iNEMI

International Electronics Manufacturing Initiative

2009 Research Priorities

Advancing manufacturing technology

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In order to help ensure the ongoing competitiveness of the electronics industry, iNEMI continues to focus on improving the manufacturing capability of its member companies. Because the infrastructure required to efficiently provision the customer base is so broad and diverse, the founders of iNEMI wisely established a planning methodology to ensure that its members could focus on high impact areas that can truly make a difference in the marketplace. At its fundamental level, that process includes technology roadmapping and technology deployment. While we continue to refine that process to improve the results, the underlying principles remain unchanged:

1. Create industry roadmaps by drawing upon the expertise of a broad cross-section of individuals from industry, academia, and government. The results of this work are open to the electronics industry worldwide.
2. Identify the major areas on which iNEMI will focus based on need, participation, and ability to make a business impact.
3. Conduct a gap analysis on these major areas that identifies the challenges and opportunities facing the industry.
4. Create five-year plans for the major areas that identify the projects and activities deemed necessary to close the identified gaps. These plans become the basis for the formation of iNEMI projects.
5. Develop a ten-year vision of research needs to ensure a vibrant, innovative electronics industry by prioritizing the research needs identified in the iNEMI Roadmap. This vision is the core of this document and these results are being distributed as resource materials for the industry, research institutes, and funding agencies.

The 2009 iNEMI Roadmap identified a number of key technology and business challenges facing the electronics industry over the next decade. Forecasts indicate that most of today's key semiconductor and electronic packaging technologies are not capable of meeting the needs of the industry in 2019. If these challenges are not promptly addressed with innovative solutions, the continued viability of the electronics manufacturing industry will weaken over the next decade.

With the downsizing of industrial research it is critical to encourage academic and institutional R&D centers to focus on technology needs identified in the iNEMI Roadmaps. Recent concern in high-cost regions over the loss of manufacturing capabilities has stimulated discussion that our industry must place greater emphasis on innovation and the development of disruptive technologies. iNEMI is committed to improving the roadmapping process to better identify disruptive technologies and research priorities.

On behalf of the iNEMI Board of Directors, I congratulate all who helped to create this Research Priorities document. Your contributions will assure that we continue to focus on those areas that can leverage our industrial base for the benefit of member companies as well as the entire electronics industry.

Sincerely yours,

Jim McElroy, Chief Executive Officer
International Electronics Manufacturing Initiative (iNEMI)

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Introduction

Background

The iNEMI Research Priorities document presents the consensus on R&D needs identified in the 2009 iNEMI Roadmap. The 2009 Roadmaps were developed by nineteen Technology Working Groups (TWGs) and the RFID-ILT group in response to inputs from representatives of OEMs in five product sectors or Product Emulator Groups (PEGs). The twenty chapters can be classified into four categories:

- Business Technologies TWG
  - Information Management (IM)
- Design Technologies TWGs
  - Modeling, Simulation, and Design
  - Thermal Management
  - Environmentally Conscious Electronics
- Manufacturing Technologies TWGs
  - Board Assembly
  - Final Assembly
  - Test, Inspection, and Measurement
- Component/Subsystem Technologies TWGs
  - Semiconductor Technology
  - Packaging
  - Interconnection Substrates – Organic and Ceramic
  - Passive and RF Components
  - Optoelectronics
  - Large Area, Flexible Electronics
  - Mass Data Storage
  - Photovoltaics
  - Solid State Illumination
  - Connectors
  - RFID-ILT (Item Level Tag)

The 2009 iNEMI Roadmap consists of over 1400 pages, with contributions from more than 550 participants representing over 250 companies, universities and associations from 17 countries. Further details on the roadmapping process and contents are contained in Appendix A: 2009 iNEMI Roadmap Overview.

The iNEMI Research Priorities document is intended to serve as a resource for all who are tasked with directing R&D funding and execution. Research needs are developed for five product sectors:

- Consumer/Portable
- Office/Large Business Systems

- Automotive
- Netcom
- Medical

We believe that these sectors are the major drivers of technology and the associated R&D needs. The technology needs for each of these sectors are summarized in chapter 2.

The R&D needs identified in the 2009 iNEMI Technology Roadmap are organized into seven categories:

- Manufacturing Processes
- Systems Integration
- Energy
- Environment
- Materials & Reliability
- Design
- Information Management

The iNEMI process is a bottoms-up Delphi process relying on numerous technology experts to give their vision of the technology needs that must be developed to meet their view of the products of the future. The roadmapping process does not explicitly identify disruptive technologies, but by identifying needs, particularly those for which there are no known solutions that meet the performance and cost requirements, members of the iNEMI roadmapping team implicitly identify areas for innovation and the utilization of disruptive technologies. As an example, the first NEMI Roadmap in 1994 determined that the introduction of area array packaging created a need for a new substrate technology.

The restructuring of the electronics industry from vertically integrated firms to specialized firms has stimulated discussion on how the industry can effectively develop and implement disruptive technologies to ensure the continued growth of the global electronics industry. Our experience over the past eight years with converting the electronics manufacturing infrastructure to Pb-free solders has demonstrated the challenge of funding and implementing disruptive technologies.

iNEMI is committed to improving the roadmapping process; to better identify disruptive technologies, find matches to current needs, and to help anticipate new applications and products.

Overview

In 2007 iNEMI held an "Innovation Leadership Forum." Leaders from industry, academia, and government addressed the market, social, and technical issues that innovation should focus on. Based on these presentations and additional input, iNEMI has chosen to focus its agenda on the technology to support miniaturization, medical electronics, and energy and the environment. The technology to meet these focus areas includes system in package, energy storage and conversion, sensors, advanced manufacturing processes, and advanced materials. We believe that the technology to support these three thrust areas will address both the converging and emerging markets.

Chapter 1 highlights the technology needs for each of the product sectors addressed in the 2009 iNEMI Roadmap.

Chapter 2 defines the three iNEMI Research Thrust Areas, Miniaturization, Energy and the Environment, and Medical Electronics and then outlines the current projects in these areas and their research needs.

Chapter 3 presents the iNEMI Research Committee's consensus of the top research priorities in each of seven research areas. Additional research needs are listed, but in no specific order. The complete chapters in the 2009 iNEMI Roadmap are available through the iNEMI Headquarters website (www.inemi.org).

Chapter 4 describes the research needs in four emerging areas of great interest to the Electronics Industry.

- 3-D Packaging
- Printable Electronics
- Energy Efficient Technologies
- Sensors and MEMS

As we move beyond the digital convergence of electronic products, we anticipate the merger of micro and nano chemical, mechanical, and biological sensors with micro and nano electronics for disruptive innovations in many areas. In some cases the disruptive technologies may also find application by being embedded in conventional product embodiments. As an example, nano-particle fillers may enhance select properties of existing polymeric materials. These applications will likely result in new opportunities for extending the life of current materials and manufacturing infrastructure, enabling them to deliver enhanced device or component functionality. Breakthroughs may take the form of disruptive technologies that supplant existing technologies. Examples of these are quantum computing systems, molecular electronics, and spintronics replacing CMOS semiconductor technology. Others may be radically new applications, such as sensor and drug delivery systems that detect emerging disease in the body or treat existing diseases. Such personal healthcare systems would give an added dimension to the iNEMI consumer and portable product sectors.

Chapter 5 provides concluding remarks on the direction of technology for electronic systems. This chapter also discusses the current weaknesses in research funding strategies for the next generation of technology.

Chapter 1: Product Technology Needs by Product Sector

This chapter provides a synopsis of the technology needs by product sector as developed for the 2009 iNEMI Roadmap. Experts from major OEMs described the market changes that they anticipated for their industry and the technical needs that would be required to meet the market expectations.

Portable / Consumer Product Sector

Consumer electronics equipment can be grouped into two major categories: portables and non-portables. Examples of products in both of these segments are listed below.

- Portables: mobile phones, digital cameras, camcorders, PDAs, game controllers, personal media players
- Non-portables: televisions, VCRs, DVD players, stereos, set top boxes

Of all segments of the electronics industry, the consumer electronics segment accounts for the greatest percentage of production in Asia. Asia accounts for about 54% of global production, followed by Europe with 19%, Japan with 14%, and the Americas with 13%. About 28% of assembly value was outsourced to contract manufacturers in 2007.

The portable and consumer electronics production reached $300B in 2007, following several years of exceptional growth. Growth, however, is expected to slow significantly through 2013 due to market saturation in key product segments (e.g., mobile phones and digital cameras) and decreasing average selling prices.

This segment is driven by “must have” consumer products. Some of the fastest growing product categories contributing to the surge in production revenues in 2004 through 2007 include mobile phones, compressed audio players (e.g., iPods), digital video recorders, and flat panel televisions. LCD TVs are expected to continue to be one of the biggest growth drivers over the next five years. In 2008, Blu-ray won the battle for the next-generation DVD technology, and this technology will see growth going forward in regions where HDTV has high penetration. IPTV is also starting to gain traction.

Mobile phone shipments were surprisingly strong over the last several years and 2007 was a stellar year for handsets as well. Global mobile phone shipments increased by 14% in 2007 to 1,140M units. In value terms, mobile phones account for about 12% of global electronics system production and 51% of portable and consumer electronics equipment production. A slowdown in this market as it approaches saturation will have a significant impact on the growth of this segment.

Overall, the consumer electronics segment is expected to increase at an average rate of only about 3.5% per year to reach $368B in 2013. Slowing mobile phone revenue growth, in particular, is expected to account for much of this slowdown. Mobile phone production revenues reached $148B in 2007, and are expected to grow to $175B in 2013—representing a CAAGR of about 3%.

Office / Large Business Systems Product Sector

Worldwide production of computers and office equipment reached $446B in 2007, and is expected to grow at an average rate of 4.9% per year to reach $595B in 2013. This is the largest segment of the $1.3Trn electronics industry, accounting for about 35% of overall production, and is driven by business and individual consumer spending.

Computers represent the largest percentage of this sector. The market for these systems was exceptionally strong in 2006 and 2007, although growth is expected to moderate in 2008 and 2009. Overall, 261M computers, including desktop PCs, notebooks, and servers, were shipped in 2007 compared to 229M and 207M in 2006 and 2005, respectively. This represents a unit growth rate of about 11% in 2006 and 14% in

2007. Notebooks are the fastest growing computer segment and now account for about 41% of total unit shipments.

In addition to computers, this category also includes computer peripherals, storage systems, and office equipment. The highest growth market in these areas is network storage (e.g. SAN and NAS), which is driven by enterprise spending. The leading manufacturers of these systems include HP, IBM, EMC, Dell, Hitachi, and Sun.

Example products in each category are listed below. A common challenge across all segments is the impending transition to more environmentally friendly solutions – materials with lead and halogen levels below 1000 ppm, lower power consumption levels, and a reduced carbon footprint during manufacturing. Also, ongoing product cost reductions continue to drive the need for technology advances in all areas of manufacturing (lower material costs, fewer process steps, faster cycle times).

- Computers: desktop PCs, notebook PCs, workstations, servers. Continued increases in functionality and integration of functions into common silicon is driving reductions in BGA pitch and ball size. The resulting smaller joints demand evolving system implementations to maintain solder joint reliability (e.g. cost-effective board level underfill solutions, material advances to push out pad crater and CAF failures, etc…) and keep test coverage from being compromised.
- Computer Peripherals: printers, scanners, keyboards, monitors, PC cameras. Mechanical and electrical reliability remain concerns in this segment. In addition, printer quality advances continue to drive the need to improve ink injection accuracy.
- Storage Systems: solid state drives, hard disk drives, SAN/NAS, optical disk drives. A key challenge in this segment involves optimizing the "carriers" (e.g. racks) for the individual storage medium used. For example, racks configured for hard disk drives don't deliver power savings with solid state drives because larger-than-necessary power supplies and cooling solutions (fans) burn more power than the solid state drives themselves.
- Office Equipment: photocopiers, fax machines, digital projectors. A requirement to implement power management technology for power efficiency is emerging for office equipment. While this isn't new, it has become a stronger driver due to increasing functionality built into various pieces of equipment as well as government energy efficiency programs. In addition, the need to improve imaging quality at low power is driving interest in LED technology and packaging technology that can handle high temperatures at the die interface.

Asia accounts for the majority of computer and office equipment regional production—57%. This region is followed by the Americas, Europe, and Japan with 23%, 13%, and 7% share, respectively. Approximately 36% of final system assembly production value is outsourced to contract manufacturers, including EMS and ODM companies.

Netcom Systems Product Sector

Netcom systems equipment size varies from small (e.g. a wireless home network box) to multiple racks of interconnected systems (e.g. a core network switch); environments range from central offices (with regulated air conditioning and filtered, uninterruptible power) to outside plant installations (with temperatures which can range between -40C and +85C, precipitation, and solar exposures); and service life stretches from a couple of years to 20+ years with 99.999% uptime. Global production of communications equipment was expected to reach $186B, moderately higher than the $176B produced in 2007, representing about 14% of the electronics industry. This segment is expected to increase at an average rate of 5.7% per year to reach $246B in 2013. Although this segment includes traditional voice and data communications systems, most growth over the next five years will be attributed to data-related equipment.

On the most basic level, communications equipment can be categorized into three groups based on the equipment environment: small office/home office (SOHO) equipment, enterprise equipment, and service provider equipment. The service provider equipment segment includes wireline and wireless infrastructure systems. Over the forecast period, growth is expected in all three groups, however, most of the growth in the service provider equipment category will be in the wireline infrastructure equipment segment. This growth will be driven by increased consumer demand for broadband services. High growth system categories include wireless LAN, service provider routers and multi-service switches, metro optical networks, Voice over IP (VoIP), and IPTV equipment. Wireless infrastructure equipment production is expected to increase moderately through 2013, driven by growth in wireless voice and data traffic in developed markets and new build-outs in emerging markets. Also, there is a continued excitement about WiMAX broadband wireless service appears to have strong potential pending the resolution of commercial and other conflicts.

Examples of products in the communications market segments are listed below:

- Small Office/Home Equipment: low-end switches and routers, modems, VoIP modems, wireless routers
- Enterprise Equipment: mid-range switches and routers, PBXs, VoIP phones
- Service Provider Equipment: wireless base stations, central office switches, cable modem termination systems, VoIP and IPTV equipment, core routers, WiMAX

Although lower-end SOHO systems are more likely to be produced in lower-cost regions, large service provider rack equipment, which represents the majority of system value, is still commonly produced in the region where it is used. The majority of communications equipment production is still in North America where equipment deployment is the strongest. However an increasing percentage of communications equipment is being produced in Asia (e.g. China) as developing countries in Asia spend more on communications equipment and as local equipment suppliers continue to gain market share (e.g. Huawei) . The Americas accounted for 44% of equipment production in 2007, followed by Europe with 28%, Asia with 23%, and Japan with 5% share. In 2007, approximately 33% of final communications system assembly was outsourced to contract assemblers. The fact that the growth of equipment expenditure is below 6%, while network traffic growth is above 50% presents a major challenge for equipment manufacturers. The outcome across the board will be a strong demand for much higher bandwidth equipment at comparable cost.

Medical Product Sector

Medical electronics equipment production reached $66B in 2007, accounting for about 5% of the global electronics industry. This market is expected to continue to increase at an average rate of 5.1% per year to reach $89B in 2013. A constantly growing market of aging people with more sophisticated lifestyles and high expectations for a continued full life is providing an opportunity for the development of specialized medical systems. Both advanced and simple electronics for assisted living (e.g., hearing, vision), monitoring, remote care, advanced diagnostics, and chemical monitoring and dispensing systems are being developed.

There are many different types of medical electronics systems, but the major products can be classified into three categories: large infrastructure equipment, small stationary and portable equipment, and implantables.

- Large Infrastructure Medical Equipment includes products such as medical imaging systems (e.g., x-ray and MRI), IT equipment (e.g., picture archival communication systems PACS), and biochemical analysis equipment (e.g., lab instruments and DNA analyzers). The significant trends in this segment are toward digital versus analog image capture, greater data processing capabilities, and increased processing speeds.
- Small Stationary and Portable Medical Equipment includes products such as patient monitoring systems that are used to measure and monitor patients' vital signs and other bodily functions. The segment also includes home diagnostics products such as blood pressure and blood glucose meters.

Within the hospital environment, major trends include portability, miniaturization, and greater use of wireless and wired communications networks to transfer data and reprogram systems.

- Implantable Medical Equipment includes major therapy devices such as pacemakers and implantable cardioverter defibrillators (ICDs), and the market is rapidly expanding beyond these systems. Devices such as neurostimulators (e.g., for Parkinson's disease) and drug pumps (e.g., for insulin release) are also being brought to market. Increased reliability, greater functionality, and miniaturization are the main technical drivers in this segment.

The medical electronics industry is one of the few major electronics system market segments where production is still concentrated in North America. Prismark estimates that 54% of medical electronics equipment was assembled in the Americas in 2007. This region is followed by Europe, Asia, and Japan, which accounted for 25%, 13%, and 8% of production, respectively.

In terms of product value, most medical electronics systems are produced in North America today. However, Asian countries, such as China and India, are the fastest growing markets for medical equipment, and leading medical electronics companies, such as Siemens, GE, and Philips, are increasing product design and assembly capabilities in these countries.

Medical electronics systems are primarily assembled in-house by the system OEM due to reliability requirements, government manufacturing regulations, and proprietary nature of most designs. Only about 11% of total medical electronics equipment assembly value was outsourced to contract assemblers in 2007.

The medical electronics industry will have specific needs for the emerging technologies discussed in "Options for Innovations," with 3-D packaging, printed electronics, sensors, and energy management being especially applicable.

Automotive Product Sector

The automotive electronics industry accounted for about 6% of global electronics production and reached $79B in 2007. This sector is expected to experience modest growth through 2013, due to an increase in average electronic module penetration per car in a slow-growing vehicle sales environment.

Global passenger car and light commercial vehicle unit shipments were expected to increase from about 69M vehicles in 2007 to 86M vehicles in 2013, representing a six-year CAAGR of 3.7%, but growth has been delayed by the dramatic dip in sales in 2009 due to the global recession. With US production running at a rate of less than 10 million vehicles per year in 2009 and equivalent production cuts in Europe and parts of Asia, any forecast numbers are speculative at this time.

From 2007 to 2009, the weakest region for automotive vehicle production was the Americas, driven by continued over capacity. On the other hand, vehicle production in China and India is robust.

The major trends driving the demand for increased electronics penetration in automobiles include:

- Stricter fuel economy and emissions mandates
- Legislated requirements for advanced safety systems, such as advanced airbags and on-board tire pressure monitoring
- Consumer demand for greater vehicle efficiencies driven by fluctuating and escalating global crude oil prices
- Consumer demand for greater safety, comfort, and convenience features

The four major challenges for automotive harsh-environment electronics manufacturers are:

- Reliability – extended warranties can now last to 10 years / 100,000 miles.
- Hybrid electric vehicles (HEVs) require high voltage and current components and connectors as well as the integration of new systems such as regenerative braking or DC-DC converters as well as energy storage in battery packs or super capacitors.
- The convergence of consumer and automotive electronics. Consumers demand the same level of sophistication in automotive electronics as in consumer electronics while maintaining performance under harsh conditions.
- Increasing environmental constraints – elimination of hazardous materials plus the use of "green" and recycled and recyclable materials.

Electronic modules addressing these issues as well as other automotive electronics systems can be segmented into six major categories:

- Powertrain Electronics, such as engine controllers, transmission controllers, voltage regulators, and any other systems that control the engine or driveline of the vehicle
- Entertainment Electronics, ranging from standard AM/FM radios to on-board video entertainment systems, satellite radio receivers, and wireless networking
- Safety and Convenience Systems, such as airbag sensors, climate controls, security and access controls, and anti-lock braking systems
- Vehicle and Body Controls that manage specific vehicle functions, such as suspension, traction, and power steering
- In-Cabin Information Systems, such as instrument clusters, trip computers, and telematic products, including the associated displays for these functions
- Non-Embedded Sensors, such as speed sensors, temperature sensors, fluid level sensors, and many others

Technical challenges include:

- Reducing cost, which is still the #1 imperative in materials and processes. Cost reductions did not follow the 2007 roadmap projections due to commodity price increases for copper, resins and glass.
- Automotive manufacturers want systems solutions, not components, forcing industry structural changes.
- The integration of consumer demands and engineering needs complicates design.
- Thermal management with HEV and conventional automobiles continues to be an issue.
- HEV high voltage management (32V to 1000V) requires new architectures and connectors.
- Replacing single wire sensor architecture with a networked approach becomes more important as complexity increases.
- Correlating field performance and reliability testing is still an issue.

Europe accounts for the majority of automotive electronics system production—approximately 33%. This region is followed by Asia with 30% production share, the Americas with 20% share, and Japan with 17% share. Automotive electronics systems are still primarily designed and assembled by the OEM. Only about 7% of automotive electronics assembly value was outsourced to contract assemblers in 2007.

Chapter 2: iNEMI Thrust Areas & Project Research Needs

In 2006-7 iNEMI held two forums on innovation to determine the areas on which research efforts should be focused to insure sustained growth for the electronics industry. In 2008 a third forum was held in Shanghai in celebration of the opening of our Asian office. These meetings concurred in the decision to focus on Miniaturization; Energy and the Environment, and Medical Electronics. Chapter 2 focuses on these thrust areas. The first part of the chapter discusses these thrust areas and their research needs. The second part of the chapter lists iNEMI's current development projects and research activities which would contribute to the next generation of technology in these areas.

Miniaturization

Miniaturization and integration for mobile computing, communication, and sensing will drive an increasing diversity in materials, designs, assembly process technologies, testing, and standards. Miniaturization will drive not only semiconductor technology but also research as far ranging as technologies for 3D integration such as TSVs and SiP components; new board materials and designs to support decreased pitch, higher frequencies, and higher I/O counts; new materials and designs for printed electronics; and nanomaterials and structures to support a post-CMOS "More than Moore" world.

Semiconductors

The predicted end of traditional CMOS semiconductor scaling has generated significant reverberations in approaches and structures of computing systems. The first consequence is the gradual but certain reduction of emphasis on the microprocessor frequency metric, and the corresponding increase in importance of the system's throughput metric. The emphasis has changed from "how fast can it go" to "how much can it do."

Traditionally, the ITRS Roadmap has focused on the continued scaling of CMOS (Complementary Metal-Oxide-Silicon) technology. However, since 2001, we have reached the point where the horizon of the Roadmap challenges the most optimistic projections for continued scaling of CMOS (for example, MOSFET channel lengths below 9 nm). While CMOS is (and will remain) the industry workhorse up to and beyond the year 2020, it is difficult for most people in the semiconductor industry to imagine how we could continue to afford the historic trends of increasing process equipment and factory costs for another 15 years! In addition, scaling planar CMOS will continue to face significant challenges. The conventional path of scaling, which was accomplished by reducing the gate dielectric thickness, reducing the gate length, and increasing the channel doping, might no longer meet the application requirements set by performance and power consumption. Introduction of new material systems as well as new device architecture, in addition to continuous process control improvement are needed to break the scaling barriers. Whether extensions of CMOS or radical new approaches, post-CMOS technologies must further reduce the cost-per-function and increase the performance of integrated circuits.

In the spirit of the new "Beyond CMOS" terminology introduced first in the 2007 iNEMI Roadmaps, the reference to Beyond CMOS terminology is to encourage research efforts which is focus on determining the characteristics and timing of the next non-CMOS (but possibly integrateable with CMOS at the chip and/or package level) computational switch and storage elements.

Packaging

In the 2008 ITRS Roadmaps and the 2009 iNEMI Roadmaps there is a new focus is on "More than Moore." With the ever increasing functionality at the chip or Multichip package level, miniaturized systems put increasing focus on developing a new generation of packaging technology to address the system needs. Traditional interconnections of surface mounted discrete components are being changed to ultra fine pitch interconnections connecting embedded ultra thin film components on ultra thin silicon and organic type substrates. The package integration will start to evolve into system integration, leveraging the system on chip, wafer level packaging, and embedded passives and actives on organic substrate technologies. Convergent micro and nano systems will not only have digital and portable wireless electronics but also bio electronics functions. These electronic and bio electronic devices, advanced interconnects, batteries, thermal solutions, and other user interfaces such as connectors and cables can lead to multi-functional systems in the short term and more integrated giga–function systems in the long run. This System on/in Package concept integrates disparate technologies to achieve multiple system functions in a single package, while providing an ultra-small form factor. Chip package co- design and considerable integration of digital, RF, optical, sensing, and biological functions in 2D and 3D architectures will be realized. These technologies will need advanced materials with enhanced electrical, thermal, and thermo mechanical properties and advanced manufacturing processes.

Materials

Materials continue to pace the introduction of packaging technologies to meet the major manufacturing requirements of low cost through increased modularity, integration for smaller size, and higher bandwidth for more functionality. In addition to these product-specific attributes, there are general requirements for environmentally friendly materials systems (e.g., bio-based polymers) that use low energy processes. While traditional technologies have focused on materials systems for electronic performance, future materials requirements will need to embrace optical, mechanical, and chemical performance for electro-optical, electro mechanical (MEMS), and chemical and bio sensor systems, respectively. Advanced fillers for nano composites and nano engineered materials with property improvements that are not possible with micron fillers, such as low CTE with high toughness, high electrical conductivity with low thermal conductivity (high ZT), and high compliance with high current carrying capability offer the promise to meet some of these enhanced performance requirements. Much of the discussion in Chapter 4 addresses thrust areas directly associated with miniaturization beyond the IC; including 3D integration, energy efficiency technologies, printed electronics, and sensors and MEMS.

Energy and the Environment

The electronics industry will continue to face increasing legislative and consumer pressure world-wide to reduce energy and materials use from “cradle to cradle.” This affects the core of iNEMI members’ businesses, driving design, materials substitution, and miniaturization of circuits (aka “dematerialization”) and will be an important focus of iNEMI projects for the foreseeable future. To remain competitive, the electronics industry must continue to keep pace with emerging material restrictions, end-of life requirements, customer preferences, and legal requirements for the development of energy efficient products. In addition, sustainable business practices and the use of innovative holistic designs that include sustainability will be crucial to the continued viability of the industry. Since the 2007 ECE Roadmap, leading electronics firms have recognized that the industry must think and act strategically and involve stakeholders (including NGOs (Non-Governmental Organizations)) in discussions on future directions regarding the industry’s environmental performance.

Sustainability

iNEMI’s environmental roadmapping group has chosen to focus on electronics as a solution to climate change (or “empowering people to live a sustainable lifestyle”). On the one hand, there is the acknowledged responsibility to minimize the electronics industry’s environmental impact from operations, products, and services. On the other, the compelling news is that the electronics industry has an opportunity to make society function more efficiently, easily, and with a lower material and energy cost and thereby reduce overall impact on the environment. For example, improving options for teleconferencing continue to facilitate business communication and reduce the need for travel. Energy efficient photovoltaics and solid state lighting offer enormous opportunity for energy savings. To harvest this potential, the iNEMI roadmapping team has identified a number of electronics-enabled solutions that offer the collective potential of reducing greenhouse gas emission by a billion tons. Innovative solutions across the product spectrum are a primary research need.

Energy

In 2006, US consumer electronics consumed approximately 163TWh of electricity, which represents 12% of domestic energy consumption. Energy consumption of electronic products is coming under scrutiny by companies, NGO's, the media, and government, with the focus on items as small as cell phones and as large as server farms. The move by consumers to energy-efficient handheld devices and netbooks (in 2009, the largest-growing consumer computing sector) rather than laptops or desktops is another market driver – smaller screens and optimized processing can mean more than a whole day's computing from a single battery charge. There is no doubt that increasing pressure will be placed on all electronic devices to have reduced energy use with increasing functionality.

Research priorities include positioning the supply chain for emerging product carbon footprint requirements, leveraging existing activities where appropriate (EICC, GHG Protocol, CDP, etc), monitoring activities focused on developing supply chain carbon accounting methods, and ensuring that key requirements are communicated throughout the supply chain. Another priority is to develop options for obtaining footprint data from suppliers based on requirements that are ultimately developed. An additional focus will be to identify new business opportunities in the areas of conservation and global warming emissions reduction that are relevant to iNEMI members and suppliers. Examples may include but are not limited to solid state lighting, organic LED, photovoltaics, the use of electronic products to improve building efficiency, and logistics systems. It will be crucial to identify means of integrating these opportunities with other iNEMI Roadmaps and to consider other methods of driving awareness of these issues within the research community (e.g. sponsor a relevant seminar or session).

Design

Recent interest in product life cycle assessments has led to a need for development of a simplified tool to more easily derive key eco-environmental information for ICT equipment/assets. The iNEMI Eco-Impact Evaluator for ICT Equipment Project will develop a simplified tool that can also provide a degree of accuracy that is suited to the industry's needs for such information. The project will provide a solution in the form of an estimator tool that will categorize targeted products/assets and a unified format for requesting LCA information from suppliers. This project is viewed as a starting point for additional R&D in this area.

Materials

The performance and environmental requirements for materials substituted for those banned by RoHS or other legislation continue to create challenges for the electronics industry. With respect to the full transition to Pb-free, the research challenges are significant and will require continued investment to reduce the risks, particularly as exemptions are eliminated. In order to make meaningful choices for future materials and products, sound scientific methodologies must be developed and implemented to assess true environmental impacts of materials and potential trade-offs of alternatives. Without having such knowledge in hand, legislation may be enacted and materials chosen that have the opposite environmental and energy impact from that which was intended. It will not be enough to have such knowledge; industry must be more involved in policy making on material restrictions so that policy makers understand the trade-offs inherent in material substitution.

Recycling

There is a generally recognized need for more effective communication and cooperation within the industry on a global basis regarding recycling challenges. Based on the current state of the art, research and development are needed to create a sustainable recycling infrastructure with appropriate recycler ESD standards and a viable recycled materials market for use in new electronic products and other applications. The use of materials that hinder recycling or create hazards related to the recycling processes must be cooperatively managed. With respect to polymers specifically, the iNEMI Sustainability Summit established the need for research to create markets for post consumer plastics as feedstock for "Green" products (e.g., polycarbonate, ABS) and for new electronic applications for post consumer blended plastics (e.g., housings for power supplies).

Medical Electronics

Advances in knowledge of human physical, electrochemical, and biological patterns; an increasing worldwide presence of medical diagnostics and therapeutics; and a shift in doctor/hospital centric to patient/home centric care is driving performance, functionality, reliability, and cost of medical electronics.

The current research approach to meeting these needs has relied on diagnostics, drug therapy/delivery, or electrophysiology technologies, often developed in isolation with large investments in effort, time, and money. With increasing global prevalence of advanced medical therapies and diagnostics, the efficacy and efficiency expectations are being addressed by a convergence of pharmaceutical and chemical, mechanical and physical, biological, electronics, and information technologies.

Although ongoing developments in consumer, communications, aerospace, and defense industries are leveraged, the medical electronics field has some key research focus areas which need further emphasis.

Materials/Components

- Nanomaterials have numerous potential applications in the medical electronics field. They can be used in clinical biomarkers, in sensors, and for advanced energy storage systems. Nanomaterials based composites are candidates for electrically activated muscles and exoskeletons. Interfaces between these materials systems and microelectronics require concurrent basic research.
- Biosensors and biochips detect chemicals such as drugs, bacteria and other cells, and biochemical molecules using electrical or optical transducers. Micromechanical devices, surface coatings, and microelectronics supporting miniaturization and selectivity of such sensor systems rely on electrochemical, impedance spectroscopy, conductivity measurements, and field effect transistor technologies, all of which need further refinement. In combination with lab-on-chips for material transport, mixing, and analysis, such advances are expected to greatly reduce sample quantities and improve the efficacy of cellular diagnostics.

Interconnects

- Electronics interconnects have traditionally been major contributors to the performance, size, and reliability of medical electronics modules. RoHS and MRI compatibility is required for any future interconnects. Flexible organic substrates are increasingly being used as interconnects in medical systems.
- Large scale medical diagnostic systems are driving the need for manufacturing and materials research for fine line, low cost scalable technology. Fine line organic substrates are also finding new applications as microfluidic channels used in lab-on-chip applications. Research efforts are needed to characterize the electrical and flow behavior tradeoffs for such fluid-substrate systems.
- With increasing sensor and electrophysiological device integration, tissue compatible conductive and isolative materials are needed. Few alternatives are currently comprehensively characterized for biocompatibility.
- Connectors that meet the high density, low volume requirements for state of the art MRI equipment could benefit from a new adaptable manufacturing technology platform.

System integration

- With increased functionality and performance expectations, higher computational speed with lower power is desired. Demands for increased energy consumption in implantable and wearable medical devices are driving the need for energy scavenging and storage solutions.

- Methodologies are required for mitigation of RF interference from machine-to-machine and/or machine-to-human.
- Interoperability expectations require standard high reliability building blocks for incorporation into medical devices.

Information Technology (IT) Integration

- A major recent development is the increasing prevalence of telemedicine and remote monitoring. With the upcoming requirement for interoperability both between devices and with a server, huge amounts of data (>5TB/yr average) will be collected, transmitted, and stored for each patient. Such data needs to be quickly accessible on demand while protecting patient privacy and addressing data security concerns. A secure IT concept and infrastructure for data encryption, data compression, patient privacy protection, and disposal of the data is needed.

iNEMI Projects and Associated Research Needs

iNEMI currently has over 20 initiatives or projects developing technology to meet the needs of the industry. Highlights of these projects are downloadable from the iNEMI web pages. The following table lists the research activities needed to support the next generation of activities for the current projects. iNEMI continues to focus on three major research areas:

- Miniaturization
- Energy & the environment
- Medical Electronics

In Table 1 miniaturization projects are grouped under three headings:

- Board Assembly
- Test
- Optoelectronics

Environmental and Medical Electronics projects are grouped under their individual headings.

Table 1 - iNEMI Projects and Associated Research Needs

Current Development Projects	Project Chair/Co-Chair	Research Needs
Board Assembly Projects		
Pb-Free Early Failure	Alcatel-Lucent	Improved methodologies for predicting and verifying electronics hardware reliability
Pb-Free Wave Soldering	Vitronics Soltec	Improve equipment, processes, and materials to increase yield and reliability
Pb-Free Rework Optimization	Celestica	
Solder Paste Deposition	Huawei	
Characterization of Pb-Free Alloy Alternatives	Hewlett-Packard	Better understanding of solder alloy characteristics so that application performance can be predicted more accurately
Board Coplanarity in SMT	Intel	Systems approach for developing assembly tolerances for standards
Test Projects		
Board Flexure Standardization	Hewlett-Packard/Intel	Research to develop tests for new failure modes
Boundary Scan Adoption	Dell, Inc/Cisco	Research to develop new test technologies (including self test capabilities) so that industry can improve results and reduce ongoing investment
Functional Test Coverage Assessment	Intel	
Optoelectronics Projects		
Fiber Connector End-Face Inspection Phase 2	Cisco/Celestica	Active Cables for rack-to-rack applications Evaluate cost impact and technology challenges Optical component integration (hybrid / monolithic) Optical waveguide, backplanes, chip-to-chip, >5 Yrs
Environmental Projects		
Pb-Free Component & Board Finish Reliability	Intel/Alcatel-Lucent	Development of next generation surface finishes for components and boards to improve manufacturability and reliability
Analytical Tin Whisker Test	Delphi	Research to identify an accelerated method to determine the risk of growing tin whiskers

Pb-Free Nano Solder	TBD	Research is needed to develop alternative low-temperature materials and processes for mass electrical and physical interconnection of components
Nano-Attach	TBD	
Eco-Impact Evaluator for ICT Equipment	Cisco/Alcatel-Lucent	Develop an easy to use tool and data base for conducting cradle to grave life cycle assessments of alternative technologies or products
PVC Alternatives	Dell	
HFR-Free High Reliability PCB	Intel	Develop improved materials for PCBs with enhanced environmental, fabrication, mechanical, and electrical characteristics at a competitive cost. These materials also need to meet all other regulatory requirements (e.g. flame retardancy).
HFR-Free PCB Materials	Intel	
HFR-Free Signal Integrity	Intel/Cisco	
Medical Electronics Projects		
Medical Components Reliability Specifications	Boston Scientific	Continued research on increasing the reliability of medical components for life-dependent applications
Medical Reliability for MLCC	Micro Systems Engineering	The preliminary results from NIST for this project suggest the need for similar studies on other medical components

Chapter 3: Research Priorities Summarized by Research Area

Over 90 topics were recommended as research needs in the 2009 iNEMI Roadmap. The following lists are the Research Committee's consensus of the top research priorities in each research area in order of importance, while the remaining priorities are listed in no specific order. This year we have split the Energy and Environmental fields and added Information Technology as a new field of research.

Manufacturing Processes

Today's R&D for electronics manufacturing must be cognizant of the following driving forces in the industry:

- Miniaturization
- Material evolution for improved electrical, mechanical, thermal, reliability and environmental performance
- The constant drive for cost reduction and faster introduction of new products
- The balance between the increasing business complexity of the industry and the increasing need for supply chain integration

Top Research Priorities

- Develop a new model for R&D funding and execution in the global outsourcing environment, including how to identify and conduct research to address shared needs of the industry.
- Develop the infrastructure to produce lower cost, high density interconnect substrates for portable electronic products.
- Improve inspection and test technologies to keep up with density of board designs and component packages.
- Apply innovation to all steps of the process for three dimensional packaging and board assembly.
- Develop DFM rules based on modeling and experiment for acceptance across supply chains.

Additional Research Needs

- Manufacturability using high frequency materials
- In-line test capability for embedded components during substrate manufacturing and PCB assembly
- Faster/widely accepted data stream needed for EMS and NPI DPMO
- Test and Measurement (T&M) as well as a rework capability for optical PCB's needs to be invented
- Wafer level test (input/output couplers) processes for practical test coverage in optoelectronics
- Standards for manufacturing information to allow efficient exchange of information across all parts of the supply chain

System Integration - Technology Integration

As we continue to combine disparate technologies into product architectures, a number of integration challenges face the industry. What once was a multi-board system is now a chip. These rapid reductions in size and increases in speed require new approaches to performance.

At the same time, the business model has changed and the ability to do systems engineering as once was done in a single organization such as IBM or AT&T is no longer possible. This change in structure has led to a number of areas where we cannot achieve the necessary level of optimization because of the new industry structure. These suboptimal solutions can limit our ability to improve performance, cost, size, and reliability.

What may be needed is for research institutes to conduct studies to optimize the next generation of electronics technology, prior to its implementation into industry. Groups such as IMEC, Fraunhofer IZM, Binghamton CAMM, and Georgia Tech PRC may be an example of this evolution. In the following list of Research Priorities we have listed areas where a systems approach may bear most fruit.

Top Research Priorities

- Develop 3D interconnect structures with associated thermal management.
- Optical component integration (monolithic) - add more functionality inside optical sub-system.
- Optimize design tradeoffs in server/netcom printed circuit assembly design to improve performance and manufacturability, while reducing cost. An example would be to focus on reducing the thickness of the PCB to improve cost and manufacturability.
- Require the capability to do system level comparisons (performance, power, and cost) between optical and RF technology from the device level to the system level.
- Understand the true value/performance relationship of ceramic versus organic substrates.

Energy

The 2009 iNEMI Roadmap has identified a number of areas where the energy efficiency of components and systems could be improved based on research. One new portion of the roadmap for solid state lighting focuses on needs and opportunities in this area. Alternative sources of energy have also been identified as an area of importance. Another new roadmap segment on photovoltaics focuses on this one technology.

Top Research Priorities

- Devise means to reduce the cost per watt through increasing efficiency
- Develop LED materials to produce high efficiency light sources for better and more efficient systems
- Improve scientific evaluation of energy alternatives
- Identify new innovative energy sources

The Environment

The focus of identified research needs for the past decade has been on materials and the development and implementation of environmentally friendly alternatives. There is also increasing activity in improving the efficiency of electronics systems as noted above. These activities will continue, but there is an increasing interest in developing evaluation tools and the data required for comparisons such as LCA and in recycling materials at end of life.

Top Research Priorities

- Develop sound, universally accepted scientific methods to evaluate environmental impact of materials.

- Develop a sustainable infrastructure and viable recycled materials market for materials used in new products and other applications.

Additional Research Needs

- Promote industry involvement in policy making on material and energy restrictions to assure better understanding of trade-offs inherent in substitutions
- Develop safety standards and testing for printed inks related to food contact, toys etc.
- Devise standards on disposal/recycling of single use items for printable electronics

Materials & Reliability

Again materials research requirements dominate the R&D needs of the electronics industry. Today's R&D for materials and reliability must be tailored to the following driving forces in the industry:

- Miniaturization
- Mandated material substitution as local and regional legislation restricts the use of materials that are presently standard components within the industry
- Materials evolution for improved electrical, mechanical, thermal, reliability, and environmental performance
- The constant drive for cost reduction and faster introduction of new products
- The balance between the increasing product and business complexity of the industry and the increasing need for supply chain integration

Top Research Priorities

- Develop a substitute for SAC and currently used Pb-free alloys for better area array shock and vibration performance, lower cost, lower assembly temperatures, and reduced copper dissolution issues during rework.
- Develop less expensive package substrates to reverse the trend of increasing substrate costs.
- Establish new materials and structures such as GaN, InGaAs, MEMS, FBAR, carbon nanotubes and molecular electronics for RF frequencies approaching 100 GHz by 2017.
- Develop non solder based interconnects to replace solder for package and PWB level interconnects.
- Develop medical electronics packaging materials and processes that are bio-compatible, RoHS compliant, and compatible with MRI systems.

Additional Research Needs

- Develop halogen free material needed for substrates and PCBs
- Develop second level underfill solution that is reliable, reworkable, and cost effective
- Develop sensor specific material standards; especially for thin films
- Develop better underfill materials for flip chip
- Develop integrated circuits and power transistors capable of operating at Tj's = 175ºC and 200ºC, respectively
- Develop better substrate materials for high frequency applications

- Develop low cost, compact, and reliable dielectric liquids for cooling
- Create efficient thermoelectric cooling technologies for high heat flux applications
- Develop cost effective composite ceramic/organic materials
- Identify improved die attach materials and conformal coatings
- Develop improved mold compounds for SiP - low modulus material that reduce stress on low k structures and reduce moisture adsorption for Pb-free apps and less package deformation
- Integrate innovative nanotechnologies into existing material systems to improve thermal performance capabilities without impact on reliability
- Create thinner, low cost dielectrics in ceramic capacitors
- Create Innovative solutions for larger capacity capacitors (film/Aluminum/Electrochemical) that can be used with multiple Pb-free mounting/rework profiles
- Identify the mechanisms for materials degradation for printed electronics
- Establish a more realistic range of battery attributes (e.g., lower cost, higher quality, improved cycle life, lower environmental impact, improved safety, and higher specific energy) for electronic applications
- Develop high reliability Pb-free die attach solder for Tj>200ºC
- Develop Pb-free solders for flip chip interconnects that support high current densities and prevent electromigration
- Develop hermetic adhesives and sealants to reduce cost of hermetic packaging for Optoelectronics
- Develop waveguide materials and methods for in/on PCB waveguides
    - Optical corner turn
    - In-board modulation/filtering/detection/couplers, etc.
    - Emitter and detector materials
    - Integration of active and passive components

Design

As noted under systems integration and manufacturing technology, there is an increasing need for integrative design tools and processes. The prioritized areas for this research are listed below.

<u>Top Research Priorities</u>

- Low cost solutions for carrying >10Gb/s signal rates between components on a PCB.
- Circuit and bus protocol changes have historically delivered the advances required to increase I/O speed. However, PCB material properties (loss, Dk) need to be scaled to deliver >15Gb/s low cost signaling on existing bus topologies.
- Assembly and reliability failure detection metrologies are predominately destructive tests. High thru-put, large form factor, non-destructive crack, void, and non-wet joint detection capabilities are needed to validate failure mode progression over time so that margin can be removed or added to products as needed.

- In addition to tools that support concurrent design of die, packages, and PCBs for thinner systems, the industry needs tools that support designing for warpage and stiffness to meet solder joint reliability requirements by design. These designs should be smaller and lighter for mobility and thinner for rack mounted servers.

Additional Research Needs

- Develop low cost fine line technology for first and second level scaling of substrates
- Design collaboration tools for use by virtual design teams scattered around the globe, including feedback mechanisms to provide repair and warranty data to designers
- Devise thermal system level efficient turbulence models, simulation methods, and solvers that incorporate radiation, convection, conduction, and radiation
- Improve optical design methodologies for integration of optics and electronics in PWBs
- Identify challenges associated with continued miniaturization across the entire manufacturing process (form, fit)
- Define a strategy to deliver adequate test coverage at the system level. Coverage is dropping due to shrinking board real estate, SOC, POP, and other high-density devices. Verify what will diminish existing coverage levels and define a comprehensive strategy to address it (components, boards, systems)
- Radically improve BGA solder joint reliability, via metallurgy, glues/epoxies, assembly flows, and other strategies
- Develop low cost board-to-board interconnect technology
- Develop low cost PCB/substrate technology for scaling to smaller form factors

Information Management

Information management is again becoming an area of greater interest to the industry, partially driven by the fragmentation of the supply chain.

Top Research Priorities

- Develop infrastructure to support the issuance, tracking, and access of secure identifiers for units within the supply chain to prevent counterfeiting.
- Devise environmental IM systems supporting full material data that are integrated into PDM systems. Use unified environmental information standards and enable tracking of material content throughout the supply chain using the BOM.
- Improve models and tools for collaborative design and feedback from manufacturing.
- Develop IT standards for cross-industry collaboration.

Additional Research Needs

- There is a need for fully automated planning, scheduling, and dispatching, including real-time analysis of factory floor data and logistics, to provide decision support
- Develop an interface of secure IDs with BOM and environmental data management systems to create unit based information systems to prevent counterfeiting
- Develop tools for system-wide optimization across complex supply webs

Chapter 4: Emerging Technologies

This chapter explores newly discovered phenomena and future technologies that may assist in meeting the R&D needs defined in the iNEMI Research Priorities and Thrust Areas. The continuing market demands for product miniaturization, increased energy efficiency, and low cost are being addressed by several newly Emerging Technologies, including Innovative 3-D Packaging, Printable Electronics, Energy Efficient Technologies, and Sensors/MEMs.

Innovative 3-D Packaging will use System in Package (SIP) concepts for next generation ultra-miniature electronic packaging and novel integrated-sensor opportunities. This next generation packaging technology will be interfaced with embedded active and passive components (some fabricated via printable electronics), cooling structures, and advanced interconnect structures in ultra thin silicon and organic type substrate platforms to realize digital, RF, optical, sensing, and biological functions in 2D and 3D architectures. While the introduction of first generation Solid State Illumination (SSI) and Photovoltaic (PV) products is being met with conventional SMT packaging, second generation products will require novel 3-D packaging solutions for more effective heat removal and increased product lifetimes.

Printable electronics are used in several applications for forming embedded passive components which impact SIP and sensor products. Next generation printable products will offer printed active components for logic functions, printed PV for energy generation, and flexible Organic-LED (OLED) devices for light emitting structures.

These emerging technologies will need advanced materials with enhanced electrical, optical/photonic, thermal, and thermo mechanical properties. New and advanced manufacturing processes will be required for cost effective manufacturing. Software to analyze and model the complex interactions arising from, for example, mechanical, acoustic, thermal, chemical, seismic, environmental, optical/photonic, and biological inputs will be vital to realizing high level integration. New types of reliability testing, accelerated life testing, and life cycle assessments will need to be developed to properly assess materials and devices used in new and expanded product opportunities.

3-D Packaging

3-D packages are in large volume production and are used mainly in handheld devices. Smart phones in particular may use 20 CSPs of various kinds, such as stacked die, package on package (PoP), package in package (PiP), and system in package (SiP). These may also be combined with embedded components where functionality dictates. Demand has stayed robust during the 2009 downturn because of increasing functionality demanded by consumers.

Through Silicon Via (TSV) technology is the next wave of development and many companies worldwide are working to bring product to market. Initially being developed for high-value processors such as logic and image sensors, its wider application to memory will be driven by cost trade-offs. Prismark's forecast for 2013 is for 6 million 200mm wafer equivalents.

Consumer drivers for the evolution of 3-D packaging in handheld applications are, as expected, "thin" and "lightweight;" in other words form factor. Performance drivers include minimizing interconnection delay and increasing bandwidth to cope with multi-core processing architectures. Implementation issues derive from the complexity of the structures and the availability of practical design software, thermal management solutions, and test management.

Printable Electronics

The rapid evolution of silicon CMOS technology to address the increasing demand for high-density and functionality has created the opportunity for new lower cost technologies to address low density semiconductor applications. Organic & printed semiconductors address this opportunity and have captured the interest of the electronics industry due to a wide range of attractive properties. These properties include solubility in organic solvents for thin film coatings, and a color of light emission which can be tuned through materials chemistry and formulation. This tunability can facilitate the device engineering to fit specific requirements, such as sensors or radio-frequency identification tags.

Thin film coatings can be applied over large areas and to a variety of substrates, including mechanically flexible substrates. Arrays of organic LEDs and TFTs have been developed, and their feasibility for large-scale manufacturing has been demonstrated for applications in large-area displays along with the corresponding interconnects and embedded passive devices.

Today, low charge carrier mobility, relatively large operational voltage and low dynamic range compared to silicon limit the number of applications envisioned for active devices. On the other hand, the infrastructure for printing passive devices, which includes interconnects for signal and bias distribution, resistors, and capacitors is much more mature.

Active devices generally refer to switching devices such as transistors; however light-emitting diodes, diodes, and photovoltaic devices may also be placed in this category. As indicated previously, printed active devices are in the developmental stage while printed passive devices have been used in high volume consumer electronics products such as mobile devices. The diverse application space makes it increasingly likely that a range of electronic materials will find use; some overlapping with materials used in passive device fabrication, notably insulators and conductors.

Process development and cost, compatibility with the application platforms, the performance of the available electronic materials, and the performance required for entry-level systems will largely determine the application space addressed first by organic and printed electronics.

Development of several new technologies will be critical to the success of printable electronics. These include thin, high resolution photo resist for fine line processing; nano copper and silver coated copper inks with particle sizes of 10-15 nm; the capability to use inkjet technology to print dielectrics between conductors; roll to roll printing for electronic packaging; and printed optical interconnect paths.

Additional innovations needed to support these new technologies will require development of superconductive printed circuits, printable and laser activated materials for conductor deposition and printing, and photo definable dielectric. Establishment of a tool set capable of printing and processing printed electronics will be required for production. Future success in this area may depend on elimination of plated through holes and use of inkjet printable materials that react with dielectric to achieve adequate adhesion. Finally, reliability standards for the next generation of printed circuits must be established.

Energy Efficient Technologies

Solid State Illumination

Solid state illumination continues to make inroads on compact fluorescent lighting just as compact fluorescent lights replace incandescent lighting at an increasing pace. Pending legislation will effectively outlaw incandescent lights in an increasing number of locations because of their inefficiency. Solid state lighting systems have more flexibility in color temperature than fluorescent lights and furthermore do not contain mercury, which is becoming a land fill concern.

The transition to solid state lighting may not be a simple plug-in solution as with compact fluorescents. Although the efficiency is higher than other light sources, the light and heat are both evolved from a very small volume and sophisticated heat-spreading mechanisms are necessary, meaning that supplying the products as luminaries (integrated light fittings) is cost-effective because of the extremely long lifetime of the LEDs. If that is a constraint, then the main initial mass markets will be in new construction and remodeling, rather than straight bulb replacement.

One of the main issues in this area is test standardization (or lack thereof) which makes it difficult for consumers to make an informed purchasing decision.

<u>Photovoltaics</u>

Solar photovoltaics was a $29.6 billion industry in 2008 and electricity generated reached a gigawatt for the first time (Clean Energy Trends 2009, Clean Edge Inc.). However the global downturn has not left this industry unscathed; governments such as Germany (with 50% of the world's installed capacity (Clean Technology Primer, Jefferies & Co, March 2009) are turning down their subsidies, capital is scarce world-wide, and consolidation of the industry is likely before the industry is projected to resume strong growth in 2010, helped by the US Stimulus Plan and other initiatives. The industry is extremely subsidy-dependent because, in most geographical areas, the amortized cost of power from solar installations still exceeds that of grid electricity.

Considerable polysilicon capacity was coming on stream just as the current downturn hit, and this will reduce prices and help to stimulate the upturn as parity with conventional grid power generation is achieved. Conventional silicon continues to dominate the market with approximately a 90% market share, although thin-film systems such as CIGS (copper-indium-gallium-diselenide) and other technologies with potential cost savings are gathering momentum.

Most solar modules are produced in Europe, Asia, and the United States, but an increasing market share is being taken by China.

With increasing involvement of the EMS industry in solar module production and the use of printable materials such as nano-enabled silver inks for interconnects, there is again an interest in test standardization especially in areas such as accelerated life testing. This makes it extremely difficult for new technologies to displace incumbent crystalline silicon because of the decades of use experience.

Sensors and MEMs

"More than Moore" is enabling sensors to become part of the chip or device package. Expanding the offerings of micro sensors and MEMs opens a wide range of new high volume applications for electronics. Micro-Electro-Mechanical Systems or MEMS refers to a broad class of micron to millimeter scale devices that are fabricated using semiconductor manufacturing techniques. These devices differ from most other semiconductor components in several key respects; they are true 3-dimensional structures, they typically have one or more moving parts, and their primary function is to provide some form of physical interface to the outside world. Perhaps more importantly, most current MEMS devices are NOT typically fabricated on a standard (e.g. CMOS) or open source process flow. In many cases, however, direct monolithic integration of MEMS technology with CMOS and other technologies is being widely demonstrated, and this is helping to drive the development of advanced interface components for a variety of applications.

This growth has led to the development of several distinct categories of MEMS devices, including (in approximate order of current commercial importance) print heads (primarily ink jet nozzles), inertial/direction sensors (accelerometers, gyroscopes & compasses), optical MEMS (macro & micro projection displays, switches and attenuators), pressure sensors, microphones, RF MEMs (switches, variable capacitors and filters), timing devices (oscillators and clocks), Bio MEMs (chemical and biological sensors, and "lab on a chip" devices).

Major new categories are also emerging on a regular basis. The fabrication of miniature MEMS microphones and timing devices, for example, have only become significant applications within the last 5 years. This trend is expected to accelerate as MEMS technology enables new features in consumer products such as "smart" cell phone handsets and PDA's, game controllers, and GPS devices.

Although the unique requirements of each application will certainly drive the need for application specific innovation (to be addressed in the 2011 iNEMI Sensor/MEMS Roadmap), several broad research issues are clear. This includes the need for improved understanding of reliability, the development of more broadly compatible MEMS process modules, and new wafer scale hermetic packaging technologies.

The main areas of concern are reliability, process compatibility, and hermetic packaging.

Reliability

As electromechanical devices, the primary failure modes of most MEMS components are mechanical in nature, rather than electrical. The extensive body of knowledge concerning semiconductor failure mechanisms is thus essentially useless in this case, and MEMS technologists have been forced to develop new formalisms (physical models and experimental databases) for each failure mechanism, and often for each class of device.

This problem is compounded by the fact that many "micro-scale" failure mechanisms (e.g. fatigue or sticking of clean surfaces) are substantially different from their "macro-scale" analogues. Perhaps more importantly, access to large bodies of statistically significant failure data is typically only available inside commercial institutions which have little or no incentive to share this information with other researchers.

Cross-category research that aims to identify, study, and model common failure mechanisms is therefore essential. This should include substantial efforts to develop a generic framework that will allow commercial leaders in each category to share critical reliability data and insight without compromising their competitive advantage.

Process Compatibility

A great deal of effort has been directed towards the development of "open source" MEMS processes; especially those compatible with CMOS and other major semiconductor fabrication processes (e.g. GaAs and SiGe). Unfortunately this work has had little commercial impact to date, primarily due to the fact that most high volume MEMS processes have been custom developed by individual manufacturers to fabricate their own specific MEMS devices (e.g. ink jet heads or digital mirror arrays). As a result, low volume "generic" processes have been available for widespread use, while lower cost, high volume processes have not. The need for higher volume/lower cost parts in emerging consumer applications, however, is driving a transition in MEMS manufacturing from 150 mm to 200 mm production facilities, and increasingly to foundries that have historically been focused on "open source" IC processes.

This situation is creating two compelling research needs. The first is for the development of process modules and design rules that can be used by open source foundries and their customers to fabricate broader ranges of MEMS devices. This work should focus on the demonstration of device features and capabilities previously demonstrated on other process flows in well defined modules that can be supported by emerging high volume foundries. This will reduce manufacturing costs across the entire MEMS industry, and create opportunities for other families of MEMS devices in high volume consumer applications.

The transition to 200 mm processes also threatens to substantially increase already high product development costs across the MEMS industry. In order to keep this from stifling innovation, significant research is needed to develop process migration methods that will allow products and processes developed on 150 mm tools to be transferred efficiently to 200 mm tools.

Hermetic Packaging

Packaging processes and costs remain one of the biggest obstacles to the broader commercialization of MEMS devices, which usually require robust truly hermetic packages for high reliability operation. Although significant progress has been made in the development of new wafer scale packaging technologies, additional research is needed in the development of materials and hermetic sealing approaches that will enable low cost high hermeticity cavity packages. This is especially true for the development of high performance packages with reliable hermetic "through via" technology.

Chapter 5: Conclusions

As we move beyond the digital convergence of electronic products, we anticipate the merger of micro and nano, chemical, mechanical, and biological sensors with micro and nano electronics for disruptive innovations in many areas. In some cases the disruptive technologies may also find application by being embedded in conventional product embodiments. As an example, nano-particle fillers may enhance select properties of existing polymeric materials. These applications will likely result in new opportunities to extend the life of current materials and manufacturing infrastructure, enabling them to deliver enhanced device or component functionality. Breakthroughs may take the form of disruptive technologies that supplant existing technologies. Examples of these are quantum computing systems, molecular electronics, and spintronics replacing CMOS semiconductor technology. Others may be radically new applications, such as sensor and drug delivery systems that detect emerging disease in the body or treat existing conditions.

The restructuring of the electronics industry over the last decade from vertically integrated OEMs to a multi-firm supply chain has resulted in 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) as illustrated in the table below, and yet these are the firms least capable of providing the resources.

Table 2: Value Creation in the Supply Chain

VALUE CREATION IN THE SUPPLY CHAIN

	Electronic Materials *$107Bn*	Active Components *$257Bn*	IC Assembly Services *$12.4Bn*	Passive Components *$213Bn*	EMS Assembly *$166Bn*	2007 Finished Equipment *$1,285Bn*
Typical Companies	Sumitomo Bakelite, DuPont, Henkel	Intel, STMicro, LSI Logic	Amkor, ASE, SPIL	Tyco, Molex, AVX, Sharp	Sanmina-SCI, Flextronics, Jabil, Hon Hai	Dell, HP, Cisco, Nokia, Teradyne, Visteon, Siemens
Gross Margin	40%	40%	17%	25%	6%	30%
Operating Margin	10%	10%	8%	8%	2%	8%
R&D	7%	10%	2%	3%	< 1%	3%
Margin Value	$11Bn	$26Bn	$0.2Bn	$17Bn	$3Bn	$103Bn
R&D Value	$5Bn	$26Bn	$0.2Bn	$6Bn	$1Bn	$38Bn
%Total R&D	7%	34%		8%		51%

(Data Courtesy of Prismark Partners)

A partial solution has been the establishment of vertical teams to develop critical new technology while sharing the costs. The entire industrial supply chain, universities, research institutions, and governments need to not only create innovative technologies, but also innovative solutions to financing the R&D base which generates these innovations. These steps must be done in a way that deals with IP in a distributed fashion (rather than the traditional single company approach) so that ROI for the R&D investments are fairly apportioned, thus encouraging sustainable innovation.

Appendix A: 2009 iNEMI Roadmap Overview

Introduction

Electronics is the single largest manufacturing employer in North America and based on the value of manufactured product, it is the second largest manufacturing industry. Electronics is also an essential input to the competitiveness and productivity of many other sectors of the economy. These include the automotive and aerospace industries, which are becoming increasingly reliant on electronics components for their manufacturing and operational activities.

The Electronics Sub Committee (ESC) under the Civilian Industrial Technology Committee of the National Science and Technology Council worked with the private sector to create the National Electronics Manufacturing Initiative (NEMI). NEMI was established to promote collaborative development by industry, government, and academia of technology and infrastructure required to facilitate the manufacture of new high-technology and electronic products in North America. This initiative, now industry-led and open to all in the electronics industry, seeks to meet industry goals of improved profitability and global competitiveness.

In 2004, NEMI changed its name to iNEMI (International Electronics Manufacturing Initiative) to reflect the growing global impact on members' supply chains and the need for an ever increasing global view of the roadmap participants. A proactive effort was made to recruit more international members in the roadmap effort and has resulted in participation from 17 different countries.

The structure of iNEMI borrows three successful elements from the Semiconductor Industry Association (SIA) and SEMATECH; a roadmapping and technology planning process driven by major end users; a council made up of executives/senior managers of electronics manufacturers; and a focus on results, particularly on infrastructure development and deployment. Unlike SEMATECH, however, iNEMI relies on a decentralized organization to leverage existing resources within industry and other consortia. The fundamental activities of iNEMI include the creation of electronics manufacturing technology roadmaps and the implementation of projects that develop and promote the necessary supply chain infrastructure.

iNEMI Roadmap Process

The 2009 International Electronics Manufacturing Technology Roadmap is driven by the five product sectors defined in Table 3. Each product category is characterized by key cost, performance, and technology drivers which were developed by OEMs with a market vision in each sector. The leading electronic systems manufacturers are basing their strategic planning for new products on the assumption that the electronics infrastructure will develop and implement the technology to meet these key drivers. These drivers were then used to develop individual technology roadmaps that identify needed technology. The 2009 iNEMI Roadmaps were developed by nineteen Technology Working Groups (TWGs) and one ad hoc RFID-ILT group in response to inputs from representatives of OEMs in five Product Sectors. These twenty-five groups included more than 550 individuals recruited from over 250 private corporations, consortia, government agencies, and universities from 17 countries. The Product Sectors are defined in the following section.

Major roadmap meetings were held in Orlando, Florida; Munich, Germany; and Santa Clara, California; leading to the iNEMI 2009 North American Roadmap Workshop, held at iNEMI HQ in Herndon, VA, on May 14, 2008. The purpose of the workshop was to present the findings of the Roadmap Committee to a wider audience. Additional international workshops were held in Leuven, Belgium on June 18, 2008 and Shanghai, China on July 28, 2008. Workshop participants from industry, academia, and government were given the opportunity to comment on the document and make recommendations on the findings. Maximum flexibility was given to the groups to identify and pursue any and all topics they felt were relevant to the iNEMI goals. Also each TWG chair was asked to update and verify the data provided in their 2007 Roadmap chapter with current industry status.

Table 3: Product Sectors of the 2009 iNEMI Roadmaps

Emulator	Characteristics
Consumer / Portable	High volume consumer products for which cost is the primary driver, but also driven by size and weight reduction. Includes hand held and battery-powered.
Office / Large Business Systems	Products which seek maximum performance from a few thousand dollar cost limit to literally no cost limit
Automotive Products	Products which must operate in an automotive environment
Netcom (Network, Data, Telecom)	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 highly reliable environment

All sectors are looking for smaller and lighter products with increased function and performance that can reliably operate in a wide range of environments. The key variables for each of the sectors are the time to market and price that the market will bear. The following paragraphs summarize the key drivers by product sector.

Portable/Consumer Product Sector Drivers

- High volume products for which cost is the primary driver, such as televisions, portable radios, CD players, and low-end portions of the cell phone and personal computer markets
- Reducing total supply chain cost is a key driver and has led to a distributed supply chain
- Hand held, battery-powered products driven by size and weight reduction
    - Typical products are high-end cell phones, palmtop computers, PDA's, and wireless email or short messaging devices
    - The key elements are:
        - Packaging, materials, and processing technology
        - Supply chain optimization
        - Design architecture
    - This product sector is a growth market with a demand for increased functionality
    - Increased energy storage and power efficiency are gating increased functionality
    - The need for rapid introduction of complex, multifunctional new products has favored the development of functional, modular components
    - Modular design increases the flexibility and shortens the product design cycle, placing the technology risk and test burden on the producers of the modules

Office/Large Business Product Sector Drivers

- Maximum performance within a few thousand dollar cost limit to high dollar products such as low-end servers and high-end personal computers, both desktop and laptop
- Stable market with demand for increased processing and storage performance

- Products have migrated towards legacy-free products
- Supply chain optimization becomes critical for cost control
- A continued focus on shorter, seasonal production cycles
- High-end products for which performance is the primary driver, characterized by very high performance, high clock frequency, high reliability, and high power density, such as routers, communications switches, mainframes, scientific computers, servers. and cellular base stations
- The market has seen significant erosion particularly in telecommunications and long haul fiber optic systems
- Packaging and design technology has changed from proprietary to commercial
- Materials and component cost reduction are increasingly important
- Material changes for increased performance is a gating item
- Cost-effective communications bandwidth is a key driver with uncertain cost-performance trade-offs between copper, optical, and wireless technologies

Automotive Product Sector Drivers

- Products that must operate in automotive environments
- Extreme reliability needed to meet warranty requirements and mission critical applications
- Sensor and actuator technology are important drivers for new applications
- Product life-cycle and design cycle are significantly longer than for other sectors
- Need to respond quickly to environmental legislation and customer specifications is driving a faster design cycle
- Conversion of analog sensor components to digital will require a systems architecture change to a system that can distribute power at a higher voltage and control commands at a high frequency on a single wire
- Typical products require both forward and backward traceability as well as stringent control of material and process change

Netcom Product Sector Drivers

- Networking, Datacom, and Telecom products
    - Small Office/Home Equipment, including low-end switches and routers, modems, WLAN cards
    - Enterprise Equipment, including mid-range switches and routers, PBXs, VoIP phones
    - Service Provider Equipment, including wireless base stations, central office switches, cable modem termination systems, core routers
- This product emulator group spans a hardware product portfolio from consumer access to long-haul transport
- Addresses system capacities ranging from kilobits per second to terabits per second
- Utilizing a diverse set of technologies, including wireless, wired over copper, and wired over optical

- Converging data and voice networks
- Sustained need to offer more functionality, performance, and capacity, while keeping costs at bay

Medical Product Sector Drivers

- Products that require high reliability
- Typically these products require forward and backward traceability as well as stringent control and qualification of material and process changes
- Encompasses implantable medical devices, information technology used for patients' records, medical diagnostic tools, and monitoring devices
- Curbing the ever increasing costs of healthcare
- Explosion of wireless sensing for remote healthcare monitoring
- Growing need to utilize telemedicine to curb healthcare cost

Appendix B: iNEMI Overview

iNEMI History

NEMI grew out of two separate efforts to recapture American leadership in electronics manufacturing. In 1993, the American Electronics Association (AEA) conducted a study (led by Mauro Walker, Senior Vice President and Director of Manufacturing at Motorola) on the US electronics manufacturing infrastructure. Based on the results of this study, AEA recommended that the Administration create a national initiative in electronics manufacturing, focusing on strategic electronic components and electronics manufacturing systems. The second effort originated with the National Science and Technology Council's Electronics Subcommittee (ESC), chaired by Lance Glasser, Director of the Electronics Technology Office at the Defense Advanced Research Projects Agency (DARPA).

In 1994, Dr. Walker and Dr. Glasser teamed up to initiate the creation of NEMI. Over a 10-month period, they met with representatives of government, executives from many of the industry's largest manufacturers of electronic home and business products, and executives from the suppliers that manufacture the constituent materials, components, and subassemblies. The first NEMI Roadmap was produced in 1994 and NEMI was incorporated in January, 1996, later to become iNEMI in 2004.

iNEMI Mission

iNEMI's mission is to identify and close technology gaps, a goal which includes the development and integration of the electronics industry supply infrastructure.

iNEMI Organization

The iNEMI Board of Directors (see Figure 1) defines the policy, strategy, and direction of iNEMI; has operational responsibility for the iNEMI organization; is responsible for the iNEMI staff and reviews the performance of all projects and programs.

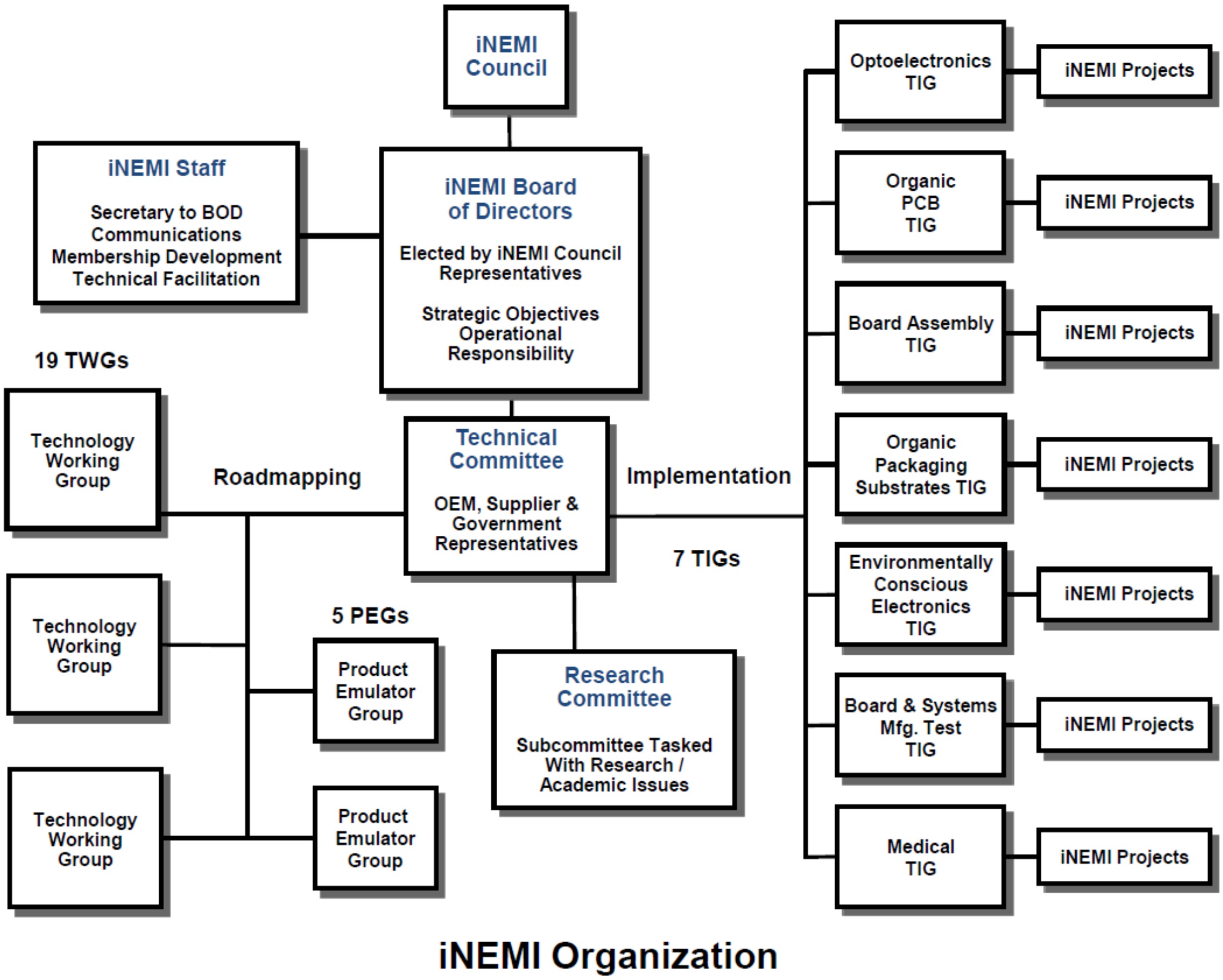
The iNEMI staff includes the Executive Director/CEO and a small support staff. This group provides the administrative support for the organization, including coordination of meetings, maintenance of data bases, publishing and distribution of documents, providing assistance to the Technical Committee, and performing other necessary administrative duties.

The iNEMI Technical Committee facilitates and coordinates all iNEMI technical activities and is comprised of OEM and supplier representatives as well as government, university, industry association representatives, and iNEMI Staff. The Technical Committee reports to the Board of Directors and Co-chairs of the Committee are ex-officio members of the Board. The Technical Committee develops and maintains the iNEMI Technical Plan and Research Priorities documents; approves development and deployment of projects; appoints Technology Integration Group and Project Chairs; and organizes, manages, and publishes the biannual iNEMI Roadmap.

The Technology Working Groups (TWGs) work with the Director of Roadmapping and are responsible for developing the technology roadmap, identifying the technology gaps, and recommending key technical areas for the TIGs to address. TWG membership is open to the entire industry, worldwide. Currently the work of some 19 industry groups, along with 5 Product Sector Chairs is facilitated by the Director of Roadmapping.

The Technology Integration Groups (TIGs), currently seven in number, report to the Director(s) of Planning and are responsible for developing the Technical Plan, identifying technology needs, and establishing projects to address them. TIG membership is limited to iNEMI members.

Figure 1: iNEMI Organization Chart



iNEMI Deliverables

iNEMI activities produce five key resources and benefits for global electronics manufacturers:

- Roadmaps showing a projection of the future needs of the electronics industry
- A list of identified gaps in the manufacturing infrastructure
- Stimulation of R&D projects to fill these gaps
- Integration projects designed to eliminate these gaps
- Encouragement of standards activities to speed the introduction of new technology

Standards

In the course of the project activities, iNEMI work often affects existing standards or requires new standards to be written. Each project considers standards activities required before it is formally approved by the

Technical Committee. However, iNEMI does not choose to release or maintain standards. Instead, iNEMI has developed relationships with existing standards organizations, such as IPC, EIA and IEEE, to develop, release and/or influence standards of interest to iNEMI members.

Further Information

For availability of referenced documents (such as the latest iNEMI roadmap or Annual Report) and other information on iNEMI, please contact iNEMI at:

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Appendix C: Glossary

3D – Three Dimensional

ADC – Analog to Digital Converter

AEA – American Electronics Association

AESF – American Electroplaters and Surface Finishers Society, Inc.

AMI – Acoustic Microscopy Imaging

AMS – Analog Mixed Signal

AOI – Automated Optical Inspection

ARC – Auto-refrigerating Cascade

ASIC – Application Specific Integrated Circuit

ATE – Automatic Test Equipment

Atm – Atmosphere

ATP – Advanced Technology Program

AXI – Automated X-Ray Inspection

B – Billion

B2B – Business to Business

BEOL – Back End of Line

BGA – Ball Grid Array

BiCMOS – Bipolar Complementary Metal-Oxide-Silicon

BOM – Bill of Materials

CAAGR – Compound Average Annual Growth Rate

CAD – Computer Aided Design

CAF – Canodic Anodic Filament

CAMX – IPC Computer Aided Manufacturing Standard

CAPEX – Capital Expenditures

Cd – Cadmium

CD – Compact Disk

CDP – Carbon Disclosure Project

CHF – Critical Heat Flux

CIGS – Copper Indium Gallium Diselenide

CM – Contract Manufacturer

cm^2 – centimeter squared

CMOS – Complementary Metal Oxide Semiconductor

COTS – Components Off The Shelf)

CrSi – Chromium Silicate

CrVI – Chromium

CS – Component Supplier

CSP – Chip Scale Package

CTE – Coefficient of Thermal Expansion

Cu – Copper

DfA – Design for Assembly

DfE – Design for the Environment

DfM – Design for Manufacturing

DfT – Design for Test

DIMM – Dual In-Line Memory Module

DNA – Deoxyribonucleic Acid

DPMO – Defects Per Million Opportunities

DRAM – Dynamic Access Random Memory

DT – Design Technology

E Field – Electric fields, created by voltage and measured in volts per meter

ECE – Environmentally Conscious Electronics

EDA – Electronic Design Automation

EDI – Electronic Data Interchange

EIA – Electronics Industries Association

EICC – Electronics Industry Citizenship Coalition

EICTA – European Information & Communication Technology Industry Association

EK – Electro-Kinetic

EMI – Electromagnetic interference

EMS – Electronics Manufacturing Services

ENIG – Electroless Nickel Immersion Gold Plating

EPA – Environmental Protection Agency

ESD – Electrostatic Discharge

EU – European Union

EuP – The Directive on Eco-design of Energy Using Products

FBAR – Film Bulk Acoustic Resonator

FBGA – Flip Ball Grid Array

FCM – Few Chip module

FDSOI – Fully Depleted Silicon-On-Insulator

FIS – Factory Information Systems

GaAs – Gallium Arsenide

GaN – Gallium Nitride

Gb – Giga bit

GHG – Green House Gas

GHz – Giga Hertz

GIDL – Gate-Induced Drain Leakage

H Field – Magnetic fields, induced by alternating current (AC) and measured in gauss or Tesla

HAMR – Heat-Assisted Magnetic Recording

HASS – Highly Accelerated Stress Screens

HDI – High Density Interconnect

HDTV – Hi Definition Television

HEV – Hybrid Electric Vehicle

Hg – Mercury

High k – High Dielectric Material Used in Capacitors For Higher Value Capacitance

High n/sq – High ohm per Square

HP – High Performance

I/O – Input / Output

IC – Integrated Circuit

ICT – Information and Communication Technology

IEEE – Institute of Electrical and Electronics Engineers

IM – Information Management

InGaAs – Indium Gallium Arsenide

iNEMI - International Electronics Manufacturing Initiative

INSIC – International Storage Industry Consortium

IPC – Institute for Interconnecting and Packaging Electronic Circuits

IPP – Integrated Product Planning

IPTV – Internet Protocol Television

IT – Information Technology

ITRS – International Technology Roadmap for Semiconductors

ITS – Intelligent Transportation System

JIETA – Japan Electronics & Information Technologies Industries Association

KGD – Known Good Die

KW/cm^2 – Kilo Watts per Square Centimeter

LAN – Local Area Network

LBMPS – Large Business Machine Product Sector

LCA – Life-Cycle Analysis

LCD – Liquid Crystal Display

LED – Light Emitting Diode

LGA – Land Grid Array

LOP – Low Operating Power

Low k – Low Dielectric Constant Materials Used with Copper Interconnects for Lower Delays in Integrated Circuits

LSTP – Low Standby Power

LTCC – Low Temperature Co-Fired Ceramic

M&S – Modeling and Simulation

MEMS – Micro-Electro-Mechanical Systems

MIMO – Multiple-Input-Multiple-Output

MLC – Multi-layer ceramic

mm – Millimeter

MPU – Micro-Processor Unit

MRAM – Magnetic Random Access Memory

MTBA – Mean Time Between Failures

N^2 – Nitrogen Gas

NAS – Network Attached Storage

NEMI – National Electronics Manufacturing Initiative

NGO – Non-Government Organization

NiCr – Nickel Chromium

NIST – National Institute of Standards and Technology

NNI – National Nano-technology Initiative

NPI – New Product Introduction

ODM – Original Design Manufacturer

OE – Optoelectronics

OEM – Original Equipment Manufacturer

OLED – Organic Light Emitting Diode

OPEX – Optoelectronics Expenditures

Pb – Lead

PBB – Polybrominated Biphenyl

PBX – Private Business Exchange

PC – Personal Computer

PCB – Printed Circuit Board

PDA – Personal Digital Assistant

PDM – Product Data Management

PE – Power Efficient

PEG – Product Emulator Group

PET – Positron Emission Tomography

PIDS – Process Integration and Structures

PIP – Package in Package

PLIM – Product Life-Cycle Information Management

POP – Package on Package

PTF – Polymer Thick Film

PTH – Plated Through-hole

PV – Photovoltaic

PWB – Printed Wiring Board

R & D – Research and Development

RASS – Reliability-Availability-Serviceability-Scalability

REACH – Registration Evaluation Authorization and Restriction of Chemicals

RF – Radio Frequency

RFIC – Radio Frequency Integrated Circuit

RoHS – Reduction of Hazardous Substances

FRID – Radio Frequency Identification

RPTV – Rear Projection Television

SAC – Tin Silver Copper Solder Alloy

SAN – Storage Area Network
SCM – Single Chip module
SECs/GEM – Semiconductor Equipment Communications Standard (SECS) and Generic Equipment Model (GEM) standard
Si – Silicon
SIA – Semiconductor Industry Association
SiGe – Silicon Germanium
SIP – System in Package
SMP – Symmetrical Multi-Processor
SMT – Surface Mount Technology
SOA – Semiconductor Optical Amplifier
SoC – System on Chip
SOHO – Small Office Home Office
SOI – Silicon on Insulator
SPE – Solid Phase Epitaxy
SPM – Standard Process Modules
SSI – Solid State Illumination
STR – Semiconductor Technology Roadmap
TaNx – Tantalum Nitrate
TFT – Thin Film Transistor
Tg – Glass Transition Temperature
TIG – Technical Integration Group
TIM – Test, Inspection and Measurement
TIM – Thermal Interface Materials
TMR – Tunnel Magnetic Resistance
TSV – Through Silicon Via
TWG – Technical Working Group
UBM – Under Bump Metallurgy
UF – Micro-Farad
UL – Underwriters Laboratory
µm – Micron
UTB – Ultra-Thin Body
UUT – Unit Under Test
VCSEL – Vertical Cavity Surface - Emitting Laser
VoIP – Voice over Internet Protocol
W/cm^2 – Watts per square centimeter
WiMAX –Worldwide Interoperability for Microwave Access
WLAN – Wireless Local Area Network
WLP – Wafer Level Packaging
XML – Extensible Markup Language
ZT – Dimensionless Thermoelectric Figure of Merit

Appendix D: Contributors

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