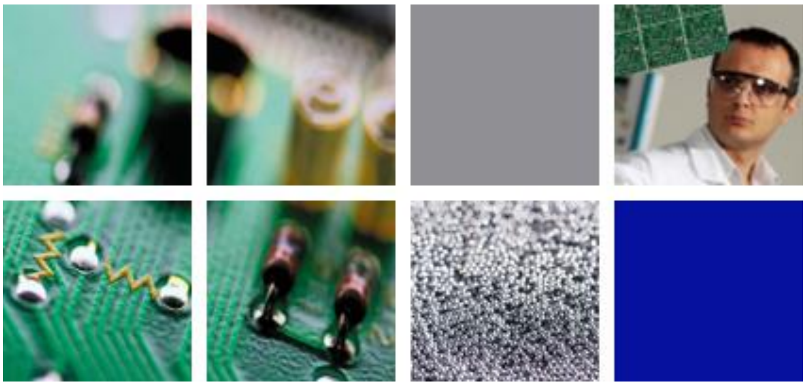
Solders Technology Roadmap 2015

Tomorrow's Solders

Roadmap



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Executive summary

ITRI represents tin producers in support of tin users, including the solders and electronics industries. Bi-annual surveys of technology threats and opportunities accelerate innovation and make new technology implementation more cost-effective. A single-question survey on legislative and technological issues over the next 5-10 years produced 276 comments from 124 respondents, reproduced in this report approximately verbatim.

Responses from the survey have been grouped together under the three themes, Technology Drivers, Technology Design and Technology Performance.

Technology Drivers

- Electronics design engineers are striving to keep up with the rapid advances in technology self-evident to all. New electronics systems such as LED, optoelectronics, flexible, printed & wearable electronics, renewable energy systems and IoT are challenging interconnection technologies to be compatible. New ways to make electronics such as 3D printing and even biological circuits are already in R&D. Technology trends are also driving use of electronics in harsher environments and these applications will challenge reliability of soldering technologies.
- At the same time they are being squeezed by increasing legislative restrictions on the type of materials available and increasing traceability paperwork. Extensions of EU RoHS2 scope and now REACH legislation are a cause for concern, not just for solders but more broadly for electronics materials and processes generally. Conflict minerals issues related to tin supply have particular focus for US-based organisations.
- The aerospace & defence sectors feel particularly threatened by imminent pressures to convert to lead-free soldering, although this is more related to market pressure than technology need.
- Increased cost is a significant concern leading, for example, to lower silver content of lead-free solders. Some respondents are also reporting impacts on quality of electronics raw materials generally and of some components.
- There are some concerns about future tin supply and also the potential impact of geopolitical issues. There will be more focus on producer responsibility for end-of-life and recycling of solders with other e-waste materials will increase.

Technology Design

- Increased miniaturisation continues to be the major technology trend as components and assemblies can be made ever smaller and more compact. On a macro level the continuing conversion to solder paste SMT technology in large developing markets, notably China, will have a significant future impact but take many years. Elsewhere the traditional SMT soldering process is reaching its limits for components with very small termination sizes and pitches.

- Increasing complexity will bring challenges both to electronics assembly and to management of global supply chains. Much better design processes are needed, including more co-design, implementation of better supply chain systems and improved modelling, including virtual prototyping.
- The drive towards elimination of hazardous substances from polymers, combined with miniaturisation and higher processing temperatures for lead-free soldering are significantly changing the types and properties of available materials in electronics assembly.
- This rapid and constant modification of material formulation gives concerns about reliability and safety impacts, particularly in the Aersopace, Defence & High Performance (ADHP) industries where there is an increasing divergence in need from commercial solutions.
- Soldering technology is rapidly diversifying to adapt to these changes and in niche high-end markets will become just one of several available joining technologies in the future. Solderless technologies will include conductive adhesives, low temperature sintering, press fit, copper-to-copper, embedded components and printed electronics.
- These challenges are exacerbated by a rapid diversification of new lead-free solder technologies now including low silver, low temperature, high reliability and high temperature variants. These are becoming increasingly customised to tackle specific applications issues or modified to find patent space. Solder producers are pushing towards finer solder powder grades. This is a major cause for concern as electronics assemblers struggle to adapt processes and testing to what seems to be a moving target. In turn solder producers need to find ways to recover rising product development costs, including a package of expensive test data for each alloy. In general this trend will challenge solder producers to increase investment in R&D and new product development to remain competitive in the future. The days of a single simple tin-lead solder product are long gone.
- As electronics assemblies become more complex, customised and mass produced there will be a need for faster, more customisable and more specialised soldering processes.

Technology Performance

- Along with the increased complexity of electronics design and the rapid diversification of new materials and new solders it is clear that a better understanding of the reliability of solder joints is critical to maintaining confidence in future electronics systems. Despite many years of detailed study there is still a perception that there is a lack of understanding of the performance and science related to lead-free solder to long life and high reliability applications in particular. In fact there has been considerable progress in understanding and modelling solder microstructures under thermal cycling for example, but this perhaps need better communication. Managing the reliability risk for high-density and applications operating under harsh environments will need to be much better and long term reliability of lead-free solder joints needs to be improved.

- Changing electronics designs will also bring increased issues and concerns over effective cleaning. Increasingly denser boards are also challenging lead-free finishes, affecting finish type and quality with no clear preferred finish.

Methodology

ITRI represents the global tin industry and monitors tin use markets on behalf of tin producing companies and tin users, including technology threats and opportunities. Improved data exchange and better communication of R&D needs will accelerate innovation and make new technology implementation more cost-effective.

Continuing its series of bi-annual solder industry consultations, ITRI issued an online survey question in October 2014 - "What are the key technological and legislative issues likely to affect your industry in the next 5 - 10 years?" A total of 276 comments were received by 124 respondents from all major use sectors, research organisations and consultants globally. Unusually, almost half of the comments were from respondents with some relation to the aerospace & defence industries. A list of contributors is appended.

These were categorised, tagged and grouped to provide a data map of the current topical thinking on solder industry challenges going into the next decade. This was then converted to the text in this report, most of which is approximately verbatim from respondents, with some added extra background where necessary.

The draft was recirculated to respondents for comments and feedback used to refine the report to a final version.

Whilst efforts have been made to moderate some inputs the report will by nature contain some repetition and some content with which not all may agree. ITRI is keen that the report represents the authentic voice of the industry and it should be read in that context.

Solder Market Overview

Global refined tin usage in 2013 is reported to be almost 350,000 tonnes per annum with the solder sector the largest consumer of refined tin (over 50%)[1]. The global transition to lead-free solders in the 2000's helped drive tin consumption in the solder sector with tonnage and percentage of refined tin use reaching a peak in 2007 of 200,000 tonnes and 55% respectively. Consumption has since dropped from this peak due to issues such as the global financial crisis of 2008-2009, cyclical weakness in the world electronics industry and a trend towards products and assembly techniques involving small quantities of solder.

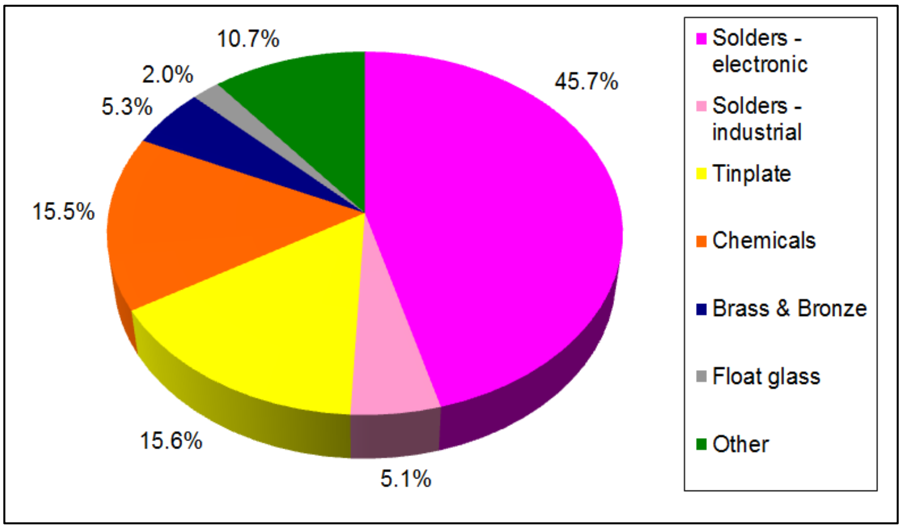


Figure 1 World refined tin use by application, 2013[1]

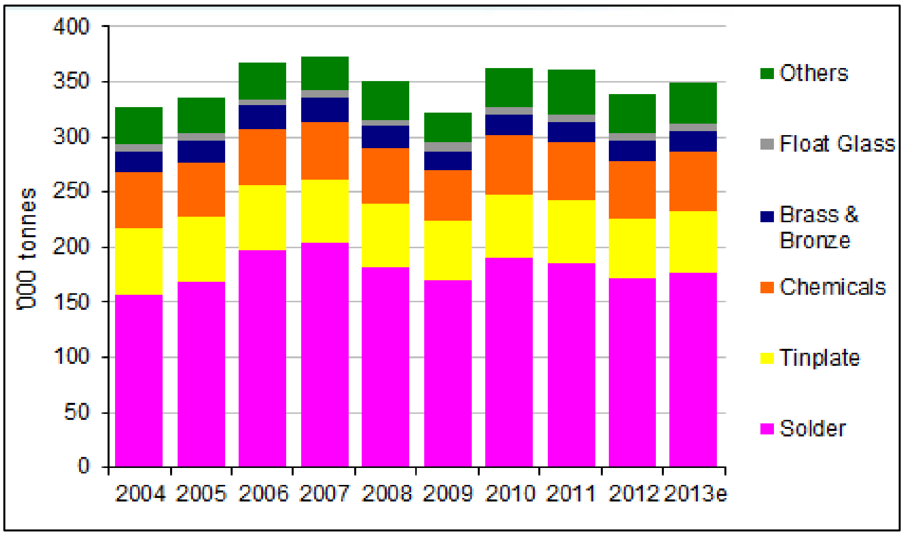


Figure 2 Global tin usage by application, 2013[1]

[1] Tin Use and Recycling 2013; including survey data on 2012, ITRI Ltd, (2014)

Analysis from ITRI has suggested that the transition to lead-free solder is set to gather pace in the next decade, from a current plateau estimate of 70% lead-free to 80% lead-free in 2017 and 95% lead-free in 2023[1]. Conversion in China will be a critical factor. This will support future tin use in the solder sector.

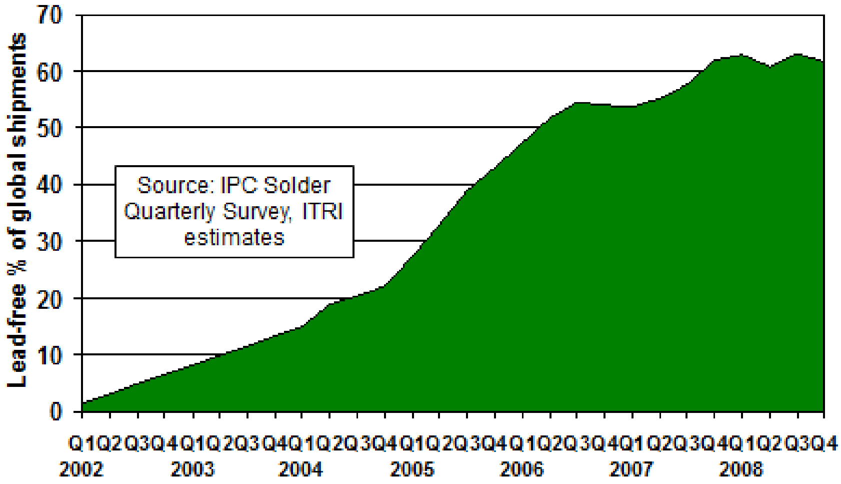


Figure 3 Lead-free solder global share 2002-2008

Data gathered from the ITRI Tin Use and Recycling survey 2012[1] on the market shares of different types of solder showed that China paste production as a percentage of total solder sales is still less than for the rest of the world. The trend to increased paste production in China is expected to accelerate as electronics design transitions to SMT technology. This will have an impact on solder use, but the growing transition to lead-free and the general economic growth in electronics will give counterbalance.

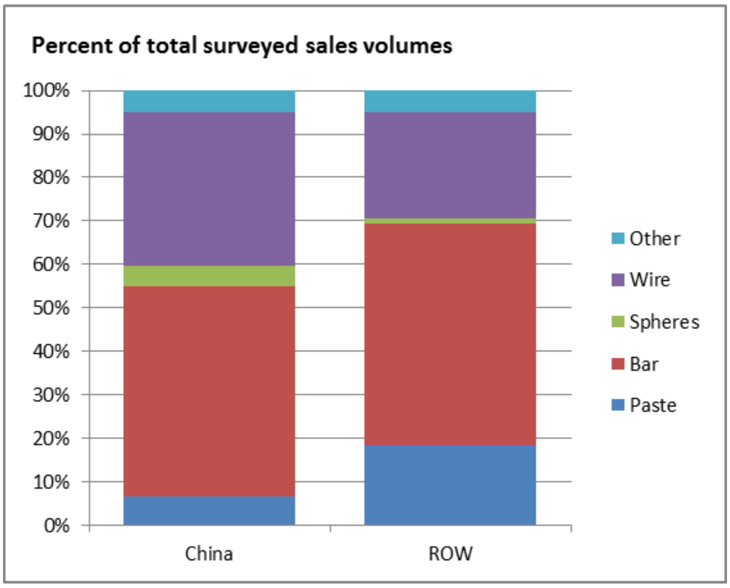
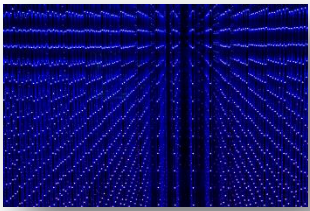


Figure 4 Solder market shares by type, 2012[1]

Technology Drivers



Electronics design engineers are striving to keep up with the rapid advances in technology self-evident to all, as well as with more use of electronics in harsher environments. At the same time they are being squeezed by increasing legislative restrictions on the type of materials available, increasing traceability paperwork and ever present cost pressures.

New electronics systems

Electronics are becoming increasingly part of technology systems that spread into diverse and multiple components and materials to deliver new functionality and user experiences.

LED is an example, with optical systems and analogue power systems also requiring new interfaces to transfer technology into adjacent spaces. Wearable electronics, printed electronics and even nanoelectronics at one end of the spectrum and renewable power applications at the other end will all require new material and packaging technologies.

Optoelectronics is a new focus for the IT/Telecoms sector particularly, with a need to find new material and assembly process technologies for silicon photonic packages, especially for high volume manufacturing. Embedded waveguide technology for high speed PCBs will also become important.

Flexible and printed electronics will need to be interfaced with conventional solder electronics using low temperature joining technologies such as conductive adhesives and low temperature sintering.

Nanoscale technologies, including integration of graphene or fluorene conductive nanostructures, will need completely new understandings of nanoscale wetting and spreading for joining materials.

Highly reliable sensor technologies will be needed in ambient and biological environments for the new area electronics products such as robots, medical and construction maintenance, or in control of airborne contaminants for example.

New energy storage, thermoelectric and solar cell materials will need interfacing, including glass and textile substrates.

As broadband efficiency increases it will become on a par or better than broadcast devices for multimedia transfer. Higher frequencies in data transfer will mean greater sensitivity to signal disturbances or antenna effects within the electronics system components. Ultra low loss materials will be developed for high speed PCB's, as will very thin, weak and small press fit connectors. Producers of specialist products such as intermodulation filters are only too aware of the how performance can be influenced by factors such as solder joint materials and design.

Power saving will continue to be important. Wider use of low power consuming Single-chip (SoC) systems will make modular construction of electronics systems simpler, although at the same time easier to copy, and encouraging more DIY or hobby-type products.

Embedded systems are becoming increasingly ubiquitous, for which there is a requirement for upgraded electrical performance, especially efficiency.

The Internet of Things (IoT) is yet another type of new generation electronics assembly. Here customers work with materials like PET and need very low temperature assemblies that are quick and cheap but, critically, have good mechanical compliance of interconnects.

To meet these increasing requirements 3D electronics assembly will probably be developed. New ways to make electronics including 3D printing and even biological circuits are already in R&D.

Harsher environments

Technology trends are also driving use of electronics in harsher environments and these applications will challenge reliability of soldering technologies. For example increased use of electronics in unventilated enclosures will mean higher running temperatures.

The automotive industry particularly is seeing rapidly increasing use of electronics systems, including integration of consumer-type entertainment and interactive devices, engine control systems and, more recently hybrid and electric power systems. Proximity to the engine and positioning in exposed parts of the vehicle is pushing extended reliability requirements, particularly at high temperature, where solder joints are at the limit of SAC technology.

High density and performing systems in the aerospace and defence sectors will also continue to be challenged by harsh environments. Tin finished lead-free components are of particular concern in regard to tin whisker failures, sometimes requiring rework to make them compatible with high reliability joining. Overall a better understanding of failure in such components is needed. Because of concern about embrittlement and the beta-Sn to alpha-Sn transformation (“tin pest”), operation at low temperature is also an issue, particularly cryogenic temperatures.

Expansion of the oil & gas industry, especially shale oil, is driving a need for higher melting point lead-free solder alloys for ‘down-the-hole’ electronics systems.

Sub-sea systems are becoming more important and thus operation in high temperature and high pressure environments. Leaded solders are still preferred until the industry is more confident about the reliability of lead-free solders in such environments. Military applications have similar issues.

Harsher environments highlight issues that are common to all electronics, especially power semiconductors for example, in that parts with different CTEs require low assembly temperatures but high application temperatures. Such needs have stimulated development of transient liquid phase processes or sintered materials. 'Smart' solders, being mixtures of high and low temperature solders, are also in R&D.

Leaded polymer ball technologies have been developed for military use where more ductile interconnects are required.

Increasing legislation

There is general agreement that there will be increasing legislation over the next decade and even beyond, restricting the availability of materials and processes and threatening the integrity of established supply chains. The transition to lead-free solders and other more sustainable materials will continue to demand adaption of existing designs and development of compatible materials, increasing cost and complexity.

RoHS and RoHS2

The headline legislation is still the EU RoHS directive and its 2012 revision 'RoHS2'. Scope was expanded to include and provide deadlines for monitoring and control instruments (July 2014), medical equipment (July 2014 & July 2016) and industrial monitoring and control equipment (July 2017), with a new 'Category 11', subject to review, covering 'other electrical and electronic equipment not covered by other categories' (July 2019). Large scale, transport, space and military uses are however specifically excluded.

RoHS-type regulations continue to expand globally although in fact production is already transitioning in sectors not directly affected, notably automotive. Brazil has recent new hazardous substance regulation in five States, although in fact it has already moved to 50% conversion. Tighter rules are expected there after two of three presidency candidates have taken an environmentally conscious platform. China will introduce new incentives for compliance in 2015. The strictest legislation is in developed countries where there is less electronics production but more consumption and disposal.

There is very real alarm, particularly in the aerospace and defence sectors, that reliability will be compromised and costs will rise. Further knock-on effects on component obsolescence and availability are also anticipated, with disruption of global supply chains. There is the impression that lead-free solders are 'being forced upon' these industries through the 'backdoor' and that changes to RoHS scope 'must be robustly countered' until continued product capability and reliability can be assured. There is even still the hope that the 'leaded solder portion can be repealed altogether'.

Although most of these sectors fall outside the RoHS scope pressure is mounting fast as leaded components come into short supply and outsourced design and production is increasingly dominated by commercial supply that is now primarily lead-free. There is also the risk of inadvertent use of lead-free BGAs and other lead-free components in leaded assembly, compromising reliability. Use conditions in the ADHP (Aerospace Defence and High Performance) industries are much harsher than in the consumer electronics sector, for which it is perceived that most lead-free soldering technology has so far been developed.

These issues have been extensively reviewed in a recent presentation[2] from the US Aerospace Industries Association (AIA) Joint Government and Industry Executive Forum for Lead (Pb)-free Electronics. The document sets out a roadmap for lead-free conversion by July 2019. Note that this is the date for EU RoHS regulation to have a full 'open scope' and has been used in the roadmap even though aerospace and defence sectors are still specifically excluded from that definition. IPC PERM (Pb-Free Electronics Risk Management) Council has also recently released a white paper identifying priority research areas across five ADHP sectors[3].

Smaller specialised companies, many of whom make components for military contracts, are also concerned about the possibility of imminent conversion. Use of heavy copper PCB designs for power supplies may give particular issues. Scientific instruments are often designed made and reworked by hand. Some in that industry claim that lead-free solders do not show up dry joints so easily and 'make it nearly impossible' to fine tune output performance – 'confidence in boards built by hand with lead-free solders is very low'. Extra build time is likely to increase prices. One producer of handmade products had needed to take more care not to damage components as soldering temperatures are higher, especially in rework.

Newer sectors such as renewable energy are also concerned. Those supplying the European market are making higher cost lead-free products in order to comply with regulations, putting them at a cost disadvantage to large manufacturers who make products only for non-EU markets.

On the component level there will continue to be pressure to replace high-lead high melting point solders, even though the RoHS2 exemption remains. Apart from AuSn, a range of new solder solutions have explored including ZnSn and more recently BiAg alloys. Nanosilver and

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[2] AIA Technical Operations, "Joint Government and Industry Executive Forum for Lead (Pb)-free Electronics Recommendations," Aerospace Industries Association (AIA), 1st Oct 2014. [Online]. Available: http://www.aia-aerospace.org/assets/Joint_Government_and_Industry_Executive_Forum_for_Lead_%28Pb%29-free_Electronics_-.pdf. [Accessed 20th Nov 2014].
[3] IPC, "IPC PERM Council White Paper Examines Lead-free Research Priorities," IPC, 5th May 2014. [Online]. Available: http://www.ipc.org/ContentPage.aspx?Pageid=IPC-PERM-Council-White-Paper-Examines-Lead-free-Research-Priorities. [Accessed 20th Nov 2014].

transient liquid bonding (TLP) technologies have also been developed, but it is still generally agreed that there is no drop-in replacement.

The RoHS2 directive also included a priority list of 56 substances for consideration and, although most are organic substances such as flame retardants and plasticisers, some metal compounds are included such as antimony trioxide and nickel sulphate. A recent report reviewed and further prioritised the list[4]. There is a concern that eventually this will lead to serious restrictions including other elements such as bismuth, antimony, silver, and perhaps even tin, limiting the number of elements available for use in solder alloys and other components. Some specialist components rely on specific elements – for example germanium diodes are critical to sound quality of some audio products. Alternatively there is concern that this could lead to RoHS elements being banned in a broader range of applications – for example both lead and cadmium alloys have unique solidus and liquidus points. It is also reported that some customers are starting to challenge the 0.1% RoHS limit on restricted elements, driving towards 0.0% solely on the basis that 'your competitors are doing it'.

REACH

Aside from RoHS there is now a growing concern over EU REACH regulations that will restrict a wide range of chemicals, with knock-on impacts globally. A recent webinar has summarised the current position[5]. The focus is on Substances of Very High Concern (SVHCs), of which 155 are on the Candidate List, 31 are already restricted and a further 22 are under consultation. They are mostly organic compounds with some metal salts, notably of lead, cadmium and boron. These can be found in some resistors, capacitors, oscillators and microcontrollers as well as peripherals and TVs. Packaging and polymers are principal targets, but uses of SVHCs in fluxes, conformal coatings, cleaning agents, plating baths and sealants for example will need to be monitored closely.

Some metal salts used as additives in tinplating baths are likely to be impacted by REACH regulations. These have been used to replace lead salts and are particularly important for suppressing tin whisker growth in lead-free finishes.

Conflict Minerals

Some are concerned over recent coverage of conflict minerals issues affecting tin, tantalum and tungsten, mainly from DRC Congo. This particularly affects large US electronics companies such as Apple and Hewlett-Packard who are registered with the Securities and Exchange Commission (SEC) and subject to the 2012 Dodd-Frank Act requiring supply chain

[4] Umweltbundesamt GmbH, "Study for the Review of the List of Restricted Substances under RoHS2," Jan 2014. [Online]. Available: http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/abfall/ROHS/finalresults/0_RoHS_AnnexII_Final_Report.pdf. [Accessed 20th Nov 2014].

[5] Silicon Expert Technologies, "REACH - Future & Impact on the Electronics Industry," Oct 2014. [Online]. Available: http://www.siliconexpert.com/customse/REACH_Webinar_2014.pdf. [Accessed 20th Nov 2014].

auditing and disclosure. This 'thorn in the side' has lately extended to NGO pressure on such companies over what are perceived to be unsustainable practices in supply of tin from Indonesia. There is some concern over potential changes that might include recycled materials, increasing complexity in compliance for solder producers.

Other

Halogen-free legislative pressures will also continue, especially in fluxes. A greater focus on end-of-life e-waste disposal will further emphasise harmful effects of halogen emissions during incineration.

Increased materials-based regulation will continue to push the limits of traceability and materials declaration, with potentially increased intervention for compliance regulation and monitoring by third parties, checking BOM and paperwork. Database and online solutions to manage this type of data will become increasingly important.

Stricter EMI/EMC criteria are resulting in a need for better protection circuitry.

Stricter controls on worker safety will bring more requirements to provide containment units to protect against breathing solder flux fumes, with associated costs.

Increased cost

Increased cost pressures exist over and above those related to legislative changes and this was significantly represented in feedback from respondents.

Rising process costs are leading to a focus in reducing BOM, rationalising and finding 'cheaper and quicker-processing' assembly materials and cutting power usage.

Some solder producers are also identifying production costs as a major issue.

This result is a downward cost pressure on raw materials and components, meaning that suppliers are struggling to maintain and improve the required quality levels. This 'has been our biggest technology challenge over the last five years'.

Quality issues have been exacerbated by the drive towards offshore sourcing and cost competitiveness, delivering non-consistent PCB quality.

The effect of silver price on lead-free solders has continued to drive technology towards low-silver, or zero-silver, solders, with resultant concerns over thermal cycling reliability in particular.

Geopolitical issues

Only two respondents referred to recent increased global tensions with concerns over potential trade barriers or embargos due to trust deficiencies among countries.

It was suggested that regional or national regulatory frameworks such as 'China RoHS' created the potential for type-approval restrictions. These regulations can be perceived as a fixed-cost barrier that discriminates against imports and against smaller manufacturers in particular.

Tin supply

Some feedback focussed on issues related to tin supply, based on some recent negative press giving the perception that there may be higher prices and tighter legislative controls over the mining of tin in the future. Supply from Indonesia has been particularly highlighted.

In practice industry efforts to implement improved traceability and sustainability practices and market self-adjustments are likely to resolve any potential issues, there being no long-term issues with tin reserves.

Miniaturisation will continue to decrease the unit volume of tin used in solder joints, but this will be counterbalanced by expected rapid growth in the number and size of electronics markets.

Recycling of solder production waste and recovery of tin and other metals from e-waste will increase. This will be partly driven by primary supply issues and partly by increased legislative and consumer pressure for increased use of recycled materials in products.

Miniaturisation will decrease the per-unit volume of tin available for recovery. Recovery of metals is likely to continue to take place further upstream as producers see the opportunities to recover more value and technologies to do so become more widely available, decreasing the amount of waste accessible by secondary tin producers.

New EU legislation to control lead impurity contents in raw materials will have some impact on tin supply as on many other metals and alloys. Those able to produce purer grades, notably secondary tin refiners, may benefit.

Electronics producers will be increasing give lifetime product responsibility, including financial and logistical responsibilities for end-of-life product disposal.

Technology Design

Key technology design trends highlighted are increasing miniaturisation and complexity in electronics assembly. Better design processes will be required to satisfy these trends utilising new materials, solders and soldering processes.

Increased miniaturisation

The trend towards miniaturisation continues as new enabling technologies mean that components and assemblies can be made ever smaller and more compact. This is driven by the burgeoning of new product markets such as wearable computers.

On a macro level the conversion to solder paste SMT technology from wave solder technology is now beginning to have an impact in China, solder's largest market, although it will be many years before the transition is complete. Local producers in South America are also still largely using wave soldering. However foreign companies (70% of large companies in Brazil and almost 100% in Argentina) are working to eliminate wave and move to solder paste, especially in the move from desktop PCs to laptops, ultrabooks, tablets and smartphones. Brazil in particular responds very quickly to change and it is expected that trends in the next two or three years will govern future years. There are similar observations on the impact of conversion to solder paste in the Indonesian market.

Elsewhere the traditional SMT soldering process is reaching its limits for components with very small termination sizes and pitches. Inevitably this will challenge accuracy of fine details of SMD pads and fine pitch connections, as well as component placement. PCB designers are using ever decreasing track and gap widths. Via hole diameters are also reducing but fabricators are still plating the same thickness of electrolytic copper.

There is consequently also an increase in Bottom Terminating Components (BTCs), with a transition from leaded to leadless fine pitch packaging, for example an increasing market penetration of QFNs and DFNs. Soldering and especially reworking 'hidden' solder joints like these and those in stacked components will become increasingly challenging.

System on Chip (SoC), 3D packaging and embedded active components will inevitably increase, challenging all interconnection technologies, including soldering. There will be an increased use of metal/alloy/polymer core solders and copper pillars for Package on Package (PoP) to maintain stand-off height between substrates,

The trend to miniaturisation also leads to higher stress concentrations, higher in-service temperatures and a higher relative volume of internal defects.

Increased complexity

The rapid diversification of electronics assemblies and integration with new systems will significantly increase complexity in electronics assembly.

Increased miniaturisation will also leads to increased complexity as ever smaller components continue to be mixed with exotic larger parts on the same board.

Screen printing can have limitations. Mixed package technology causes challenges that in reality require expensive multi-level stencils. As packaging becomes increasingly complex solder processes may not be fully qualified and proven before the next smaller step.

Securing the supply chain will be more and more difficult as complexity increases. There will be fewer capable suppliers or unique supply chain setups, including materials, to meet product requirements.

Better Design

These rapid technology changes will require continuously improved design processes and rapid updating of guidelines and databases. An example is the development and updating of recommended substrate designs – solder mask designs, mask thickness, pad sizes etc. – for optimum assemblies using reflow soldering. Design for Wavesoldering is also desirable. Design for Excellence however is still a ‘moving target’ in the industry.

Managing the supply chain and co-design for highly integrated products such as 3D MCP (Multi Chip Package) modules will become more important. For high performance applications co-design will certainly be increasingly needed, with related questions on IP and knowledge transfer.

This will fit with an increase in big data as supply chains work more closely together, using Computer Aided Manufacturing and IoT to connect suppliers and customers together with real-time data sharing from warehouse to shipping. This will give faster reaction globally for strategy and direction in production as well as design.

Two research organisations highlighted the need for increased and improved modelling activities. These will be required for process and project improvement, decreasing the new projects timetable. Miniaturisation and integration of a broad range of technologies including fluidics puts stronger demand on design for reliability based on physics of failure. To save cost in the development phase virtual prototyping is an essential component to mitigate hardware failures in the design phase. The whole system rather than separate components needs to be treated in a physics of failure approach.

New materials

The drive towards elimination of hazardous substances from polymers, combined with miniaturisation and higher processing temperatures for lead-free soldering are significantly changing the types and properties of available materials in electronics assembly.

This rapid and constant modification of material formulation gives concerns about reliability and safety impacts, particularly in the ADHP industries.

There is a specific and significant reliability issue associated with the trend towards new 'green' epoxy moulding compounds because they have a lower CTE and this increases stress on solder joints. In extreme cases component leads have been sheared. The impact of this effect on electronics reliability is bigger than the introduction of lead-free soldering.

In general there is a perception that quality of current package mould materials can be an issue in relation to moisture absorbance, causing cracks and delamination during the reflow process, and new replacement materials or technologies would be desirable. However, such 'popcorning' effects are a known and manageable issue for the industry and do not drive any specific materials developments in relation to reflow resistance.

The defence sector is increasingly finding a difficulty with using commercial packaging due to a design divergence in the assumed life needed. Consumer packaging solutions need to be upgraded to high reliability applications.

The most dynamic changes are occurring in the materials and design of PCBs as they adapt to meet the needs of miniaturisation, better thermal management, increased speed and performance. New materials such as Halogen-free FR4 are challenged CTE mismatch issues causing pad cratering, for example. There is a continued need for ultra-low loss materials to be used in high speed PCBs.

New techniques for conformal coating are also needed, as are new underfill processes.

Optimisation of flux technologies will continue to be important.

At the same time new types of electronics systems such as IoT, renewables, LED and wearables will require integration with a significant number of new material types, including those yet to be developed. Entirely new reliability aspects can be expected, perhaps even contradicting the experience of multiple decades.

These trends are already leading to development of new and sometimes customised interconnection solutions, including new finishes. Soldering technology is rapidly diversifying to adapt and in niche high-end markets will become just one of several available joining technologies in the future. Solderless technologies will include conductive adhesives, low temperature sintering, press fit, copper-to-copper, embedded components and printed electronics.

In the longer term we need to expect even more radical trends for new materials. The PCB industry is already thinking beyond the basic FR4-type PCB concept into new 3D printed solutions that could be a paradigm change for the electronics industry over the next decade.

New solders

The proliferation of new lead-free solders is a major cause for concern as electronics assemblers struggle to adapt processes and testing to what seems to be a moving target. Solder producers on the other hand have needed to make significant investments in R&D to develop the new products and keep pace with changing needs. The net cost to the industry in identifying and qualifying suitable alloys is huge.

This is especially true for those in the high reliability ADHP industry contemplating lead-free conversion who feel they 'cannot cope with such rapid changes', reinforcing their view that even after many years of work with lead-free solders they still do not have sufficient information or confidence to change.

The initial introduction of SAC3/405 products was quickly followed by variants with proprietary microalloying elements, then by a second generation of similar low-silver products and now a complementary third generation of low and high temperature solders. Zero-silver SN100C has consistently been available. Development of new lead-free solder formulations in China has been extensive, including much government sponsored R&D. However there there is sometimes a lack of clarity on composition, difficulties on patent issues and evidence of some counterfeiting.

To some extent this is a process of 'Darwinian evolution' and already there is some convergence apparent around basic underlying formulations.

Solder producers have needed to work to establish a proprietary or patented position in a highly competitive market and keenly advocate their own solutions, often leaving users unclear of the relative benefits of different solutions in different applications. Industry associations such as IPC and iNEMI have needed to work together to develop guidelines and standards for comparative testing.

Despite a significant amount of work globally, there is still a perception that newer 'alternative' low silver lead-free alloys can't clearly demonstrate better long-term reliability than SAC305 in all applications. However, SAC305 is also not a universal solution and low silver solders found early use particularly in applications where better drop-shock reliability was needed and continue to do so.

Latest trends focus on temperature issues and the creation of a wide variety of new formulations that can be processed low temperatures (150-180^{o}C) and at high temperatures (>250^{o}C). In general bismuth is being used more - as tin-bismuth for low temperature and bismuth-silver for high temperature for example. Indeed, the new concept is of 'smart solders' based on mixtures of solder with differing thermal properties that can be tailored to meet specific requirements of melting, conductivity and expansion.

Low temperature solders are being used to eliminate wave soldering by substituting a two-stage reflow process. There is however some concern that they could soften or remelt under conventional assembly processes if present inadvertently. Poor reliability or lack of mechanical robustness could be other limitations.

There remains a need for new low temperature alloys that can match the reliability of tin-lead or SAC305 solders. A lot of adhesives are used for low temperature assemblies such as IoT products, but low temperature solders could be a cheaper option.

There is also still a gap for lead-free solder alternatives that have suitable properties for use at cryogenic temperatures.

High temperature lead-free solutions do exist to meet a wide variety of use environments but a necessary replacement for high-lead products use in die attach and other specialist component applications remains elusive. Transient liquid bonding, silver sintering technologies and conductive adhesives are all being explored. A recent report for the European Commission in the context of the ELV Directive has summarised available technologies and recognised that there is not yet a suitable a solution for the automotive industry[6].

New high thermal reliability solders, such as the Innolot technology, are needed with > 3000 thermal cycle performance. These multi-element products have better thermal and mechanical properties than standard SAC305 and are becoming increasingly adopted by the automotive industry particularly, although there is still a general lack of knowledge about their reliability and their effects on components. There is increasing use of solid-state devices (SSDs) and some also require such high reliability solders. High power applications and power modules are relevant markets too.

At the same time, in response to the challenges of miniaturisation, solder producers are pushing towards finer solder powder grades – Type 5 and 6 typically. Production and use of ultrafine solder powders (<2 micron) is already envisaged. Some Chinese solder producers are claiming to have produced Type 8 powders, though not at a commercial level. These are much more expensive to make – sieving and grinding takes more time, oxidation can strongly affect shelf life and yields are low. Incorporation into solder paste is also more challenging. Solutions to stabilise solder powder surfaces are being developed in the context

[6] Oeko-Institut, Fraunhofer Institut IZM , "7th Adaptation to Scientific and Technical Progress of Exemptions 8(e), 8(f), 8(g), 8(h), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV)," 5th Nov 2014. [Online]. Available: http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/20141105_ELV-Exemptions_Final_20141121.pdf. [Accessed 21st Nov 2014]

of room temperature storage for solder pastes and similar chemistries will also facilitate the necessary size reduction.

There is also a need for ultra-micro solder balls (<80 um) for wafer bumping.

In general rapid diversification and increased customisation in soldering will challenge solder producers to increase investment in R&D and new product development to remain competitive in the future. However solder producers may have to be more confident that any patent protection can be respected and enforced. The days of a single simple tin-lead solder product are long gone.

New soldering processes

As electronics assemblies become more complex, customised and mass produced there will be a need for faster, more customisable and more specialised soldering processes.

There will be more automation in assembly especially for high end products such as smart phones. More robotics will be used, for example in solder jetting, selective or laser soldering.

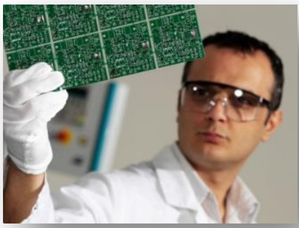
To meet such demand lead-free solder technologies will be needed that can deliver reliable and robust joints under such conditions. In one current example this means less than 0.05% solder balls on application with minimum flux splatter at faster speeds, higher capacity outputs and lower maintenance.

For high value batch processing such as in small specialised or military production, vacuum soldering will be increasingly beneficial as it gives greater control and decreases voiding. Low activation fluxes can be used, eliminating the need for cleaning of flux residues.

Automatic Optical Inspection (AOI) of Through Hole (THT) joints is particularly challenging, although it can be achieved, even in combination with SMT in-line AOI.

The imminent challenge may be to integrate soldering technology with 3D printing processes. The relatively low melting point of solders and the existing use of solder pastes and of solder wire fed selective soldering suggest that it should be more than possible but clearly much work will be needed once this opportunity begins to be taken seriously.

Technology Performance



There is a continual push for improved product performance and a key part of this is increasing knowledge of reliability in a range of topic areas, such as solder joints, tin whiskers, component counterfeits, board cleaning and finishes.

Better understanding of reliability

Along with the increased complexity of electronics design and the rapid diversification of new materials and new solders it is clear that a better understanding of the reliability of solder joints is critical to maintaining confidence in future electronics systems. Electronics are intrinsic not only to modern lifestyles but also to safety, communications, transport, manufacturing and medical care.

However, the science of electronics joint reliability is racing to keep up with fundamental changes in design and materials and now has to also account for the realisation that it is the holistic system that must be accounted for and not just the solder joint itself.

Despite many years of detailed study there are still concerns that there is a lack of understanding of the performance and science related to lead-free solder to long life and high reliability applications in particular. Managing the reliability risk for high-density and applications operating under harsh environments will need to be much better and long term reliability of lead-free solder joints needs to be improved. There are reliability issues with 'most advanced IC nodes', although these are not related to solder.

New models need to be established, based on 'proven science'. There is a concern that when using lead-free components there is an 'inability to predict' the ultimate life of a delivered product, with an expressed view that 'items marketed now cannot be expected to last longer than ten years'.

Increase in density and smaller less compliant solder joints increase reliability risks, making it difficult to maintain existing reliability levels in HDI PCBs and military applications particularly.

Fundamental studies will focus on topics such as controlling the technology of grain orientation in lead-free solder during ageing recrystallisations to give a better understanding of long life reliability in automotive applications for example.

Electromigration and thermal migration in high power and high density electronics also needs more work as electrical current needs to pass through smaller solder joints. The development of relatively thick intermetallic layers in small solder joints will become a concern. Resistance to dissolution in substrates will be increasingly important in relation to Electrochemical Conductive Anodic Filament (CAF) failures.

Reducing component lead pitch and intermixing high pin count components with low pin count will create thermal imbalance in assembly profiles, which in turn influences board reliability. Increased warping of area array packages leads to additional component interconnect problems like HIP (Head in Pillow) and HOP (Head on Pillow). Such lead joint reliability issues are expected to persist in spite of technical advances. EMS and board designers will find it in increasingly difficult to pinpoint reliability issues.

The issue of tin whiskers with lead-free plated components is particularly mentioned by several from the ADHP industry, based on historical experience in this sector. Some lead-free components are re-terminated to tin-lead by specialised companies, but this includes a hot-dipping step for components which can be a reliability concern, especially those subjected to harsh environment cycles. A better understanding of failure in tin-finished components is needed. There is a trend to reduce the maximum acceptable size of tin whiskers on components from 40µm towards 30 µm and beyond that 25µm.

Rework and repair also particularly important to the ADHP industry and there is a question about what impact introduction of lead-free soldering will have in relation to issues such as alloy identification and compatibility.

New markets also bring new challenges. For example industrial controls for renewable energy infrastructure grade products should be as reliable as possible, but there is the perception that risks of tin whiskers and vibration failures for lead-free solders in such applications has not been fully assessed.

There will also need to be a continual updating of knowledge and databases related to lead-free solder joint failures, including for example the occurrence of 'cold' solder spots.

Better inspection criteria for bottom side termination are needed, for example for voiding, particularly on ground pads.

There is generally a 'poor competence' in reliability assurance in the electronics industry, including the high reliability sectors and there is a poor understanding of physics-of-failure.

Assembly testing and especially reliability test regimes will need constant revision. There needs to be a clear differentiation between pre-conditioning reliability requirements (Moisture Levels (MSL) 3,2,1) from normal reliability requirements such as thermal cycling thermal shock, temperature humidity storage etc. Some of the standards rely on obsolete methodology - for example MIL-HDBK-217 type failure probability assessment uses obsolete historical data.

Qualification of new component types such as PoP will also need continuous development.

The issue of component counterfeits is still a key quality concern potentially impacting reliability of electronics.

Better cleaning

Changing electronics designs will also bring increased issues and concerns over effective cleaning. There is an increasing demand on board cleanliness and reduction of organic fluxes. No clean technology can have limitations. At the same time there may be a restriction on cleaning compounds under REACH legislation.

Specifically, for example, there is a trend towards open architecture parts, such as Xilinx BGA's, with open cavities where commercial no-clean processing is assumed. However military assembly still requires cleaning even with no-clean assembly processes.

Use of increased multi-step lamination and embedding processes in PCB manufacturing may require a better knowledge of the effects of cleaning or not cleaning process residues.

Not all manufacturers provide clear data or warnings about compatibility of components with standard reflow and cleaning processes.

Overall, a more definitive industry consensus is required on the evaluation and measurement of 'board cleanliness' with respect to organic fluxes and other residues.

Better finishes

Increasingly denser boards are also challenging lead-free finishes, affecting finish type and quality with no clear preferred finish.

Finishes are a particular concern to the ADHP industry in relation to the impact that lead-free soldering will have, bearing in mind Design/Airworthy Authorities for avionic equipment have a reluctance to use pure tin.

GEIA-STD-0006A – the standard for hot dipping used to refinish components to tin-lead – is under revision and rollout will impact the industry. Changes to robotic hot solder dipping will also be important.

It has been commented that tin plating on commercial parts is poor and getting worse.

Solderability storage for over two years will be an increasingly challenging requirement.

Improved conformal coating techniques will mitigate reliability risks, especially in harsh environments.

Specialist manufacturers have specific issues over introduction of new types of coating that, for example, are not up to food grade standards, or that can impact technical performance of intermodulating filters.

Survey participants

A.A. Training Consulting & Trade Ltd
Aamir Metal
Aero Stanrew Ltd
Aeroflex
Airbus group
Alent Brasil Soldas Ltda
Altera Corporation
API Technology
Artesyn Embedded Technologies
Aurubis AG
Avago Technologies
AWS Electronics
Axiom MAnufacturing Services Ltd.
Axis Electronics Ltd
BAE systems
Boeing
Bosch Car Multimedia Portugal
Brainboxes Ltd
CEAM ROM SRL
Cisco International
Clement Clarke Communications/Holdings
Cobar Europe BV
Cognition AM Ltd
Coining, Inc
Controls and Data Services
Curtiss-Wright
Diehl Aerospace
DKL Metals Limited
Doble Engineering
Dow Electronic Materials
E&G Technology Partners
Elbit
Ericsson AB
ERSA GmbH
FCI
Fenix Metals
Fraunhofer CSP
Fraunhofer IZM/Technical University Berlin
GE Aviation Systems
GE Druck
GE Sensing
Grand Tellumat Manufacturing
H.T.O. Inc.
Heraeus
HITEN, University of Oxford
Honortone Ltd
Huawei
Hytek
Imec
Intel Corporation
Ipeco Electronics
Jaltek Systems
Jarvik Heart employee
Kaelus
Keihin Carolina System Technology, LLC
Kentech Instruments Ltd.
Kester
Kostal Irl GmbH
LCL Electronics
LFSMD
Lockheed Martin UK Integrated Systems
MAN Diesel & Turbo
MBO (UK) LTD
Merlin Circuit Technology Ltd
Microsolder Kft.
Mirion Technologies (IST Canada) Inc
MK Electron Co. Ltd
MSI
Nihon Superior
NSK Co.
Nuance Document Imaging ULC
Olympus KeyMed
PandA Europe
PC Precision Engineering
Persang Alloy Industries Pvt.Ltd
Philips
Pi Innovo
Plextek
PT Solder Indonesia
PT. Belitung Industri Sejahtera
Renewable NRG Systems
Rolls-Royce Plc
Rolls-Royce Submarines
RS Components
S.I.T.Controls
Schrader Electronics Ltd
Selex ES
Shu-Te University
SIMTech
SINTEF
Stompnorth Ltd.
Swerea IVF
Tamura Kaken UK Ltd
Tejas Networks Ltd
Terma A/S
Thales
TRW Automotive
Université de Lorraine
University of Minho
Wallac Oy
ZTE Corporation