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To Dr. David Cranmer, Deputy Director, NIST MEP

To contextualize our response to the NIST MEP RFI and to give greater meaning to our response, first we will provide some background information about the respondents and the process we used to gather the information provided. Then we will answer the five questions you have posed.

We have based our response upon information gained during the roadmapping process that produced the *2016 Integrated Photonic Systems Roadmap* (IPSR). This roadmap was built upon the foundation of the NIST AMTech funded *Photonic Systems Manufacturing Technology Roadmap* (PSMR). It employed the processes and lessons learned from previous roadmap developments by the two Integrated Photonic Systems Roadmap Partners: The International Electronics Manufacturing Initiative (iNEMI) and the MIT Microphotonics Center. Although this information is specific to the electronics manufacturing sector, the fundamental issues also are relevant to SMEs attempting to join the supply chains that support other technology sectors.

In spite of the fact that most companies and individuals are "oversubscribed" in their daily jobs, 700 professionals from 16 countries, representing 254 organizations, came together to create this roadmap. Through sharing, analyzing, debating, and reviewing, this diverse team contributed to the initial roadmaps for the photonics industry.

As Principal Investigators of the PSMC Roadmap, we committed to play a major role in the Obama Administration's Institutes for Manufacturing Innovation and now in the AIM Photonics Institute to develop a strong integrated photonics manufacturing base. We also are committed to aiding the NIST MEP program in charting its future direction, based upon insights we gained during the roadmapping process. In that spirit we submit our response to your request for information.

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Response to NIST MEP Request for Information

Table of Contents

Background Information

This response for information has extracted information learned while preparing the 2016 Integrated Photonic Systems Roadmap and the NIST AMTech funded 2015 Photonic System s Manufacturing Roadmap. These two roadmaps focused on enabling manufacturing technology for integrated silicon photonic systems. Appendix A of this response describes the process used to prepare these roadmaps. In addition the 2015 iNEMI Research Priorities Document has discussed the technology needs for additional emergent, enabling manufacturing technologies including:

- Heterogeneous Systems Packaging
- Integrated Silicon Photonics
- Printed and Flexible Electronics
- Extremely Low Power Systems
- Highly Efficient Energy Conversion
- Design for Sustainability
- Sensor Systems
- Nano Electronics
- Organic Light Emitting Diodes (OLED).
- 30 Manufacturing

Manufacturing USA has established Manufacturing Innovation Institutes for many of the emerging technologies listed above. We believe that the MEP needs that we have identified for Integrated Silicon Photonics will also be needed by these other emergent technologies and their related institutes.

The acknowledgement chapter of the IPSR roadmap identifies the 254 organizations from 32different categories in the integrated photonics supply chain that came together to produce this roadmap. The IPSR Leadership Team analyzed which portions of this supply chain were dominated by SMEs and what their technical and workforce development needs would be required to succeed in establishing and expanding their businesses in a new and developing enabling technology. These requirements are summarized in the following section, Situation Analysis.

Situation Analysis

In analyzing the SME firms involved in the roadmap, we found that in general they fell into two developmentally different categories:

- **Start-up firms that had a technical concept often at the system level for a potential new technology:** These firms often have limited financial resources, limited knowledge of their potential market and potential business model, uneven management experience, and little concept of the cost objectives needed to succeed in the emerging market. They often are trying to enter the market at the top of the supply chain and appear to have reluctance and little understanding of how to build a supply chain.

- **Existing Firms with Latent Technology Competencies.** These firms do not recognize that they have valuable process or manufacturing skills needed to establish a new enabling manufacturing technology. They often are reluctant to take the risk of applying their latent competencies to a new market or application. These firms are not at the top of the supply chain and often are focused narrowly in a single supply chain. In the past large vertically integrated firms that were lacking in needed competencies would seek them out. This process established a number of current large manufacturing equipment, component manufacturers, and material firms in the supply chain. Today MEPs need to facilitate this process of linking firms with latent competencies with opportunities in order to become part of the supply chain for emerging Technologies.

Question 1. Key Problems and Issues

Among the key problems and issues facing small U.S. manufacturers, their competitiveness, and opportunities for growth in the near-term (one to two years) include the following: Established SMEs often lack an awareness of the impact that today's dramatic changes in technology will have on their businesses. They do not recognize the impact that the following changes will have on their current business and markets:

- Renewable energy
- Demand for increasing product capabilities at reduced cost
- Globalization
- New enabling Manufacturing Technology

In order to survive, an existing SME manufacturing firm must be cognizant of these changes and must react to them. The key issue for start-up manufacturing technology firms is how to identify and assess volume-cost targets that they must achieve to displace existing technologies and to create sustainable growing businesses.

Mid-Term (three to five years) concern centers on establishing a plan to transition to a business model that is sustainable in light of the anticipated market and technology changes.

Long-term issues related to more than five years focus on developing business practices that can anticipate changing opportunities and risks.

Question 2. Critical Manufacturing Technologies

SMEs require not only critical manufacturing technologies, but also the know-how to access them. We have learned that they do not necessarily need to develop the technologies themselves; we found as we analyzed critical advanced manufacturing technologies that there were several characteristic needs of the SME firms near the top of the supply chain that relate not only to technical expertise, but also to access to important resources, rated short -term (ST), mid-term (MT), and long term (LT) needs: These resources already may have the technologies available for the SMEs to access.

Advanced Manufacturing Technology and Resources	Related Manufacturing or Technology Readiness Level
1. Rapid prototyping of new concepts or products (ST).	1a. Advanced readiness, not well know. Many distributed resources exist, but not well advertised.
2. Qualified sources for critical manufacturing processes such as plating, micro machining and assembly, polishing, testing (ST).	2a. Advanced readiness, not well known or advertised. Many distributed resources exist, but not well advertised.
3. Practice facilities supported by local governments (ST).	3a. Starting to build capability. This is a new concept, just initiating in MA now.
4. Help in linking SME equipment developers to High Volume Manufacturers (MT).	4a. Advanced readiness and capabilities, not well known or advertised State and regional governments should help facilitate.
5. Training SMEs to identify photonics sensing applications (MT).	5a.Not aware of specific activities, roadmap is a good way to become aware of expected applications and needs.

The most effective ways to deliver information about advanced manufacturing technologies to SMEs, and at the same time enable them to learn how to enter the supply chain, are through local, regional, and state economic development and higher education programs. SME's should be engaged and recruited to host targeted projects at their facilities. Students or trainees, under the joint supervision of company supervisors and academic adviser, would execute projects. SME's should be engaged by inviting them to use the advanced capabilities in education and practice facilities in order to explore new product concepts, to learn about capabilities of novel equipment and processes, and to train and retrain their employees.

Question 3. Technologies and/or Business Models to Support Supply Chain Development

As noted in the introduction to this section, we have learned that development of the supply chain is a critical issue in developing any new enabling manufacturing technology, and we have addressed this need extensively in our roadmaps. In the case of integrated silicon photonics, one of the major supply chain issues is to educate the supply chain that a cost effective integrated supply chain needs to be developed leveraging the electronics supply chain wherever possible. MEP activities that could contribute to an SME's business model development and could aid in building cost effective supply chains are:

- Aid SME managers to identify their “Latent Competencies.”
- Provide local/regional lists of SME Supply Chain capabilities. Developing this list will encourage firms to identify their technology capabilities.
- Encourage supply chain firms to strengthen the content of the capability descriptions on their web sites.
- Train the work force of SME on/for emerging manufacturing processes and technologies.
- Help SME’s engage to host targeted education and training projects at their facilities. Students or trainees, under the joint supervision of company supervisors and academic adviser, would execute projects.
- Invite SMEs leaders to use the advanced capabilities in Education and Practice Facilities in order to explore new product concepts, learning about capabilities of novel equipment and processes, and to (re) train their employees.

Question 4. Potential Business Services and Information Services to Support SME Supply Chain Development

We have identified that for existing SME firms there are a number of complementary business services including business education, business services, and information services that need to be provided to reduce their risk and increase the possibility of success when they enter new markets or applications.

- A one-term, broad-picture course on business issues, cost, and marketing.
- Cost modelling and cost accounting training.
- Learning curves and the impact of volume on the cost of manufacturing.
- Using web resources to obtain information.
- Credentialing the workforce on new manufacturing processes.

Question 5. Other Technologies or Services to Enhance Global Competition

The IPSR leadership team has had global experience in networking and understanding global supply chains including transient shifts and migrations of technology. All have had experience in introducing new technology into manufacture and in creating a world class supply chain to support the new technology. SME firms often lack these skills. When new enabling manufacturing technologies are developed, it is critical that a firm or subset of firms guides the development of a supply chain. Consequently we recommend general education on developing supply chains for new enabling technologies and technology clusters.

Conclusions and Recommendations

Discovering and Commercializing "Latent Competency"

"Latent competencies'" are knowledge, experience and skills that provide unanticipated-critical-path-value to developing commercial markets. Education and training lead the SME needs. With little capital to invest in adapting to new technology, the SME would benefit from roadmap briefings on markets and opportunities where they could add value and create revenue and jobs. We recommend webinar series and regional industry manufacturing days to inform SMEs of the new technology and its commercial timelines. To be successful, these events should be two-way exchanges that result in i) discovery of opportunities to redirect the embedded competency in an SME to new, profitable targets, and ii) linkage to supply chain vendors and customers.

Creating Local Commercial Partnerships.

The infrastructure component to developing "latent competency" is establishment of the equivalent of a categorized "yellow pages" of supply chain needs and SME competency. For AIM Photonics we envision an I-90 Corridor Development Program that works with regional Massachusetts constituencies to 'discover' value chain opportunities. This value is built initially on unrelated revenue bases, but it is developed with roadmap education of companies regarding technology supply chain needs and applications. The Massachusetts industrial foundations in optics, fiber communications, semiconductor packaging and precision machining and assembly will be important for technology nodes for AIM. The Massachusetts leadership in applications to medicine, security, mixed signal processing, sensors, design and new materials, for example, can be developed into leading commercial directions. Creating local commercial partnerships for SMEs can provide a foundation for economic development that is built on the competencies in which they have a strategic advantage.

Education and Practice Factory Facilities

Education and practice factory Facilities are factory floor replicas that house state of the art manufacturing tools. Such on-campus facilities must provide a place for students and professionals to participate in, and practice, the real-time operation of a production system as part of their education and training. The education and practice factory presents a four-fold value proposition: i) education of students and retraining of professionals in manufacturing design and process flow; ii) certification of competency in area and tools; iii) low-cost test and prototyping and early scale-up; and iv) employee and customer training. The AIM Academy Roadmap team is developing a critical path concept for amplification of 'latent competency' residing in SMEs. If the practice facility concept provides education, prototyping and demonstration capabilities, in the Commonwealth of Massachusetts, for example, a string of specialized and collaborating installations along I-90 could be very effective in developing an industrial base and its associated workforce from existing talent. Appendix B of this response summarizes the disciplines and skills to be developed through training and education.

Community Building

Business, technology, and job transactions utilize informal organizational structures to exchange information, needs and opportunities. This value point underscores the need to have "SME hub partners" involved in reviewing Center R&D project and state cost sharing opportunities. The AIM Massachusetts Supply Chain Forum engaged the Commonwealth, SMEs, large component and systems companies, MIT and community colleges in introductory presentations of markets, needs and capabilities.

Appendix A: IPSR Roadmapping Process

The IPSR roadmapping process is based on the iNEMI/ITRS process. This 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 Delphi technique1, developed by Dalkey and Helmer at the Rand Corporation, is a widely used and accepted method for achieving convergence of opinion concerning real-world knowledge solicited from experts within certain topic areas. 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 IPSR roadmapping team implicitly identify areas for innovation and the utilization of disruptive technologies.

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 such as integrated silicon photonics, to ensure the continued growth of the global electronics industry. 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 full systems engineering within 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 collaboration is required to achieve the necessary level of optimization. Suboptimal solutions can limit our ability to improve performance, cost, size, and reliability.

This roadmap is the product of numerous large and small meetings between industry, government, and academia that took place over a period of eighteen months. The roadmapping process engaged scientists, researchers, and executives from throughout the supply chain in the study and prioritization of the challenges facing the manufacture of low-cost high-volume integrated silicon photonics.

Six Product Emulator Groups (PEGs) and nine Technology Working Groups (TWGs) developed the 2016 Roadmap. These groups included 700 participants from 254 private corporations, consortia, government agencies, and universities in sixteen countries. The following figure illustrates in red the five groups that originally developed this roadmap. We have established four new groups shown in blue that are at various stages in developing their first roadmap. These additional groups will increase the completeness of our technical planning

[1] Dalkey, N. C., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science*, *9* (3), 458-467.

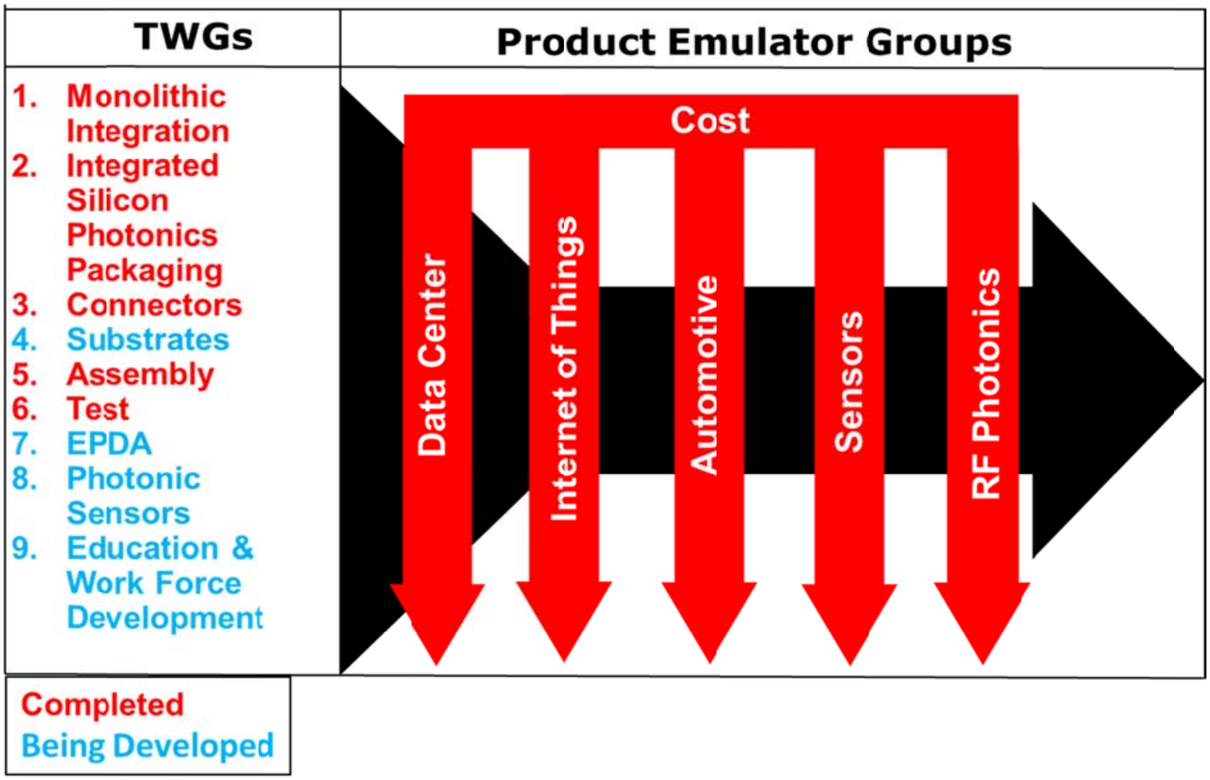

Figure 1. TWGs and Product Emulator Groups

The IPSR Roadmapping Organization consisting of the members of the IPSR Leadership Committee, Product Emulator Groups from three sectors of the photonics industry, and the members of five Technology Working Groups (TWGs) was assembled to identify the key technology and infrastructure needs of the global integrated silicon photonics manufacturing industry. The Roadmapping Organization was spearheaded by industry. The document is divided into four independent (but complimentary and consistent) technology roadmaps on topic areas deemed important by the IPSR Leadership Group. Each technical roadmap was prepared by a TWG and has associated with it one or more Gaps, Showstoppers, and Recommendations. In future roadmaps we anticipate expanding the number of TWGs. The IPSR is committed to improving the roadmapping process; to identifying disruptive technologies; to finding solutions to current needs; and to help anticipate new applications and products.

The structure of the roadmaps and the editing of this document were led by the Director of Roadmapping. An effort was made to keep the roadmapping process as open as possible and to include all constructive inputs as part of the final roadmap document. The process was opened to global participation and review, including Europe and Asia. Each technology roadmap, although written as a stand-alone section, inter-relates with other topics referenced in this document and may also refer to other industry roadmaps.

Each PEG (with TWG feedback) was asked to complete an “Excel” spreadsheet, consisting of a quantified roadmap of key attribute needs for each of the four specific years (2015, 2017, 2020, 2025,). The TWG Chairs were also challenged to forecast potentially disruptive technologies that might appear in the 2018 -2025 time frame – in order to focus on the most strategic aspects of the roadmap.

Major IPSR roadmap meetings, each attended by approximately 125 participants were held in Cambridge Massachusetts in April 2014, November 2014, April 2015, December 2015, and June 2016. One purpose of these workshops was to present the developing findings of the Roadmap Organization to a wider audience for input. 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 IPSR goals. Each TWG chair gathered needs and priorities from a variety of experts. Each roadmap lists some of the experts who participated.

Members of the IPSR Leadership Committee and/or the IPSR Executive Advisory Board carried out a technical review of each chapter draft. Robert C. Pfahl, IPSR Director of Roadmapping, edited the final written document

Appendix B. Source Material on Training and Education

Manufacturing activities require education and training in a series of disciplines and skills. The tables below provide some guidance on these needs from the perspective of the 2016 ITRS Roadmap.

Academic Education Requirements	
Knowledge Required	Content
Basics of materials	Properties of metals, polymers, ceramics. Properties are Young's modulus, Poisson's ratio, melting point, Tg, strength, ductility, etc.
Mechanics of Materials	Bending, thermal expansion, Hooke's General Law, thermal conductivity, corrosion, water absorption
Chemical and electrical properties of materials	Dielectric constant, loss tangent, effect of water, etc. solubility in water and common liquids, effect of UV and other environments on properties. Surface properties, adhesion, oxides, etc.
Processing of materials	Extrusion, rolling, casting, forging, injection molding, compression molding, transfer molding, etc.
Basic chemistry of organics	Epoxies, their structure, curing properties mechanical and chemical properties pre and post cure as well as their processing characteristics. Acrylates and their properties, both pre and post cure with UV and thermally. Also urethanes, silicones, liquid crystal polymers, etc.
Standard joining methods	Typical joining methods and their pros and cons; welding, soldering, adhesives including epoxies, acrylates. CiO_2 to SiO_2 bonding, plasma surface prep, etc. (Harmon and Manko have good books on metal to metal bonding and soldering.)
AC/and DC electricity & electronics	Voltage, current, frequency, power, electronics, transformers, capacitors, inductors, transistors, ions, conductors, semiconductors, non-conductors
Maxwell's Equations in integral form	Relation to electricity, magnetism, radio signals, light signals, electromagnetic spectrum, properties vs frequency, interaction with matter vs frequency.
Signal transmission and processing	Modulation methods, signal processing, impulse response, propagation in free space, over conductors, through waveguides including fiber and in media in general.
Basic programming	Stored program concept, self-changing, iteration, solution seeking, etc.
Computer controlled equipment and microprocessors.	Computer control of machinery, networking, program storage, program management, etc.
Basics of Statistics	Gathering data, maintaining integrity, managing data bases, standard deviation, mean, median, Parato charts, statistical process control, control limits, Cp, Cpk, etc..
Measurements	Basics of mechanical, electrical, optical metrology.
Financial basics	Basic business financial concepts; revenue, costs, elements of cost, product cost elements, overhead, cash, AR, AP, depreciation, equity, etc. "The \$ in must be greater than the \$ out". "We make investments in order to make more money back utilizing the result of the investment," etc.

Training Requirements	
Skill Require	Areas of Training*
Personal Behavior	Show up on time. Be prepared to perform your job. (Be present mentally and not preoccupied with a non-job related issue, rested, healthy, properly dressed, etc.)
Safety	Rules, behavior, precautions, etc., related to safety for machinery, chemicals, slips and falls, people related, spills, MSDSs.
Quality	Follow the rules. Ensure procedures are followed. Go beyond the formal requirements and propose improvements. Follow the Japanese "5S" rules. Follow "Deming's 14 Rules For Management". Use statistics to improve yield and minimize variation.
Cost	Why cost is important, sources of cost, minimizing cost, proposing cost reductions, minimizing waste, maximizing reuse and recycling.
Equipment operation	Safe operation, machine setup, standard operations, maintaining records, impact of each process on cost, use of the operating manual, machine maintenance,.
Metrology	Use of calipers, electronic and optical measurement methods, storage of data and analysis, ensuring accuracy, measuring joint strength.
Joining methods	Training in soldering, welding,, adhesive application, pot life, mixing of epoxies, storage and handling of organics and other materials,
Interpreting Instructions	Read what it says, ask question, make sure you understand, do not "assume", eliminate and resolve ambiguities,
Completing Jobs On Time	Ensure you understand what is required; ensure all of the instructions, materials equipment and other resources are available. Start as soon as possible. Look for potential barriers ahead and ensue they are eliminated. Be prepared to revise your approach. Ask for help. When you error, admit you made a mistake, learn from it, ensure you do not make it again. Do not hide your errors.
• *While training is often highly specific to each job, basics apply to all jobs.	