The 2004 International Electronics Manufacturing Initiative (iNEMI) Technology Roadmaps

R. C. Pfahl, Jr., James McElroy, Sr.
International Electronics Manufacturing Initiative (iNEMI), 2214 Rock Hill Road, Suite 110m Herndon, VA 20170 USA

Abstract

The tenth anniversary edition of the biennial roadmap is the first edition under our new name: International Electronics Manufacturing Initiative (iNEMI). The nineteen technology roadmaps identify future research, development, and implementation needs to continue the growth of the world-wide electronics industry. During this roadmap cycle, we consciously targeted participation from key Asian and European firms/organizations in order to help insure that the technology projections truly represent a global view. With this roadmap we established an international collaborative agreement with the IEEE / CPMT (Institute of Electrical and Electronics Engineers / Components, Packaging and Manufacturing Technology), while continuing our strong linkages with other international roadmapping organizations - ITRS, IPC, IMAPS, INSIC, SCC, and OIDA- and with USDC. The 2004 iNEMI Roadmap consists of over 1200 pages, with more than 470 participants from over 220 companies, universities and associations from 11 countries. This paper highlights technology needs, paradigm shifts, strategic concerns, and key recommendations from the roadmap. Emphasis is placed on the advanced packaging, sensors, system in package, and organic and ceramic substrate roadmap chapters. This roadmap has increased the focus on forecasting potentially disruptive technology in the 2012-2015 time frame such as the use of nanotechnology to address the projected end of Moore's law and the scaling of CMOS devices. This roadmap balances the market needs against the future technology capabilities. The 2004 iNEMI Roadmap is a valuable snapshot of our industry in the third millennium. The challenge now shifts to leveraging these findings for the good of the electronics manufacturing supply chain. .

Introduction

The tenth anniversary edition of the biennial roadmap is the first edition under our new name: International Electronics Manufacturing Initiative (iNEMI). The nineteen individual technology roadmaps identify future research, development, and implementation needs to continue the growth of the world-wide electronics industry. Figure 1 Illustrates the nineteen roadmaps.

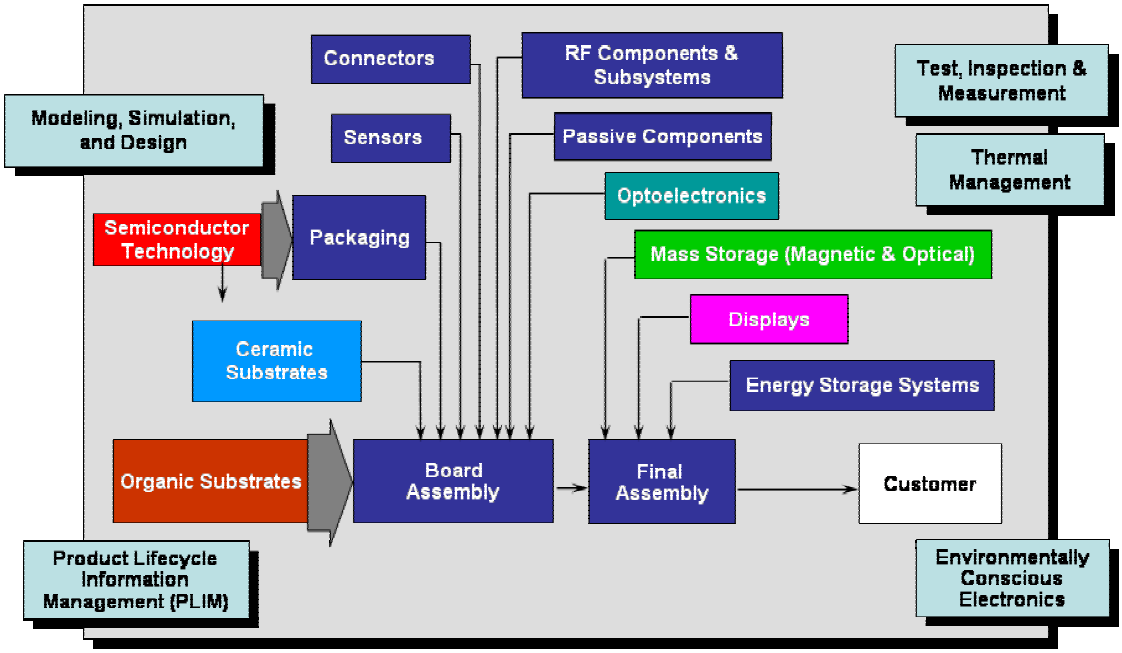

Figure 1. 2004 iNEMI Roadmaps

The roadmapping process benefits the entire global electronics supply chain. We believe this product will find increasing usefulness to industry, government, and academia to help set the future direction of electronics manufacturing.

The 2004 iNEMI Roadmap consists of over 1200 pages, with more than 470 participants from over 220 companies, universities and associations from 11 countries. During this roadmap cycle, we consciously targeted participation from key Asian and European firms/organizations in order to help insure that the technology projections truly represent a global view. With this roadmap we established an international collaborative agreement with the IEEE / CPMT (Institute of Electrical and Electronics Engineers / Components, Packaging and Manufacturing Technology), while continuing our strong linkages with other international roadmapping organizations - ITRS, IPC, IMAPS, INSIC, SCC, and OIDA- and with USDC as illustrated in Figure 2.

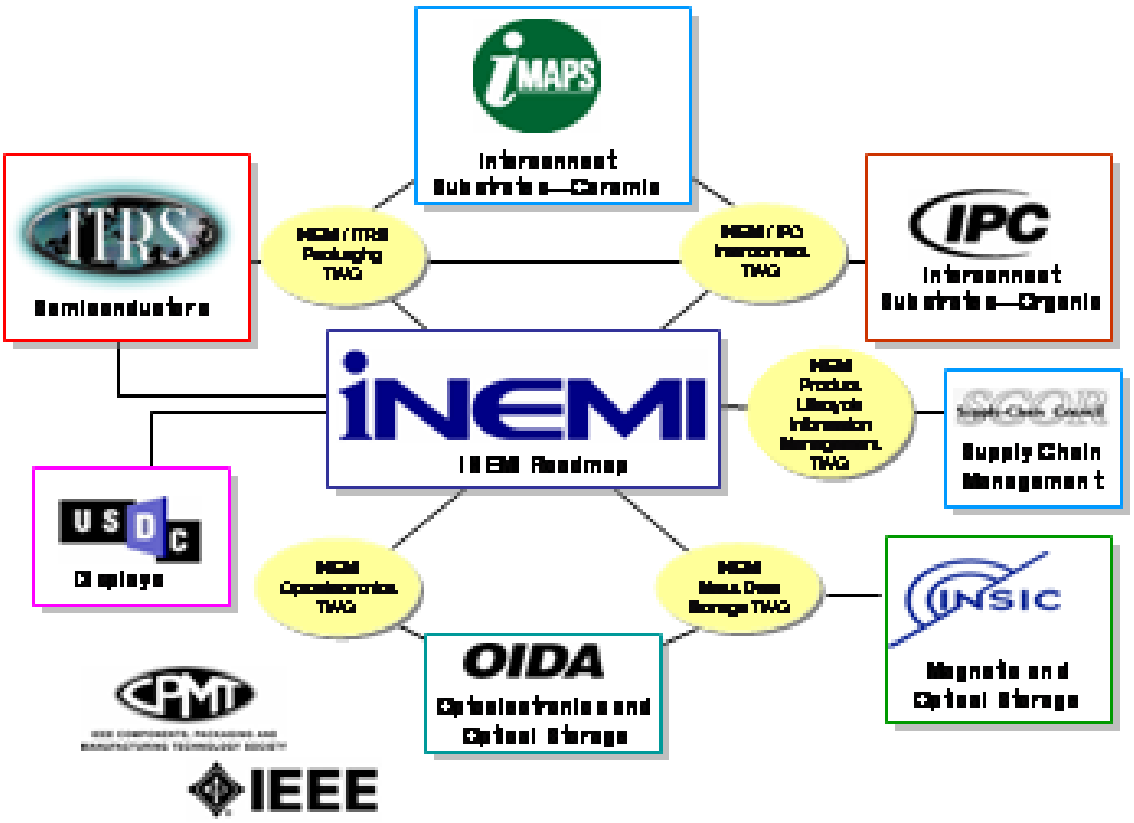

Figure 2. Roadmap Linkages

2004 iNEMI Roadmapping Process

The 2004 Roadmaps were developed by nineteen Technology Working Groups (TWGs), in response to inputs from representatives of OEMs in seven Product Emulator Groups. The nineteen TWGs can be classified into five categories:

Business Technologies – (Product Lifecycle Information Management (PLIM))

Design Technologies (Modeling, Simulation, and Design; Thermal Management; Environmentally Conscious Electronics);

Manufacturing Technologies (Board Assembly; Final Assembly, and Test, Inspection, and Measurement);

Component/Subsystem Technologies (Semiconductor Technology, Packaging, Interconnection Substrates – Organic and Ceramic, Passive and RF Components, Optoelectronics, Displays, Mass Data Storage, Energy Storage Systems, Sensors, and Connectors).

The following table defines the seven Product Emulators used in the 2004 iNEMI Roadmap.

	Characteristics
Portable / Consumer	High volume Consumer Products for which cost is the primary driver
System in a Package	Complete function provided in a package to system manufacturer
Office Systems / Large Business Systems	Products which seek maximum performance from a few thousand dollar cost limit to literally no cost limit
Network / Datacom / Telecom Products	Products that serve the networking, datacom and telecom markets and cover a wide range of cost and performance targets
Medical Products	Products which must operate within a high reliability environment
Automotive	Products which must operate in an automotive environment
Defense and Aerospace	Products which must operate in extreme environments

The 2004 iNEMI Roadmap activity accomplished the following:

- Globalized the Roadmapping Process. Individuals and firms from more than eleven countries from around the world participated in the process
- Strengthened the Product Emulators by creating Product Emulator Groups (PEGs) and creating a more comprehensive set of attributes to be tracked
- Introduced three new Product Emulators:
    - Medica1.
    - Network/Data/Telecom
    - System in Package (SiP)
- Expanded the emphasis on disruptive business and technical events.
- Utilized the JISSO Levels Nomenclature for the first time in any major international roadmap

Situation Analysis

Business

As the electronics industry matures, some product segments are entering the commodity phase of the life cycle. Accordingly, break-through technology may no longer be sufficient to insure business success. Customers are demanding the right solution at the right cost from winning enterprises. This drives a whole series of business behavior that is quite different from the past. The electronics industry is completing a major re-structuring, moving the center of manufacturing competence from the OEMs (Original Equipment Manufacturers) to the EMS (Electronics Manufacturing Services) providers and ODMs (Original Design Manufacturers).

- Business models across the electronics industry have changed leading to significant shifts in roles and responsibilities across the supply chain.
- There has been a dramatic movement of manufacturing and manufacturing support to China from North America, Europe, and other Asian countries: because of a low-cost, highly skilled workforce, and a massive market opportunity.
- Supply Chain Management (SCM) offers the potential to increase productivity.
- The ability for supply chains to support lead containing and lead-free bills-of-materials (BOMs) is providing significant challenges and increasing investments.
- The increasing scope of outsourced operations requires loosely coupled business processes spanning multiple companies.

Regulatory

Two European Union Directives, RoHS (Restriction on use of certain Hazardous Substances) and WEEE (Waste from Electrical and Electronic Equipment), which will govern the material content and end-of-life management of electronic products must be implemented by July 1, 2006 and August 13, 2005 respectively. Legislation impacting the design and recycling of electronic products is being enacted throughout the world including China.

- Environmental legislation in various product segments requires the electronics industry to share detailed material content data of their products and components.
- To meet regional legislative requirements, manufacturers must remove environmental "Materials of Concern," such as lead.
- The electronics industry is facing end-of-life or producer responsibility legislation.

Market

During the past year sales of electronics products has recovered. The boundaries between computers, communications and entertainment products are blurring. Large, flat panel displays are experiencing rapid growth. Wireless products particularly WiFi and Bluetooth are now widely used, and digital cameras are merging into cellular phones. Home and office functionality is being added to automotive products. RFID systems are being used for security and increased efficiency of commerce. The needs of the telecommunication and data communication infrastructure are converging. We expect further increases

in product functionality over the next four years. Data provided by Prismark predicts that:

- Worldwide production of computers and office equipment is expected to reach $379Bn in 2004, and grow at an average rate of 6.2% per year to reach $483Bn in 2008. This is the largest segment of the electronics industry, accounting for about 37% of overall production.
- Global production of netcom equipment is expected to be $180Bn in 2004—about 18% of the electronics industry. Driven primarily by Internet use, this segment is expected to increase at an average rate of 6.3% per year to reach $230Bn in 2008.
- Portable and consumer electronics production are expected to reach $183Bn in 2004, and increase at an average rate of 5.1% per year to reach $223Bn by 2008.
- Medical electronics equipment production is expected to be $39.5Bn in 2004, accounting for about 4% of the global electronics industry. This market is expected to continue to increase at an average rate of 4.9% per year through 2008.
- In 2004, 1.89Bn SiPs are expected to be assembled. By 2008, this number is expected to reach 3.25Bn, growing at an average rate of about 12% per year.

Technology

The end of traditional semiconductor scaling is generating significant reverberations in approaches and structures of computing systems. The first consequence is the gradual but certain reduction of emphasis on the frequency of microprocessor frequency metric, and the corresponding increase in importance of the system's throughput metric. This shift in the system's performance metric will generate an increased demand for higher bandwidth to and from the microprocessor. Another consequence of the expected demise of the traditional scaling of semiconductors is the increased need for improved cooling and operating junction temperature reduction due to large leakage currents and increase in chip power. At some point, circa 2010-2015, the limits of electrical transmission in high performance systems may be reached. Optical systems are likely to provide part of the solution, particularly if Optical ICs are developed.

- Growth in silicon device size is slowing.
- The rate of reduction in feature size has resumed a three-year cycle, its historical rate.
- SiP applications have become the technology driver for small components, packaging, assembly processes and for high density substrates.
- LCD and plasma displays are starting to encroach on the CRT market, while OLED (Organic LED) has the promise of providing thin, lightweight – even roll-up – display technology that could compete with LCDs.
- Application of MEMS technology is making new capabilities feasible in a number of old and new markets such as displays; servo control for mass data storage, optical and RF switches.
- A number of alternative approaches to today's established data storage technologies will develop over the next decade. These include magnetic random access memory (MRAM), probe-based, molecular, fluorescent multilayer optical, near-field optical and 3-D holographic storage components and systems.
- Li-ion and Li-ion polymer electrolyte batteries will become the dominant rechargeable energy sources across the entire portable electronics segment.
- System in Package (SiP) has emerged as the fastest growing packaging technology although still representing a relatively small percentage of the unit volume.

Highlighted Needs

Significant needs and trends in Design Technologies, Manufacturing Technologies, and Component/Subsystem Technologies have been identified in the 2004 iNEMI Roadmap efforts. They are already affecting electronics manufacturing and the way we do business.

Design Technologies

Design and simulation tools are the main roadblocks to more rapid introduction of new technologies in a number of rapidly developing areas:

- Mechanics and Reliability Modeling.
- Thermal and Thermo-fluid Simulation.
- Co-design of mechanical, thermal, and electrical performance of the entire chip, package, and associated heat removal structures.
- Simulation tools for Nano devices and materials.
- Improved design tools for emerging technologies like embedded passives and optoelectronic PCB's.
- Integrated design and simulation tools (circuit, EM, thermal, mechanical, manufacturing, etc.) for higher functionality in mixed-mode wireless chips and modules.

Manufacturing Technologies

With research and development (R&D) responsibility shifting from OEMs to the EMS companies, government, academia and industry consortia need to formulate new ways to adopt and develop emerging technologies (such as nanotechnology) into the manufacturing process. These new approaches will have to be consistent with viable business and funding models required to create new industrial infrastructures.

Component/Subsystem Technologies

- Implementation of advanced, non-classical CMOS device with enhanced drive current.
- Improved performance and reduced leakage in low power applications.
- Medium-power, low-loss, high-selectivity filters for Consumer and Portable products.
- Integrated passive component technology on silicon substrate to enable the RFCMOS MMIC realization.
- An effective Optical electronic circuit board (OECB) technology is needed to reduce, if not eliminate fiber handling cost and provide a "standard" assembly method that will develop higher volume and thus lower costs.
- Higher thermally conductive materials such as carbon nanotubes, carbon fiber, aluminum nitride, and even diamond to cool optical and electronic devices.
- Cost reduction for flat panel displays if CRTs are to be fully displaced.
- New technologies and materials that provide super resolution and low-noise operation at UV wavelengths will be required to drive the future of optical storage beyond the projections of the current roadmap.
- In-circuit test technologies that can be incorporated into the build process.
- Cost and performance models that help highlight the benefits of embedded passives.

.

Paradigm Shifts

All of the Technology Working Groups identified paradigm shifts that are taking place now and potential paradigm shifts that might occur in the future. This information is critical for infrastructure providers to identify where non-linear changes may occur in the future. These changes provide both opportunities and risks for individual firms.

The need for rapid introduction of complex, multifunctional new products to address the converging markets, has favored the development of functional, modular components or System in Package (SiP). This paradigm shift in the design approach increases the flexibility and shortens the product design cycle, and places the test burden on the producers of the modules. The SiP is changing the dynamics of the supply chain as predicted by the 2002 NEMI Roadmap.

Other paradigm shifts, identified in the 2004 iNEMI Roadmap include:

- Wireless applications have quickly grown to become an important driver for semiconductor products and technologies. Resulting in the development of highly integrated RFICs for Consumer and Portable products. (primarily driven by the Bluetooth and wireless LAN systems products).
- System in Package (SIP) architectures (based on both organic and ceramic materials) have been developed and are now in full production. This same architecture, with capability for buried cavities and channels, allows for MEMS device construction with a variety of new applications in Fuel Cells and Life Sciences (DNA/Blood testing).
- New Product Introduction (or NPI) is becoming increasingly structured.
- New IT and business models are giving rise to highly leveraged or virtual manufacturing enterprises. The Internet enables small, highly leveraged companies to compete in many markets, head to head with traditional, larger companies.
- Manufacturing organizations are producing smaller batches more frequently.
- Mixed-signal (combined analog and digital) device fabrication technology allows development of single-chip radio excluding RF power functions.
- Ceramic interconnect technology has transcended from a "black art" to a science based understanding of processing & characterization technology.

Emerging or potential paradigm shifts, identified in the 2004 iNEMI Roadmap include:

- Multichip modules will be replaced by integrated RFICs in many portable communication products.
- Digital representation of analog functions will move from 1 GHz to 5 GHz as silicon CMOS and BiCMOS performance increases.
- Organic LEDs are emerging as alternatives for LCDs allowing the potential for flexible displays and reel-to-reel processing.
- A transition from analog to digital sensor architectures for automotive applications.
- Nanotechnology has the potential to be a very disruptive technology during the period covered by this roadmap.
- Energy Storage Systems technologies that may present a new opportunity are fuel cells and high power batteries for hybrid electric vehicles.

Strategic Concerns

Given the flow of technology and manufacturing between countries (globalization), many of the key component industries are looking for alternative business strategies to maintain business leadership. Impacted component industries include Organic Interconnection Substrates, Optoelectronics, Displays, Mass Data Storage, Energy Storage Systems, and Electronic Connectors. Several of these industries are considering using technology

innovation, as the Mass Data Storage Industry has, to maintain business leadership. Other strategic concerns include:

- Finding innovative approaches to implementing Enterprise IT and Supply Chain Management that address return on investment and organizational change.
- EMS companies are being asked to provide R&D leadership while keeping their overhead functions low. This desire may not be strategically viable.
- The disaggregated supply chain is leading to non-optimized packaging solutions and delaying the introduction of technology.
- The present materials supplier base does not have adequate demand (at a high enough sales price) to drive many of the needed new materials developments.
- Rapid improvement in the productivity of design, test, and modeling software is becoming critical throughout the supply chain.
- The mechanisms for cooperation between industries and among researchers working in all advanced technologies must be strengthened. Cooperation between OEMs, EMS Firms, and component suppliers is needed to focus on the right technology and to find a way to deploy it in a timely manner.
- Disruptive technology offers opportunity for innovation. In order to ensure success, the supply chain must be willing to invest with a long-term perspective in mind.

Key Recommendations.

Standards Development

The need for standards development has been identified in a number of areas. Many participants felt that the lack of standards was significantly slowing the implementation of technology and growth of markets:

- EMSs, ODMs should require that their equipment suppliers support the new standards (IPC 254x) for shop floor communication.
- Develop standardized final assembly process definitions and metrics.
- Develop and adopt standards and guidelines for Ceramic Interconnection Substrates.
- Develop a broad agreement on the mechanism required to provide an open architecture for best in class test integration.

Design

The increasing OEM focus on time-to-market and the complexity of emerging technology will require significant development and investment in design tool infrastructure. The following areas need increased research and development:

- Mechanics and Reliability Modeling.
- Thermal and Thermo-fluid Simulation.
- Co-design of mechanical, thermal, and electrical performance of the entire chip, package, and associated heat removal structures.
- Simulation tools for Nano devices and materials.
- Improved design tools for emerging technologies like embedded passives and optoelectronic PWBs.
- Integrated design and simulation tools for RF modules and devices.

Manufacturing Technology

- Development of automated printing, dispensing, placement, and rework equipment capable of the pitch requirements for SiP package assembly at current process speeds.
- The ceramic substrate interconnection technology industry must make a conscious effort to adopt innovative technology to provide cost effective electronic system solutions.
- Development and deployment of surface micromachining technologies for sensor components, as well as LIGA (Lithografie, Galvanoformung, Abformung) technology.

Materials Development

- A combination of materials and fabrication research is needed to support the development of monolithically integrated optics and electronics that take advantage of the electronics infrastructure.
- Technology development is needed in areas such as ‘optical solders’ and board level wave-guides to enable more complex and higher density, board level products.
- Low cost, higher thermal conductivity, packaging materials, such as adhesives, thermal pastes, and thermal spreaders.
- Next generation of solder materials to replace the high cost silver containing alloys.
- New interconnect technologies deploying nano-materials to support decreased pitch and increased interconnect frequencies.
- High-performance laminates that are competitively priced.

Energy and the Environment

- Development and implementation of good scientific methodologies to assess true environmental impacts of materials and potential trade-offs of alternatives.
- Develop cost-effective, energy efficient power supplies.

- Develop a common, meaningful, straightforward definition of sustainability that is relevant to the electronic 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.

Technology Development

- The rapid market growth and technology advancement in RF subsystems is constrained by the pace of research and development of new designs, design tools, materials, and manufacturing processes for semiconductors, SiPs, RF components, and RF MEMS. Government, consortium, and academia need to focus funding to address these research and development needs.
- The development of new approaches to organic substrate fabrication which address needs for dramatic increases in density, reduced process variability, improved electrical performance, and radical reductions in cost.
- Government, consortia and academia need to focus research funding on final assembly manufacturing processes for the electronics industry.
- Advanced cooling technology such as high performance heat pipe, thermoelectric cooling technology, and direct liquid cooling technology need to be developed.
- Fuel cell systems, lithium-metal/SPE technology, and thin-film batteries have the potential of providing very high energy density and specific energy. These technologies are recommended for further development on an R&D level.
- Develop a strategy to create a new integrated opto-electronic systems interconnect infrastructure, based on industries evaluation of alternatives for their technical feasibility, reliability, manufacturability, and cost.

iNEMI Technical Projects

- EMS companies need to take the lead in electronics manufacturing technology development, utilizing pre-competitive consortia like iNEMI to leverage their R&D and technology deployment budgets. Continued cooperation with government and academia should also be adopted to help address the R&D gap.
- Establish an iNEMI SiP Technology Implementation Group (TIG) to develop a research and development plan for closing the SiP gaps identified in the roadmap.
- Establish an iNEMI Final Assembly TIG to develop a research and development plan for closing the gaps identified in the roadmap.
- An iNEMI project needs to be developed in the interconnect arena that explores dimensional stability of materials used in PWB manufacturing as related to fine pitch and microvia technology.
- A research project on new organic materials with improved properties for electronics packaging.

iNEMI Business Leadership Team

- Push for standardization in CAD libraries, both across companies using a common ECAD system, and across ECAD vendors.
- Organize an effort to document and communicate changing roles and responsibilities brought about by the restructuring of the industry. This effort would also identify gaps and issues with evolving business models/business practices.
- Hold a workshop to investigate the impact of the EU environmental directives on financials and the IT infrastructure.

Conclusion

This roadmap has increased the focus on forecasting potentially disruptive technology in the 2012-2015 time frame such as the use of nanotechnology to address the projected end of Moore's law and the scaling of CMOS devices. The credibility gained by previous roadmaps and their subsequent global use, have made the iNEMI roadmap self-fulfilling. This roadmap balances the market needs against the future technology capabilities. The 2004 iNEMI Roadmap is a valuable snapshot of our industry in the third millennium. The challenge now shifts to leveraging these findings for the good of the electronics manufacturing supply chain.