# Lead-Free Electronics and the RoHS Directive

John R. Barnes KS4GL, PE, NCE, NCT, ESDC Eng,
ESDC Tech, PSE, SM IEEE
President and Chief Engineer, dBi Corporation
President, Robust Electronic Design

Lexington Section of the IEEE
Lexington, Kentucky
January 26, 2006

(photo of bookcase)

(photo of two 5-drawer file cabinets)

130+ books

5,500+ other documents

Over the last two decades, politically-active environmentalists (“Greens”) have become seriously concerned about the number and sheer volume of electronic products that are being discarded in landfills. In addition to this junk being ugly, they are concerned about toxic materials in these discarded products finding their way into the groundwater.

Especially in Japan, environmentally-conscious consumers show a strong preference for lead-free and “green” electronic products.

(photo of computers, printer, monitors, etc. in attic)

1976: European Union (EU) published the Restrictions on the Marketing and Use of Certain Dangerous Substances and Preparations Directive (Directive 76/769/EEC, amended 39+ times).

1985: EU published the Product Liability Directive (Directive 85/374/EEC).

1986: California passed Proposition 65, the Safe Drinking Water and Toxic Enforcement Act of 1986.

1988: EU Council resolved to take Community Action to combat cadmium pollution.

1991: EU published the Batteries and Accumulators Containing Certain Dangerous Substances Directive (Battery Directive, 91/157/EEC).

2000: EU published the End of Life Vehicles Directive (ELV Directive, Directive 2000/53/EC), which took effect **July 1, 2002**.

2003: EU published the Waste Electrical and Electronic Equipment Directive (WEEE Directive, Directive 2002/96/EC), which took effect **August 13, 2005**.

2003: EU published the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Directive (RoHS Directive, Directive 2002/95/EC), to take effect **July 1, 2006**.

2003: California passed Senate Bill No. 20 (SB20), which took effect **April 1, 2004**.

2005: EU published the Energy-using Products (EuP Directive (Directive 2005/32/EC), which took effect **August 11, 2005**.

The WEEE Directive requires “producers” (manufacturers, importers, or anyone who puts their brand name on electrical/electronic products) to arrange for the:

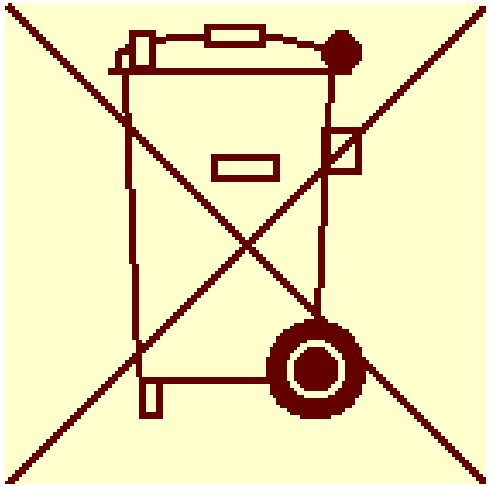
- Collection,
- Reuse,
- Recycling,
- Material recovery,
- Energy recovery

of waste electrical and electronic equipment.

Electrical/electronic waste from consumers is to be collected at no cost to the consumer. Arrangements for the collection of waste from companies/organizations is to be negotiated between buyers and sellers.

The main impact of the WEEE Directive is that electronics manufacturers must:

- Register their products in each EU country where they will be sold.
- Arrange for the collection/proper disposal of discarded products, including providing disassembly & warning information to recyclers.
- Pay into a recycling fund in these EU countries.
- Mark their products with the crossed-out wheelie bin (EN 50419).



The RoHS Directive bans the use of certain toxic materials in residential, commercial, and industrial electrical/electronic products. Batteries and accumulators are covered separately under the Battery Directive. Military and implanted/infected medical products are exempt from the RoHS Directive because they are specifically exempted from the WEEE Directive.

The RoHS Directive does not require finished electrical/ electronic equipment to be marked in any way, or for the material content of the equipment to be provided to consumers. But if a EU country determines that a product is not RoHS-compliant, the producer must prove “due diligence” to avoid massive fines and/or prison sentences for executives and other responsible personnel.

Article 4 of the RoHS Directive says: “Member states shall ensure that, from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).”

Why all the fuss about these chemicals?

- Lead ingested by infants and children can cause brain damage.
- Ingesting some mercury compounds can cause nerve damage.
- Ingesting cadmium can cause poisoning or death.
- Ingesting hexavalent chromium can cause cancer.
- Inhaling fumes of improperly-incinerated PBB’s or PBDE’s can cause cancer.

The Annex to the February 13, 2003 version of the RoHS Directive listed some applications that were exempt from these requirements, including:

- Mercury in fluorescent lamps.
- Lead in the glass of cathode ray tubes, electronic components, and fluorescent lamps.
- Lead as a minor alloying element in steel, aluminum, and copper alloys.
- Lead in solders for servers and storage array systems (until 2010).
- Lead in solders for network infrastructure equipment.
- Lead in electronic ceramic parts.

On August 19, 2005, the Annex to the RoHS Directive was amended to tolerate:

- 0.1% lead by weight,
- 0.1% mercury by weight,
- 0.01% cadmium by weight,
- 0.1% hexavalent chromium by weight,
- 0.1% polybrominated biphenyls by weight,
- 0.1% polybrominated diphenyl ethers by weight,

in *homogeneous materials*.

On October 25, 2005, the Annex to the RoHS Directive was again amended to exempt:

- Lead in solders for servers, storage array systems, and network infrastructure equipment— permanently.
- Additional specific applications of lead and cadmium.

Complying with the RoHS Directive is expected to cost the worldwide electronics industry between $40,000,000,000 and $80,000,000,000…

The material bans in the RoHS Directive affect our:

- Material choices.
- Component choices.
- Manufacturing/testing/repair processes.
- Design rules.
- Qualification of materials/components/processes.
- Reliability testing.

Since the 1950's, the electronic industry has preferred soft soldering to connect electronic components, printed circuit boards (PCB's), and cables. Typical solders were:

- 60Sn40Pb with 188°C liquidus (melting point).
- 63Sn37Pb with 183°C liquidus.
- 62Sn36Pb2Ag with 179° liquidus.

Typical component-lead platings and terminations were:

- Tin-lead.
- Silver.
- Gold over nickel.

Typical PCB protective platings/coatings were:

- Tin-lead.
- Organic solderability preservatives (OSP's).
- Gold over nickel.

Soldering was usually performed at 210-220°C, spending 5-10 seconds at the peak temperature. Most components were designed to withstand 235°C for 1 minute, permitting multiple rework cycles with a 15-25°C process window.

Banning the use of lead in solders, platings, and terminations forces us to start all over from scratch.  We must evaluate many alternatives, some of which may not be compatible with one another.

Lead-free solders:

- AuGe
- AuIn
- AuSi
- AuSn
- BiIn
- GaInSn
- GeAl
- In
- InAg
- SnAg
- SnAgBi
- SnAgBiCu
- SnAgBiCuGe
- SnAgBiCuIn
- SnAgBiIn
- **SnAgCu**
- SnAgCuBi
- SnAgCuBiIn
- SnAgCuIn
- SnAgCuSb
- SnAgCuZn
- SnAgIn
- SnAgInBi
- SnAgSb
- SnAgZn
- SnBi
- SnBiAg
- SnBiIn
- **SnCu**
- SnCuNi
- SnCuSb
- SnIn
- SnInAg
- SnInAgBi
- SnInAgBiCu
- SnInAgCu
- SnInCuGa
- SnInZn
- SnSb
- SnZn
- SnZnAl
- SnZnBi
- SnZnInBi
- ZnAl
- Etc.

Lead-free component-lead platings and terminations:

- Ag
- AgPd
- Au
- Au over Ni
- Cu
- Ni
- NiPd
- NiPdAu
- Pd
- Pd over Ni
- PdAu over Ni
- Sn
- Sn over Cu
- Sn over Ni
- SnAg
- SnAg over Ni
- SnAgCu
- SnAgNi
- SnBi
- SnBiAu
- SnCu
- SnCuNi
- SnZnNi
- Etc.

Lead-free PCB protective platings/coatings:

- Au over Ni
- Immersion silver
- Immersion tin
- NiAu
- OSP
- Pd over Ni
- Sn
- Etc.

Lead-free soldering is usually performed at 230-250°C for reflow soldering and 240-260°C for wave soldering. 20-40 seconds at the peak temperature is usually required because most lead-free solders have much poorer wetting than tin-lead solders.

Most lead-free components are designed to withstand 245-260°C reflow soldering and/or 250-260°C wave soldering. Some parts are limited to a maximum of only two soldering cycles without showing damage. Because of the ≈35°C higher soldering temperature and 4x soldering time, lead-free parts are much more prone to *popcorning* than lead-bearing components. Moisture sensitivity levels (MSL's) may drop by 1-2 steps, permitting only 25-50% of the "open time" of equivalent lead-bearing parts.

Lead-free process windows can be as narrow as 5°C, requiring extremely-tight process control, and soldering profiles individually customized for each type of PCB produced.

Even good, reliable lead-free solder joints have a “frosty” appearance.  Inspectors must learn new criteria for discriminating good from bad solder joints.

Lead-free repair processes may require new equipment to stay within the narrow process window of lead-free solders.

PCB designs may need to be tweaked to achieve acceptable yields in manufacturing.  For instance, immersion silver PCB coatings can cause severe corrosion of PCB traces right at the edge of holes in the soldermask, causing narrow traces to open.  Pads and vias may require “tear-dropping”, an additional step during PCB layout, to prevent these failures.

Material, component, and process changes may force the manufacturer to completely re-qualify a PCB/product after going lead-free/RoHS-compliant, even if there weren’t any design changes.

Compared to lead-based electronics, we have very little field history for lead-free electronics. Most of the lead-free products that have gone into production so far were designed for maybe a *one-year lifetime* before they are expected to be discarded.

Manufacturers will need to do extensive reliability testing before they can be confident that lead-free products will even approach the proven quality, longevity, and reliability of lead-bearing electronics. Unfortunately, some of the likely failure modes for lead-free electronics are maximized at temperatures of 30-50°C, which doesn't give us any way to do accelerated life testing.

The NASA Electronic Parts and Packaging Program (NEPP) has done a great deal of work on the reliability of lead-free electronics. They have an extensive web site at http://nepp.nasa.gov/

The results of NEPP's research are not encouraging… Lead-free solders are very susceptible to the following failure modes, which have been almost unknown/ unheard-of with lead-bearing solders:

- Tin whiskers, causing short circuits.
- Tin pest, causing opens (the solder turns to dust).
- Sensitivity to shock, causing solder joints to crack if the product is dropped onto a hard surface.
- Kirkendall voids, causing opens.
- Conductive anodic filaments, causing shorts inside PCB's.

I expect the quality of many new electronic products will plummet over the next six months, despite the best efforts of manufacturers, as they try to simultaneously master:

- New materials.
- New components.
- New manufacturing/testing/repair processes.
- New design rules.

I figure that it will take at least a year, with billions of electrical/electronic products as the unwilling subjects of the “Great RoHS Experiment”, before we know with any confidence whether lead-free electronics are worth a damn in *any environment*, regardless of whether the products:

- Are in continuous use.
- Are used intermittently.
- Are sitting idle.
- Are sitting untouched in the original box!

I fear that people will be killed or injured, and many homes/businesses will burn down, when lead-free electronics develop tin whiskers, tin pest, Kirkendall voids, etc., because of this misguided push to make electronics “green”— while ignoring physical reality.

Furthermore, if/when the European Union decides that taking lead out of electronic solder was a really stupid idea, it will still take years to get the lead-free garbage out of the system.

For manufacturers, I recommend not converting every product in your product line to be lead-free and RoHS-compliant *if you don't have to*.

For consumers, I recommend:

1. Don't buy any *new* electronic products between January 2006 and June 2007.
2. If given a choice between a product that claims RoHS-compliance and one that doesn't, buy the latter.
3. If offered extended warranties, buy the longest one available— and hope that the company offering it doesn't go bankrupt…
4. If you are replacing a working unit, *hang onto your old working unit!*

http://www.dbicorporation.com/rohs.htm discusses:

- Applicable laws and Directives.
- Lead-free & RoHS-compliant solder.
- Lead-free & RoHS-compliant components.
- Identifying lead-free and RoHS-compliant components.

http://www.dbicorporation.com/rohsbib.htm references:

- 16 laws and Directives.
- 130+ books.
- 5,350+ papers, reports, and magazine articles.
- 190+ web pages on these topics.
- 2,400+ links to the above documents.

http://listserv.ipc.org/scripts/wa.exe?REPORT&z=3#SUBSSUBSCRIBE subscribe to the IPC's Leadfree Forum