LEAD FREE ELECTRONICS ASSEMBLY
How Will This Unfold?

- Today, lead free assembly is in low level production and accounts for less than 5% of all electronic systems.
- Lead free legislation will likely be enacted by 2006 and will probably include a recycling exemption.
- Recycling is a more comprehensive solution.
- Manufacturers may choose to either recycle or implement lead free and lead free assembly will therefore not become universal.
- Prismark recommends that companies that are involved in lead free solder implementation invest defensively in ongoing lead free developments, and strongly encourage all levels of the industry to recognize the benefits of recycling over lead free.

May 2002

PRISMARK PARTNERS LLC

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Prismark has already published three bulletins dealing with lead free solder assembly. (February 1999, December 1999, and May 2001). In the last bulletin we discussed some of the impediments to high volume lead free assembly and ascribed this to unfavorable economics. We also discussed the driving forces to lead free including impending legislation and consumer sentiment.

In this bulletin we will examine lead free production from an industry-wide longer-term perspective and forecast its ultimate status.

Current Lead Free Status

Today, lead free electronic assemblies can really only be found in consumer (personal use) products (TVs, cameras, radios, tape players, cell phones, computers, etc.). Prismark estimates lead free production to be 5% to 10% of these consumer type products, or less than 5% of all electronics products by value.

There are no laws anywhere today that ban lead in electronics; however, proposed legislation by the European Union's ROHS (Reduction of Hazardous Substances) Organization (formerly WEEE) could enact laws by 2006. The draft legislation as written today would only affect consumer-type products, with possible exceptions, e.g., lead in CRT glass, lead inside components, high lead flip chip, etc. Most of this lead free production is centered in Japan. The largest and most assiduous Japanese consumer electronics companies have already committed to 100% lead free assembly by the 2004 – 2005 timeframe, as shown below.

ROADMAPS FOR LEAD FREE SOLDERING BY ELECTRONICS MANUFACTURERS – 2001

Manufacturers	Lead Free Target	Year	Note
Sony	All Lead Free	March 2005	All Production
Toshiba	Mobile Phones	2002	—
NEC	All Lead Free	Dec. 2002	—
Hitachi	All Lead Free	2004	All Hitachi Group
	All Lead Free	2003	—
Mitsubishi	Half	2004	Major Four Products
	All Lead Free	2005	—
Fujitsu	Lead Free	December 2002	—

Separately, recycling has been gaining momentum around the world. Recycling is considered a more comprehensive solution than lead free production since it also deals with the waste volume, other hazardous materials (cadmium, mercury, silver, brominated plastics, etc.), and provides a raw materials supply base.

Several leading consumer electronics companies have announced take back programs for a fee. Some of the leaders here include Philips, Sony, Hewlett-Packard, and IBM. While many lead free advocates claim recycling can never be made efficient because of the collection issues and the low valued waste stream, others are making it happen with certain products. In Taiwan, some retailers tack on a $20 refundable deposit fee for computers. Philips has been recycling television CRT tubes for many years in Europe. Recently, metal reclamation companies have been bidding up the price of used cell phones. Yokohama Metals in Japan, for example, pays 7¢ per cell phone, which contains about 21¢ of precious metals (gold, palladium, tantalum, silver, etc.). Last year they processed 1.7M cell phones, or about 4% of the Japanese market. The precious metal content of these higher-end consumer electronics has not gone unnoticed by many other metal refiners and miners. All across Asia recyclers are collecting millions of tons of old electronics from the US and elsewhere, and mining some of them for precious metals. A cell phone, for example, contains gold in concentrations thirty times higher than in an average gold mine.

Impediments to Lead Free Solder Assembly

Almost everyone in the electronics industry is aware of the inexorable trend towards lead free electronics, even if one disagrees with its merits. Solder has been at the heart of electronics assembly with equipment, processes, and materials catering to its characteristics for over a half century. Since there is no drop-in lead free replacement for eutectic tin/lead solder, significant development activity is required by all strata of the electronics industry. The table below illustrates some of the major issues facing the electronics industry as we move towards lead free assembly.

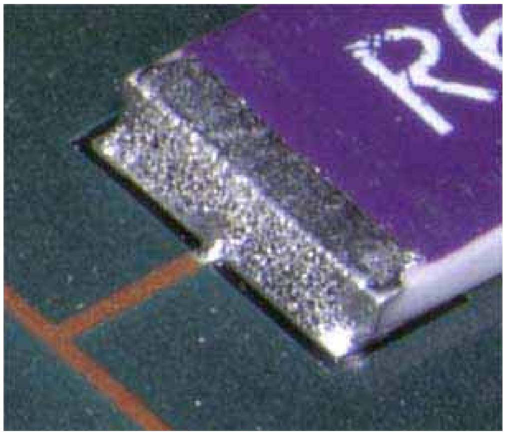
LEAD FREE IMPLEMENTATION ISSUES

OEMs	Device Manufacturers	IC Packagers	Contract Manufacturers	Material Suppliers	Process Equipment Manufacturers
• Lower margins • Will consumers pay more for lead free products? • Legislation • Poor reliability	• Dual component stocking and processes (leaded and non-leaded) • Will there be long-term demand? • Reliability	• High temperature resistance • Lead free termination • Moisture sensitivity	• Depressed yield • Increased capital • Lower throughput • Dual assembly processes (leaded and non-leaded)	• Lead free solder paste • Compatible board finish • High temperature flux • Board damage with high temperature	• Compatibility to high tin solders • High temperature capability • Inspection of lead free solder joints • Decreased throughput

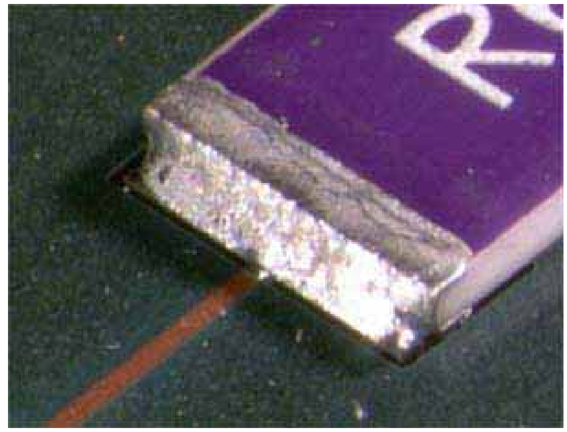
There are very few companies serving the electronics industry that would be unaffected by the move to 100% lead free assembly. This is why it is crucial to understand how and when the industry will move to lead free.

One example of the assembly difficulties associated with lead free solder has to do with the solder joint. The photographs below illustrate the inspection difficulty associated with lead free solder. Dull joints have been the marker for poor joint quality using conventional solder. This is no longer valid for lead free joints. Also note that the lead free solder joint has less wetting.

LEAD FREE SOLDER PASTE JOINT



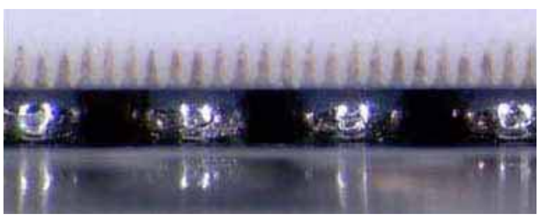
CONVENTIONAL TIN/LEAD SOLDER PASTE JOINT



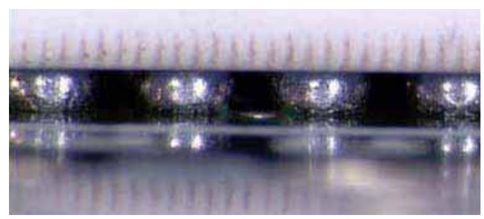
Courtesy: NEMI

Array packages tend to exhibit more solder ball voiding with lead free solder. Lead free solder balls with lead free solder paste have the worst voiding as illustrated below.

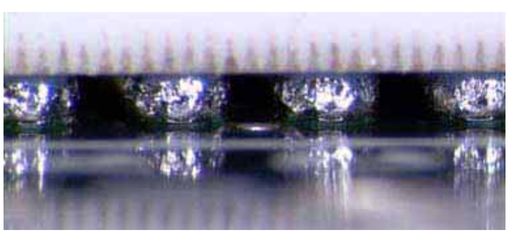
TIN/LEAD SOLDER PASTE AND BALL



TIN/SILVER/COPPER SOLDER PASTE AND TIN/LEAD BALL

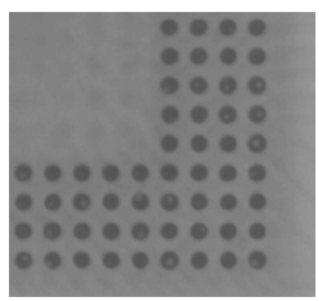


TIN/SILVER/COPPER SOLDER PASTE AND BALL



Source: NEMI

X-RAY SHOWING SOLDER BALL VOIDS WITH TIN/LEAD SOLDER BALLS AND TIN/SILVER/COPPER SOLDER PASTE



The Key Decisions

The industry's migration to lead free assembly is evolutionary. All the materials, equipment, and process knowledge required have not been invented yet to practically assemble all electronics lead free. (One could assemble a large telecommunications board lead free, if yields, reliability, and 50% lower throughput were not issues.) As a result, lead free assembly will progress through key decision points with opposing alternatives. The outcomes of these decisions (e.g., can high volume lead free manufacturing be demonstrated or not; lead free legislation or no legislation; recycle or no recycling, etc.) will dictate the ultimate penetration of lead free solder in electronics. Each of these key decisions points will be discussed below.

Can High Volume Lead Free Manufacturing Be Demonstrated?

Today, 5% to 10% of consumer electronics (personal use) is manufactured lead free. The real question is whether high volume manufacturing is feasible. While lead free manufacturing is obviously technically possible, the economics and infrastructure support for high volume are unproven. This is still true for consumer type electronics and especially true for high-end electronics.

Many leading Japanese consumer electronics manufacturers have already committed to 100% lead free production by the 2004 – 2005 time frame, as shown earlier. While many of these dates had slipped out two to three years ago, most companies have stuck with them since, giving them credibility. Also, JEIDA (Japanese Electronics Industry Development Association) further supports this conversion to lead free by 2005 as illustrated below.

JEIDA LEAD FREE ROADMAP (Ver. 1.3., published 2001)
(Japan Electronics Industry Development Association)

First adoption of lead free solders in mass production goods	1999
Adoption of lead free components	2000
Adoption of lead free solders in wave soldering	2000
Expansion of use of lead free components	2001
Expansion of use of lead free solders in new products	2001
General use of lead free solders in new products	2002
Full use of lead free solders in all new products	2003
Lead-containing solder used only exceptionally	2005

Will Legislation be Enacted for a Major Region?

If Japanese consumer electronics companies can demonstrate high volume lead free production, legislation restricting lead usage is far more likely. Clearly, lead restrictions are difficult to legislate if product manufacturers will inherently loose money because consumers will buy fewer products due to higher prices or lower quality.

Today, the ROHS draft proposal legislation contains a number of exemptions. Prismark believes that by 2006 (the date when the law could be enacted) a very important recycling exemption or option could be offered. The most deleterious effect of leaded assembly is environmental contamination, which could be solved if products were recycled or reclaimed after their useful life. In fact, recycling is a more comprehensive solution because it also deals with the waste volume, other toxic constituents of electronic products, and provides a raw materials supply base.

While the European WEEE (Waste from Electrical and Electronic Equipment) is concentrating on recycling/reclamation, and ROHS is focused on lead free, Prismark believes they will partner to allow leaded production with recycling. One could envision a tariff levied upon the manufacturer or importer of leaded electronics that would fund a regional recycling program. A return deposit on electronics, similar to glass bottles or aluminum cans, could also work toward getting the customer to dispose of products responsibly. The manufacturer would have the option of paying the tariff or producing a lead free product.

Will Manufacturers Implement Recycling Over Lead Free?

There is overwhelming evidence to suggest that lead free assembly is inherently more expensive and less reliable (using like comparisons) than leaded products. Lead free solders wet less, translating into more solder opens and shorts with ominous reliability implications. All potential lead free solders reflow at a higher temperature, requiring 15% to 25% more energy, and require more expensive packaging materials, processes, and equipment. Most practitioners claim that assembly cost increases range between 4% to 15% depending on the sophistication of the assembly, which can translate into a final product cost increase of up to 5%.

The total recycling cost of electronics products is an unknown today; however, it will decrease as the infrastructure matures. We expect that municipalities will figure out waste collection systems while recyclers and reclaimers will align themselves with the valued waste streams.

Today, lead free production may be ahead of recycling; however, recycling is gaining more momentum. Keep in mind that the European Commission is the primary instigator for lead free. Even the Japanese, who lead in the technology, may only follow the Europeans in legislation. Japan is leading in legislation for recycling with their "Home Electronics Recycle Law," which was implemented in 2001. The following JEIDA survey results illustrate these points.

JEIDA SURVEY
(54 MAJOR JAPANESE COMPANIES INTERVIEWED)

1. HAPPY WITH LEGISLATION MOVEMENT IN JAPAN?
   - 75% ACCEPT IT
   - 60% NOT CERTAIN WHETHER ADVANTAGEOUS TO THEM
   - 20% THINK WILL BE DISADVANTAGEOUS
2. WHEN SHOULD LEGISLATION BE ENFORCED IN JAPAN?
   - 84% SAID "*…WHEN IT HAPPENS IN EUROPE*."
   - 32% SAID "*…BEFORE EUROPE*."
3. WILL MEET JAPANESE HOME ELECTRONICS RECYCLING LAW?
   - MOST COMPANIES WILL MEET IT WITH LEAD FREE PRODUCTS
   - BASIC REQUIREMENT FOR RECYCLING
     - AIR CONDITIONER 60%
     - TV 55%
     - REFRIGERATOR 50%
     - WASHING MACHINE 50%

Decision Tree Analysis

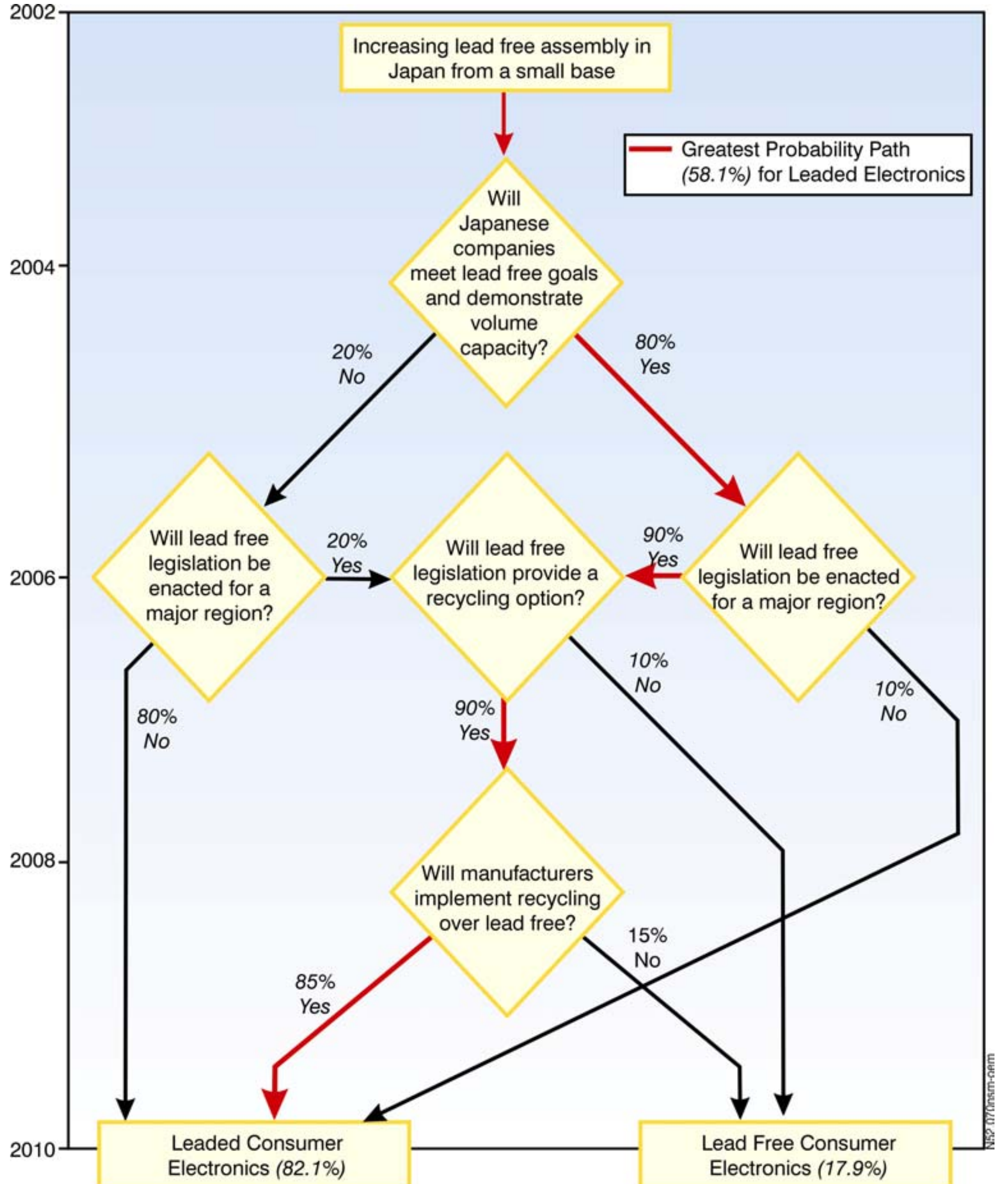
Prismark attempted to calculate the probability of lead free solder conversion using decision tree analysis. Each decision point, as discussed previously, was assigned an individual probability of occurrence based on key technical, legislative, or trend type arguments. For example, Prismark believes there is an 80% chance that the Japanese consumer electronics companies will demonstrate high volume lead free production by 2005 and that there is an 85% chance that companies will elect recycling tariff over lead free manufacturing. In reality, this series of complex decisions may not necessarily be binary (have yes or no outcomes) or occur sequentially (legislation will be resolved after volume manufacturing is proven). Even so, Prismark believes the key decision paths can be described with a conventional decision tree because certain decisions are best made when the outcomes of other events are known and when technical data becomes available. For example, a decision to replace lead free solder products with leaded recyclable products is too premature since insufficient technical and economic data about recycling is available today, but is likely to be developed by the 2006 – 2007 time frame.

Since the decisions to adopt lead free solder into consumer electronics (e.g., cell phones, PCs, entertainment products, etc.) are very different than for adoption into high-end electronics (e.g., ATM switches, servers, routers, automotive modules, military weapons, etc.), Prismark created two decision tree diagrams. High-end products require higher reliability and may operate in harsher environments, making a lead free assembly far less likely. In addition, these products often use large boards, which makes even heating challenging, potentially resulting in higher component failure rates from higher component temperatures.

While the decisions required to introduce lead free into high-end products are the same, the probabilities of a lead free solution are far less compared to consumer electronics. In addition, the decision dates would be further out because it is more technically challenging and there is no tentative legislation restricting lead usage. The decision tree for high-end electronics reflects these factors.

Included with the two diagrams below are the regional participation splits (%) for Japan, Europe, Asia, and the Americas. Note that while most consumer electronics are manufactured in Asia, this is strongly controlled by the Japanese OEMs. The timeline on the left side shows when these decisions are likely to be made, while the probability of the outcomes is assigned to each path (% yes and % no). Note that the percentages shown are probabilities and do not represent percent of products. Each of these probabilities is added up, starting with 100% probability in 2002, to calculate the final probabilities for both the leaded and lead free outcomes.

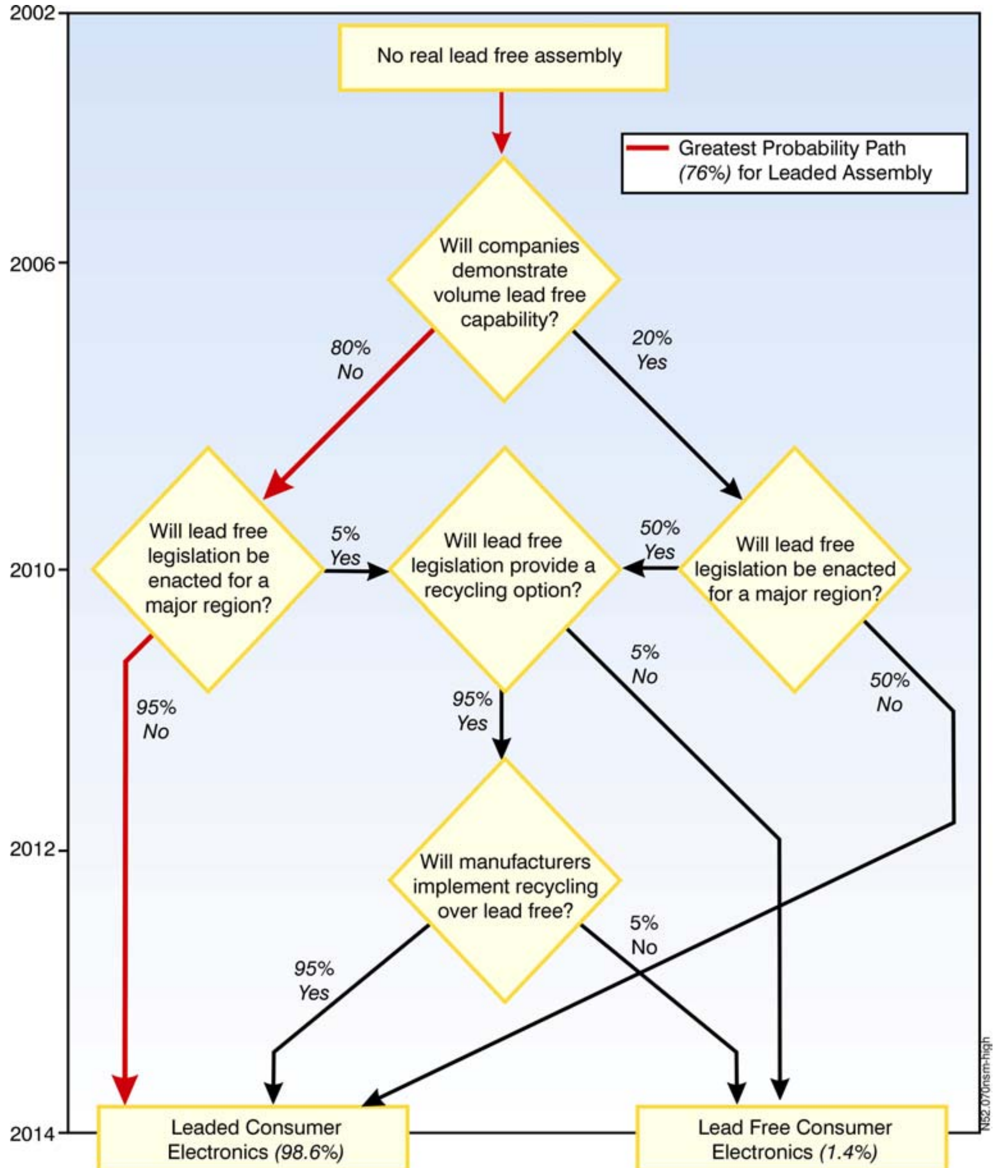
LEAD FREE PROBABILITY FOR CONSUMER/PERSONAL ELECTRONIC SYSTEMS
(Asia 35%, Japan 27%, Europe 23%, N. America 15%)



The most likely path (58.1% probability) is highlighted in red and is through the "*Japanese companies meeting their high volume goals*," "*Lead free legislation with a recycle option*," and "*Manufacturers choosing to build recyclable products instead of lead free*." The final results from this decision tree analysis shows only a 17.9% probability of lead free consumer electronics becoming mainstream.

A similar decision tree analysis was performed for the high-end electronic systems, as shown below.

LEAD FREE PROBABILITY FOR HIGH END ELECTRONIC SYSTEMS
(Asia 18%, Japan 15%, Europe 22%, N. America 43%)

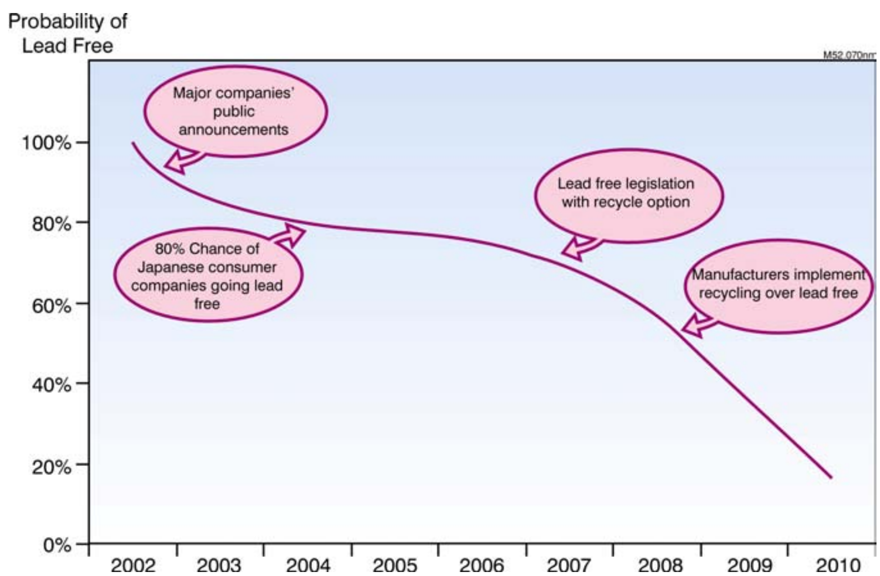


For high-end electronics, the probability of lead free becoming mainstream is 1.4%. Higher-end product manufacturers and their customers are more concerned about reliability, making lead free assembly much less likely. Also, most of this electronic equipment resides in company buildings, making it easier to reclaim than consumer electronics. The most likely path for high-end products (76% probability) is through companies not being able to demonstrate high volume lead free capability, resulting in no legislation and a leaded product.

In reality, recycling will be gaining momentum across all electronic products, ultimately resulting in nearly all products (consumer, high-end, lead free, and leaded) being subject to recycling/reclamation before 2014.

The probability of lead free consumer electronics changes as we pass through decision points. If we assume the probability of lead free assembly to be 100% in 2002, based on all major consumer electronics companies' pronouncements, then this probability would be expected to decline over time going through key decision points. Prismark calculated these probabilities at different points in time to generate the graph below. Major curve inflection points are attributed to outcomes of key decisions, which are highlighted in bubbles.

PROBABILITY OF LEAD FREE CONSUMER ELECTRONICS OVER TIME



Lead Free Implications

Clearly, if one wants to play in the consumer electronics area, a lead free strategy must be in place today. Even though the probability of lead free assembly will decline over time, there could be significant product volumes in the interim. Direct translation of lead free probability into product volumes over time is challenging. Of greater importance than the number of products assembled lead free is the board area and solder paste volume. This will dictate the assembly infrastructure size and materials requirements. If we assume a 5% lead free product penetration in consumer (personal use) products today and estimate a penetration of 40% by 2006, the following lead free assembly printed circuit board area and lead free solder paste consumption can be estimated. The table below shows the total consumer product consumption of PCBs and solder paste, estimated lead free percentage, amount lead free, and the percent of the world total PCB and solder paste consumption (includes non-consumer products) that could be used for lead free assembly in years 2001 and 2006.

POTENTIAL LEAD FREE ASSEMBLY MATERIALS CONSUMPTION

	2001				2006			
	Total Consumed	% Lead Free	Lead Free Consumed	% Total Consumed	Total Consumed	% Lead Free	Lead Free Consumed	% Total Consumed
PCB Area (M m^2)	134	5%	7	3.7%	158	40%	63	26%
Solder Paste (tonnes)	2,752	5%	138	2.7%	3,928	40%	1,571	21%

We would expect the lead free product production ramp to level out once lead free legislation is passed with a recycle option. 2006 may represent the largest lead free product penetration percentage. At that point, new product designs are more likely to use leaded assembly and recycling, resulting in a decline in lead free production.

A surprising outcome from the above analysis is that the lead free assembly board area could be over one-quarter of the total assembled board area worldwide, which could consume 21% of all solder paste by 2006. This is a potential opportunity that should not be overlooked even if you believe, as Prismark does, that lead free assembly is unlikely longer term.

Prismark recommends that companies that are involved in lead free solder implementation invest defensively in ongoing lead free developments, and strongly encourage all levels of the industry to recognize the benefits of recycling over lead free.

Prismark will be tracking events as the probabilities of lead free implementation change.

COMPANY PROFILE

Prismark is an electronics industry consulting firm. We are consulted by many of the leading systems houses, semiconductor companies, and the materials, components, and tool companies that enable electronic equipment to be manufactured. These companies use Prismark to plan their tactics and set their strategies in an industry that continues to undergo complex technological and structural change.

Prismark works in all market sectors:

WIRELESS COMMUNICATIONS	MILITARY
COMPUTING	MEDICAL
DATA COMMUNICATIONS	INSTRUMENTATION &
AUTOMOTIVE	CONTROL ELECTRONICS

Prismark's consultants have expertise in:

SEMICONDUCTOR PROCESSING	TEST
DEVICE LEVEL PACKAGING	DISPLAYS
INTERCONNECTION	OPTOELECTRONICS
ASSEMBLY	MEMS

Prismark has developed a global reputation for providing clients with an extremely clear understanding of the complex dynamics that drive the electronics industry. Clients use Prismark's knowledge and interpretation to make confident business decisions about uncertain technology and market developments. Prismark's clients include some of the largest electronics companies as well as much smaller innovators, and financial institutions.

Prismark focuses on providing very personal and highly specific research recommendations to the relatively few companies that are becoming leaders at every tier of the electronics industry. Our consultants operate globally and are based in our main office in Cold Spring Harbor, New York.

Contact us in person (631 367 9187) at 130 Main Street Cold Spring Harbor NY 11724,
at our website: www.prismark.com, or e-mail us at partners@prismark.com

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PARTNERS LLC