A National Institute for Advanced Optics, Photonics, and Imaging Manufacturing and Innovation

A Response to Request for Information on Proposed New Program: National Network for Manufacturing Innovation (NNMI)

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And

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Introduction

This white paper is a response to the Request for Information (RFI) issued by the NIST-Advanced Manufacturing National Program Office for input concerning the National Network for Manufacturing Innovation (NNMI). This initiative is intended to address issues concerning the U.S competitiveness in manufacturing including the deteriorating trade balance in manufacturing. The RFI states "One key source of the competitiveness challenge is a gap between research and development (R&D) activities and the deployment of technological innovations in domestic production of goods." Closing this gap requires advances be made by small, medium, and large companies alike. The RFI goes on to say that "the U.S. must build on its strengths, leverage its unique research, innovation, and workforce capabilities, and create an infrastructure for manufacturing innovation to ensure that the next generation of processes and products not only will be invented in the U.S., but scaled up and manufactured in the U.S. as well."

To meet this challenge the RFI is seeking input on the focus areas and structure of the NNMI. In order to address some of the questions in the RFI we will suggest an Innovative Manufacturing Institute (IMI) focused on the combined areas of optics, photonics and imaging (OPI). Manufacturing innovation in these areas would enable the commercialization of many wide-ranging research results into a variety of new products. The three areas of optics, photonics, and imaging function together in numerous products across all industry sectors. Bringing all three together in one Innovative Manufacturing Institute will provide hybrid system solutions that can be applied across a wide range of manufacturing processes and manufactured products.

Broad Impact of Optics, Photonics and Imaging as Synergistic and Enabling Technologies

1. What criteria should be used to select technology focus areas?

The most important criteria used to select focus areas for the NNMI program should be that the technologies have a major impact across numerous sectors in our nation's economy, and the greatest potential for job creation. Measuring the total current economic impact of any one technology or group of technologies can be difficult, and predicting the future impact of technologies yet to be developed is indeed a daunting task. In the case of OPI, we are fortunate that the National Research Council has just issued a landmark report on the importance of optics and photonics to our nation's future.[1] This 200-page report delves deeply into the many

[1] National Research Council. *Optics and Photonics: Essential Technologies for Our Nation*. Washington, DC 2012.

ways that optics and photonics technologies are used in a wide range of industrial sectors, and has an entire chapter dedicated to the impact of optics and photonics on the national economy. We will refer to this report frequently in this white paper. Furthermore, we suggest that the approaches and metrics used in this report to measure economic impact may be used by the NNMI program as a guide for measuring and predicting the impacts of other technologies as well. It is not sufficient, however, to measure the current economic impact of the technology under consideration. Fasteners such as nuts and bolts, for example, are essential components of many manufactured goods, but further innovations in fastener technology may not have a broad enough economic impact to be considered as the sole focus of an IMI. The pace of development in the technology, as well as its pervasiveness, must both be taken into consideration.

A second consideration for selecting focus areas is the range in technologies to be covered by any one Institute. Defining too narrow of a range can mean the Institute will fail to have enough of an economic impact to be considered for one of the remaining 14 Institutes. Defining the range to broadly, however, or not defining the right set of technologies, runs the risk of the Institute becoming defocused, not being able to deliver on its promises, and reducing it's capital productivity.

A third consideration should be how each Institute relates to all of the other Institutes to create a cohesive and comprehensive network having the maximum overall impact.

A fourth criterion should be that the Institute develops manufacturing technology that can help keep jobs in the US and address the trade deficit.

2. What technology focus areas that meet these criteria would you be willing to co-invest in?

We suggest that one of the NNMI Institutes focus on optics, photonics, and imaging. As mentioned in the answer to the previous question, the NRC report on optics and photonics does a very good job of describing the role these technologies play in several industries and the size of their total economic impact. OPI are enabling technologies, so their true impact is difficult to measure. This is made more difficult by the lack of appropriate NAICS codes for these technologies. On the other hand, because these technologies <u>are enabling across nearly all industry sectors</u>, their impact is considerable. Virtually every sector of the economy depends in some way on optics and photonics. Communications depend on the fiber optic network, IT data centers rely on high speed fiber optic links, health care relies on x-ray imaging and photonics based diagnostic equipment, the defense sector uses optically guided smart bombs, energy is looking to solar power to reduce carbon emissions and advanced manufacturing uses lasers for precision cutting, welding, and additive manufacturing.

As an example of the importance of OPI technology on the national economy, the NRC report quotes a study by Baer and Schlachter [2] on the size of three economic sectors that rely on laser technology:

- Transportation (production of transport equipment, etc.), estimated to account for $1 trillion in output during 2009-2010
- The biomedical sector ($2.5 trillion)
- Telecommunications, e-commerce, information technology (IT) ($4 trillion)

The laser alone is an enabling technology in $7.5T of the nation's GDP. To give some indication of the overall size of the optics and photonics industry itself, the NRC report looked at publicly traded and privately held companies that were corporate members of either OSA or SPIE [3]. These companies are assumed to have a very strong interest in optics and photonics. As shown in Table 1 these companies account for over $500 billion in revenue and employ over 1.5 million people.

Company Type	Number	Revenue ($millions)	No. of Employees (000s)	R&D Expenditures ($millions)
Public	45	501,551	1,495	27,445
Private	291	1,394	10	Not available
Total	336	502,945	1506	

The report goes on to state:

> "Optics and photonics, an enabling technology with widespread impact, exhibits the characteristics of a general-purpose technology, i.e., a technology in which advances foster innovations across a broad spectrum of applications in a diverse array of economic sectors. Improvements in those sectors in turn increase the demand for the technology itself, which makes it worthwhile to further invest in improving the technology, thus sustaining growth for the economy as a whole." [4].

In addition to being pervasive, the pace of development in optics, photonics, and imaging technology is impressive, and the number of new products and product categories that are being created by advances in these areas is considerable. Again drawing from several sections of the NRC report:

> "Optics and photonics are technical enablers for many areas of the economy, and dramatic technical advances have had a major impact on daily life. For example, in the last decade, advances in optical fiber communications have permitted a nearly 100-fold increase in the amount of information that can be transmitted from place to place, enabling a society-transforming Internet to thrive."

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[2] Ibid., p. 2-16.
[3] Ibid., p. 2-23.
[4] Ibid., p. 1-11.

> "In the course of the study, the committee observed that exciting progress has been made in the field and believes that the future holds much promise. A small anecdotal indication in the popular press of the breadth and depth of the field is that roughly 12 of the 50 best inventions of 2011 listed by Time Magazine had optics as a key technological part of the invention."[5]

The R&D conducted at an Institute for OPI will enhance the nation's economic strength in multiple ways, indicative of the pervasiveness of OPI in our economy. We provide a few specific examples and refer the reader to the NRC report for many more.

Optoelectronics.

Photons first started replacing electrons in communications with the introduction of fiber optics for long distances. As the bandwidth requirements continue to rise rapidly, optical communications begins to become an attractive replacement for electrical systems for shorter and shorter distances. This is true for telecom where we see fiber-to-the-premises and fiber-to-the-home solutions becoming commonplace. Another application with tremendous potential is for data networking within data centers, within individual servers, and on a board from chip to chip. Eventually on-chip optical interconnects will begin to replace electrical interconnects for longer runs. As distances shrink, the number of optoelectronic devices increases. Currently most optoelectronic devices are made in Asia. This is because optoelectronic devices are made out of discrete components that require a lot of manual labor to assemble. As described by Fuchs and Kirchain[6], transitioning from discrete components to monolithic integration will help bring the manufacturing of optoelectronic devices back to the US. That is because these devices are made using common semiconductor fabrication facilities that require large investments in state-of-the-art fabrication facilities and not so much manual assembly. There are many challenges to realizing monolithically integrated optoelectronic devices, such as a silicon integrated photonic devices. Integrated optoelectronics will be an important research area for an Institute focused on OPI.

Additive Manufacturing

As briefly described above, additive manufacturing relies heavily on lasers for several different approaches. An OPI Institute will have a strong competency in the design of new lasers and in light-matter interactions that can be leveraged by the National Additive Manufacturing Innovation Institute to accelerate development of new AM processes and equipment.

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[5] Ibid., p. p-viii.

[6] Erica Fuchs and Randolph Kirchain, "Design for Location? The Impact of Manufacturing Offshore on Technology Competitiveness in the Optoelectronics Industry", Management Science, 56, no. 12, (2010): 2323-2349

Defense Applications

Optics and photonics have played key roles in developing advanced defense and national security systems for several decades. Lasers are a key element of guided weapons and synthetic aperture laser radar, and many other systems. Surveillance systems use advanced optical technologies. We envision a strong participation by leading US defense contractors and their suppliers to develop the manufacturing technologies that will enable wide area surveillance systems, laser weapons, and many other advances that will be key to our nation's security. Advances in manufacturing in these areas will aid the US economy by helping to reduce the cost of maintaining our national security. There will also be crossover benefits where advances in manufacturing processes for military applications will be leveraged in commercial applications. A perfect example of this is in the area of freeform lenses. Freeform lens design is referred to as the third generation of lens design, following spherical lenses and aspheres. With freeform lenses, there is no axis of symmetry and the entire surface of the lens is defined by a set of complex mathematical equations. Freeform lens design will be used in advanced weapons systems as well as in many commercial applications. Providing a common location for the development of freeform lens design will have strong benefits for both applications and provide the US with a competitive advantage in the design and manufacture of advanced optical systems.

Laser Vision Correction

Lasers and other advances in optics have enabled a revolution in eye care. Lasik was developed in the US and has enabled millions of people to improve their vision without the need for glasses or contact lenses. Wavefront sensing was a more recent advance that has greatly improved the performance of LASIK surgery. Today, refractive index shaping using femtosecond blue lasers is being developed for the cornea[7]. A national institute for optics, photonics, and imaging manufacturing and innovation will not only strengthen US competitiveness in existing markets, but will help create entirely new markets in which the US can be a leader, just as fiber optics helped the US take the lead in the creation of the internet. We therefore believe that an IMI focused upon OPI technology easily meets our first criteria of achieving broad economic impact.

The second criterion is the breadth of technologies to be covered by any one Institute. Optics, photonics, and imaging are three tightly linked technologies that leverage much of the same science and are used in combination in many products.

For example, the development of a semiconductor laser relies on the same principles and technology of wave guides used to develop fiber optic transmission systems. Imaging array detectors are often used to characterize laser beams and test

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[7] Lana J. Nagy, Li Ding, Lisen S. Xu, Wayne H. Knox and Krystel R. Huxlin, "Potentiation of Femtosecond Laser Intratissue Refractive Index Shaping (IRIS) in the Living Cornea with Sodium Fluoresce", *Investigative Ophthalmology & Visual Science* Volume: 51 Issue: 2 Pages: 850-856 Published: FEB 2010

optical systems. The development of new light sources often relies on the development of new detectors that can then be used in imaging arrays as in the field of terahertz imaging.

An Institute for OPI will be able to leverage equipment and technical expertise across the three fields of optics, photonics and imaging leading to rapid and significant innovation.

There are also many applications where optics, photonics, and imaging are used together to create a system solution. Consider a typical smart phone camera. The lens in the camera is a high volume precision optic. The image capture device is a CMOS detector which is based on photonics and whose design is dictated by fundamental imaging principles and the characteristics of the optical system. The image captured by the camera can be transmitted around the world on a fiber optic network powered by photonic lasers. In this simple case, we see how elements of optics, photonics, and imaging play together to produce a device that provides extraordinary capability to a user.

As another example, the lithography equipment used to produce integrated circuits relies entirely upon optics and photonics and is essentially an imaging system. The lithography light source is typically a UV laser. The laser beam is controlled by a precision optical lens system that focuses the light on the silicon surface. The alignment and control of the process is usually accomplished with imaging systems and pattern recognition software.

So optics, photonics, and imaging use much of the same science and are combined in many important applications. We therefore suggest these three technologies address the second criterion.

The third criterion suggested above addresses how an Institute for OPI innovation and manufacturing technology could fit in with the rest of the NNMI. There are many examples of how OPI is an enabling technology for a broad range of advanced manufacturing technologies, and there are many examples of how other advanced manufacturing technologies enable new OPI applications. For example, additive manufacturing, the focus of the first NNMI, relies heavily upon lasers for several additive manufacturing methods including selective laser sintering and stereo lithography. Lasers are also used for cutting and welding processes. Optics and imaging are critical technologies for manufacturing automation as well. Conversely, advances in CNC machining techniques will allow the manufacture of new lens designs required for freeform optics. And advances in nanofabrication will enable a new generation of integrated photonic devices. Optics and imaging are critical technologies for manufacturing automation as well. A National Institute for OPI Manufacturing Technology Development and Innovation will link tightly with the other IMIs and help form a comprehensive and cohesive network for the development of advanced manufacturing technologies.

The fourth and final criteria we suggest is that the technology developed by the Institute reduce the trade deficit. An Institute for optics, photonics, and imaging manufacturing and innovation would address this criterion in two ways. First, although most of the advances in photonics technology were developed in the US, many for defense systems, the overwhelming majority of photonic devices are now made in Asia. The challenge is described in the NRC report:

> "In considering actions for global leadership in the photonics industry the committee took note of several important points. For example, although many key optics and photonics innovations occurred in the United States, including in display and communication technologies, the multibillion-dollar display industry has moved mostly to Southeast Asia, with a negligible fraction of display production remaining in the United States. Furthermore, whereas the United States for decades led the manufacture of telecommunications equipment, China went from having no company in 1998 in the top 10 largest telecommunications companies in the world to having three such companies in 2011. A similar scenario exists for Chinese companies that specialize in selling optical components and subsystems.
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> A theme evident in several of the presentations made to the committee was that innovation will remain critical to ensuring a U.S. leadership position in optics and photonics."

By providing the OPI industry with leading edge manufacturing technology and helping the industry come up with innovative new products, an OPI Institute would help address the trade deficit in OPI products.

The Institute will also help address trade deficits in other manufacturing sectors. Advances in OPI product and manufacturing technology will enable these other sectors to implement new manufacturing technologies more quickly and reduce manufacturing costs thus improving the competitiveness of US manufacturers.

An Institute focused on OPI manufacturing technology and innovation meets all four of these requirements and would therefore be an attractive area for co-investment by US manufacturers.

3. What measures could demonstrate that Institute technology activities assist U.S. manufacturing?

Based upon our experience at the Center for Emerging and Innovative Sciences (CEIS) at the University of Rochester, which is funded by New York State to promote technology-driven economic development, we suggest that an annual reporting process with documented inputs from member companies or licensees of Institute technology could be used to demonstrate the impact of Institute technology on US manufacturing. Metrics could include:

- Sales of domestically manufactured products that are made using Institute technology or that incorporate Institute technology. Such a measure should use a prorated formula based on the percentage of sales attributed to the

Institute technology. It is important to break out export revenues for this metric, as this will address the balance of trade challenge.

- Prorated cost savings in domestic manufacturing achieved by companies using technologies developed at the Institute
- Number of new jobs attributed to Institute technologies
- Total wages of jobs attributed to Institute technologies
- Number of retained jobs attributed to Institute technologies
- Amount of added investments in companies using the technologies that can be attributed to work at the Institute (including foreign investments)
- Number of successful companies spun out of the Institute

A successful Institute will contribute to the growth in both revenue and employment at the member companies and technology licensees. Over time, total employment and revenue at the member companies should rise. This must be part of the impact analysis. Another way of saying this is that the government should invest in companies that drive economic growth.

4. What measures could assess the performance and impact of Institutes?

Based on our experience, the following performance measures could be used:

- Number of member companies
- Total amount of industry matching funds
- Number of external publications generated by projects
- Citation index of publications
- Number of internal reports issued
- Number of invention disclosures
- Number of issued patents
- Number of licenses granted
- Amount of licensing royalty
- Number of visiting scientists
- Number of PhDs done in collaboration with the Institute
- Satisfaction survey conducted by independent organization
- Number of companies started or redirected in their product mix

If the Institute activities are actually assisting U.S. membership then the number of members will grow as companies realize the benefits of membership. In addition, the number of projects and the reported results will increase. The citation index can be used as a measure of the value of those publications. The Insitute should promote the creation of intellectual property and patent generation by having an on-site liason to one of the regional USPTO offices or a regionally-based PTO staff member.

The actual economic impact of the Institute on the US economy should be assessed using the measurements described in Question 3.

Institute Structure and Governance

5. What business models would be effective for the Institutes to manage business decisions?

Perhaps the first question to be addressed on structure and governance is whether the 15 Institutes within the network should fall under one legal entity, as is the case of the Fraunhofer Institutes, or be operated as a network of individual entities, as is more or less the case for the labs that carry out the National Nanotechnology Initiative. Also, if each Institute is a distinct legal entity, should each Institute be structured and governed in the same way or should the structure and governance of each Institute be set up to fit the particular focus and set of circumstances of each Institute? Another important consideration is whether the Institutes should be privately owned or government run. The focus of this paper is an Institute for optics, photonics, and imaging manufacturing and innovation. However, many of the recommendations we make are suitable for Institutes with other areas of focus as well.

We briefly discuss here four examples of research and development Institutes that can serve as models for an IMI and then propose a structure we see as optimal for the proposed optics, photonics, and imaging institute as part of the NNMI.

One possible example for the business model is provided by the Fraunhofer Institutes in Germany.[8] All of the 60 Fraunhofer Institutes fall under the Fraunhofer Society, which has 18,000 employees and an annual operating budget of $2.1billion US. These institutes foster innovation by combining the efforts of private industry, government, and academia. The German government owns the Fraunhofer Society. A base funding of 30% comes from the government (approximately 27% from federal and 3% from individual states). The remaining 70% comes from contract research carried out at each institute with either industry or individual government agencies.

A second model is SEMATECH. SEMATECH was formed in 1987 by 14 U.S.-based semiconductor manufacturers and the U.S. government to solve common manufacturing problems by leveraging resources and sharing risks. The impetus for SEMATECH was the growing strength of international competition in the semiconductor industry that threatened the strength and, in some cases, the very survival of some of the member companies. The original budget for SEMATECH was $200M, with half of that coming from DARPA and half coming from the member

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[8] See the article in Wikipedia on the Fraunhofer Institutes http://en.wikipedia.org/wiki/Fraunhofer_Society

companies. A description of the original model is given in a 1996 paper by the National Academy of Sciences[9].

> Under its by-laws, SEMATECH is prohibited from engaging in the sale of semiconductor products. SEMATECH also does not design semiconductors, nor does it restrict member firms' R&D spending outside the consortium. SEMATECH members contribute financial resources and personnel to the consortium. They are required to contribute 1% of their semiconductor sales revenue, with a minimum contribution of $1 million and a maximum of $15 million. Of the 400 technical staff of SEMATECH, about 220 are assignees from member firms who stay at SEMATECH's facility in Austin, Texas, from 6 to 30 months. Because the objective has been to bolster the domestic semiconductor industry, membership has been limited to U.S.-owned semiconductor firms. U.S. affiliates of foreign firms are not allowed to enter (a bid by the U.S. subsidiary of Hitachi was turned down in 1988). However, no restrictions are placed on joint ventures between SEMATECH members and foreign partners.

A third model is the National Nanotechnology Initiative (NNI). The NNI coordinates Federal nanotechnology research and development. The NNI creates a framework for shared goals, priorities, and strategies for each Federal agency to leverage the resources of all participating agencies.

Established in 2000, the NNI serves as the central point of communication, cooperation and collaboration for all Federal agencies engaged in nanotechnology research. The NNI consists of 26 Federal agencies with a range of research and regulatory roles and responsibilities. Fifteen of the participating agencies have R&D budgets that relate to nanotechnology, with the reported Federal NNI Budget representing the collective sum of these. The NNI, as a program, does not fund research; however, it informs and influences the Federal budget and planning processes through its member agencies.

A fourth model for consideration is the Wellman Center for Photomedicine at Massachusetts General Hospital. The Wellman Center is the world's largest academic research facility dedicated to investigating the effects of light on human biology and to the development of light-mediated, minimally invasive diagnostic and therapeutic technologies. Although Wellman is an academic center, the funding model may be helpful in designing the NNMI as discussed in question 11.

While all of these organizations provide models that can be used as guides in designing the NNMI program in general and an IMI for optics, photonics, and imaging in particular, none of them meet all of the requirements. The model we propose for an Institute for Photonics, Optics, and Imaging Manufacturing Technology Development and Innovation most closely resembles SEMATECH. For sake of brevity, and to help create a mental picture of what we discuss, we will refer to this entity for the rest of this white paper as POMATECH.

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[9] Douglas A. Irwin and Peter J. Klenow, "SEMATECH: Purpose and Performance", *Publication of the National Academy of Sciences,* 93 no. 23 (1996): 12739-12,742.

Proposed Business Model

We envision POMATECH as a private, not–or-profit institute owned and operated jointly by the members. The business model would be similar to the SEMATECH model. However, there would be key differences due to the important participation by small and medium sized enterprises and by major research universities as described in Question 7. This model, or elements of it, may also fit the other Institutes.

The leadership of POMATECH will be composed of a board of directors and a paid full-time executive staff. The board of directors would consist of representatives from each of the founding large corporations, a proxy to represent the SMEs, and representatives from the major participating research universities. There could be multiple proxies representing different groups of SMEs. In the case of POMATECH there might separate proxies for optics, photonics, and imaging reflecting the differences in interests of the three.

POMATECH could be a completely stand alone institute or it could be operated by one of the major participating research universities. This will reduce the initial investment and provide significant savings in terms of purchasing power, HR support, and other functions, while maintaining neutrality among the corporate members. POMATECH could be located on or near the campus of one of the participating universities. This will greatly increase the intensity of collaboration between people at the Institute and research faculty.

6. What governance models would be effective for the Institutes to manage governance decisions?

The governance model must also reflect the membership makeup as discussed in the next question. The board should be tasked with making major decisions such as setting the direction of the Institute, appointing new board members, selecting executive leadership, and deciding on major research projects and major capital improvements.

The executive team would be responsible for day-to-day operations of the Institute, including hiring the rest of the management team and authorizing expenditures below a certain threshold.

The staff at SEMATECH is composed of a combination of assignees from the large corporations and a paid staff. We think this model could work for POMATECH with changes to reflect the important roles of SMEs and universities.

An important element of the governance is how research projects are chosen and funded. A voting group representing all members could choose projects. In this case the projects would be funded by membership dues, additional money supplied by all members, and government funds intended to support the Institute as a whole.

These would likely be major projects that require substantial resources relative to the overall size of the Institute. In this case all members would have equal access to the results. Alternatively, there could be individual projects that are proposed and funded by one member or a group of members, in which case those members would fund the projects separately. In this case only those members would have access to the results. Due to the breadth of technologies covered by POMATECH we feel there must be some allowance for the latter. There could also be contract projects that are funded by non-member companies or Federal agencies, similar to the way the Fraunhofer Institutes operate. This will provide revenue that could be necessary to support the operation of the Institute. Contract research will also allow more US companies, both large and small, to benefit from the Institute. We envision a model that combines all three types of projects.

7. What membership and participation structure would be effective for the Institutes, such as financial and intellectual property obligations, access and licensing?

The models discussed in Questions 5 and 6 and access to IP must reflect the types of members that make up the Institute. Similar to SEMATECH, we envision POMATECH having founding members made up of large US corporations that rely on optics, photonics, and imaging for a substantial part of their business. Members should include companies that operate across the value chain including manufacturers of materials, components, sub systems, and end equipment. Applications will include fiber optics, communications equipment, integrated photonic electronic circuits, defense systems, lasers, optical materials, optical medical imaging equipment and others. We offer here some examples of companies that might be founding members. This list is only intended to communicate the scope we have in mind for POMATECH and in no way is an expression of support by any these companies.

- Integrated Optoelectronics (IBM, Intel)
- Optical Material and Components (Corning)
- Optical communications equipment (Alcatel Lucent, Cisco, Agilent)
- Laser Manufacturers (Coherent, Cymer, IPG, Spectra-Physics)
- Optical Components (Newport)
- Defense Contractors (Lockheed Martin, Northrop, L3)
- Imaging Systems (Kodak, Xerox)

Membership should also be open to companies that rely on imaging for a large part of their business such as providers of smart phones and internet-based imaging solutions. Examples include Google, Apple, Microsoft, and Facebook.

SMEs must also have a vested interest in the Institute, participate in collaborative research efforts, and be encouraged to commercialize resulting technology. This is called for in the NNMI program description and is in keeping with the fact that much of the innovation and job growth in America today comes from small and medium sized companies. The importance of SME participation in the NNMI program is indicated in the NRC report on optics and photonics.

> During 1984-2001, the structure of U.S. industrial R&D performance also has changed Significantly. The share of overall industrial R&D performance accounted for by the largest U.S. firms has declined significantly, from 60 percent in 1984 to less than 40 percent by 2001. The share of the smallest firms (fewer than 500 employees) has more than doubled during this period, and the share of industrial R&D performance accounted for by firms with 500–9,999 employees also has grown significantly. Some of this growth in the share of smaller firms may reflect alliances with larger firms and other types of outsourcing. Nonetheless, the role of the largest U.S. firms in industrial R&D has declined significantly during this period.[10]

When SEMATECH was first constructed in 1987 all of the voting members were large semiconductor companies. There was a separate organization co-located with SEMATECH called SEMI/SEMATECH made up of companies that provided equipment and materials to the semiconductor industry. Today, SEMATECH has 11 member companies that manufacture integrated circuits and 48 partner companies most of which are equipment or service providers. The State University of New York at Albany College of Nanoscale Science and Engineering, where SEMATECH is located, is also a full member because New York State provides significant financial support to the organization. The member companies pay dues that are the same for all companies with a 40% premium for companies with semiconductor revenues above a certain threshold. The partner companies provide equipment or other financial support on a project-by-project basis. We propose a model similar to this. However, the POMATECH partner companies would be SMEs that manufacture optics, photonics, and imaging products themselves.

Another key aspect of any Institute, particularly a POMATECH, is that it should have strong participation from leading research universities. This is important for both innovation and education. America's universities are increasingly important sources of innovation in the US. A strong presence of universities will help bridge the gap between research and manufacturing thus enabling the Federal Government to leverage its research investments to produce more manufacturing jobs. A POMATECH that is an industry-government-academia partnership will also help ensure that the investments the Federal government is making in research gets translated into economic development and job growth. University members will provide innovation via several routes. Most directly university research labs will provide new approaches to optical technology, i.e. devices, optical communication modes, radically new materials and technology, and new design algorithms and approaches. The educational importance of university membership is discussed in Questions 17-21.

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[10] National Research Council. *Optics and Photonics: Essential Technologies for Our Nation*. Washington, DC 2012, p. 2-30.

The important roles of large corporations, SMEs and Universities should heavily influence on where POMATECH is based. For strong SME participation, POMATECH must be located near a large cluster of SME OPI companies. Many do not have the financial resources to place employees at remote locations for extended periods of time or pay travel expenses for frequent trips to the Institute. POMATECH must also be located near one or more leading research universities in the areas of optics, photonics, and imaging. This will encourage strong participation on the part of faculty and students, enhancing both the innovation and education objectives of the NNMI program. The region should also have a strong track record for innovation, with metrics such as patents per capita and number of publications in the field of optics, photonics, and imaging being used. There should be a business incubator located nearby with strong ties to the Institute to assist spinout companies in getting started. Another key aspect influencing the choice for locating POMATECH in a region is that it has a healthy thriving ecosystem in OPI including suppliers of raw materials, components, devices, sub assemblies, and complete OPI systems. This will encourage innovation up and down the up and down the value chain and accelerate the development of innovative manufacturing processes and products. Eventually POMATECH will encourage more companies to locate facilities near the Institute and enhance the region's position as a leading cluster, accelerating the development of innovative manufacturing and product technologies.

Intellectual property is a delicate subject when it comes to any industrial consortium. This is true today more than ever, as companies use patents to establish market share. There are multiple considerations that must be made and multiple approaches that can be taken to establishing IP rights.

One aspect could be for POMATECH to own all the intellectual property developed as a result of the projects funded out of membership dues. In this case the major member companies would be given IP rights, including licensing terms. Access to intellectual property by the SMEs, which pay much smaller dues, makes this aspect more complicated.

8. How should a network of Institutes optimally operate?

This question was partly addressed in our responses to Question 2 in which we discussed the importance of OPI to many manufacturing technologies and Question 5 in which we discussed possible operating models for the NNMI. We feel it is important that the Institutes form a comprehensive, complementary, and cohesive network. The Network should be comprehensive in that it should benefit a large portion of the nation's manufacturing sector. The Institutes should be complementary in that each Institute should be able to draw from the other Institutes for pieces of solutions that each Institute may not cover. We have described how this will be the case for a POMATECH. The Institutes should be cohesive in that their results should be freely exchanged. In this white paper we do not address specific processes for sharing expertise and technology. There are several examples of on-line sharing of expertise across multiple organizations that could be used such as the USA National Innovation Marketplace provided by NIST. The NNMI program could build on the NIST service without having to create another infrastructure.

9. What measures could assess effectiveness of Network structure and governance?

Network structure could best be assessed by monitoring how effectively the Institutes work with and support each other. If the Institutes are truly working as a Network then the results from each Institute will feed into the other Institutes. Members of one Institute will seek to become members of other Institutes.

Institute governance could be assessed by surveying the member organizations to make sure that their concerns are being addressed appropriately. The governance of an Institute will be successful if the Institute can effectively accomplish the things its members want to accomplish.

Strategies for Sustainable Operation

10. How should initial funding co-investments of the Federal government and others be organized by types and proportions?

Initial funding for an optics, photonics, and imaging Institute could come from the Federal Government and the private sector in equal proportions. The Federal government could contribute money as capital upfront to fund infrastructure development. Private sector matching funds could be used to develop initial projects that help set the direction for future research and development at the Institute.

11. What arrangements for co-investment proportions and types could help an Institute become self-sustaining?

As mentioned above in question 10, a co-investment model based on equal contributions from the Federal Government and the private sector will propel a new Institute toward sustainability. The funds from the Federal Government could be used to build up the infrastructure providing the means to generate results while the contribution towards fundamental manufacturing issues from the private sector would rapidly allow the Institute to generate intellectual property revenue and clearly demonstrate the value of the Institute. This demonstrated value could then be used to generate more contract revenue from both the Federal Government and the private sector.

As an example, consider the Wellman Center in Boston. While not involved in manufacturing, the center has a reputation for research involving light and medicine and has used this reputation to attract extramural finding to support its operations. Currently, the center receives 65% of its budget from ongoing research for Federal agencies such as NIH, NSF and DOD. The remaining 35% of its budget comes from intellectual property revenue and contract research for foundations and private industry.

Alternatively, consider the Fraunhofer Institutes mentioned in question 5 above. These Institutes receive 70% of their revenue from ongoing contracts with government agencies and the private sector. Government funds amounting to 30% of their budget are used to develop infrastructure.

Thus, a combination of Federal Government funds for infrastructure and private sector funds for immediate projects could be used to quickly establish an Institute as a valuable partner to both government an industry for ongoing manufacturing research.

12. What measures could assess progress of an Institute towards being self-sustaining?

The Institute's progress toward economic sustainability could be measured by tracking the success of the Institute in obtaining extramural funding. Extramural funding will come from intellectual property licensing and contract projects with private industry and the Federal Government.

13. What actions or conditions could improve how Institute operations support domestic manufacturing facilities while maintaining consistency with our international obligations?

Institute operations could support domestic manufacturing facilities by arranging licensing terms that favor domestic manufacturing. While many member companies may be international firms, the Institute could provide incentives in its licensing arrangements to encourage these firms to develop domestic manufacturing facilities.

In addition, the strong presence of small and medium sized companies in an optics, photonics, and imaging Institute will lead the development of domestic manufacturing facilities.

14. How should Institutes engage other manufacturing related programs and networks?

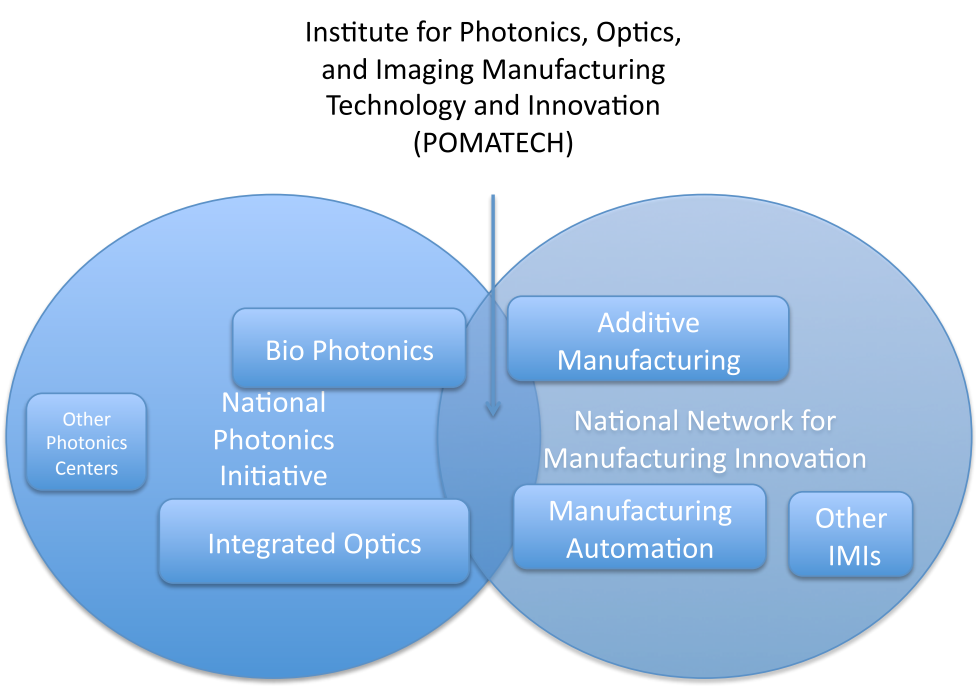
As mentioned in question 8 above, the Institutes should work collaboratively with other Institutes and other manufacturing related programs.

There will be at least two ways in which a POMATECH will link with the national effort to develop advanced manufacturing capabilities: SEMATECH and a National Photonics Initiative.

SEMATECH

As described above, SEMATECH is the primary, world-wide consortium for the development of advanced semiconductor manufacturing technology. Located in Albany, New York, SEMATECH develops technologies that support leading edge semiconductor manufacturing at scales reaching below 14 nm. SEMATECH is also leading the industry transition from 300mm wafers to 450mm wafers and it conducts research in 3D interconnects and advanced packaging technologies.

As discussed in chapter 3 of the NRC report, advances in information processing will rely on optics and photonics. In particular, the report discussed the need for optical interconnects on an integrated circuit to reduce power consumption and delay time. This requires the development of silicon photonics where optoelectronic devices are integrated on a CMOS IC. Manufacturing leading edge CMOS devices requires a multi-billion dollar investment. A POMATECH will benefit greatly from the ability to fabricate full flow CMOS devices at SEMATECH. Conversely, SEMATECH will benefit greatly from capabilities developed at POMATECH, where some of the worlds leading photonics technology will be developed.



A National Photonics Network
The NRC report calls for the establishment of a National Photonics Initiative, similar to what was done for nanotechnology with the National Nanotechnology Initiative. If an NPI is established, a POMATECH would be the link between the NPI and the NNMI. POMATECH would serve as an advanced manufacturing development resource for the NPI. Specific programs within an NPI such as bio-photonics and integrated optics would benefit greatly from a POMATECH.

NIST Manufacturing Extension Partnership Program
The NIST MEP program helps small and mid-sized manufacturers create and retain jobs, increase profits, and save time and money. Ideally, there would be a NIST MEP center located in the same region as POMATECH to further assist SMEs in commercializing technology developed at the Institute.

15. How should Institutes interact with state and local economic development authorities?

The Institutes developed as part of the NNMI would be able to work together with state and local development agencies. All these organizations share the same ultimate goal – to drive job creation in the US economy. For example, New York State has already established 15 regional Centers for Advanced Technology. These centers are public private partnerships dedicated to facilitating the transfer of technology from research universities into commercially successful products.

An optics, photonics and imaging Institute could work collaboratively with centers such as these in all states to access technology from around the state. There may also be opportunities for the states to co-fund projects at the manufacturing Institute.

16. What measures could assess Institute contributions to long term national security and competitiveness?

A manufacturing Institute focused on optics, photonics, and imaging would have enormous value the DOD in its national defense mission. Defense systems rely heavily on optics, photonics, and imaging components and advancing manufacturing is key to obtaining these components with the correct specifications and at a reasonable cost. The development of manufacturing technology by an optics, photonics and imaging Institute would help local manufacturers supply DOD with critical components.

The contributions of the Institute to national security could be measured by tracking the use of technology developed by the Institute in DOD contracts and by determining the value of these contracts. The Institute's contribution to competitiveness could be seen in the increase in the value of manufactured goods produced by private industry. Ultimately, it may be possible to see the return of previously off-shored manufacturing to the US using advanced technology developed at the Institute.

Education and Workforce Development

17. How could Institutes support advanced manufacturing workforce development at all educational levels?

An advanced manufacturing Institute has enormous potential to contribute to education and workforce development at all levels. Exposure to the science and engineering involved in advanced manufacturing can motivate students to pursue careers in STEM related fields providing the most critical resource needed to improve U.S. manufacturing

An optics, photonics, and imaging Institute could work closely with local community colleges to develop training programs in OPI related industries. Faculty at the community college would have ready access to manufacturing technologies and could easily bring these technologies into the classroom. Students who would be well trained by these programs would be a very valuable resource to the member companies.

In addition, the Institute would work closely with area colleges and universities. Co-op programs could be developed to provide engineering students with hands-on work experience. Students pursuing advanced degrees would find research projects at the Institute that would have high value in the engineering world.

Finally, all participants in the Institute could be involved in developing science kits and lesson programs that could be used by K-12 teachers to bring STEM subjects into the classroom. These experiences could help excite students about STEM subjects early in their education.

18. How could Institutes ensure that advanced manufacturing workforce development activities address industry needs?

In order to ensure that workforce development addresses the needs of industry, industry partners would be well represented on the board of the Institute. In addition, the Institute could sponsor co-op programs that give students the opportunity to work on advanced manufacturing projects. Through these programs colleges would maintain close contact with their co-op sponsors ensuring that the programs meet the needs of industry.

19. How could Institutes and the NNMI leverage and complement other education and workforce development programs?

As mentioned in Question 18 above, an Institute could easily leverage and complement other education and workforce development programs by offering co-op programs to students from local colleges. Such programs would help the Institute accomplish its goals by providing an enthusiastic and well-trained workforce to work on specific projects. Academic programs would benefit from the opportunity to offer students hands on experience with specific companies. Such programs would clearly offer two-way benefits to industry and academia and would serve the Federal Government's interest in providing a better-trained workforce.

20. What measures could assess Institute performance and impact on education and workforce development?

The Institute's impact on education and workforce development could be measured by tracking the increase in STEM graduates. As students learn about the benefits of working in the manufacturing area more students would enroll in STEM subjects.

Additionally, measuring the hiring of graduates into manufacturing related jobs could be used to assess the performance of the Institute in relation to workforce development. If the Institute is working well with academia, member companies will be willing to hire graduates from local schools.

As the Institute develops programs to work with academia it would also be useful to measure how often these programs are copied to other Institutes and to other companies across the country.

21. How might institutes integrate R&D activities and education to best prepare the current and future workforce?

There are at least three ways in which the Institutes can integrate R&D activities and education. First, the Institutes can find ways to involve local faculty in the research efforts underway at the Institute. In doing this, the Institute benefits from the knowledge of the faculty and the faculty benefit from obtaining a clear picture of industry needs that they can take back to the classroom.

Second, the Institute can work with member companies to develop co-op programs that will benefit both students and employers by providing flexible and well trained employees for industry and valuable experience for the students.

Thirdly, the Institute should have strong ties with local community colleges and highschools for two reasons. This will ensure there are strong training programs in place to develop the local workforce for the focus industry. The industry specific training programs developed at these levels could also be replicated in other regions where there is a high concentration of companies in the focus industry.