enclosures and printed circuit boards.

Sony Ericsson product development teams are confident that their BFR-free products fulfill, or exceed, the performance requirements for similar products that are not halogen-free. This confidence is reflected in its launch of the GreenHeart concept in June 2009. The GreenHeart phones are bromine- and chlorine-free, and Sony Ericsson has pledged that the GreenHeart concept will be rolled out across its entire product portfolio in the coming years. This will require that all Sony Ericsson's suppliers provide full material declarations. Sony Ericsson met some resistance from its suppliers when it began requiring these full declarations for their two GreenHeart phone models launched in June 2009. However, by working with the supply-chain, Sony Ericsson expects to achieve full compliance for all its phones by 2010.

DEFINING HALOGEN-FREE

In order to achieve flame retardancy through the use of halogenated material, such as brominated flame-retardants, one must typically use very high concentrations of bromine. It is not uncommon to find BFRs concentrations of 50,000 parts per million (ppm) in plastics. However, Sony Ericsson's experience is that traces of halogen can still be found in today's halogen-free applications. This is often due to issues associated with companies that supply products not only to customers who demand halogen-free materials but also to customers who have not yet made the transition to halogen-free products. In such cases, residues of halogenated material can be spread throughout the supply-chain, due to contamination in the production process. However, these residues are present in quantities that are much too low to fulfill a flame-retarding function. Sony Ericsson has therefore chosen to apply thresholds to their halogen-free applications. By establishing thresholds on elemental bromine and chlorine, such as the 900 ppm limit currently set for each element, the company is able to uphold a high halogen-free standard that excludes the intentional use of bromine and chlorine.

To verify compliance with Sony Ericsson's halogen-free or low-halogen standards, the company requires an analysis of products' elemental bromine and chlorine concentrations. If the bromine levels are below 900 ppm, no further testing is necessary. However, if test levels indicate a presence above 900 ppm, further testing using advanced equipment like gas chromatography and mass spectrometry is needed to identify the compound or compounds that are the source of the bromine.

In order to achieve full supplier compliance with the company's chemical restrictions, Sony Ericsson works closely with its suppliers. This takes the form of site visits, assessments, and audits, as well as education, training, and workshops. Educating suppliers in providing full disclosure also takes time. However, this education may actually be beneficial for both the suppliers and the industry since this facilitates compliance. In addition, Sony Ericsson predicts that the requirement for full disclosure will become more standard in the industry. A few other electronics companies are already starting to follow suit.

MOVING FORWARD

The experience of Sony Ericsson has proven that halogen-free devices can be manufactured on a mass scale for the mobile phone industry. The company's success could be optimized and leveraged across the industry if other major electronics manufacturers adopted their approach for full material disclosure and applied the elemental bromine and chlorine definitions to ensure cost-effective compliance with BFR and PVC restrictions. Also critical is the development of clearly defined restrictions in the next iteration of the Restriction of Hazardous Substances (RoHS) directive. Sony Ericsson has supported the development of additional substance restrictions to ensure industry-wide changes and to reduce the cost of compliance for those companies who led the industry in overcoming technical challenges to produce reliable halogen-free products.

Bromine- and Chlorine-Free Plastic Components

COMPANY PROFILE

DSM ENGINEERING PLASTICS

Manufacturer of engineering plastics used in a variety of industries, including electronics.

DSM Engineering Plastics is one of the world's leading suppliers of high-performance plastics, with a permanent focus on innovation. DSM EP delivers materials for customers who design or produce electronic equipment, cars, and barrier packaging films, as well as many electrical, mechanical, and extrusion applications.

Headquarters:	Sittard, The Netherlands
Sales:	€760 million (Euros, 2008)
Employees:	1,500 worldwide

www.dsmep.com

"We cannot be successful, nor can we call ourselves successful, in a society that fails."

– Feike Sijbesma, CEO of DSM EP.

DSM

ABSTRACT

DSM Engineering Plastics was one of the first chemical companies to offer a range of halogen-free products that can be used in electronics. DSM Engineering Plastics overcame technical, performance, and cost challenges to produce its new bromine- and chlorine-free high-temperature plastics. These new products can be used as PVC replacements for electronic wires and cables as well as internal and external electronic connectors.

DSM Engineering Plastics's long history of and commitment to product stewship has guided its journey in developing new bromine- and chlorine- free materials for electronic products. DSM EP's Living Solutions approach to sustainable product and process design includes four key tenets: reducing the use of hazardous substances; improving overall eco-efficiency; promoting recycling; and developing bio-based polymers. By keeping abreast of market trends, DSM EP became one of the first companies to recognize the value of developing solutions to replace bromine and chlorine in electronic connectors and cables. Over the past five years, growing demand for bromine- and chlorine-free products justified the investment required to develop a range of new halogen-free products, including polyamides (46, 6, and 66) and polyesters (TPC, PET, and PBT).

Until recently, the electronics industry generally considered brominated flame retardants and PVC plastic to have an ideal performance/safety balance. However, the inappropriate incineration of end-of-life electronics equipment via informal recycling has led to a growing concern that these materials can have risks to human health and to the environment. DSM EP recognized this concern as the result of several OEMs bringing it to the company's attention.

By working together with partners throughout its entire value chain, including OEMs and suppliers, DSM EP developed and now produces new bromine- and chlorine-free engineering plastics that meet high technical and environmental performance standards. These solutions enforce the competitive advantage for the emerging market demand for BFR- and PVC-free products in the electronics sector. DSM EP was among the first chemical companies to offer a complete portfolio of engineering plastics that are free of these substances.

Two key bromine- and chlorine-free DSM EP products with desirable qualities for electronic connectors and cables are:

- **Arnitel XG (www.arnitel.com)** is a high-performing thermoplastic co-polyester that contains no BFRs, PVC, halogens, or plasticizers. The product has been successfully commercialized for PVC replacement and approved for use with electronic wires and cables by the Underwriters Laboratories (UL), the world's largest, not-for-profit product safety testing and certification organization.

- **Stanyl ForTii (PA4T, www.fortii.com)** is a bromine-, chlorine-, and halogen-free polyamide resin that can be used for internal and external electronic connectors. Stanyl ForTii has the optimal balance of qualities desired in high-temperature polyamides: high stiffness, high melting temperature, and high glass-transition temperature. The material retains its mechanical and thermal performance throughout its lifecycle, from production to operation, to the recycling process of OEMs.

Re-tooling or specialized equipment is not required to use these new plastics to produce connectors and cable products. This significantly reduces the costs for electronic manufacturers using these products. DSM EP is now able to produce its halogen-free plastic resins in high volume to meet the increasing demand projected to arise as more customers move away from the use of BFRs, PVC, and other halogens.

OVERCOMING TECHNICAL CHALLENGES

When DSM EP began its quest to develop halogen-free versions of the high-temperature plastics used in electronics connectors and cable insulation, the viability of such formulations was in question due to reliability issues, such as brittleness, blooming, and corrosion. The company formed a large multidisciplinary team to conduct its own in-house research and development effort to find better solutions. The company's material scientists and engineering teams credit some of their success in solving many of the reliability issues to working relationships they established with some of the other manufacturers in the large and diverse electronics supply chain who were also grappling with some of the same challenges in their efforts to remove bromine and chlorine from their products.

These efforts included large OEM clients who were attempting to convert complete product lines, as well as "Tier 1" connector and cable manufacturers who needed viable engineering plastics. These companies collaborated to set up a feedback system whereby customers could report on the performance characteristics of new compounds. The information gleaned through this system allowed DSM EP's engineering teams to quickly address problems and incorporate changes into new versions of their products. The company also worked closely with suppliers to identify environmentally preferable flame retardants. DSM EP's engineering teams conducted both internal and external "Safety, Health and Environment (SHE)" studies to ensure that the new compounds met high environmental standards.

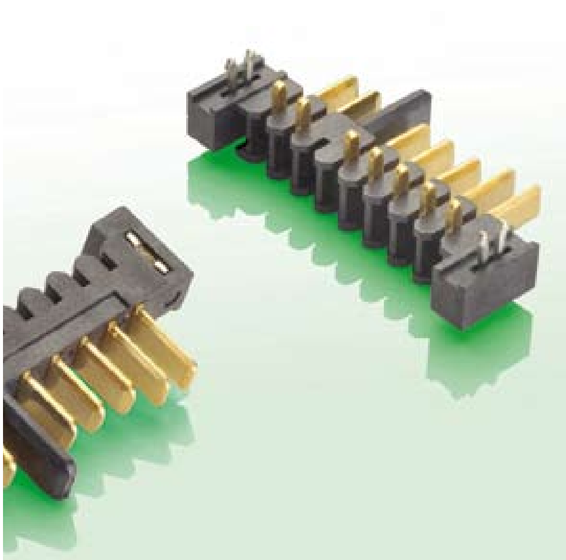
In addition to overcoming the technical, performance, and cost challenges that previously inhibited commercialization of new bromine- and chlorine-free high-temperature plastics, DSM EP also helped facilitate the development of new flame retardency standards. For the past decade, electronics suppliers and manufacturers only used plastic materials that conformed to the Underwriters Laboratories UL94-V0 flammability standard. This blanket approach to fire safety did not provide incentive for innovative designs. In some cases, it even encouraged the use of flame retardants in applications where the risk of fire was low.

DSM EP developed green design strategies based on a new fire safety standard (IEC 62368) being proposed by the International Electrotechnical Commission (IEC). The new standard would allow designers to address fire-safety by either preventing ignition (distancing the placement of flammable materials and heat sources) or controlling the spread of fire (using flame retardants and or fire barriers).

MOVING FORWARD

DSM EP's achievements would not have been possible without a forward-thinking management team who supported this work even through the economic downturn, when many other companies were cutting research and development expenses. By actively driving the development of halogen-free plastics components for the electronics sector, DSM EP was able to achieve breakthroughs that enabled the company to sprint ahead of its competitors.

DSM EP fully intends to continue developing sustainable solutions that meet the emerging market demands for eco-friendly products. In keeping with its corporate motto, the company expects to continuously improve the quality of its halogen-free portfolio. DSM EP is also active in developing bio-based plastic polymers that avoid or reduce the use of petroleum, as well as improve the recyclability and eco-efficiency of its engineering plastics.



Over the past five years, growing demand for bromine- and chlorine-free products justified the investment required to develop a range of new halogen-free products, including polyamides (46, 6, and 66, 4T) and polyesters (TPC, PET, and PBT).

Bromine- and Chlorine-Free Printed Circuit Boards (PCBs)

COMPANY PROFILE

NAN YA CCL

Manufacturer of copper-clad laminates used in the manufacture of printed circuit boards (PCBs).

Nan Ya CCL is a division of the Nan Ya Plastics Corporation, which is the market-leading supplier of the laminate material used to connect a printed circuit board's insulating layers together. Nan Ya Plastics Corporation was founded in 1958, and it is now part of a vertically integrated manufacturing corporation, Formosa Plastics.

Headquarters:	Taipei, Taiwan
Sales:	$6.4 billion (US dollars, 2008)
Employees:	12,529 worldwide

www.npc.com.tw

COMPANY PROFILE

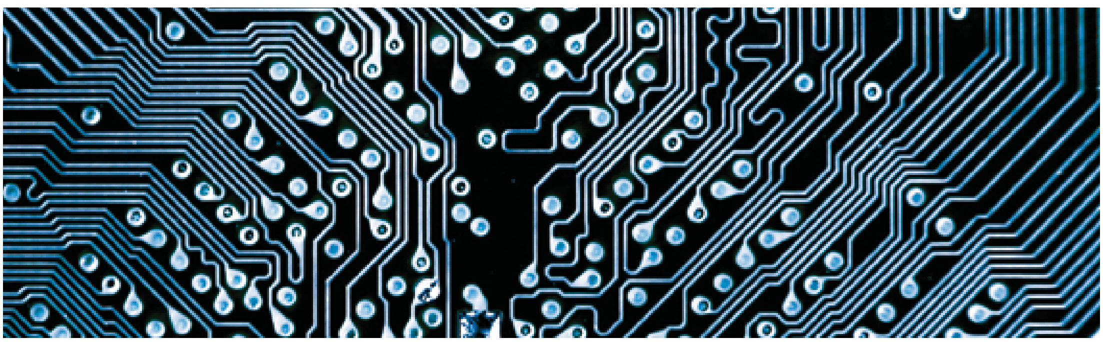
INDIUM CORPORATION

Manufacturer of solder pastes and fluxes for PCB assembly.

Indium Corporation is a premiere materials supplier to the global electronics assembly, semiconductor fabrication and packaging, solar photovoltaic and thermal management markets. Founded in 1934, the company offers a broad range of products, services, and technical support focused on advanced materials science.

Headquarters:	Utica, NY, USA
Sales:	Privately held, not publicly disclosed
Employees:	Privately held, not publicly disclosed

www.indium.com



NAN YA

INDIUM CORPORATION

ABSTRACT

Nan Ya and Indium both surmounted numerous obstacles to achieve their ultimate successes in producing bromine- and chlorine-free materials for use in printed circuit boards (PCBs). Nan Ya is the world's largest supplier of the rigid laminates used to connect PCBs' insulating layers, and it was one of the first to produce halogen-free laminates that performed as well as the halogen-containing FR-4 industry standard. Indium developed a new halogen-free solder paste that negates the need for intentionally added bromine and chlorine.

For several decades, brominated and chlorinated compounds have been used extensively in the manufacture of printed circuit boards (PCBs). However, there has been increased demand for PCBs produced without these halogenated chemicals from OEMs and electronics suppliers who have become increasingly aware of the environmental health issues associated with the improper disposal of halogen-containing electronic products.

The main source of halogens in finished PCBs is brominated flame retardant (BFR). Although chlorinated compounds are used to manufacture epoxy resins of the laminate boards, only trace concentrations of chlorine (around 100 parts per million (ppm)) remain in the final product. For this reason, chlorine poses less of a concern.

TBBPA is the brominated flame retardant primarily used to meet fire-safety standards for PCB assemblies. However, PCB assemblies contain hundreds of components, so simply removing TBBPA is not enough to ensure that the entire PCB assembly would consistently comply with the OEM manufacturers requiring that all homogeneous materials (defined within the industry as materials of uniform composition which cannot be mechanically disjointed into separate materials) contain less than 900 ppm elemental chlorine or bromine. As the world's largest supplier of the rigid laminates used to connect PCBs' insulating layers, Nan Ya was one of the first to overcome the technical challenges of taking bromine out of PCB laminates. In the past few years, Nan Ya has increased its sales of bromine- and chlorine-free laminates, and the company now boasts a 24 % share of the global market. The company has offered a bromine- and chlorine-free laminate since 2001, and laminates meeting this definition now account for 8.8 % of Nan Ya's total sales volume.

Other PCB materials that have historically included bromine are solder paste and flux. Solder paste is a viscous compound, and it typically consists of 90 % powdered metal and 10 % flux by weight. The paste is used to affix integrated circuits and connectors to the PCB. The halogenated compounds in the flux serve as activators, which help facilitate the soldering process.

Although industry organizations had been classifying fluxes based on their halide content since the 1970s, Indium's engineers determined that these older "halide-free" designations did not ensure compliance with IEC's current halogen-free specification. Halogenated compounds can be either ionic or covalently bonded. Tests specified by the IPC (originally the Institute for Printed Circuits), the association representing companies in the electronic interconnection industry, only detect one of two kinds of chemical bonds that halogenated compounds can form, and it isn't the covalent bonds typically found in fluxes. Therefore, the IPC test method may suggest that there are no halogens present when it could be loaded with covalently bonded halogens. The IPC method also tests the flux prior to heating and soldering. The soldering process actually evaporates about 50 % of the flux but virtually none of the halogens, so the concentration of halogen in the residue is about twice as much as in the raw flux.

To successfully produce PCB solder pastes and fluxes that meet the IEC's current halogen-free designation, which was defined as 900 ppm of bromine or chlorine, Indium successfully overcame a complex set of technical challenges. Indium and Nan Ya are now part of the group of suppliers that have the technical expertise to produce PCB materials that meet the reliability standards required for their halogenated counterparts. This group of PCB material suppliers is now well-prepared to meet the supply demands when new OEMs ramp up their production of Br-Cl-free electronic devices. That's important, because the International Electronics Manufacturing Initiative (iNEMI), an industry-led consortium of approximately 70 electronics manufacturers, suppliers, and related organizations, predicts that the global market for bromine- and chlorine-free PCBs is set to more than double from approximately 6 % of the overall electronics marketplace to over 12 %. Bromine- and chlorine-free PCBs are already in mobile phones and laptops sold in high volumes. Currently 50 % of mobile phones use bromine-free laminates.

OVERCOMING TECHNICAL CHALLENGES

Some of the big hurdles that had to be overcome to produce bromine- and chlorine-free PCB assemblies first came to light when PCB component manufacturers were grappling with how to remove lead from their products to comply with the EU's RoHS directive. Because removing lead and halogens required some of the materials used to produce PCBs to be redesigned, companies were able to capitalize on the opportunity to find solutions that simultaneously met RoHS and bromine- and chlorine-free requirements.

Halogen-free laminates

One of the first steps Nan Ya and other laminate manufacturers were required to take to develop new methods and processes to reliably produce bromine- and chlorine-free PCB laminates was finding a new flame retardant to replace TBBPA. The use of reactive TBBPA (the form primarily used in PCBs) complicated compliance with new material standards since it is bound into the polymer and no longer detectable as a compound in the final product. Most laminate manufacturers moved to reactive phosphorus-based flame retardants, which changed some of the laminates' physical, thermal, and electrical characteristics. Some electronic devices had to be redesigned to ensure that they could operate reliably with the newly formulated PCBs.

Nan Ya worked to successfully overcome the following technical challenges of bromine- and chlorine-free laminates:

- Increased brittleness of the material could cause cracks, which compromised the reliability of the device.
- Poor adhesion strength to the copper conductive layer could cause a phenomenon known as delamination in which the copper layer peels away from the epoxy.
- The hardness of the material caused issues during the etching phase of PCB assembly, resulting in instability in the manufacturing process.
- The hardness of the material also incurred additional costs because of the additional wear on equipment such as drill bits.

In the past few years, Nan Ya has increased its sales of bromine- and chlorine-free laminates, and the company now boasts a 24% share of the global market.

iNEMI's assessment showed that bromine- and chlorine-free laminates met or exceeded the performance in eight of the nine tested categories.

Engineers eventually developed new technologies that relied on different curing agents and alternative proprietary formulations. These solutions allowed PCB material manufacturers to offer bromine- and chlorine-free components that are as reliable as the halogen-containing FR-4 material that is considered an industry standard. A testament to how effectively laminate manufacturers, and the industry as a whole, have dealt with these issues comes from an extensive 2007/08 iNEMI evaluation that investigated the technical performance of bromine- and chlorine-free laminates. The organization evaluated nine key physical, thermal, and electrical properties of the new laminates by comparing them with the FR-4 material. iNEMI's assessment showed that the bromine- and chlorine-free laminates met or exceeded the performance in eight of the nine tested categories (see table [add position info]). In the ninth category, peel strength, some but not all bromine- and chlorine-free laminates boards met the performance of FR-4 laminates. In its evaluation, iNEMI stressed that not all bromine- and chlorine-free laminates were equivalent and all performed differently than the FR-4 material. iNEMI is currently conducting a project to further evaluate bromine- and chlorine-free laminates PCB materials, with an eye toward developing industry standards for producing such materials.

PERFORMANCE OF HALOGEN-FREE VS. BROMINATED LAMINATES

(+ means better, - = worse and o = indifferent)

Thermal properties	Thermal expansion	Lower	+
	Thermal conductivity	Higher	+
Physical properties	Flammability	Equal	o
	Moisture absorbtion	Comparable	+ / o
	Peel strength	Lower	- / o
	Modulus	Equal	o
Electrical properties	CAF resistance	Higher	+
	Dielectric constant	Slightly higher	+
	Dissipation factor	Lower	+
Workability	Drill bit wear	Higher	-

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It is important to note that the bromine- and chlorine-free PCBs perform with better thermal reliability in the higher temperature manufacturing environment required to produce RoHS-compliant lead-free electronic devices. They also have a lower dielectric constant, which results in a more stable electric circuit. This renders the signal strength from one point of a circuit to another more predictable.

BROMINE- AND CHLORINE-FREE SOLDERS AND FLUX

To reliably produce bromine- and chlorine-free solder and flux, Indium had to overcome two major challenges: "graping" and "head-in-pillow defects."

GRAPING is a phenomenon in which the flux-to-powder ratios are reduced due to a variety of reasons. The exposed solder powder then combines into a mass instead of being dispersed evenly, which creates unreliable solder joints. To solve the problem, PCB manufacturers redesigned their products to reduce exposed metal traces and increase the use of solder mask defined pads. This creates a "well" around the pad and helps to keep the flux around the solder paste deposit, which assists with the effectiveness of the flux. Indium also had to change its process by using a higher volume of solder paste and optimizing the airflows in its reflow ovens.

HEAD-IN-PILLOW DEFECT (HIP) is a common failure in the industry that occurs when the solder paste does not mix with the metal on certain types of semiconductor packages. This failure causes the circuit in the electronic device to fail. There are several reasons for these types of failures to occur, including:

- oxidation being present where the semiconductor package meets the solder during certain phases of the production process;
- PCBs not designed for optimal performance with bromine- and chlorine-free flux; and
- using insufficient quantities of solder paste during the process.

To prevent this type of failure, Indium developed a new solder paste that expanded what is known as the oxidation barrier. The new solder reduced the need for increasing the use of bromine- and chlorine-free activation agents. This innovation is considered a major breakthrough, and it enables the production of PCBs that comply with the 900 ppm threshold for bromine and chlorine without compromising the reliability of the product.

GOING FORWARD

Nan Ya and Indium provide key examples of an industry finding workable solutions to the technical challenges manifested by the transition to bromine- and chlorine-free materials. Some of these solutions required minor tweaks to current processes, while others led to better PCB design and more efficient manufacturing. However, the 5 to 30 % cost premium associated with these new PCB materials is still a major issue. The higher prices are largely attributed to the following factors: a relatively small number of OEMs specifying bromine- and chlorine-free components; the higher costs of new flame retardants; and the residual costs incurred in developing the new design and production processes necessary for bromine- and chlorine-free PCB assembly.

Now that much of the research needed to develop the new materials and techniques has already been conducted, many PCB material suppliers are prepared to meet the supply demands expected when large OEMs ramp up their production of new bromine- and chlorine-free consumer electronic devices. The predictability of a more guaranteed market demand for these products, such as a government mandate and/or a higher number of OEMs specifying them, will allow suppliers to more efficiently scale-up their production and lower product costs.

The bromine- and chlorine-free PCBs perform with better thermal reliability in the higher temperature manufacturing environment required to produce RoHS-compliant lead-free electronic devices.

Bromine- and Chlorine-Free Hard Disk Drives

COMPANY PROFILE

SEAGATE TECHNOLOGY

Manufacturer of hard disk drives and storage devices.

Seagate is the world's largest manufacturer of hard disk drives. Hard drives are the primary medium for storing electronic information in systems ranging from desktop computers and consumer electronics to data centers. The company produces a broad range of hard drive products, and it currently holds a 34% share of the overall market, the highest in the industry. The company leads the world in every segment of the storage market but the notebook segment, where it is in the top three.

Headquarters:	Scotts Valley, CA, USA
Design Centers:	Colorado, Minnesota, and Singapore
Sales:	$2.1 Billion (US dollars, Q3 2009)
Employees:	43,000 worldwide

www.seagate.com

Seagate®

ABSTRACT

Seagate is the world's largest manufacturer of hard disk drives, and approximately 50 % of the disk drives Seagate ships today meet halogen-free specifications. Hard disk drives comprise several hundred individual components that Seagate sources from between 250 to 300 suppliers, and bromine and chlorine had to be eliminated from the hard drives' printed circuit boards, circuit cabling, adhesives, and plastic housings. Seagate's implementation of an automated Compliance Assurance System for tracking the use of all materials in hard-drive components helped with its transition to chlorine-and bromine-free materials.

According to Seagate's Global Citizen Annual Report, first produced in 2005, the company adopted product stewardship principles to mitigate the impact of its products on the environment throughout their lifecycles, from design and manufacture to end-of-life management and disposal. The objective of Seagate's product stewardship program is to meet or exceed requirements of product-related environmental legislation and customer environmental requirements related to its products, packaging, user documentation, and manufacturing processes. This program ensures global compliance with all current regulatory requirements, such as RoHS, as well as its customers' requirements for bromine- and chlorine-free devices.

Seagate faced the same issues as many other manufacturers in producing bromine- and chlorine-free hard drives. Suitable materials had to be acquired from multiple vendors, and testing had to be conducted to ensure the high level of field reliability demanded by the company's customers. In addition to developing the requisite technology, the company's engineers needed to ensure that they could effectively integrate the necessary changes into their streamlined high-volume manufacturing systems. To tackle this challenge, Seagate followed its customary approach of forming a multi-discipline taskforce to study the issue and develop solutions. The team was so successful in resolving the technical and cost issues that approximately 50 % of the disk drives Seagate ships today meet bromine- and chlorine-free specifications. Seagate is also ready to scale-up and meet the higher volume demands that will arise as more OEMs adopt these material specifications.

OVERCOMING TECHNICAL CHALLENGES

Seagate's corporate culture, which focuses on meeting or exceeding customer requirements, helped make it possible for the organization to tackle the challenges of redesigning disk drives to avoid the use of bromine and chlorine. Hard disk drives comprise several hundred individual components that Seagate sources from between 250 to 300 suppliers. In addition to the hard drives' printed circuit boards, which can contain TBBPA, the halogen-containing components include the circuit cabling, adhesives, and plastic housings. The company had to also address another banned substance, antimony trioxide, which was used on certain bearing surfaces, although not as a flame retardant.

Environmental liabilities were not the only concern with bromine use in printed circuit boards. Bromine can pose potential reliability problems in a hard drive's printed circuit boards. Bromine-containing materials, specifically the acoustic foam commonly used in hard drives, may convert to a gaseous form and subsequently precipitate onto circuit boards, which can pose a corrosive hazard. Such bromine contamination can eventually corrode critical electrical components and circuitry to the point of failure.

Although Seagate drives have not succumbed to this type of bromine contamination, such drive failures have been reported in hard drives from other manufacturers. This issue is being resolved by advances in drive acoustics, as well as by the use of halogen-free substitutes in instances where the acoustic foam is necessary.

OPTIMIZED MANUFACTURING TO MEET LOGISTICAL CHALLENGES

Seagate's business strategies to adopt new materials and honor chemical restrictions, which were developed as early as 1998, has streamlined the company's manufacturing processes in a way that enables it to be sufficiently flexible to meet the demands of a wide variety of customers. In Q3 FY2009, the company shipped over 38 million hard drives into markets ranging from personal computing to cutting-edge applications intended to provide digital support throughout all facets of modern life, from home to office to automobile. Since the company owns, develops and manufactures the underlying technology, it is able to leverage technological innovations and changes across multiple product lines. Because many of Seagate's products share the same components, the company can also more easily optimize its manufacturing. A halogen-free component can be manufactured using the same line, manpower, and tools simply by exchanging one printed circuit board for a halogen-free variant. This allows Seagate to have the flexibility to scale-up manufacturing of the halogen-free products to meet emerging market demands while still adhering to the principles of just-in-time manufacturing.

ESTABLISHING STRONG MATERIAL COMPLIANCE PROGRAMS WITH SUPPLIERS

Seagate's implementation of an automated Compliance Assurance System for tracking the use of all materials in hard-drive components also helped with the transition to bromine- and chlorine-free materials. The system was based on an industry-standard reporting form developed by IPC (originally the Institute for Printed Circuits), the association representing companies in the electronic interconnection industry. Seagate used it to launch a full material reporting and disclosure requirement across its supply chain. The system requires component suppliers to report on all substances present, regardless of whether or not the substance is restricted. To do so, the vendors provide the Chemical Abstracts Service, or CAS, registry numbers assigned by the American Chemical Society for each compound they use. Seagate also specified that suppliers

The team was so successful in resolving the technical and cost issues that approximately 50% of the disk drives Seagate ships today meet bromine- and chlorine-free specifications.

provide independent lab analyses to prove conformance to RoHS and low-halogen restrictions, as well as an official statement confirming that the materials conform to Seagate's list of several hundred banned substances.

This approach required upfront infrastructure investments that were initially time-consuming and resource-intensive for both Seagate and its vendor base. Once the program was developed, however, Seagate was able to reduce costs to both the company itself and to a vast number of its vendors. The use of automated tools and a standardized reporting format put Seagate in a good position to quickly identify if components contained certain banned substances. This allowed the company to address nonconformance with corrective resolutions. The system enables Seagate to assure its customer base that the products it supplies comply with specified material restrictions.

MOVING FORWARD

As is the case with other major suppliers producing bromine- and chlorine-free products, the cost of bromine- and chlorine-free materials remains a major challenge for Seagate. This cost premium can dampen the pace of adoption, particularly in an increasingly price-sensitive economy. Because Seagate has overcome the technical challenges, the company stands ready to scale up production to meet higher demand as more OEMs adopt bromine- and chlorine-free materials in their products. This will bring costs down, but it requires a commitment from some of the larger OEMs.

Bromine-Free Semiconductor Chips

COMPANY PROFILE

SILICON STORAGE TECHNOLOGY, INC. (SST)

Manufacturer of flash memory-based components.

SST is a market leader in its niche, producing low-density flash memory semiconductors for storing the code required to boot electronic devices such as PCs and mobile phones.

Headquarters:	Sunnyvale, CA, USA
Design Centers:	Sunnyvale, CA, USA; Hsinchu, Taiwan; Shanghai, China
Sales:	$315.5 million (US dollars, 2008)
Employees:	614 worldwide

www.sst.com

"We are committed to preserving our environment by managing and eliminating the impact of harmful substances, as defined by industry standards, in the manufacture of SST products."

– Bing Yeh, Executive Chairman and CEO, Silicon Storage Technology, Inc.

Silicon Storage Technology, Inc. was one of the first semiconductor companies in the electronics sector to provide customers with bromine-free products. The company's impetus for developing its bromine-free semiconductor chips was its customers' increasing demand for halogen-free products, as well as the EU RoHS directive's requirement that materials be lead-free. Over a six-year time frame, SST was able to successfully remove both lead and brominated compounds from its product lines.

Of the numerous challenges that SST's engineering team succeeded in overcoming, the most formidable was identifying a viable molding compound that could be substituted for the readily available material that had been used in the industry for decades. SST invested in an approach that allowed the company to become one of the first semiconductor manufacturers to supply major customers, like Apple, with components that met new bromine- and chlorine-free supply chain specifications. By 2008, 100 % of SST's semiconductor devices were bromine-free.

SST's products meet the following goals that the company developed for substitute materials:

- **Compliant with international environmental standards;**
- **No compromise in reliability and performance of the structure of the package used to mount the semiconductor to a printed circuit board;**
- **Negligible increase in cost per unit;**
- **Achievement of UL94-V0 fire safety rating.**

It is important to note that because chlorine-based compounds are not used in the final product of semiconductor devices, they are not applicable to this case study.

OVERCOMING TECHNICAL CHALLENGES

SST's success in removing bromine from its products required a great deal of collaboration with other suppliers because the company sits in the middle of the electronics supply chain and does not own its own manufacturing facilities. The company's journey in eliminating bromine is inextricably tied to the semiconductor industry's use of antimony trioxide, another substance of high concern that was used in conjunction with bromine for 25 years to increase the flame retardancy of semiconductor chips.

ABSTRACT

Silicon Storage Technology, Inc. was one of the first electronics companies to produce bromine-free semiconductors. The most formidable hurdle the company had to overcome was discovering a bromine-free molding compound to encapsulate its semiconductors. Eventually the company found a multiaromatic resin (MAR) formulation that was both bromine-free and able to withstand the higher solder temperatures needed to comply with RoHS' lead-free solder requirements. By 2008, 100 % of SST's semiconductors were bromine-free. As chlorine-based compounds are not used in the final product of semiconductor devices, they are not applicable to this case study.

At the turn of the millennium, industry restrictions on antimony trioxide forced resin manufacturers, such as Sumitomo Bakelite, to evaluate alternative flame retardants that could be used in the molding compounds needed to encapsulate semiconductor devices. Identifying reliable alternatives proved to be a real challenge. The first alternative to emerge used red phosphorous, but this formulation was discontinued after manufacturers discovered that it had a serious reliability flaw.

Eventually, continued research led to the development of a more successful alternative, multiaromatic resin (MAR). This resin reformulation took advantage of a blistering phenomenon that offered the same fire retardancy protections as the additives but without the use of brominated flame retardants (BFRs). Fortuitously, the resin's ability to withstand higher solder temperatures also resolved the industry's need to find a resin capable of complying with the RoHS requirement eliminating the use of lead. The main use of lead was in soldering materials. Lead-free solders, such as those that are based on 100 % tin, operate at higher temperatures. The significant cost increases initially required to use the MAR compounds were ameliorated in 2001. That year, increased availability from multiple sources made it cost effective for SST to use compounds that were free of both bromine and antimony trioxide in its new RoHS-compliant devices.

In addition to identifying safer flame retardants, the SST engineering team had to overcome the challenges of delamination, which can cause the material used to encapsulate the semiconductor to fail. SST initiated joint studies with key suppliers to engineer materials that would be moisture-resistant for each size and thickness of the various semiconductor packages used to mount SST's integrated circuits onto printed circuit boards. The company's close working relationship with its suppliers allowed it to identify cost-effective and reliable solutions ahead of its competitors.

Once the technical and availability issues were resolved, the challenge shifted to SST teams that dealt with manufacturing and inventory management issues. Since SST does not own its own manufacturing facilities, the company had to carefully manage the product revision cycle to ensure that its manufacturing partners were not burdened with the need to store old raw material inventory reserved for SST's forecasted volume. To maintain good vendor relations, SST implemented a slow phase-in of the bromine-free compound even though the new material was readily available.

PRODUCT	TIMELINE
SST semiconductors in "leadframe*" based mounting packages	2001 – first set of Pb-free products 2006 – 100 % Pb-Free 2006 – 90 % BFR-free 2008 – 100 % BFR-free
SST semiconductors in substrate-based leadless* mounting packages	2006 – 100 % Pb-free 2006 – BFR-free molding compound 2008 – 100 % BFR-free

** In this context, the term "lead" refers to the methodology used to connect the semiconductor's mounting package to a printed circuit board. It does not imply anything about the semiconductor product's chemical composition or whether the lead (Pb) element is used in it. (Leadframes can be lead-free (Pb-free).)*

SST's microprocessors have two different mounting package options, which are known in the industry as leadframe and leadless. The terms do not imply anything about the product's chemical composition. By 2006, 90 % of all the leadframe-based devices that SST shipped to its customers were bromine-free. The only remaining use of bromine was in the company's leadless substrate materials. In 2007, when Apple restricted the use of bromine in all homogeneous materials, SST's engineering and manufacturing teams removed the element from the company's remaining product lines and shipped its first set of products to Apple that were entirely bromine-free. Many companies run parallel product lines, but SST made the decision to sell entirely bromine-free product lines to avoid product mixing. Product mixing is very difficult to prevent in high-volume production facilities where non-conforming parts can inadvertently contaminate other lines, increasing the risk of shipping products that fail to meet specific material specifications.

ENSURING COMPLIANCE WITH MATERIAL RESTRICTIONS

Since SST is situated in the middle of the electronics industry supply chain, the company had to submit documentation to its customers that ensured the products the company was providing to them met required technical and environmental specifications. The company conducted standardized qualification studies using guidelines produced by JEDEC (originally the Joint Electron Devices Engineering Council), the technical organization that oversees standards for the solid-state industry.

These studies were summarized in Reliability Qualification reports, which SST provided to its customers. In order to prove compliancy to standards such as RoHS, SST was also required to produce chemical analysis reports of each homogenous material (molding compound, leadframe, and substrates) used in their products. The analysis tests were conducted at independent labs using standardized tests such as IPC (Inductively Plasma Coupling), a very accurate method of measuring the level of restricted compounds down to 5 parts per million (ppm). To easily provide SST's customers with analysis data, these test results were populated into a custom-designed database system that was available to the company's worldwide sales force. For compliance tests covering the six substances restricted under the RoHS directive, the reports typically cost $150 (US). It costs SST an additional $90 (US) to run tests for compliance with bromine-free specifications. This increase is negligible given that the complete qualification process for a new product typically costs $150,000.

MOVING FORWARD

SST's experience has shown that semiconductor manufacturers can attain an elemental restriction on bromine without incurring excessive research and development costs or affecting product reliability. As new chemical and material restrictions are developed for the electronics sector, it is critical that clear thresholds and definitions be established. Global harmonization of these thresholds and definitions using joint industry standards and/or new policy regulations allows companies like SST, which have limited research and development resources, to develop engineering solutions that successfully eliminate substances of high concern.

Many companies run parallel product lines, but SST made the decision to sell entirely bromine-free product lines to avoid product mixing.

REFERENCES

CHAPTER 2. HUMAN HEALTH AND ENVIRONMENTAL CONCERNS

1. Henschler, D. "Toxicity of chlorinated organic compounds: Effects of the introduction of chlorine in organic molecules." Angewandte Chemie International Edition (English) vol. 33 (1994): 1920–1935.
2. Bernes, C. Persistent Organic Pollutants: A Swedish View of an International Problem. ISBN 91-620-1189-8. Stockholm, Sweden: Swedish Environmental Protection Agency, 1998.
3. Thornton, J. Pandora's Poison. Cambridge, Mass.: MIT Press, 2000.
4. U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program. Report on Carcinogens, Eleventh Edition. http://ntp.niehs.nih.gov/index.cfm?objectid=32BA9724-F1F6-975E-7FCE50709CB4C932.
5. Shibamoto, T. et al. "Dioxin Formation from Waste Incineration." Reviews of Environmental Contamination & Toxicology, vol. 190 (2007): 1-41.
6. Wichmann, H. et al. "Thermal formation of PBDD/F from tetrabromobisphenol A–a comparison of polymer linked TBBPA with its additive incorporation in thermoplastics." Chemosphere, vol. 47 (2002): 349–355.
7. Costner, P. "Correlation of chlorine input and PCDD/PCDF at a full-scale hazardous waste incinerator."Organohalogen Compounds, vol. 36 (1998): 147–152.
8. Bertazzi P.A. et al. "The Seveso studies on early and long-term effects of dioxin exposure: a review." Environmental Health Perspectives, vol. 106 (suppl 2, 1998): 625–631.
9. Mocarelli, P. et al. "Dioxin exposure, from infancy through puberty, produces endocrine disruption and affects human semen quality." Environmental Health Perspectives, vol. 116 (2008): 70–77.
10. Lebel, G. "Organochlorine exposure and the risk of endometriosis." Fertility and Sterility, vol. 69 (1998): 221–228.
11. Pauwels, A. et al. "The risk of endometriosis and exposure to dioxins and polychlorinated biphenyls: a case-control study of infertile women." Human Reproduction, vol. 6 (2001):2050–2055.
12. Pelclová, D. "Biochemical, neuropsychological, and neurological abnormalities following 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) exposure." Archives of Environmental Health 6(2001): 493–500.
13. Mocarelli, P. et al. "Clinical laboratory manifestations of exposure to dioxin in children: a six-year study of the effects of an enviromental disaster near Seveso, Italy." Journal of the American Medical Association, vol. 256 (1986): 2687–2695.
14. Theobald, H.M, et al. "Developmental and reproductive toxicity of dioxins and related compounds." Dioxins and Health. Ed. Schecter, A. et al. 2nd ed. Hoboken, N.J.: John Wiley & Sons, 2003.
15. Roman, B.L. et al. "Developmental male reproductive toxicology of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and PCBs." Reproductive and Developmental Toxicology. Ed. Korach K.S. New York, N.Y.: Marcel Dekker, 1998.
16. Guo, Y.L. et al. "Semen quality after prenatal exposure to polychlorinated biphenyls and dibenzofurans." Lancet, vol. 356 (2000): 1240–1241.
17. DeVito, M.J. et al. 1995. "Comparisons of estimated human body burdens of dioxinlike chemicals and TCDD body burdens in experimentally exposed animals." Environmental Health Perspectives, vol. 103 (2000):820–31.
18. Li, H. et al. "The PCDD/F and PBDD/F pollution in the ambient atmosphere of Shanghai, China." Chemosphere, vol. 70 (2008): 576–583.
19. Leung, A. et al. "Spatial distribution of polybrominated diphenyl ethers and polychlorinated dibenzo-p-dioxins and dibenzofurans in soil and combusted residue at Guiyu, an electronic waste recycling site in southeast China." Environmental Science & Technology, vol. 41 (2007): 2730–2737.
20. U.S. Environmental Protection Agency. Health Assessment Document for 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. vol. III of III. EPA/600/BP-92/001B. Cincinnati, Ohio: U.S. Environmental Protection Agency, August, 1994.
21. New York State Department of Health. "Chemicals in Sportfish and Game: 2009-2010 Health Advisories." http://www.health.state.ny.us/environmental/outdoors/fish/fish.htm.
22. Lorber, M. et al. "Infant Exposure to Dioxin-like Compounds in Breast Milk." Environmental Health Perspectives, vol. 110 (2002): A325–A332.
23. Chan, J.K.Y. et al. "Body Loadings and Health Risk Assessment of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans at an Intensive Electronic Waste Recycling Site in China." Environmental Science & Technology, vol. 41 (2007): 7668-7674.
24. Shi, Z. X. et al. "Dietary Exposure Assessment of Chinese Adults and Nursing Infants to Tetrabromobisphenol-A and Hexabromocyclododecanes: Occurrence Measurements in Foods and Human Milk." Environmental Science & Technology, vol. 43 (2009): 4314–4319.
25. Johnson-Restrepo, B. et al. "Tetrabromobisphenol A (TBBPA) and hexabromocyclododecanes (HBCDs) in tissues of humans, dolphins, and sharks from the United States." Chemosphere, vol. 70 (2008): 1935–1944.
26. Li, H. et al. "Severe PCDD/F and PBDD/F Pollution in Air around an Electronic Waste Dismantling Area in China." Environmental Science & Technology, vol. 41 (2007): 5641-5646.
27. Yienger, J.J. et al. "The episodic nature of air pollution transport from Asia to North America." Journal of Geophysical Research, vol. 105 (2000): 26931-26946.
28. Söderström, G. et al. "PBCDD and PBCDF from incineration of waste-containing brominated flame retardants." Environmental Science & Technology vol. 36 (2002): 1959-1964.
29. Birnbaum, L.S. et al. "Health effects of polybrominated dibenzo-p-dioxins (PBDDs) and dibenzofurans (PBDFs)." Environment International, vol. 29 (2003): 855–860.
30. Samara, F. et al. "Determination of relative assay response factors for toxic chlorinated and brominated dioxins/furans using an enzyme immunoassay (EIA) and a chemically activated luciferace cell bioassay." Environment International, vol. 35 (2009): 588–593.
31. Olsman, H. et al. "Relative Differences in Aryl Hydrocarbon Receptor-Mediated Response for 18 Polybrominated and Mixed Halogenated Dibenzo-p-Dioxins and -Furans in Cell Lines from Four Different Species." Environmental Toxicology and Chemistry, vol. 26 (2007): 2448–2454.
32. World Health Organization. "Dioxins and their effects on human health." Nov. 2007. http://www.who.int/mediacentre/factsheets/fs225/en/index.html.
33. Korach, K. Reproductive and Developmental Toxicology. CRC Press, Boca Raton, FL: 1998.
34. Hayakawa, K. et al. "Polybrominated diphenyl ethers (PBDEs), polybrominated dioxins/furans (PBDDs/DFs) and monobromo-polychlorinated dioxins/furans (MoBPXDDs/DFs) in atmosphere and bulk deposition in Kyoto, Japan." Organohalogen Compounds, vol. 59 (2002): 299– 302.

35. Ohta, S. et al. "Contamination levels of PBDEs, TBBPA, PCDDs/DFs, PBDDs/DFs and PXDDs/DFs in the environment of Japan." Organohalogen Compounds, vol. 57 (2002): 57–60.

36. Terauchi, H. et al. "Polybrominated, polychlorinated and monobromo-polychlorinated dibenzo-p-dioxins/dibenzofurans and dioxin-like polychlorinated biphenyls in marine surface sediments from Hong Kong and Korea." Environmental Pollution, vol. 157 (2009): 724–730.

37. Xizehi, Y. et al. "E-waste Recycling Heavily Contaminates A Chinese City with Chlorinated, Brominated, and Mixed Halogenated Dioxins." Organohalogen Compounds, vol. 70 (2008): 813–816.

CHAPTER 3. E-WASTE AND RECYCLING INFRASTRUCTURE

1. Consumer Electronics Association. "Global Consumer Electronics Industry Will Grow to $700 Billion by 2009, CEA/GfK Study Finds." http://www.ce.org/Press/CurrentNews/press_release_detail.asp?id=11535.

2. Europa, the portal site of the European Union. "Questions & Answers on EU Policies on Electric and Electronic Waste." MEMO/05/248. http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/05/248&type=HTML&aged=0&language=EN&guiLanguage=en.

3. European Commission. "Commission Staff Working Paper Accompanying the Proposal for a Directive of the European Parliament and of the Council on Waste Electrical and Electronic Equipment (WEEE) (Recast) Impact Assessment." SEC (2008) 2933. Brussels: 3.12.2008.

4. US Environmental Protection Agency Office of Solid Waste. "Municipal Solid Waste Generation, Recycling and Disposal in the United States: 2007 Facts and Figures." EPA5340- R-08-010. November 2008.

5. United Nations Environment Programme. "E-waste, the hidden side of IT equipments' manufacturing and use." Environment Alert Bulletin 5. January 2005. http:/www.grid.unep.ch/product/publication/download/ew_ewaste.en.pdf.

6. Basel Action Network et al. "Exporting Harm—The High-Tech Trashing of Asia." 25 Feb. 2002. http://www.ban.org/E-waste/technotrashfinalcomp.pdf.

7. Yasuhara, A. et al. "Formation of PCDDs, PCDFs, and Coplanar PCBs from Incineration of Various Woods in the Presence of Chlorides." Environmental Science & Technology, vol. 37 (2003): 1563-1567.

8. Costner, P. 1998. "Correlation of chlorine input and PCDD/PCDF at a full-scale hazardous waste incinerator."Organohalogen Compounds, vol. 36 (1998): 147–152.

9. Li, H. et al. "Severe PCDD/F and PBDD/F Pollution in Air around an Electronic Waste Dismantling Area in China." Environmental Science & Technology, vol. 41 (2007): 5641-5646.

10. United Nations Environment Programme. "Draft Guidelines on Best Available Techniques and Provisional Guidance on Best Environmental Practices relevant to Article 5 and Annex C." December 2004. http://chm.pops.int/Programmes/BATBEP/ProcessesProcedures/tabid/187/language/en-US/Default.aspx. Accessed 14 August 2009.

11. Grosso, M. et al. "Environmental release and mass flux partitioning of PCDD/Fs during normal and transient operation of full scale waste to energy plants." Chemosphere vol. 67 (2007): S118–S124.

12. Odusanya, D.O. et al. "Polybrominated diphenyl ethers (PBDEs) in leachates from selected landfill sites in South Africa." Waste Management, vol. 29 (2009): 96–102.

13. Steen, P.O. et al. "Photochemical Formation of Halogenated Dioxins from Hydroxylated Polybrominated Diphenyl Ethers (OH-PBDEs) and Chlorinated Derivatives (OH-PBCDEs)." Environmental Science & Technology, vol. 43 (2009): 4405–4411.

14. Li, J. et al. "Recycle Technology for Recovering Resources and Products from Waste Printed Circuit Boards." Environmental Science & Technology, vol. 41 (2007): 1995–2000.

CHAPTER 4. ESTABLISHING VERIFIABLE BROMINE AND CHLORINE RESTRICTIONS

1. IPC-4101B with Amendment 1: Specification for Base Materials for Rigid and Multilayer Printed Boards, Association Connecting Electronic Industries, February 2007, www.ipc.org.

CHAPTER 5. ALTERNATIVES TO BROMINE AND CHLORINE BASED COMPUNDS

1. Factsheets on hazard profiles of some non halogenated flame retardants can be found at www.halogenfree-flameretardants.com.

2. Washington State Department of Health (2008): Alternatives to Deca-BDE in Televisions and Computers and Residential Upholstered Furniture. Department of Ecology State Washington, www.ecy.wa.gov/biblio/0907041.html.

3. German UBA 2001: Substituting Environmentally Relevant Flame Retardants: Assessment Fundamentals Volume 1: Results and summary overview. www.umweltbundesamt.de/uba-info-median/deteien/1998.htm.

4. Danish EPA: Environment Project no.1141, 2007, Deca-BDE and Alternatives in Electrical and Electronic Equipment, www2.mst.dk/Udgiv/pdf/978-87-7052-350-9.pdf.

5. Illinois Report: "Report on Alternatives to the Flame Retardant DecaBDE: Evaluation of Toxicity, Availability, Affordability and Fire Safety Issues", Illinois Environmental Protection Agency, March 2007, www.epa.state.il.us/reports/decabde-study/index.html.

6. The Green Screen for Safer Chemicals: Evaluating Flame Retardants for TV Enclosures, Dr. Lauren Heine and Dr. Mark Rossi, Clean Production Action, March 2007.

CONCLUSION

The electronics industry has made significant technical strides in reducing its dependency on toxic substances. Earlier this decade, the industry demonstrated that it could dramatically reduce the content of lead, cadmium, and other toxic substances in order to meet the European RoHS directive's 2006 deadline. Today, the seven companies in this report have demonstrated that toxic-free objectives can be extended significantly beyond RoHS. They have proven that dioxin forming brominated and chlorinated compounds are not fundamental to product safety, performance, or reliability.

THE COST OF TRANSITIONING PRODUCTS away from the use of bromine and chlorine, including materials development, qualification, testing, and validation has to be assessed through a comprehensive economic analysis. A forward-looking analysis requires product manufacturers to integrate the costs of using substances of high concern when assessing the the research and development resources needed to remove them from new product lines. Through increased demand and a full transition by industry to bromine-and chlorine- free products, the economies of scale can be leveraged to bring down costs and increase availability of these new materials.

THIS REPORT PROVIDES CRITICAL GUIDANCE from the experience gained by companies that have undergone a transition away from the use of bromine and chlorine. To leverage these changes across the entire electronics sector, regulators and industry associations have a role to play. As such this report concludes with the following recommendations:

- **New supply chain specifications** should employ the elemental approach, which creates a transparent and verifiable material management system to ensure that bromine and chlorine are removed from products. This is critical for verification purposes, whereby other methods such as material declarations are often inconclusive and unverifiable for suppliers, OEMs, and regulators.
- **New government regulations** can leverage these positive environmental changes by adopting elemental restrictions on bromine and chlorine. The 2006 RoHS directive introduced elemental restrictions for lead, cadmium, and mercury but it did not apply elemental limits on bromine. Today regulators continue to have difficulty verifying conformance to the RoHS restrictions on poly brominated compounds due to lack of reliable and readily available detection methods. Applying elemental restrictions to bromine and chlorine would simplify the regulators task in testing and verifying whether or not products are RoHS compliant.
- **Procurement standards** such as EPEAT (Electronic Product Environmental Assessment Tool) that differentiate products in the marketplace based on their green attributes need to incorporate bromine and chlorine restrictions to provide a driver for other companies to restrict these substances.

THE COMPANIES FEATURED IN THIS REPORT had the foresight to understand the business value of investing in new materials development in order to eliminate substances with negative environmental and human health profiles from their consumer products. Their actions have demonstrated, yet again, that substances once thought to be essential to consumer electronics products can be eliminated with new material development efforts. These companies are now well-positioned to gain a competitive advantage in a marketplace and regulatory environment increasingly sensitive to the environmental and human health impacts of consumer products.

Print Billes, Sept 2009, on Munken Pure (170 and 120 g). Munken Pure is manufactured completely without chlorine (TCF) and without any additive of optical brightening agents (OBA).

Layout formera reklam

Photos Niklas Maupoix, Basel Action Network, StockExpert

Electronics manufacturers, standards bodies, and legislators have begun to take notice of the human health and environmental concerns associated with the use of brominated and chlorinated compounds in electronic products. An array of conflicting definitions and policies have emerged to address these concerns at various levels. This report is intended to show the feasibility of re-engineering consumer electronic products to avoid the use of these compounds and recommends a definition to address human health and environmental concerns that is implementable by industry.

CPA and ChemSec have compiled case studies that provide examples of seven companies that have removed most forms of bromine and chlorine from their product lines. The purpose of this report is to allow parties outside the industry to see the level of conformance that can be met today, as well as provide a tool for engineers designing the next generation of greener electronic devices.

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