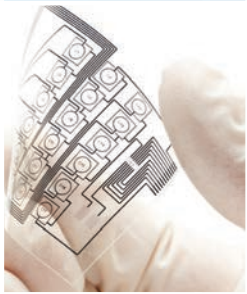
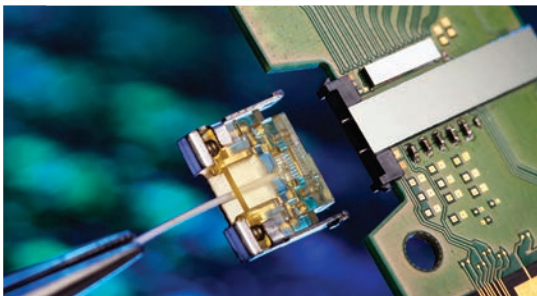
2015 Roadmap

iNEMI®

Advancing manufacturing technology





2015 iNEMI Roadmap

EXECUTIVE SUMMARY HIGHLIGHTS

The 2015 iNEMI Roadmap is full of valuable information and updates about the challenges and opportunities facing the electronics manufacturing industry over the next 10 years. It provides direction on what technologies are going to be required to meet the ever-evolving needs of the rapidly diversifying and growing applications for electronics.

iNEMI's roadmaps are dynamic tools, recognized for defining the "state of the art" in the electronics industry as well as identifying emerging and disruptive technologies. Organizations use them to validate their own internal roadmaps, and to guide their technology choices and research developments so as to ensure the greatest return on investment.

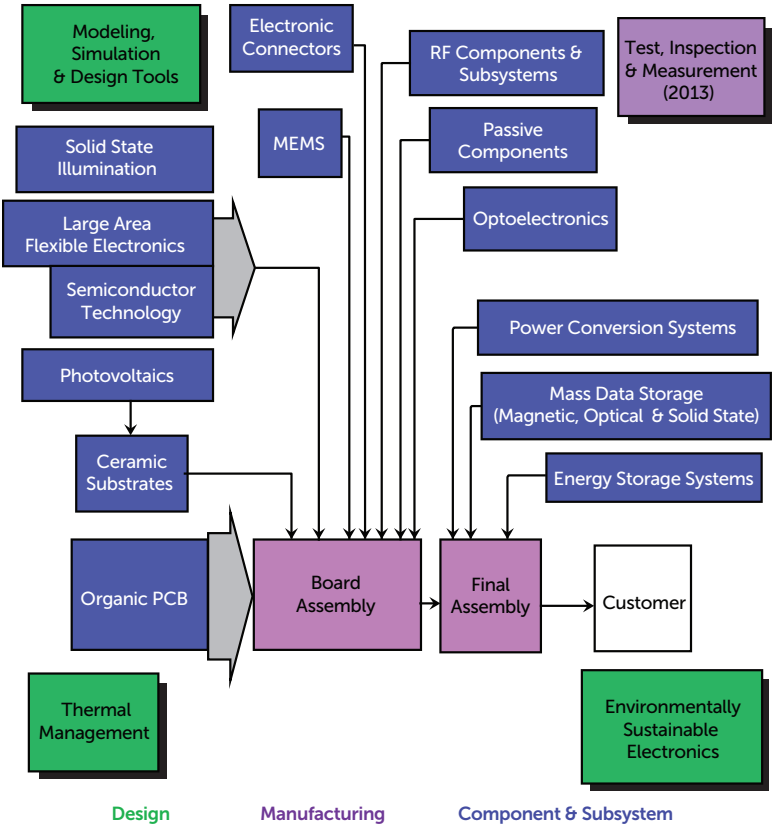
iNEMI has been developing roadmaps for the last 20 years, publishing updates biennially. This is the 11th publication of the roadmap, which has grown from six chapters in 1994 to 24 chapters this cycle. The 2015 iNEMI roadmap contains five chapters that anticipate the product needs of the future. They define the future technology needs of "virtual generic products" from key market segments by focusing on the market demands and functionality requirements of these industry segments *(see Table 1)*.

Table 1 - 2015 Product Emulator Groups (PEGs)

Emulator (Industry Sector)	Characteristics
Automotive	Products that must operate in an automotive environment
Consumer Stationary & Office Systems	Driven by the need for maximum performance over a wide range of cost targets
High-End Systems	Products that serve the high-performance computing, server, data storage, networking, datacom and telecom markets
Medical	Products that must be highly reliable and, in some cases, support life-critical applications
Portable & Wireless	Produced in high volumes, cost is the primary driver; hand-held, battery-powered products are also driven by size and weight reduction

The remaining 19 chapters identify technology and infrastructure trends *(see Figure 1)*. They focus on the key technology capabilities and developments anticipated and required within the electronics manufacturing supply chain to meet projected product needs between now and 2025. In this edition, the roadmap has continued to broaden the technologies addressed by adding an important new chapter on Power Conversion Electronics, which is provided by the PSMA (Power Sources Manufacturing Association). In addition, the RF Components & Subsystems chapter, which has been absent for two cycles, has returned.

Figure 1 - 2015 Technology Working Groups (TWGs)



The 2015 Roadmap builds on the processes of, and lessons learned from, previous editions. It is a global collaborative effort that involves many individuals who are leading experts in their respective fields and represent many perspectives on the electronics manufacturing supply chain.

In spite of the fact that most companies and individuals are oversubscribed in their "day jobs," approximately 500 individuals from at least 20 countries, and representing more than 280 corporations, consortia, government agencies and universities came together to create this product. Through sharing, analyzing, debating and reviewing, this diverse team developed the 2015 Roadmap.

Among the contributors to this latest roadmap are 14 other industry consortia and associations, helping to ensure a comprehensive view of the changes and challenges that need to be addressed throughout the supply chain.

Many thanks to everyone for their efforts and contributions to this valuable and dynamic roadmap for the industry.

BUSINESS CLIMATE & MARKET GROWTH

All indicators point toward continued modest growth for the electronics industry overall in the next few years. IHS Technology predicts a 3.6% compound annual growth rate (CAGR) through 2018. However, there are segments within the industry that show potential for greater growth. For example, New Venture Research (NVR) anticipates that sales among EMS suppliers will grow at a CAGR of approximately 7.7% between 2013 and 2018 — more than twice that of the electronics industry as a whole. IHS Technology predicts market growth of the various product sectors as discussed below.

Portable & Wireless

The portable and wireless sector is by far the largest sector of the electronics industry and accounted for $518 billion (Bn) in equipment production in 2013, representing 26% of total production. As wireless products continue to proliferate, this sector is expected to experience a CAGR of 4%, achieving $599Bn in sales in 2017. This sector has been reclassified for the 2015 iNEMI Roadmap and now includes the following representative products: mobile phones, smart phones, notebook computers, digital cameras, camcorders, PDAs and media tablets.

Consumer Stationary & Office Systems

This sector is the only one expected to experience a decline. Worldwide production of consumer/office equipment totaled $378Bn in 2013, and is expected to fall to $341Bn in 2017. The expected CAGR over the 2013 to 2025 horizon of the roadmap is –1.2%. This is the third largest segment of the $2.0 trillion (Trn) electronics industry, accounting for about 19% of overall production, and is driven by consumer, business and small office spending. This sector also features a new grouping of products for

the 2015 Roadmap. It now includes a broader set of product categories, such as: desktop computers, computer peripherals, storage systems, office equipment, small office/home equipment and stationary consumer products.

Automotive Electronics

The confluence of accelerating electronic content in vehicles around the globe, in parallel with strong vehicle sales growth worldwide, bodes well for the automotive electronics market over the next 10 years. Automotive electronics accounted for about 5.4% of global electronics production and reached $107Bn in 2013. The sector is expected to experience relatively strong growth through 2025, increasing at a CAGR of approximately 4.4%.

Medical Electronics

Medical electronics equipment production totaled an estimated $58Bn in 2013, accounting for about 3% of the global electronics industry. This market sector is expected to continue to increase at a CAGR of 5.3% to reach $72Bn in 2017.

Aerospace & Defense

Military and aerospace electronics equipment production is estimated to have totaled $107Bn in 2013, accounting for about 5% of the global electronics industry. This market is expected to continue to increase at a CAGR of 5.4% to reach $135Bn in 2017.

Note: *All market projection data was provided by IHS Technology, unless otherwise noted. In previous roadmaps, Prismark Partners LLC supplied the data. Due to the differences in the methods of data presentation, there are some differences between current and previous iNEMI Roadmap market forecast numbers. Please use caution when comparing the data published in this Roadmap directly with the data in previous iNEMI roadmaps.*

TECHNOLOGY TRENDS

The 2015 Roadmap provides in-depth discussion of 19 different technology areas that cover the entire electronics manufacturing supply chain, encompassing design, manufacturing, and components and subsytems. Several key trends identified in the roadmap have significant impact in technology areas up and down the supply chain. Highlights of some of these trends are discussed below.

MEMS & Sensors

Microelectromechanical systems (MEMS) are some of the most rapidly growing components of the electronics industry. MEMS devices are a key enabling technology for many of today's high-technology products, including automotive sensors, smart phones and wearable fitness devices. They are also supporting new breakthroughs in portable medical diagnostic and treatment technologies — expected to be the next wave of medical electronics applications — and the future of the Internet of Things *(see discussion beginning on page 8)*.

- Increased integration and greater connectivity of devices, along with a convergence of markets and their applications, are making sensors ubiquitous.
- The demand for MEMS devices with higher performance, lower cost, new functions and integration of multiple sensor functions has led to the integration of tri-axis accelerometers with gyroscopes and magnetometers, enabling new device technologies, and advancing signal processing and communications interfaces.

- According to Yole Développement, the first memories integrating 3D through silicon via (TSV) technology will be in volume production in 2015, taking full benefit of MEMS processes.
- Focus of portables will shift to "wearables" with multiple sensors providing unique user interfaces and user interaction.
- Device calibration and testing accounts for 30-60% of the cost of manufacturing MEMS devices. As more functionality is integrated into MEMS sensors, testing requirements become more complex and, potentially, more expensive. At the same time, systems integrators are demanding more functionality at the same, or lower, cost. One challenge in lowering the cost of testing is that manufacturers have developed proprietary protocols, hindering the development of standard testing protocols and test equipment that could potentially lower testing costs.

The Internet of Things

We continue to see enormous growth of mobile Internet applications, including massive demands for mobile data, the growth of mobile video, and the dramatic increase of smart

phones as the gateway to the web. This "Internet of Things," as it has come to be called (IoT) has far-reaching effects.

Growth in IP traffic. According to a June 2014 report from Cisco, annual global IP traffic will surpass the zettabyte (1000 exabytes) threshold in 2016, and reach 1.1 zettabytes per year, or 91.3 exabytes (one billion gigabytes) per month, in 2016. By 2018, global IP traffic will reach 1.6 zettabytes per year, or 131.6 exabytes per month. Overall, IP traffic is forecast to grow at a CAGR of 21% from 2013 to 2018.

Video traffic. Cisco also projects that, globally, IP video traffic will be 79% of all consumer Internet traffic in 2018 (up from 66% in 2013). This percentage does not include video exchanged through peer-to-peer (P2P) file sharing. The sum of all forms of video (TV, video on demand, and P2P) will be in the range of 80-90% of global consumer traffic by 2018.

- The telecommunications system and everything down to semiconductor chips must grow proportionally (from both a capacity and performance viewpoint) to support this traffic. In addition, new mobile applications require large amounts of computing power resulting in warehouse computers that consume 50+ megawatts.
- These changes drive optical technologies. As data rates increase, optical methods are replacing copper/electronic methods at

ever-shorter distances. The current transition point is at data rates of 10 Gb/s and distances of 10 to 100 meters. When data rates or distances greater than those are needed, optical methods are attractive because they often reduce both power consumption and physical size up to 75%.

RF manufacturing. Although not strictly an innovation in wireless/RF technology, there is an expectation that wireless sensing and devices will play a significant role in the IoT. If the number of connected sensors and devices increases as expected, it could disrupt the existing RF manufacturing technology landscape by creating a sudden and large increase in the consumption of RF semiconductors, antennas, and RF SiPs (systems-in-package). In order to meet these new demands, manufacturing of RF components would need to become more cost effective and efficient. Further, future designs of RF systems and components would need to take another look at making designs even more efficient and physically smaller.

Self-organizing wireless networks. As the IoT revolution causes the number of devices to increase rapidly, new technologies will be required to enable these devices to connect with each other and the Internet. Instead of having each individual device connect to the Internet, one possibility is to have self-organizing networks. If implemented at the protocol level, it would allow many devices out of range of an access point to still connect to the Internet via other devices. From a hardware perspective, implementation of this technology could cause significant reductions in power consumption as devices could be designed with a reduced RF range. This technology is one of the keys to enabling the growth and success of the IoT.

Silicon Integration

Consumer demand for thin multifunctional products continues to grow; and cost, power, bandwidth and form factor of these devices continue to be driving factors for acceleration of integration of silicon and system capabilities into a single package or single die.

- It is forecast that, by the end of 2019, it will be necessary to augment the capabilities of the CMOS process by introducing multiple new devices that will be designed to realize some properties beyond those of CMOS devices. However, it is believed that these new devices will likely not have all the properties of CMOS devices; therefore, it is anticipated that heterogeneous integration — either at the chip level or at the package level — will integrate these new capabilities around a CMOS core.
- The convergence of mobile phones with computing and entertainment devices in effect enforces the further ramp of CMOS into SoCs (systems-on-chip), both in homogeneous and heterogeneous technologies. The classical mixed technologies in 2D SiP and MCP (multi-chip package) forms is now evolving and growing to more of a 3D MCP with a new set of electrical, mechanical and thermal challenges.
- The 3D stacking of chips will be mostly dominated by three key components: memory, application processor and communication silicon. They will leverage through-silicon via (TSV) and through-mold via in integrated, mixed technologies in single-package as well as chip-on-chip (CoC) and chip-on-interposer solutions over the next five-year horizon. Of course, the commercial challenges associated with 3D stacking,

especially in the world of memory integration, are expected to remain a significant barrier. Consignment, material, need for liquidity of memory size and even the supply chain and test challenges will remain the ramp barriers as they all impact the bottom line.

Environmental Issues

Regulations. Regulatory requirements for electronics manufacturing continue to grow. In particular the industry is subject to a proliferation of laws and regulations that seek to restrict the use of certain materials in electrical and electronic equipment ("EEE") due to human health and environmental concerns. Across the world there are new directives being developed, along with updates and reviews of existing laws and guidelines. In addition to RoHS, WEEE and REACH, new requirements are emerging from many regional, national, and local governments. This ever-expanding portfolio of regulations requires in-depth technical management by many sections of the electronics manufacturing supply chain. Harmonization of global requirements is a major challenge, one with which companies continue to struggle, and this issue needs to be addressed by international standardization.

Sustainability. Sustainability needs to materialize as a qualifier for product design and procurement decisions. Currently, sustainability is often a differentiator, whose value is only partly recognized. Industry needs a widely accepted, workable and proven international sustainability standard based on common databases and data sets.

Lifecycle impact. In response to the ever-expanding list of banned materials and substances, industry must continue to assess the true lifecycle environmental impact of materials and potential trade-offs of alternatives.

Corporate commitment. A study by Technology Forecasters International (TFI) found that three-quarters of the companies surveyed provide employees with formal training in product environmental regulations. Fewer provide training in eco-design (i.e., design for environment (DfE) or design for sustainability (DfS)) and lifecycle assessment (LCA).

The study also found that, when an organization's CEO is personally in charge of the company meeting product environmental compliance and sustainability goals, the likelihood of the goals being funded, understood, well managed and met are much higher.

PARADIGM SHIFTS

The predominant paradigm shift identified in the 2015 Roadmap is — once again — the impact of cloud-connected digital devices. The movement to the cloud is causing, and has the potential to cause even further, disruptions across the industry. In the next few years, the industry is likely to see major transitions in business models. For example, huge data centers will likely operate more like utilities (selling data services), and local compute and storage growth may slow (as data moves to the cloud). "Rent vs. buy" will become increasingly more common for software (monthly usage fees charged for cloud-based solutions).

Other paradigm shifts identified in the 2015 iNEMI Roadmap include:

- The board assembly roadmap again indicates a migration to lower temperature and lower cost lead-free solder materials in 2013-2017; however, there is no clear strategy for achieving lower temperature other than high bismuth containing alloys.
- Need for continuous introduction of complex multifunctional products to address converging markets favors modular components or SiP (2D, 2.5D & 3D).
- Rapid evolution and new challenges in energy leading businesses such as solid state lighting (SSL) and automotive, such as EVs (electric vehicles) and HEVs (hybrid electric vehicles).

- The "Internet of Things" (IoT) is making sensors ubiquitous; however, there are concerns about network security as cyber attacks become more pervasive.
- The focus in portables will see a shift to "wearables" — devices that are so unobtrusive that they are considered to be "worn" rather than "carried" and that use sensors and connectivity in a much smaller form factor.
- Automotive safety systems are proliferating with migration from high-end vehicles to lower cost segments. Primary emphasis is on collision avoidance.
- Electronic component suppliers are utilizing embedded passive and active components, systems-in-package, systems-on-chip, or any other means to densely pack ICs with increased functionality.
- While healthcare providers transition to tablet-sized devices to replace the traditional patient information system, a revolution of remote patient care is in the making. Patient monitoring as a proactive and preventive measure is expected to see major growth.

STRATEGIC CONCERNS

Analysis of the roadmap chapters has identified some strategic concerns or deficits. A key one is regarding who pays for new technology development. In today's supply chain, there is a disparity in R&D needs versus available resources. Critical needs for research and development exist in the middle part of the supply chain (IC assembly services, passive components and EMS assembly), yet these are the firms that traditionally have been least capable of funding R&D resources. Consortial efforts across industry and the research communities are trying to address this issue. In addition, public-private partnerships (e.g., NIST's Advanced Technology Program in the US, EU-funded projects in Europe) can also play a seminal role in addressing R&D funding deficits.

Other strategic concerns highlighted in this roadmap include:

- Consumers are increasingly concerned about the impact of electronic products on safety, energy usage and the environment. Conflicting sources of public information can cause confusion and less-than-optimum solutions.
- Harmonization of environmental regulations for electronic products must be driven through international standardization.
- The mechanisms for cooperation between industries, and among researchers working in all advanced technologies, must be strengthened. Cooperation among OEMs, ODMs, EMS providers 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.

A USEFUL TOOL

The credibility gained by previous roadmaps, and their subsequent global use, have made the roadmap self-fulfilling. It balances market needs against future technology capabilities, and through this creative tension, the industry has created a highly useful and relevant roadmap. Work has been specifically applied to make the top five development and top five research needs and gaps in each technology area clear such that a cross-section of industry and academic resources can focus on the areas of highest need. This is a unique deliverable of the iNEMI roadmap.

With the growth of global inputs, the iNEMI roadmap has proven to be highly useful to industry, government and academia in helping set the future direction of electronics manufacturing. This latest edition 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 infrastructure.

TAKING ACTION

In many cases the opportunities and challenges identified by the roadmap require collaborative work involving many of the stakeholders in the industry to ensure that key strategic needs are met. iNEMI uses the roadmap as a tool to identify critical technology and infrastructure gaps, prioritize R&D efforts to address those gaps and initiate collaborative iNEMI projects to meet those needs. Some of these efforts are described below.

New materials. The needs of our industry demand high reliability at lower cost and with new material sets. iNEMI continues to focus on evaluating the long-term reliability and performance of new materials, such as our project on ultra low loss laminates/PCBs for high reliability and performance.

Environmental challenges. iNEMI has led strong cross-industry efforts — from whitepapers to multi-year projects — to address environmental challenges for the electronics manufacturing industry. Topics, identified through the roadmap and industry workshops, have included rare earth metals, alternative materials assessment, and the elimination of halogenated flame retardants.

Industry-standard solutions. Currently, iNEMI has projects addressing the needs for standardized approaches and guidelines in the high-growth market areas of medical, automotive, MEMs, and power conversion. These include work addressing automotive material challenges, component specifications for medical devices, and reliability performance qualification methods for portable devices.

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