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Lead-free and waste prevention requirements in the European Union: Cleaner products at lower cost

The term lead-free describes a number of technical and environmental issues with the goal of removing hazardous substances and reducing the amount of waste. In Japan the transition into lead-free production (for consumer products only) is almost complete. The European Union (EU) has set more ambitious goals of reducing initially six of the most hazardous substances from consumer and professional products and reducing electronic waste significantly. All this is complex and time consuming, but to almost everybody's surprise, can save money for the manufacturer and the user if done correctly.

Occasionally these EU directives are claimed to be unfair acts of industry protection. However, this is not the case, since European manufacturers suffer more than others. They have to comply with the laws. Manufacturers in countries outside the EU may choose to sell their lead-containing products in other markets. According to the Restriction of the use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) directive, there is no established production available yet in the EU. European companies do not have a time or technological advantage. Their production quantities are typically lower than in other parts of the world. Hence, the cost of transition and running costs thereafter are higher in Europe than somewhere else. As mentioned, Japanese companies are already producing lead-free consumer products. So they might have an advantage when they do the same thing in the production of professional products for business use.

Legal requirements

Some of the legislation for RoHS and the directive on Waste Electrical and Electronic Equipment (WEEE) started about 25 years ago. So everybody knew it was coming. Both directives became effective on January 2, 2003. The EU is a union of sovereign states; therefore it issues directives rather than laws. These directives must be translated into the local languages and made into national laws in each country. Typically, this takes about 18 months. The main objective is harmonization of laws, regulations, and standards, in all of the member states to provide equal and fair trade, labor, and business conditions.

The RoHS (directive 2002/95/EC) specifies the maximum content of certain hazardous substance in goods produced or *placed onto the market* in the EU. The term lead-free is often used to generically describe all that is specified in the RoHS directive. Table 1 shows the current six hazardous substances and their maximum weight content.

The RoHS directive becomes effective on July 1, 2006. There are exceptions for national defense, fluorescent lamps, spare parts, and similar items. Manufacturers typically use the last two items on the list in large quantities to make flame-retardant plastic (such things as housings, cable insulation) to comply with UL 94 and similar requirements.

The WEEE (directive 2002/96/EC) specifies the amount of mandatory recycling and nonhazardous disposal of waste material and return of products at their End-Of-Life (EOL). For example, private users in Germany can now return used electrical and electronic equipment free of charge, typically to municipal waste collection yards. This waste material is then recycled or disposed of properly. In the future, manufacturers or importers will have to finance this waste collection and recycling either directly or by paying a fee to those organizations that do it on their behalf. The term *green* is often used to generically describe all that is specified in the WEEE directive.

Categories of electrical and electronic equipment covered by the WEEE directive include:

- Large household appliances
- Small household appliances
- IT and telecommunications equipment
- Consumer equipment
- Lighting equipment
- Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
- Toys, leisure, and sports equipment
- Medical devices (with the exception of all implanted and infected products)
- Monitoring and control instruments
- Automatic dispensers

This equipment list is also used to specify the applicability of the RoHS directive. Specific notes or exceptions reference some or all of these listed categories.

The WEEE becomes effective on August 13, 2005 when all consumers can return their electronic waste (such as mobile phones, computers, and CD players) free of charge to public collection points or to the original producers. Dealers may accept old product when they

Substance	Proposed Maximum Concentration
Lead – Pb	0.1 %
Mercury – Hg	0.1 %
Cadmium – Cd	0.01 %
Hexavalent Chromium – Cr (VI)	0.1 %
Polybrominated biphenyls – PBB	0.1 %
Polybrominated diphenyl ethers – PBDE	0.1 %

Table 1

sell new product. The return of used cars (Directive 2000/53/EC End-of-Life Vehicles) has been regulated since July 2003.

Technical solutions

There are several dozen alloys, using tin, silver, copper, and other substances in various concentrations. It should be noted that not all have been fully qualified for long-term durability, mechanical rigidity, or neutral chemical reaction. Tin is prone to whisker growing in leaded or lead-free alloys (soldering materials), which is a serious problem. Some of the lead-free solder replacements have been found superior to lead-based solder. IBM (see report 0-0000-0000-7/03, IEEE 2003) has done substantial fundamental research to find some of these better alternatives, which show such qualities as lower inductance and improved reliability. Fujitsu-Siemens Computers (FSC) fine-tuned their solder (reflow) process for a long time. Carefully rearranging the physical position of components on a board and adjusting the speed of the board over the reflow bath is necessary to obtain best results. FSC assumes that they have a lead-time of approximately one year in comparison to competition in the mass production of consumer and business products. Equipment for lead-free reflow soldering is readily available on the world market. However, it takes a long time and extensive experience to get flawless mass production to work reliably. There is definitely no drop-in replacement for lead-based equipment or processes. The contamination of a lead-free production line with leaded components or solder residues is a very serious problem.

Most alternative soldering substances melt at higher temperatures than lead-based solder. This is a problem with certain chips or components. It is important to keep temperature and the speed of movement through the reflow trough tightly controlled, especially with reflow soldering. For example, a chip with several hundred solder balls in a Ball Grid Array (BGA) dissipates heat much faster than a diode with just two solder points. This means that the BGA might be underheated, and the diode might be overheated.

Logistic challenges

Most chip manufacturers still do not list any information on lead or other hazardous content on their data sheets. This makes it very time consuming to establish and maintain a bill of materials that contains only lead-free components. Documentation, such as component libraries, must be available and accurate along the supply chain from the basic components to the finished products. During a transitional period, there will be two of everything, lead-based and lead-free. Some distributors and resellers have already updated their product databases to identify lead-free components in their catalogs. However, there is no standardized way of doing this. Supply chain management has to take care of alternate sources, different delivery times and channels, product shelf life, and proper documentation, as proof of compliance.

FSC has already improved their logistics, for example, material flow significantly. They are now developing self-organizing flow algorithms based on ant and wasp behavior in a research project together with scientists from the University of Stuttgart and the Neural Computation Centre at Siemens Corporate Technology. Experimental results show a 44 percent reduction in delivery delays.

The transition to RoHS and WEEE compliance should be taken as an opportunity to clean up and streamline business processes and establish less complicated management procedures.

Economic effect

Currently, about six million metric tons of electric/electronic waste have to be properly disposed of in the EU at a very high cost to the user. Significantly reducing this amount will result in comparable cost savings. Therefore, not using hazardous substances will make it much cheaper to dispose such waste, eliminating the high cost of extracting these hazardous substances.

Using the FSC situation again as an example, they have calculated an overall savings of more than 4.5 million EURO per year by eliminating the weight and cost of packaging, reducing the relative cost of recycling. As mentioned, the cost of lead-free soldering and optimized assembly is cost neutral in comparison to legacy lead-based production.

Obtaining favorable results demands examining and streamlining the entire production and product life cycles. Individual actions just disrupt smooth operation and might actually have an overall negative effect.

Fast-growing waste mountains

With the high population density in Europe, there is the issue of fast-growing waste mountains. For example, the population density per square kilometer is 466 in Holland, 244 in the United Kingdom, and 29 in the United States. This means that the United States would need more than 15 times its current population to be as densely populated as Holland. This is why waste reduction by way of recycling or nonhazardous disposal is several times more important in Europe (or Japan) than in the United States, Canada, or other less densely populated countries.

In 1998, approximately six million metric tons of electric and electronic waste had to be disposed of in the EU. Growth rates for electronic waste are estimated at five to 10 percent annually. The EU wants to get to a recycling rate of 75 percent by end of 2006. FSC products are already approaching a rate of 98 percent.

The US Agency for Toxic Substances and Disease Registry (ATSDR), Centers for Disease Control and Prevention (CDC), Environmental Protection Agency, Occupational Safety and Health Administration (OSHA), and others warn about the specific health problems in the central nervous system (especially in children) caused by lead. The ATSDR lists lead as the most toxic of all environmental substances on a list of 275 substances which they examined.

The IPC (Association Connecting Electronics Industries) organization's board of directors claims that soldering components to boards uses only two percent of the world's lead. It references studies that indicate lead poses no health danger in their industry. However, it also states support for lead-free activities.

Most lead is used in car batteries. Car batteries are already 100 percent recycled in practically all industrialized countries. Microscopic lead particles in the food we eat or in fumes around soldering operations, in dust from leaded paint, or smoke from cars using leaded gasoline, is slow and painful in harming or killing people.

Modern day chemical analysis and research on corpses from the late Middle Ages show that a significant proportion of these people died of lead poisoning or suffered from it as a result of *plumbing*. Plumbum is the Latin name for lead and the chemical



element symbol is Pb. Plumbing, such as water pipes made from lead, were for a long time practically the only way of getting water directly into European houses, which improved hygienic conditions for those who could afford it. Our ancestors did have at least some knowledge about lead being a hazardous substance. The former Republic of Venice locked up their worst criminals in lead chambers for extremely severe punishment (lead harms the central nervous system). World famous Giacomo Casanova managed to escape from the *lead chambers* of Venice telling the world about his fortunes and misfortunes in his memoirs and other books.

Lead as a piece of metal may not be very toxic, but it is very toxic in the form of microscopic parts, such as dust or debris from leaded paint or in fumes during soldering or as exhausted particles from leaded gasoline. As with many substances they are very active (good or bad) on a microscopic scale. Divalent lead (Pb +2) is considered to be quite active. Just counting the tons of materials used does not provide much useful information. Lead accumulates through the food chain and in human bodies year after year. Therefore, even small doses become dangerous after some time. Lead is a chemical element. It is highly persistent, for example, it does not decompose (rot, dissolve) as many organic substances do, into non- or less-toxic substances. Blue mussels are generally considered to have an especially high concentration of lead. Statistics by US health authorities show that the accumulation of lead in children's bodies dropped from 88 percent to 4.4 percent after the introduction of lead-free (unleaded) gasoline. Lead, while it was used in gasoline, was only a very tiny fraction in weight or volume in the gasoline as used for the family car. The transition level between harmless and harmful is set at 10 micrograms per decilitre ($\mu\text{g}/\text{dL}$) for children and 45 $\mu\text{g}/\text{dL}$ for adults.

Lead-free progress

Boeing and other companies in the Aerospace Industries Association (AIA) have set up the Lead-free Aerospace Electronics Working Group (LAEWG) to propose a unified, industry-wide approach for the transition to lead-free production. LAEWG's purpose is to develop and implement actionable, deliverable items that enable the aerospace industry to accommodate the global transition to lead-free electronics. In turn, the deliverable items address issues that are unique to and within the control of the aerospace industry. Other organizations are encouraged to participate and share the results of their work.

Air Liquide, Houston (USA), offers electromagnetic pumps for lead-free soldering equipment because this variant shows significantly less corrosion than rotating or piston-based pumps as proven by research from Rahn-Tec, Canada.

Tundra Semiconductors (Canada), a world leader in interface and communication chips for AdvancedTCA, CompactPCI, VMEbus, and other interface standards, started offering in August, 2004 lead-free variants and green packaging for most of their chips. A list of lead-free chips on their website shows the current status of lead-free and green products (product codes Y and V, respectively). Tundra quotes compliance for their lead-free parts with EU and Japanese requirements and specifically with the IPC/JEDEC J-STD-020B specification, Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface

Mount Devices. Tundra recommends a tin/silver/copper alloy for lead-free soldering.

Celestica (Canada), one of the leading contract manufacturers worldwide, has an ongoing plan for conversion to RoHS and WEEE compliance that started in 1998. They also provide Electronic Manufacturing Services (EMS) consulting for their customers.

Xilinx (USA) started delivering lead-free products as early as 2002 for the European and Japanese markets compliant with the RoHS directive. They have delivered well in excess of 1.5 million lead-free chips.

Japan has laws about Promoting Green Purchasing, Promotion of Effective Utilization of Resources, Pollutant Release and Transfer Register (PRTR), and others. Companies such as NEC or Sony produce all their consumer products for the Japanese market in compliance with these laws.

JVC, Panasonic, and Thomson are working on a joint project to collect electronic waste in accordance with WEEE regulations in Germany and other EU countries. This is to ensure that a system of return and recycling of waste can be established where community waste disposal centers or industry-wide collection systems are not available or not economic.

The Canadian Standards Association has issued a number of standards on environmental management, anaerobic biodegradability of plastic materials, green procurement, and many others.



Figure 1

Lead-free solder is available in the electronics/computer section of electronics stores such as Radio Shack, at prices of around \$5 for a 56 gram (approximately 2 ounces) reel. There is no information about its long-term quality or suitability in specific applications. Scientific proof does not exist for traditional leaded solder either.

Manufacturers, distributors, and resellers selling or trading in the EU need to comply with WEEE by August 2005 and RoHS by July 2006. Therefore it is not necessary to quote their commitment. However, some have announced early compliance and support for their customers during the transition period. For example BuS Elektronik, (Germany), a medium-sized EMS, started soldering and assembling lead-free boards in 2002. They introduced reflow and selective lead-free soldering in 2003 and lead-free wave soldering in 2004.

Summary

It is important to start very early to have adequate time for experimenting and fine tuning. Doing just lead-free alone will not solve the issue. Getting the logistics right may very well be the more time consuming and costly part of the transition to lead-free and green operation.

Compliance to RoHS, WEEE, and similar Japanese legal requirements can be done both from a technology standpoint and economically. It reduces the amount of hazardous substances for everybody and reduces the size of the waste mountains significantly. In Japan, nondemanding consumer products have been produced lead-free for some years.

Numerous websites cover just about every aspect of lead-free and green with focus on technical, political, or economic issues. Listed here are some starting points for your own research.

RoHS Directive

http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf

WEEE Directive

http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00240038.pdf

General information on lead-free and waste reduction

www.atsdr.cdc.gov/tfacts13.html

www.atsdr.cdc.gov/toxprofiles/phs13.html

www.cdc.gov/nceh/lead/lead.htm

www.fujitsu-siemens.com/environment

www.fujitsu-siemens.com/recycling

www.jedec.org

www.leadfree.org

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