BEYOND ROHS: iNEMI'S ACTIVITIES TO STRENGTHEN THE ELECTRONICS MANUFACTURING SUPPLY CHAIN

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Abstract: iNEMI's 2004 Environmentally Conscious Electronics Roadmap [1] emphasized the concept of 'sustainability,' the impact of European legislation on the entire supply chain, and the R&D needs to support environmentally conscious design in the electronics industry. Specific findings/needs identified by the roadmap included:

- Development and implementation of appropriate scientific methodologies to assess true environmental impacts of materials and potential trade-offs of alternatives.
- Development of cost-effective, energy-efficient power supplies.
- Development of a meaningful, straightforward definition of sustainability that is relevant to the electronics industry and its supply chain, can be applied quantitatively at the business level, can be easily communicated to stakeholders, can be used to set targets, and that encourages an integrated lifecycle sustainability strategy.

This article discusses preliminary conclusions from the 2007 iNEMI Roadmap. It also discusses the work that remains to be done over the next years to reduce the ongoing costs of maintaining RoHS compliance, address additional legislation and changing regulations around the world, and complete and optimize the conversion from eutectic solder. We also focus on the future: What's ahead, and the alternative directions that industry could take. The thrust of our argument is that industry should take a proactive approach, work with stakeholders, and direct our activities where there is technical/ecological evidence we could and should be doing a better job to protect the environment. We should involve stakeholders in the process of evaluating alternative technologies to determine trade-offs between product functionality, environmental impact, reliability, safety, and cost. We will give an example of the approach we recommend for working with stakeholders (evaluation of alternatives to brominated flame retardants) and discuss areas we believe warrant industry's attention.

1. INTRODUCTION

The RoHS Directive went into effect in the European Union (EU) in July, and the big question was, "Are we ready?" Since the directive was passed in January of 2003, the electronics industry has been working feverishly to prepare for its requirements, with a particular focus on the transition to Pb-free processing (undoubtedly the most challenging aspect of the legislation). Industry, for the most part was ready, but much work remains to be done over the next years to reduce the ongoing costs of maintaining RoHS compliance, to address additional legislation and changing regulations around the world, and to complete and optimize the conversion from eutectic solder.

2. CURRENT SITUTATION

2.1. Industry readiness

In general larger companies were well-prepared to comply with RoHS, but many small and mid-sized companies are lagging behind. This viewpoint is borne out by research conducted by *Electronics Supply & Manufacturing* (*ESM*) [2] and Design Chain Associates in December 2005. Their survey of 162 OEMs and EMS providers found disparity in preparedness between large and small companies.

While 80 percent of responding companies with sales exceeding $1 billion said they expect to comply with RoHS by July 1, only 47 percent of companies with sales under $100 million expect to comply. Among midtier companies (sales between $100 and $1 billion), 55 percent said they expect to be in compliance by the deadline.

A benchmarking study by Technology Forecasters Inc. conducted for one of TFI's *Quarterly Forum for Electronics Manufacturing Outsourcing and Supply Chain* [3] members provides more in-depth discussion of RoHS compliance issues. This study, conducted in January and February of 2006, included interviews with 11 telecommunications OEMs and five of their suppliers (EMS providers, component suppliers and solutions vendors). Nine of 11 OEMs planned to take the Pb-free exemption for networking/ telecommunications products and four planned to take the spare parts exemption.

The decision to take the allowed Pb exemption — by the companies surveyed and others that manufacture high-reliability products — has led to a dual technology and supply chain structure, which poses additional challenges for industry (*see discussion below*). The U.S. military has recently recognized that, in spite of being exempt from RoHS, they are being impacted because of the difficulty in purchasing Pb-bearing components.

2.2. Reducing the ongoing costs of RoHS compliance

The TFI benchmarking study showed that nearly all companies surveyed plan to perform due diligence in declaring their products compliant and said they intend to take the same compliance approach for China RoHS. Most of the OEMs surveyed said they are using third-party software to track and report materials contents, while a few have developed and implemented proprietary tools.

The entire electronics supply chain is concerned about being able to establish the information necessary to demonstrate compliance in a cost effective manner. The iNEMI Materials Composition Data Exchange Project and the IPC 2-18 Supplier Declaration Subcommittee developed the IPC-1752 standard, which allows companies to utilize a consistent format both for collection of data as well as its distribution. The associated XML schema and standard forms allow for the automation and direct integration of this information into key internal systems, greatly reducing the manual effort required in managing compliance. OEMs and EMS firms are implementing this standard using third-party software. This initial standard is but the first step in working to reduce the financial impact of RoHS on the industry.

2.3. RoHS Exemptions and Dual Supply Chain

The past two years were extremely active from a legislative viewpoint in the EU. All 25 member states have now implemented the RoHS Directive through national legislation, and several member states have detailed regulations and guidance in place. Maximum concentration values for the substances controlled by RoHS were established in August 2005 (up to 0.1% by weight in homogeneous materials for lead, mercury, hexavalent chromium, PBB and PBDE and up to 0.01% by weight in homogenous materials for cadmium).

Exemptions have been a critical area of focus. The RoHS Directive lists several product and application exemptions, and several more are currently under review. The EC issued decisions regarding additional exemptions on October 13 and October 21, 2005, and on February 26 and April 21, 2006. Sixty additional exemptions have been proposed through "stakeholder consultations," and the majority of these are still under consideration. Independent consultants are reviewing the proposed exemptions and their recommendations will be documented in a final report. Among the exemptions being considered are: 1) the use of lead in tin whisker resistant coating for fine pitch applications; 2) lead in connectors, flexible printed circuits and flexible flat cables; and 3) use of the six restricted substances in electrical and electronic equipment (EEE) used in the aeronautics and aerospace sectors that require high safety standards.

The RoHS Pb exemptions allowed for certain high-reliability products (military applications, control circuits, servers and telecommunications, to name a few) have created a dual supply chain. As a result, some SnPb eutectic manufacturing will co-exist with Pb-free manufacturing for the near future. This duality significantly increases costs and complexity throughout the supply chain, requiring companies to create and maintain duplicate component part line items, duplicate manufacturing processes, duplicate suppliers, etc. This duality also increases the risk of non-compliance due to the potential of mixing, and it complicates industry's ability to meet quality and reliability requirements.

Those that took "exemption" to maintain reliability are discovering that they may have to take greater risks because of a lack of components and or the need to use Pb-free components with eutectic solder – a configuration for which they have not evaluated the reliability.

2.4. Evolving From a Dual Technology to a Pb-Free Technology

The transition to Pb-free manufacturing is really just beginning. The industry has nearly 50 years of experience with SnPb-based eutectic electronics manufacturing and, even with a 5X learning curve, manufacturers will be coming up the Pb-free learning curve for another decade to get to the same knowledge level they currently have with PbSn eutectic processes.

From an electronics manufacturing perspective, the industry has generally converged on a few key parameters to comply with RoHS:

1. **Solder alloy** is typically SnAgCu (SAC), in varying compositions, such as SAC 305 (3% Ag, 0.5%Cu) or SAC405 (4% Ag, 0.5%Cu).
2. **Surface finishes** are typically one of three: Organic Solderability Preservative (OSP), Immersion Silver (ImAg) or Electroless Nickel Immersion Gold (ENIG).
3. **Solder reflow temperatures** are in the range of 230-250ºC.

Industry is still actively working to solve a number of issues related to the conversion. iNEMI, for example, has eight ongoing projects that are investigating various issues related to Pb-free processes but will not be completed until 2007:

- Pb-Free BGAs in SnPb Assemblies
- Pb-Free Defects Per Million Opportunities
- Pb-Free Nano-Solder
- Pb-Free Rework Optimization
- Pb-Free Wave Soldering
- Substrate Surface Finishes for Pb-Free Assembly
- Tin Whisker Accelerated Test
- Tin Whisker Modeling

Intel Corporation recently held a Pb-free symposium, sponsored by IPC. Based on their early implementation of Pb-free (RoHS-compliant) components, modules and circuit boards, Intel found that the electronics industry has not yet optimized Pb-free manufacturing parameters to meet the best cost, quality/reliability and delivery requirements for the entire spectrum of electronic products. The primary purpose of the symposium was for Intel to share the experiences, knowledge and lessons learned during their conversion to Pb-free manufacturing, and to encourage other manufacturers to do the same.

During this meeting, the 170 attendees, representing 76 different companies across the entire supply chain, openly exchanged technical information and concerns about lessons learned and challenges to be faced with Pb-free manufacturing. Break-out sessions provided additional discussions in six key areas:

1. Ball grid array solder alloy optimization for drop shock performance
2. Solder flux optimization for ball grid arrays
3. OSP metrologies and standards
4. Laminate crack/pad crater metrologies and standards
5. Planar micro-voids root cause, metrologies and standards
6. Common reliability/shock test methods and metrology specification for mechanical performance assessment

Each session closed with a call-to-action to the electronics manufacturing industry to work together on the solutions by engaging in, or forming new working groups as appropriate within industry bodies such as IPC, iNEMI, JEDEC, etc. These efforts have now begun, with a focus on defining clear problem statements and working to understand which industry body is the best fit for the work to be done. There is much work to do in each of these areas, and plenty of opportunities to contribute.

3. NEXT STEPS

This section focuses on the future: What's ahead, and what are the alternative directions that industry could take. The thrust of our argument is that industry should take a proactive approach, work with stakeholders, and direct our activities where there is technical/ecological evidence we could and should be doing a better job to protect the environment. We should involve stakeholders in the process of evaluating alternative technologies to determine trade-offs between product functionality, environmental impact, reliability, safety and cost. We will give an example of the model we recommend for working with stakeholders (evaluation of alternatives to brominated flame retardants) and discuss areas we believe warrant industry's attention.

iNEMI's 2004 Environmentally Conscious Electronics roadmap emphasized the concept of "sustainability," the impact of European legislation on the entire supply chain, and the R&D needs to support environmentally conscious design in the electronics industry. This approach reflects a more forward-looking posture for the industry and relates to developing a sound scientific basis for environmental considerations. Specific findings/ needs identified by the roadmap included:

- Development and implementation of appropriate scientific methodologies to assess true environmental impacts of materials and potential trade-offs of alternatives.
- Development of cost-effective, energy-efficient power supplies.
- Development of a common, meaningful, straightforward definition of sustainability that is relevant to the electronics industry and its supply chain, can be applied quantitatively at the business level, can be easily communicated to stakeholders, can be used to set targets, and that encourages an integrated lifecycle sustainability strategy.

3.1. The Worldwide Legislative Landscape

As industry adapts to the long anticipated, well-advertised challenges of European WEEE and RoHS laws, an unprecedented expansion of legislative initiatives is spreading across the global landscape. To some degree, this "next wave" of product-based environmental regulations represents the globalization of WEEE/RoHS requirements; however, it also introduces additional labeling, eco-design, energy efficiency and certification mandates. Legislation such as EuP (Energy using Products Directive), REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) and the updated Batteries Directive will keep a certain focus on Europe; however, going forward, the drivers may come from any region of the world.

Table 1 presents an overview of four primary categories of product-based legislation across the globe. Although not inclusive of all legislative activity, there is a clear trend of increasing regulatory complexity — without much time for industry to catch its breath from WEEE and RoHS. The state/provincial-level legislative activities in the US and Canada are particularly problematic due to the diversity of regulatory approaches. Such diversity runs counter to the theme of harmonization, which industry must promote to allow efficient and effective adoption of worldwide requirements. When coupled with ongoing activities in China, Japan, Australia, Mexico and South America, industry may be put in a position of allocating greater-than-anticipated resources to deal with the inherent inefficiency of non-harmonized requirements. Broader participation in trade associations and standards bodies can help promote stakeholder approaches and improve worldwide harmonization of product-based requirements.

Table 1: Key Legislation On the Horizon

Region	Substance Bans	Recycling	Eco-Design	Energy Efficiency
Europe	RoHS REACH	WEEE	EuP	EuP Codes of Conduct (Voluntary)
North America	35 states 5 provinces	35 states 5 provinces	Referenced in some state legislation	Power supplies in CA, other states pending
China	Management methods (China RoHS)	China WEEE	Management methods	Labeling
Japan	RoHS Labeling	Japan WEEE	Voluntary Standards Activity	METI Standards/ labeling

The following sections discuss how industry might proactively address substance concerns, energy usage and design restrictions

3.2. Halogen-free Case Study: Proactive evaluation of alternative technologies

In the introduction we proposed a proactive model involving stakeholders in the process of evaluating alternative technologies to determine trade-offs between product functionality, environmental impact, reliability, safety and cost. Two linked projects, a technical evaluation project organized by iNEMI, and an environmental and human health assessment project organized by the US Environmental Protection Agency (EPA), have been created to evaluate alternatives to the brominated flame retardants currently used in epoxy resin circuit boards. The RoHS Directive prohibits the use of polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) in nonexempt electronic equipment (note an exemption is allowed for Deca-BDE in polymeric applications). These compounds are typically used as flame-retardants and some have been shown to have cumulative exposure potential in humans and adverse health effects on laboratory rodents. Although PBBs and PBDEs are not used in circuit board materials, stakeholders are beginning to urge the electronics industry to take a precautionary stance on the use of other non-regulated halogenated organic substances, such as the use of brominated epoxies for circuit board applications.

Currently, the UL 94 V0 fire safety standard is achieved in epoxy resin circuit boards by covalently reacting TBBPA (Tetrabromo bisphenol A) with the epoxy resin backbone. After the reaction TBBPA ceases to exist as a chemical entity. Approximately 96% of printed wiring boards utilize TBBPA. One of the reasons cited for using alternative materials is to eliminate the potential for dioxin/furan formation during certain end-of-life scenarios for FR-4 boards. However, the environmental and human health profile of a material is not solely defined by impacts at the end of life. Environmental impacts occur throughout the lifecycle of a material, from development and manufacture, through product use and finally at end of life of the material or product.

*3.2.1. iNEMI Halogen-Free Project***.**

iNEMI is organizing a technical project on halogen-free electronics, focusing on printed wiring boards (PWBs). The thrust of the project is to characterize and encourage the supply base for alternate materials. The project will evaluate key electrical, mechanical and reliability requirements of PWBs for various market segments. The first phase of the project will identify the market segment requirements, identify candidate materials and key performance characteristics, and design test vehicles and test methodologies. The second phase will construct test vehicles and perform mechanical and reliability tests on the candidate materials. The third phase will evaluate the test results and compare them with the requirements. Technical risks will be identified.

3.2.2. US EPA Assessment of Alternative Flame Retardants.

The electronics industry is engaging in a multi-stakeholder partnership with EPA's Design for the Environment Program to better understand the full range of options for achieving the UL 94 V0 fire safety standard for printed circuit boards. This multi-stakeholder partnership will develop information to improve everyone's understanding of the environmental and human health impacts of new and current materials that meet the fire safety requirements for circuit boards. This information will be presented to allow industry to consider environmental and human health impacts along with cost and performance of circuit boards (as identified in the iNEMI project) as they review alternative materials and technologies. The participation of all relevant stakeholders is critical to understanding flame retardant formulations and developing scientifically sound information. The partnership will incorporate lifecycle thinking into the project as it explores the hazards associated with flame retardants and potential exposures throughout the lifecycle of flame retardants as used in electronic FR-4 printed circuit boards. As appropriate, the scope will include aspects of the lifecycle where public and occupational exposures could occur. For example, consideration of exposures from incineration or burning at the end of life will be included, as will exposures from manufacturing and use. The partnership will focus the study on the candidate materials selected by the iNEMI project. The outcome of the project will be a report that outlines the environmental and human health hazards associated with flame retardants in FR-4 boards.

3.2.3. Lessons learned to date.

The iNEMI and EPA projects have revealed that NGOs, regulators and concerned citizens may not have a full understanding of the complex trade-offs the electronics industry faces when it makes major changes in materials and manufacturing processes. The process of defining the two projects has helped raise stakeholders' awareness of the many levels of the supply chain that must be engaged to evaluate and introduce alternative technologies. It has also made them aware that there are technical risks as well as environmental, health and safety risks that must be balanced.

3.3 Systems Approach to Environmental Concerns: Energy and Design

It is important for the electronics industry to take a systems approach to design for the environment (DfE) and to engage stakeholders in the process. Regulations frequently do not take a systems approach but, rather, a tactical approach focusing on the current concern. An example is the reduction of energy usage, which is of concern to everyone. Often a significant fraction of energy usage is determined by the system architecture at the beginning of the design process. It is important for industry to show the gains we are achieving in reducing overall energy consumption at a systems level, even if local loads may increase where processing is concentrated. Industry needs to be proactive in making stakeholders aware of the energy savings that we are constantly achieving through new technology.

Design processes are unique to each firm and are often the key to their market success. Design is a creative process and needs broad input, not regulatory oversight. Many firms have integrated DfE criteria into their extensive design processes. Firms need to make stakeholders aware of their processes and seek input from environmental stakeholders in those processes.

4. CONCLUSION

For the past decade, industry worked to develop alternatives to eutectic solder in anticipation of legislative restrictions. While the impacted segments of industry have adapted to comply with these restrictions, much work remains to be done to optimize the process. In particular, we need to adopt harmonized models that allow efficient and effective integration of the worldwide regulatory and market access requirements evolving under the environmental banner.

The experience of this decade has demonstrated that legislators and other stakeholders were not fully aware of the potential for "unintended consequences" of regulations to cause significant and unproductive disruptions in the global supply chain. These effects can hinder progress toward the fundamental regulatory goals of reducing overall environmental impacts of electronic products. We are about to enter a new phase, where the full spectrum of impacted stakeholders must work together to proactively identify and resolve potential areas of environmental risk and develop rational risk reduction alternatives. Priorities must be defined and industry must proactively drive for harmonized regulatory standards to support two mutually beneficial outcomes: Protecting the global environment while promoting an efficient means for business to comply on a global basis.

5. REFERENCES

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[3] P.J. Gordon, "Environmental Product Improvements in the Communications Industry: Strategies and Progress," summary of a private client study, Technology Forecasters, Inc., February 2006.