Unraveling the Lead-Free Knot : Roadblocks and Resolutions toward a Greener Tomorrow

Chris JORGENSEN*

鉛フリーの課題解決のために：グリーンの明日に向けてその障害と解決

クリス・ヨルゲンセン*

*IPC-Association Connecting Electronics Industries (2215 Sanders Road, Northbrook, IL 60062-6135, USA.)

概要 エレクトロニクスの鉛フリー化に際しての障害とその解決策を、米国エレクトロニクスの立場から総括し、IPCの役割を明らかにした。

The electronics industry has made a long-time friend of tin-lead. The electronics manufacturing industry has relied almost entirely on the use of tin-lead solder for attaching surface mount or through hole components to PWBs. SnPb solders are preferred due to their reliability, solidus/liquidus point, melting temperature, availability, cost and extensive database of use.

Over the past decade, pressures from legislative and environmental groups have called for the industry to eliminate or limit the use of lead-based materials. Its genesis was The Reid Bill, proposed US legislation in 1991 that called for the elimination of lead from such household items as paint, toys, recreational game pieces, plumbing solder and fixtures and inks.

When the Bill was reintroduced to the US Senate in 1993 as the Lead Exposure Reduction Act, the US electronics industry, led by IPC, fought for and won exemption from this legislation. The industry based their reasoning on the fact that there was no scientific proof that lead from electronics leaches into the water table. They also pleaded that they wouldn't have enough time to find a replacement alloy(s), all the while producing reliable, cost effective products.

Following its exemption, the industry indicated it would begin programs (individually or through concerted efforts) to find a drop-in replacement for tin-lead. Even with this promise, very few companies in the industry followed through with the research, and the issue was thought to have gone away. And for the meantime it did.

In late 1998 the issue found its way back into the minds of the US electronics industry, as people began to hear of legislative efforts in Europe and stepped-up pressure coming from companies in Japan. What the industry found was that instead of the lead elimination issue being dead,

it was alive, well, stronger than ever and coming at them at a rapid fire pace.

The first issue the industry was confronted with was the Waste from Electrical and Electronic Equipment (WEEE) Directive, a European Council-based proposal that would call for, among other things, the elimination of lead from most electronics. When the IPC Board of Directors was approached in late 1998 to help fund the fighting of this effort, it declined the opportunity.

The Board cited increased legislative and environmental pressure continuing to call for the elimination of lead as a reason not to invest money into such a fight. It recognized products being developed in Japan and Europe, and coupled with European legislation, it knew it would only be a matter of time before these things would make their way to US shores and possibly back on Capitol Hill.

Based on this decision, IPC began the task of preparing the US industry for the transition to lead reduction and possible elimination. In this effort, IPC aligned itself with several other organizations the world over, such as the National Electronics Manufacturing Initiative (NEMI) and the International Tin Research Institute (ITRI).

This paper will highlight the work done by IPC and the results of its efforts in educating and assisting the US industry in properly positioning themselves for a successful transition to lead-free electronics.

1. Mapping the Road Ahead

IPC felt the best way to help the industry was to find a way to have the industry help itself. Because it would not be funding any round robin or other testing programs, IPC decided to use its most valuable resource – its extensive membership and worldwide contacts – to pool its resources and develop an industry roadmap. Before this

(参考) IPCが主宰する鉛フリー専門ホームページ www.leadfree.org

document could be developed, it was of significance to have the industry as informed and consistent in their thinking as possible.

Utilizing the benefits of the Internet, IPC developed a Web site (www.leadfree.org) for keeping the industry abreast of all aspects of lead-free electronics. IPC also geared up an e-mail forum for peer interaction and sharing of information and experiences.

Through these electronic resources, the industry was able to gather unsolicited information unsolicited on the legislative, environmental and marketing issues that would shape the way their company would do business. Technical papers posted on the Web site and information provided by those accustomed to lead-free application through the e-mail forum also provided the industry with a steady diet of relevant technical information.

During this time IPC staff took on grass roots efforts for the development of a first draft of the lead free roadmap. By communicating with its membership, the staff was able to gather information on status of programs, research and development by member companies and get their thoughts on the issue.

Through these discussions, staff was able to get a general idea of the information the industry was lacking and provide it in the first draft. These discussions also served as the basis for some initial company position statements. All of the findings were compiled into the first draft of the IPC Roadmap for Lead-Free Electronics Assemblies.

The roadmap was presented to the industry for the first time during breakout meetings held during IPCWorks '99, An International Summit on Lead-Free Electronics Assemblies. Using these finding as the boilerplate for the roadmap, the meeting attendees were then called upon to share their thoughts, concerns, experiences, roadblocks

and resolutions.

Following two more meetings and revisions of the document, the roadmap had shaped into a user-friendly guide for any company in the industry looking to implement or learn about lead-free electronics.

The main focus of the IPC roadmap is to cover the issues relating to lead-free electronics assemblies and provide a company at any area of the supply chain with a valuable resource for making a transition. The following are the findings of the roadmap. These findings include the necessary components for lead-free electronics (solders, components and PWBs), as well as current and impending roadblocks and their resolutions.

1.1 Soldering Materials

The main focus of the document, which correlates to the focus of the US industry as a whole, is the down-selection of lead-free solders. Although the first proposal was to propose one to three solders for use, those involved with the roadmap development felt it better to list as many available solders as possible. This was done to limit discrepancies with solder manufacturers and patent issues, as well as to avoid any possible restrictions on companies with uncommon solder solutions planned or in place.

■SnAgCu

Tin-silver-copper, with or without the addition of a fourth element is the most popular of the solders selected. This solder was also chosen as a replacement for tin-lead by NEMI, as well as the International Tin Research Institute (ITRI). This solder has also been chosen as the benchmark (SnPb will be the baseline) for testing any other alloys to be included in the listing to be provided to the industry.

Concerns with this alloy family include higher processing temperatures and their compatibility with lead bearing finishes. It should also be noted that metals cost for this alloy are about 2.2 to 2.7 times that of SnPb eutectic at current market values.

■SnCu

This alloy composition is a low cost alternative for wave soldering, its main area of use and is compatible with most lead bearing finishes. Process considerations must be addressed with this alloy, which has a higher melting temperature than most SnAgCu alloys. This alloy is also 1.5 times more expensive than SnPb eutectic at current market values.

■NEMI Proposal

In 1998, while working on their technology roadmap, NEMI noted the worldwide activities for lead elimina-

tion/reduction. Based on this, NEMI foresaw a need to provide its members with solutions for lead-free electronics.

In their plan, NEMI formulated several task forces to cover each area pertaining to lead-free soldering (i.e., solders, components, processes, reliability, etc.). Because OEMs were initially calling for drop-in replacements for tin-lead, NEMI saw the need to first enact its Lead-Free Solder Task Force.

Using resources such as the National Center for Manufacturing Sciences (NCMS) *Lead-Free Solder Report* and the Department of Trade and Industry's (DTI) *Lead-Free Soldering: An Analysis of the Current Status of Lead-Free Soldering*, and by sharing data compiled within their own companies, the task force set out to propose a drop-in replacement(s).

In its conclusions, much like the NCMS study, the group was unable to find a drop-in replacement for tin-lead. Instead it proposed the following three solder solutions :

Sn3.9Ag0.6Cu – A predominantly tin-rich alloy, this solder, which represents at least 70% of all board assembly production, has been proposed for reflow applications.

Sn0.7Cu – The group recommends the use of this less expensive solder for wave applications.

Sn3.5Ag – This solder has been proposed as an alternative to SnCu.

With these solders proposed to the industry, NEMI now plans to continue its work with its other task forces to make recommendations for component finishes and terminations, processes and reliability. Because these programs will now be member specific, parties interested in taking part in and receiving resulting data from these continuing programs should contact NEMI.

■SnAgBi

This alloy has been chosen as a candidate alloy, especially for use in SMT applications. The major concerns of bismuth are fillet lifting that occurs in lead-based through hole applications, its toxicity, and low melting phase.

According to the NCMS study, SnAgBi has better thermal cycle reliability for certain surface mount components than SnAgCu using 1206 resistors and capacitors with lead-free finishes and PWBs with lead-free finishes. The study also showed this alloy having better wetting characteristics than SnAg and SnAgCu.

Metals cost for this alloy are 2.2 to 2.7 times more that of SnPb eutectic at current market values.

■SnZn

Although this alloy has lower melting temperatures

(<200°C), there are concerns with the oxidation of Zn and the long term corrosion of the finished solder joint. This alloy also requires special fluxes, and its wetting characteristics aren't as good as SnAgCu.

Industry needs more long-term data for this alloy to determine if it is a strong candidate alternative.

■SnAg

This alloy has a slightly higher melting point (221°C) than SnAgCu, and is comparably priced as well. Because it has been used for years in step soldering and special applications (i.e., die attach), there is an extensive database, which is attractive to companies looking for backup data.

Table 1 and Table 2 display the various solders being used and their application, as well as proposed/studied

Table 1. Solders used by area of industry served

Solder	Melting range (°C)	Industry served	Company
SnAg	221-226	Automotive	Visteon (Ford)
SnAgBi	206-213	Military/Aerospace	Panasonic
		Consumer	Hitachi
SnAgBiCu		Military/Aerospace	Panasonic (FA Controller?)
SnAgBiCuGe		Consumer	Sony
SnAgBiX	206-213	Consumer	Panasonic
SnAgCu	217	Automotive	Panasonic
		Telecommunications	Nokia
			Nortel
			Panasonic
			Toshiba
SnBi	138	Consumer	Panasonic
SnCu	227	Consumer	Panasonic
		Telecommunications	Nortel
SnZn	198.5	Consumer	NEC
			Panasonic
			Toshiba

Table 2. Specific alloy compositions reviewed and/or recommended by other organizations

Organization	Solder
NEMI	Sn0.7Cu
	Sn3.5Ag
	SnAgCu
NCMS	Sn3.5Ag
	Sn58Bi
	Sn3.0Ag2.0Bi
	CASTIN
	Sn3.4Ag4.8Bi
	Sn20In2.8Ag (Indalloy)
	Sn3.5Ag0.5Cu1.0Zn
ITRI	SnAgCu
	Sn2.5Ag0.8Cu0.5Sb
	Sn0.7Cu
	Sn3.5Ag
	SnBiAg
	SnBiZn

solders of industry organizations.

■Fluxes

Selection of a new alloy will require deviations in flux chemistries used. Operators shouldn't plan on plugging a currently used flux into the new process. Expect to tweak current chemistries for high-temperature alloys and possibly use entirely different chemistries for Zn-based alloys.

Variations in flux chemistries will also affect the cleaning process, solder mask, coating, materials, etc. If voiding occurs after making the transition, the user may need to work with solvent or resin systems to alleviate the problem.

1.2 Components

Several types of lead-free component finishes are available to the industry, several already being successfully used in assembly operations. There are concerns over cost, reliability, and workability with lead-free alloys due to factors such as higher melting temperatures.

For those companies who choose to use components with lead bearing finishes, there is also the concern with fillet lifting resulting from the use of some lead-free alloys. Although the fillet lifting does not occur in all circumstances of through hole or surface mounting applications, it is an important consideration when in deciding whether to use alternative component finishes.

The industry is also seeking information on the dissolution of various lead finishes in new solder alloys and the damage inflicted by test probes on new alloys. The most common alloy used in component finishes is palladium, which is usually used with nickel, silver or as a stand-alone finish.

Some other concerns expressed by industry include requalification that may be needed for temperature-sensitive components

■Molded Components

With molded components come concerns with "pop-corning", delamination and the time needed to define new materials. Temperature-sensitive components may also need time for requalification and redesign. The industry has also noted the concern for the time needed to develop new molding compounds. The compounds developed to meet the higher temperature lead-free requirements should also meet the requirements of halogen-free materials in the WEEE Directive.

■Ball Grid Array(BGA), Chip Scale Packaging (CSP) TBGA, and Flip Chip

One resolution for die applications appears to be the use of balls formed with solder from the SnAgCu family. If

this path is chosen, concerns need to be addressed regarding the affects of high-temperature solders on the substrate and warpage of BGAs. One must also have an understanding of the intermetallics and shear strength of balls made with new materials.

There is very limited reliability data available for these applications, but work is being done by such organizations as NEMI to gather data.

■Connectors/Through Hole

Materials for connectors and through hole components will be the same as those used for molded components. The one concern for these components is warpage under higher melting temperatures, but more data is necessary before making specific determinations on these applications.

Table 3 lists some molded component surface finishes (some without manufacturing experience) and their concerns. As can be seen in this table, the use of Sn and SnCu tends to exhibit tin whiskering.

There are several studies underway to stimulate tin whiskering and then determine if a coating (possibly bismuth) may be necessary to eliminate whisker growth. Another way of preventing whiskering is through a "large grain" tin plating process that is advertised as reduced whisker tendency plating or perhaps even whisker free.

1.3 PWB Materials

PWB materials covers more than just lead-free finishes. Making the transition to lead-free soldering alone can lead to damage and reduced reliability of the base materials used to manufacture the board.

■Laminate

Manufacturers must work with their laminate suppliers to ensure they will be providing materials that will be able to withstand multiple reflows at higher processing temperatures. Two concerns with higher soldering temperatures are the z-axis expansion and decomposition of the laminate.

Higher soldering temperatures result in higher levels of z-axis expansion, which may affect PTH reliability. Laminate suppliers will be able to provide the correct T_g

Table 3. Surface finishes for molded components

Finish	Manufacturing Experience	Concerns
NiPd	Yes	Material cost
NiPdAu	Yes	Material cost
SnBi	No	The assembly must be totally Pb free.
Sn	Yes	Tin whiskers
SnCu	Yes	Tin whiskers (needs evaluation)

for the material to prevent the z-axis expansion.

Decomposition, or breaking of polymeric bonds, happens during high-temperature soldering. Although tests are conducted regularly for laminate, which calls for the materials to survive a steady 288°C temperature for 15 to 20 minutes, mere seconds during a soldering operation could break polymeric bonds within the material.

Although the polymeric bonds broken will most likely be a very small percentage (i.e., 3 to 5 percent), one should consider this from a reliability standpoint the same as breaking a few cables on a suspension bridge. The results of small bond breakage could lead to moisture inclusions and even poor T_g .

Aside from those issues and warpage of the PWB, higher reflow temperatures will also affect inks adhesives and markings.

■Available Finishes

Because it is important to protect the copper conductors on PWBs from degradation, PWBs are applied with finishes via hot air solder leveling (HASL), electroless metals, and organic solderability protectants (OSPs). Because a fully lead-free electronic assembly will call for there to be no lead in the finish, board fabricators must select an alternative rated on cost, reliability, and shelf life.

・Organic Solderability Protectants (OSPs)

OSPs are a viable candidate because they are almost in the same price range as SnPb (about 25 cents/sq. ft. in the current market) and contain no lead. These finishes are also easily processable, relatively free of ionic contaminants, and are smoother than HASL. They also exhibit good solderability (based on flux/solder atmosphere selection) and are reworkable.

These finishes are known for their short storage life, which can be up to 12 months if stored properly (i.e., dry nitrogen, desiccants), but manufacturers with quick turnover of PWBs may not see this as an issue. There are also concerns with handling of these finishes, durability with higher soldering temperatures, and flux chemistries used.

■Lead-Free Hot Air Solder Level (HASL)

Even though lead-free HASL is available for PWBs, some manufacturers may choose to move away from this process if required to produce lead-free product.

If chosen, alternative HASL finishes will most likely work well with most alternative alloys and will wet faster than plated finishes or coatings. Concerns with this finish include warpage due to higher processing temperatures and PWB absorbed process chemistries, although they can

sometimes be removed with cleaning.

■Immersion Finishes

Immersion finishes have been considered as one replacement for HASL because of its surface flatness and ease of process.

Concerns must be addressed regarding the thinness of the coating, because higher soldering temperatures could result in out-diffusion of base metals and oxidation, leading to reduced solderability.

■Electroless NiAu

These finishes are attractive because of their resistance to damage during handling/processing and improved shelf life over other finishes. These finishes are also free of ionic contaminants, compatible with most flux chemistries, and smoother than HASL.

2. Roadblocks and Resolutions

2.1 Lack of Singularity of Alloy

In order to resolve this issue, industry needs to continue consortia efforts in down-selection of alloys. The continued efforts of IPC working with other organizations, such as ITRI (UK) and NEMI will enable companies to have the best information possible when selecting an alloy or alloys that meet their product(s) requirements. These efforts will achieve IPC's goals of making the transition as cost effective as possible, all the while maintaining quality and reliability in end product as well as avoiding delays in time to market.

2.2 Rework and Repair Impact

In cases where companies would be required legislatively to work with non-lead-bearing alloys, it's essential for the operator to have an understanding of existing materials on any PWBs they may need to rework or repair. Although there may not be a conclusive workable alloy, it is essential for the PWBs to have a marking indicating the materials used on the PWBs.

2.3 Recycling Requirements

IPC will continue to monitor state-level activities, such as those already in place in Massachusetts. In order to maintain workability of these activities, it may be necessary for industry consortia to take the first step in developing recycling requirements.

2.4 Worker Safety/Exposure Issues

For companies to properly prepare themselves for worker safety/exposure issues, it will need data from EPA's Design for Environment (DfE) efforts.

2.5 No Definition for Lead Free

Because there is no industry recognized definition for

lead-free electronics, IPC may be called upon to take the initiative to make this recommendation. Based on current practices, OEM requirements and environmental restrictions, the proposed definition is <0.1%. More studies and work with other consortia activities is necessary before making such a statement.

2. 6 Lack of Industry Partnership

Although many US companies are reluctant to share or communicate their lead elimination/reduction efforts, it is essential for them to work together in this effort, because it is one that affects them, one and all. This partnership is already seen and continually growing through efforts by IPC, NEMI, ITRI, etc., as well as through regular conversations taking place on the IPC lead free e-mail forum.

2. 7 Need to Know Process Requirements

It is essential for companies to share their process experiences. This is being seen already through the suppliers and PWB manufacturers, who are discussing results of using alternative alloy systems and other experiences.

IPC has been called upon to deliver training and informative programs on the issue. As a result it co-sponsored a lead-free assembly training seminar, and IPC staff has given several presentations in the US and Japan on the issue.

2. 8 Lack of Reliability and Long-Term Data

Again, it is essential for industry to share their data and experiences using alternative alloy systems. Because most of the alternatives don't have a long history of use (if any at all), this will most likely be seen through commercial/consumer electronics. Because these products usually carry a life of three years, they will be the best host for this information.

As this information is gathered and shared over the next two to three years, it will be easier for companies with products with long-term reliability requirements to make their selections. In the meantime it is important to focus on what data are needed and to scope the dissemination and acceptance of those data.

2. 9 Toxicity/Environmental Impact of Alternatives Not Clear

There is tremendous concern in selecting an alloy that could contain a material that could be considered for an eventual ban. A frustrating issue for many in the industry is that some of the alternatives being used are just as harmful to the environment as lead.

Working closely with the EPA and other environmental testing laboratories will enable the industry to make sound decisions in their selection of alternative solutions.

2. 10 No Government Pressure in US to Switch to Lead Free

To preclude any possible legislative activities, the US electronics industry should take the initiative to research alternatives in anticipation of US legislation. In doing so, they can be prepared for any future legislation calling for the reduction or removal of lead from PWBs.

2. 11 Slow Pace of Standards Development

A rigorous streamlining of standards revision process is necessary, and standards under revision must focus on lead-free as a priority.

To ensure the US electronics industry is on par with requirements in Asia and Europe, IPC staff must intensify liaison work with international associations. As requirements for lead elimination/reduction change to affect certain areas of industry, there may be a need for sectorization of standards and specifications (i.e., telecommunications, consumer, automotive).

3. The Path Ahead

It is essential that the US electronics industry keeps lead-free electronics fresh in their minds, not letting it be forgotten as it was following exemption from earlier US legislation. Whether there is legislation in any part of the world or not calling for lead elimination/reduction, lead-free electronics is inevitable.

Continuing marketing pressures by Japanese and some European OEMs will continue to force materials suppliers and manufacturers to adjust their processes to meet their customer's needs. IPC understands that there will be other concerted efforts to fight or delay legislation, but while that happens, there will be no slowing down for lead-free electronics.

IPC's continuing focus is to position US electronics manufacturers for a successful transition to lead-free electronics, should they choose to do so. Since companies are independent of any pressing requirements, it is imperative that they objectively look at the facts, research the alternatives and then determine if they want to be a market leader, or a market follower. (2000.7.3-受理)

Chris JORGENSEN

A project manager with the IPC Technical Programs department. Most recently Mr. Jorgensen's responsibilities have revolved around issues with environmentally friendly electronics. He coordinated IPC's 1999 International Summit on Lead-Free Electronics Assemblies, developed the IPC roadmap, devised and maintains IPC's Web site on lead-free electronics and has given presentations on the issue in the U.S. and Japan.