WORLD SEMICONDUCTOR COUNCIL 2001: LEAD FREE WHITE PAPER

European Electronic Component Manufacturers Association/European Semiconductor Industry Association (EECA/ESIA) * Japan Electronics & Information Technology Industries Association (JEITA) * Korea Semiconductor Industry Association (KSIA) * U.S. Semiconductor Industry Association (SIA) * Taiwan Semiconductor Industry Association (TSIA)

Information technology and related products are driving economic growth and development worldwide. The spread of personal computers and data communications and telecommunications infrastructure is making both small and large businesses more productive, it is improving access to information and education, and helping to drive economic development. The ever- increasing functionality of information technology products is driven and enabled by semiconductors. In addition, semiconductors provide the capability to make end products more environmentally friendly through such means as increased fuel efficiency or reducing energy usage.

The members of the World Semiconductor Council – representing the largest semiconductor makers in the European Union, Japan, Korea, Taiwan, and the United States – are committed to pursuing environmentally sound manufacturing processes and products. For example, the WSC has pro-actively pursued voluntary agreements to aggressively reduce our emissions of PFCs. As a group, the industry is actively addressing issues related to chemicals, materials and equipment management, including efforts to develop timely and effective methodologies to ensure that new chemicals can be utilized in manufacturing while protecting human health, safety, and the environment.[1]

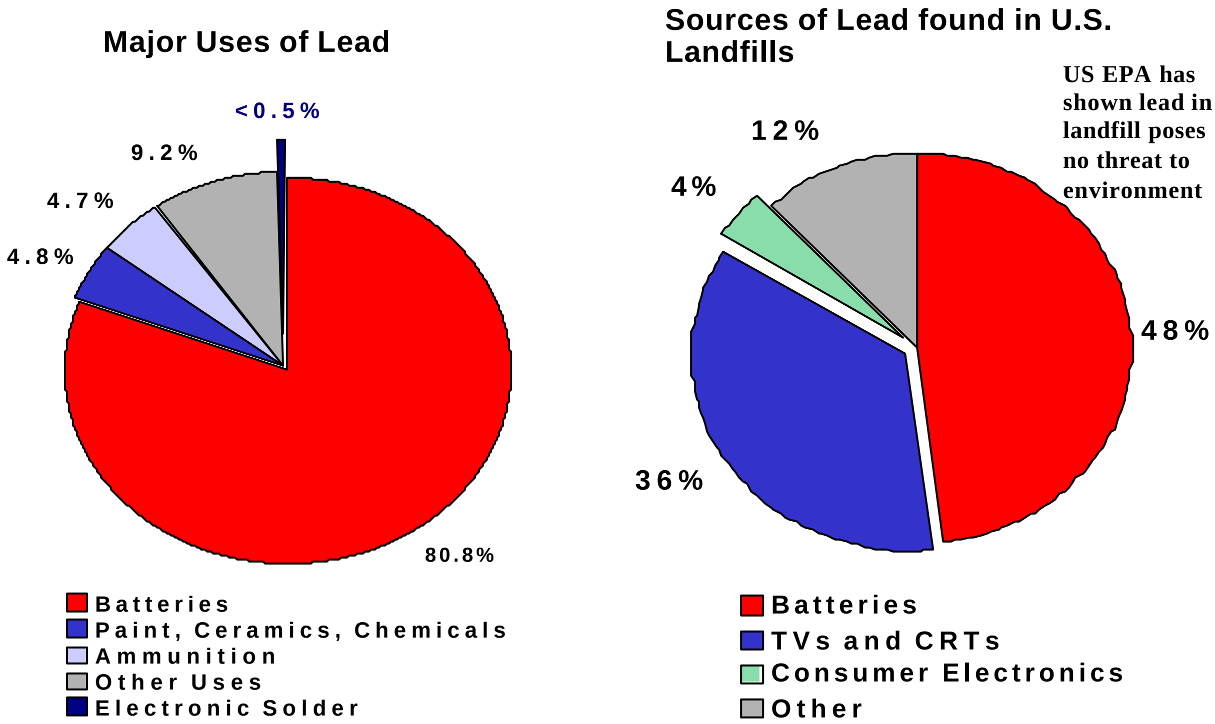
Today, the semiconductor industry is actively engaged in efforts to reduce the use of lead in electronics and electrical equipment in an environmentally sound manner. However, we have some serious concerns about pending regulations that would seek to completely eliminate the use of lead, including the Restriction on Hazardous Substances (ROHS) in the European Union. The U.S. Environmental Protection Agency (EPA) has also tightened its reporting requirements for the use of lead in manufacturing.

Proposed regulations to ban the use of lead are drafted with the intent to protect the environment -- in order to ensure that this goal is met, regulations must be undertaken in a scientific manner that allows for the assessment of the impact of alternative compounds, including their impact on the environment and on product functionality as well as a realistic assessment of the impact that lead in electronics has on the environment and whether or not it is technologically feasible to eliminate lead. Industry has identified a number of applications in electronic components where there are no known substitutes for lead, and it is important that these applications be exempted from the ban. These include, for example, lead in flip chips, high temperature solder, ceramic capacitors, lead zirconium titanate (PZT), and lead glass frits.[2] Any ban must also provide a realistic and transparent exemption process, and must provide for confidentiality in cases where a manufacturers' confidential information must be disclosed in order to justify an exemption. Without a scientifically based review process that allows for

[1] International Technology Roadmap for Semiconductors: 1999, Difficult Challenges Tables, p 19.

[2] PZT is lead zirconium titanate, it is used for electromechanical movements and capacitors. Lead glass frits are used as substrate materials. High temperature lead solder is used in several applications, including internal interconnections and to seal lids onto some components.

Chart I: Lead in Electronics



consideration of the impact of substitutes, product failures and other factors, there is no guarantee that banning lead will actually reap the intended benefits.

Background:

Lead is a critical material in virtually all electronics because it is uniquely capable of meeting high technology performance requirements in a cost efficient manner. Lead is used primarily as solder in most electronics[3] – the current lead solder process is widely used and integrated in equipment assembly lines worldwide. Because of the widespread use of lead, it is estimated that at least 200,000 electronic products as well as 200,000-plus sub-assemblies will be affected by regulations seeking to ban lead. Many of these lead-containing products are small but critical; examples of critical electronic products for which solutions are not yet available include medical equipment utilizing off-the-shelf components, aviation equipment and complex communications equipment.[4]

[3] A tin-lead solder alloy is usually used to join computer components to printed circuit boards.
[4] Avionics and medical equipment utilize many off-the-shelf components – exempting these applications from the lead ban will not totally solve the problem, because the off-the-shelf components that are used in numerous applications will still be affected.

Despite the widespread application of lead in electronics, these uses account for less than 0.5 percent of the total amount of lead used today. Consumer electronics other than TVs and CRTs today account for approximately 4 percent of the lead found in landfills in the United States (see Chart I). Seeking to drastically reduce the small amounts of lead found in electronic components like semiconductors – and in most cases totally eliminate it – is thus a huge undertaking for the industry. This effort requires extensive research, evaluation, and collaboration not only at the individual company and product sector level, but within the entire electronics industry, to ensure compatibility.

Industry Efforts

The semiconductor industry is working hard to seek technologically feasible alternatives to lead. A number of international consortia are actively seeking to identify and qualify reduced lead or lead free solutions. Millions of dollars a year are being invested in these efforts. Among the challenges and obstacles that the semiconductor industry must address are:

- the higher solder temperatures required by lead alternatives and associated manufacturing specifications,
- supply chain readiness issues,
- the need to screen alternative compounds to ensure that they are environmentally preferable to lead,
- the need to address the definition of lead free,
- the characterization of reliability performance of lead free solders over a wide range of applications,
- and a long transition phase during which lead free components and lead containing components must be able to co-exist without causing technical or other disruptions.

Currently, there are a number of products that can be manufactured without lead solder paste. However, most viable substitutes require higher manufacturing temperatures than do lead compounds and thus substantially increase the amount of energy used during manufacturing. These higher temperatures can also result in moisture problems and delamination, which causes product failure. In addition, the issue of "whiskers" in the case of tin usage must also be addressed.

While the reliability of lead-tin solder has been well established over a wide range of applications and operating conditions, little data exist on the reliability performance of lead-free solders in the diverse conditions for extended periods of time. Thus, accelerated failure models may not accurately predict product lifetime. Many critical applications such as those in aviation and medical equipment are based on commercial components – replacing the lead in these applications, which are often used in severe environments, may induce new failure modes.

Alternatives

The industry is actively seeking to identify commercially available, technologically viable alternatives (see Table I). However, there is no consensus on which of these alternatives should be used. The industry is working strenuously to select the best alternative, however, it will take time to verify not only product specifications and quality standards utilizing the new solder, it is also necessary to verify that the alternative is environmentally superior to lead –

Table I: Lead-free solder – No clear choice

Partial List of Commercially available Pb-free Alloys

Solidus	Liquidus	Alloy	Solidus	Liquidus	Alloy
118	125	In50Sn50	221	221	Sn96.5Ag3.5
118	118	In52Sn48	221	221	Sn96Ag4
118	131	Sn52In48	221	226	Sn97.5Ag2.5
118	145	Sn58In42	227	349	Sn95.5Ag0.5Cu4
141	237	In90Ag10	227	300	Sn97Cu3
143	143	In97Ag3	227	227	Sn99.3Cu0.7
157	157	In100	227	232	Sn99Cu1
183	183	Sn61Pb39	232	232	Sn65Ag25Sb10
188	188	Sn77.2 Ag2.8In20	232	240	Sn95Sb5
219	219	Sn98Sb2Cu.2Ag2*	232	238	Sn97Sb3
217	221-227	Sn95.75Ag3.5Cu0.75	232	232	Sn100
217	221-227	Sn95.5Ag4Cu0.5	234	245	Sn91.5Sb8.5
221	295	Sn90Ag10	280	280	Sn20Au80
221	240	Sn95Ag5			

NOTE: Sn/Pb solder currently used in >90% of electronic applications
Pb-free alternatives are many and diverse - no clear consensus among industry.

ideally such a review should be completed not by industry but by an independent scientific authority.[5] Currently proposed regulatory bans on lead contemplate no such environmental reviews.

In addition to environmental and product quality and standards issues, it is also necessary to ensure that there are adequate supplies of alternative compounds. Some potentially technologically viable compounds may not be available in sufficient quantities to satisfy worldwide demand should the de facto standard be shifted (see Table II). Currently proposed regulatory bans on lead do not include any assessment of the availability of technically viable alternatives.

[5] Several of the potentially technically viable alternatives to lead are mined with lead.

Table II: World Reserves of Select Metals

Metal	World Reserves (thousand metric tons)
Antimony (Sb)	3,200
Bismuth (Bi)	260
Copper (Cu)	650,000
Indium (In)	6
Lead (Pb)	140,000
Silver (Ag)	420
Tin (Sn)	12,000
Zinc (Zn)	440,000

Conclusions

The semiconductor industry is fully engaged in seeking alternatives to replace wherever practical the very small amounts of lead found in our products – this will require further advances in technology and care to avoid unintended adverse environmental consequences caused by substitute materials. To be effective and to ensure product quality is not adversely affected, these efforts require very close coordination throughout the worldwide electronics industry and its supply chain. Key technical challenges include the development and availability of de facto standard manufacturing equipment and the re-tooling of production lines using them. In addition, from both a technical and environmental standpoint new waste streams and higher energy consumption must be addressed.

The industry's efforts to date have yielded some products that can be manufactured without lead solder paste. However, there are applications and products for which a lead free alternative is not yet available and some applications and products that may never be lead free. Any new environmental regulations banning lead should take these technological factors into account. In addition, regulation must be based on a scientific review of the impact of small amounts of lead in electronics versus the potential environmental and other consequences of alternatives. Industry has identified a number of applications where there are no known substitutes for lead in electronic components and it is critical that these be exempted from the ban. Finally, any new regulations must include a review and exemption process that is fully transparent to participants, protects manufacturers' confidential information, and is capable of dealing with these various technological and environmental factors. Without an exemptions process that takes all of the various relevant factors into account, there is no guarantee that new regulations will in fact be beneficial or achieve their stated goals.