Status of and Vision for the Additive Manufacturing Ecosystem in New York State

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Notice

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Acronyms and Abbreviations

AM	Additive manufacturing
AMPrint Center	Additive Manufacturing & Multifunctional Printing Center at Rochester Institute of Technology
CAD	Computer-aided design
Community	NYS Additive Manufacturing Community
Consortium	NYS Additive Manufacturing Consortium
ESD	Empire State Development
EWI	Edison Welding Institute
FDA	United States Food and Drug Administration
IP	Intellectual property
MEP	Manufacturing Extension Partnership
NASA	National Aeronautics and Space Administration
NNMI	National Network for Manufacturing Innovation (now Manufacturing USA)
NY-BEST	New York Battery & Energy Storage Technology Consortium
NY MEP	New York Manufacturing Extension Partnership
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
NYSTAR	ESD Division of Science, Technology & Innovation
NIST	National Institute of Standards and Technology
RIT	Rochester Institute of Technology
R&D	Research and development
SBIR	Small Business Innovation Research program
SLA	Stereolithography
STEM	Science, technology, engineering, and math (disciplines)
STTR	Small Business Technology Transfer program
SUNY	State University of New York
UTEP	University of Texas at El Paso
3DP	Three-dimensional printing

Executive Summary

Additive manufacturing (AM) presents substantial opportunities for manufacturing innovation and economic growth in New York State (NYS). Whether through existing manufacturers' adoption of 3D printing; use of 3D printing to speed research and development (R&D) and product development cycles; proliferation of applications in various end-use sectors and within their supply chains; the incorporation of new materials and processes; or the growth of markets for ancillary goods and services, AM has the potential to transform the manufacturing and innovation landscape.

NYS is home to a wealth of assets and expertise in AM, both in the private sector and academia, and these assets have begun an initial effort to organize into an ecosystem. There is now a ripe opportunity to accelerate and shape this coalescence in a way that maximizes the job creation potential associated with the sector's growth. A concerted effort to boost and mature this nascent ecosystem will yield a positive economic impact for NYS in the following ways:

- Help the NYS manufacturing sector to modernize and compete using current AM technology where it is immediately applicable.
- Support the development of the next generation of manufacturing technologies.
- Encourage the development of superior products that would otherwise be impossible/impractical to manufacture, including the creation and incubation of new applications for AM and attendant first-to-market advantages.
- Foster new talent and/or retraining the existing workforce for employment in AM and related industries.

An organized sector can streamline the optimization of supply chains impacted by AM, leverage alliances and pursue innovation opportunities with other sectors, specify and facilitate relevant workforce training, compete more effectively to secure federal funding for NYS teams, and attract additional high-tech and manufacturing companies to NYS.

NYS government can help to convene AM resources. Specifically, if sufficient stakeholders concur, a NYS Additive Manufacturing Consortium (consortium) should be created to sustain marketplace ownership of the drivers for growth. The recommended hub and spoke model would involve the designation of a physical Hub to serve as the nexus of the Consortium, with additional resources serving as the Spokes. The Consortium would focus on materials-related research and parts testing (both prototype and production) instead of on AM equipment (some of which will inevitably be out-of-date before new Spokes are launched). The Consortium should complement and address gaps in these existing global efforts by specifically addressing the two critical and co-related hurdles of technology advancement and technology adoption.

NYS government and core stakeholders should continue interim activities to build momentum en route to formation of a Consortium, starting with simple/low-resource activities and progressing through a series of more substantial efforts (in ascending order of intensity): informational newsletters, outreach to promote manufacturers' adoption of AM based on current capabilities, and workforce development and training.

- Newsletter. A periodically recurring electronic newsletter is arguably the lowest-hanging fruit and would be a valuable, low-cost way to sustain the engagement and dialogue of this emerging community.
- Immediate AM adoption within industry. There is a wealth of immediate opportunity for existing manufacturers to adopt AM as a new tool in their toolboxes, including, but not limited to, lightweighting of products, creating specialty tooling & fixturing, making small-quantity production runs, mass customization, production-on-demand in lieu of widely varying inventory of parts, consolidating multiple parts into an integrated structure, and prototyping.
- Workforce development and training. There is a large spectrum of need and opportunity regarding workforce, from a lack of materials scientists, to a lack of middle-skill technicians and operators trained in CAD, to a labor pool of engineers whose earlier training has limited their ability to think creatively about the possibilities of AM (e.g., redirecting design engineers to dream big and imagine products that can't be made today using conventional manufacturing techniques, such as the GE LEAP engine and other products that can revolutionize energy production and/or usage).

1 Introduction

"It took the additive manufacturing industry 20 years to reach $1 billion in size. In five additional years, the industry generated its second billion. At $3.07 billion in 2013, the industry is expected to more than quadruple to about $12.5 billion by 2018. The compounded annual growth rate of worldwide revenues produced by all additive manufacturing products and services in 2013 was 34.9% and exceeded $3 billion for that year, and is forecasted to exceed $21 billion by the year 2020."[1]

Today, AM is transitioning from its early roots, in which it was used for rapid production of prototypes, to now being employed in industrial-scale manufacturing. The economic growth opportunities presented by the emergence of AM and by this transition are numerous. They include applications of relevance to NYS in end-use sectors, including, but not limited to, aerospace, energy, biomedicine, 3D printing services, consumer goods, electronics, and apparel as well as to the supply chain constituents that provide specialty materials (i.e., those used as consumables in the additive processes), machinery, software, and design and operational know-how.

Moreover, a wealth of expertise currently exists within NYS regarding AM materials, methods, and machinery, within companies both small and large as well as within academia (Appendix B). Western New York is home to world-class 2D printing expertise that can serve to buoy the entirety of NYS into becoming a dominant force in 3D technology. The recent launch at the Rochester Institute of Technology (RIT) of the Additive Manufacturing and Multifunctional Printing (AMPrint) Center—a Center for Advanced Technology designated by Empire State Development's Division of Science, Technology & Innovation and supplementing RIT's existing multifunctional printing infrastructure—further positions NYS to capitalize on the economic opportunities presented by AM.

1.1 Vision

This fledgling AM sector in NYS has started an initial effort to organize itself into an ecosystem, and there is now a ripe opportunity to accelerate and shape this coalescence in a way that maximizes the job creation potential associated with the sector's growth. A concerted effort to boost and mature this nascent ecosystem will yield a positive economic impact for NYS:

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1 Wholers Report 2014: 3D Printing and Additive Manufacturing State of the Industry.

- Help the manufacturing sector to modernize and compete using current AM technology where it is immediately applicable.
- Support the development of the next generation of manufacturing technologies.
- Encourage the development of superior products that would otherwise be impossible/impractical to manufacture, including the creation and incubation of new applications for AM and attendant first-to-market advantages.
- Foster new talent and/or retraining the existing workforce for employment in AM and related industries.

An organized sector can streamline the optimization of supply chains impacted by AM, leverage alliances and pursue innovation opportunities with other sectors, specify and facilitate relevant workforce training, compete more effectively to secure federal funding for NYS, and attract additional high-tech and manufacturing companies to locate in NYS.

NYS government can help to convene AM resources. Specifically, if sufficient stakeholders concur, a Consortium should be created. The recommended hub and spoke model would involve the designation of a physical Hub to serve as the nexus of the Consortium, with additional resources (like the AMPrint Center) serving as the Spokes. The Consortium would focus on materials-related research and parts testing (both prototype and production) instead of on AM equipment (some of which will inevitably be out-of-date before new Spokes are launched).

This recommended model is consistent with Governor Andrew M. Cuomo's Moving the New, New York Forward 2014 proposal for scaling up manufacturing and commercialization. The policy book states, "Building upon NYSERDA's NY-BEST model, the State should establish an additive manufacturing center and consortium to ensure New York is at the forefront of this industry."[2]

Key State-supported Centers for Advanced Technology and Centers of Excellence, as well as the small and medium-sized enterprise companies outreach-specialization of regional New York Manufacturing Extension Partnership centers, would together provide expertise to companies seeking assistance to grow their businesses through access to financing, research capabilities, new partners, developing and/or adopting new technologies and processes, and other resources. The Consortium and network of spokes would work collaboratively and in a coordinated manner to identify the most pressing challenges and

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[2] Full text available at http://andrewcuomo.com/wp-content/uploads/sites/44/2014/10/Moving-the-New-NY-Forward-by-Andrew-M-Cuomo.pdf

opportunities on which to focus, and assemble and deploy the skills and resources needed to address them.[3]

The Consortium should engage with national and international efforts to advance the AM field (see Appendix C). There is an opportunity for NYS to participate in America Makes—the national accelerator for AM and 3D printing technology—as a State Affiliate in order to influence its agenda so as to emphasize issues of value to stakeholders in NYS.

The Consortium should complement and address gaps in these existing global efforts by specifically addressing two critical and co-related hurdles, as defined below. This would enable the Consortium to launch with an initial and meaningful focus around which to build critical mass, and subsequently the effort can be expanded to maximize impact.

- Technology advancement initiatives for achieving industrial-scale repeatable production yielding part-to-part consistency, not only for a series of parts made on a single machine, but also including the challenge of controlling variability from machine-to-machine.
- Technology adoption initiatives for further expansion of users of AM, to occur in a subsequent phase, should seek to maximize the potential statewide benefits through outreach and education of key potential adopter sectors and through workforce training. A consortium with representation from industry, academia, and State government can spur the creation and retention of high-tech jobs in NYS by facilitating the creation of new markets (machines, enabling materials, applications, consumables, etc.) along with the necessary talent pools.[4]

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3 A Consortium model has been highly effective in other advanced technology fields. For example, SEMATECH is a consortium that provides “market-pull” signals, and SUNY Polytechnic Institute provides responsive expertise and sharable infrastructure. In the case of additive manufacturing, prototyping equipment for industrial manufacturing and specialized high-precision equipment for product testing and characterization would be potential assets to house in a shared facility (by leveraging some existing infrastructure, this could be expanded into a collection of regional or topical spokes coordinated via a hub). Such assets must be selected through a process that ensures complementarity to, rather than competition with, NYS-based companies offering related services and resources.

4 Grooming the talent pool is critical because the emerging performance requirements of additive manufacturing drive a need to tailor and balance a wide array of increasingly difficult-to-combine material properties. For example, the talent pool must be cognizant of interactions bridging many technologies in order to apply a “systems approach” to solve these key material design optimization challenges.

This vision identifies challenges, frameworks for solutions, and potential beneficial impacts associated with the growth of the AM and 3D printing industry in NYS, and recommends a role for government to act as an ecosystem convener. It was created through a stakeholder process guided by a steering committee and other advisors, and vetted with additional parties, including via a scoping session held at GE Global Research in June 2016. Participants are listed in Appendix D.

A most-valuable revelation from this initial phase of research and stakeholder discussions is that currently the greatest imperatives and opportunities focus on sustaining the engagement of the AM ecosystem in order to further coalesce it. A community of stakeholders has been created and requires continued engagement to sustain that momentum and excitement. Although it would be ideal for industry to drive this congealing, State involvement will be required for a period of time to provide the glue to hold the community together. This is partly due to the fact that many companies are not immediately aware of their potential connection to this field, and expanding the community to engage them will require coordinated and purposeful outreach.

2 Interim Measures to Sustain and Build Momentum

Interim activities are necessary to build momentum en route to formation of a Consortium, and should start with simple/low-resource activities and progress through a series of more-substantial efforts, namely (in ascending order of intensity): informational newsletters, outreach to promote manufacturers' adoption of AM based on current capabilities, and workforce development and training.

It is therefore recommended that the current leaders of this initiative establish an interim core effort—a NYS Additive Manufacturing Community (Community)—that can be built upon in stages as further funding is sought and as industry takes on additional responsibility for the ecosystem. The Community would have two cochairs, one from industry and one from academia. Initially, the structure could consist of these cochairs, a few advisors (i.e., NYSERDA and Empire State Development [ESD] designees), and a flat participation structure in which any organization can become a community member for free (leaving room for a future paid tier). This Community would require staff time, potentially from an existing partner organization, to establish and maintain. A sequence of activities that the NYS Additive Manufacturing Community could undertake, in order of increasing effort/resources required, and culminating in the establishment of a more formal organization capable of implementing more substantial activities are explained in the sections that follow. By starting small and reaching for the lowest-hanging fruit, we can sustain the momentum already created, make progress toward a more substantial effort, and allow the initiative to be shaped by funding opportunities as they become available.

Table 1. Recommended sequence of activities for the NYS Additive Manufacturing Community

Increasing degree of effort/resources required as list progresses	Initiative/Task	Resources Required	Potential Lead
	Issue regular newsletter	Staff time	FuzeHub or similar
	Create/maintain shared asset catalog map	Staff time and potentially web hosting/design	FuzeHub or similar
	Monitor potential funding opportunities and convene committees to explore/pursue	Staff time	FuzeHub or similar
	Market 3D's potential to existing traditional manufacturers	Full-time staff person. Funding for workshops, events, technology demonstration cases, mobile parts hospital, etc.	NY MEP
	Guide manufacturers in adopting 3D	Project funds (e.g. eligible activity under FuzeHub Manufacturing Innovation Grants)	NY MEP
	Establish consortium or other formal entity	NY-BEST as potential financial model	Industry-led with state contribution
	Incentivize technological advancements in the field via challenges and other tools	R&D and award funding from consortium member dues and potentially NYSTAR	Consortium, NYSTAR, NYSERDA, FuzeHub
	Workforce efforts		SUNY
	Acquire additional shared infrastructure	Dependent on equipment needed	Consortium and/or state agencies

The following sections provide detailed notes on early-phase activities from this table.

2.1 Newsletter

An electronic newsletter is arguably the lowest-hanging fruit and a valuable, low-cost way to sustain the engagement and dialogue of this emerging community. A weekly or bimonthly email blast would cover AM developments in NYS, highlight noteworthy AM developments at companies or universities, identify opportunities for collaboration, and note upcoming funding opportunities, project calls, and conferences of interest. If this option is pursued, the first and easiest task could be under the auspices of the Editorial Board for the NYS Additive Manufacturing Community and/or be labeled the Voice of the NYS Additive Manufacturing Community.

2.2 Marketing and guiding companies to AM adoption

Most stakeholders are in agreement that marketing is a critical role that needs to be filled—marketing with the goal of getting more companies using AM to improve existing manufacturing processes and design and produce new products. The following are possible component activities:

- Involving the creation of a new position—an AM outreach coordinator or similar—whose responsibility it is to travel the state speaking to industry and entrepreneur groups and referring companies to research and innovation resources that can help them begin utilizing AM.[5]
- Creating a library of technology demonstrators, i.e., case studies that illustrate manufacturers' successful utilization of AM in order to provide food for thought to other potential adopters. Ideal case studies would be ones in which companies made use of student labor, redesigned an existing product to be additive manufactured, or designed a new product only producible using AM. Transferrable examples of approaches where commercially available AM has already been shown to impart value could center around lightweighting of products, creating specialty tooling and fixturing, making small-quantity production runs, mass customization, production-on-demand in lieu of widely varying inventory of parts, consolidating multiple parts into an integrated structure, and prototyping.
- Building on the AMPrint Center's planned annual conference, to make it a larger ecosystem-wide event.
- Creating an online space where members and prospective members can discuss needs and opportunities, explore what it takes to apply AM to their processes, and view and access online tools (e.g., Autodesk or GE's GrabCAD site).
- Creating a mobile parts hospital or similar traveling AM facility.
- Having key Community leaders (e.g., the cochairs and advisors) hold office hours during which companies and entrepreneurs could visit them for free consultation on AM.

2.3 Workforce development

Workforce development activities would potentially include the following ideas:

- Promoting materials science as a field of study that has new relevance.
- Creating more mechanisms for relevant departments in the State's institutions of higher education to work more closely with industry.
- Supporting SUNY's efforts to infuse science, technology, engineering, and math (STEM) curriculum with the arts and humanities, to improve the pipeline of creative technical graduates.

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5 NYSTAR is employing such an individual for 18 months starting February 2017 as part of the New York Manufacturing Extension Partnership.

- Strengthen AM industry stakeholders' relationships with the SUNY community college system; potentially work collaboratively to develop a new AM-specific training program, offering it to students and manufacturing employees at low cost from a variety of potential partners.
- Expand the use of hands-on labs and coops (see SUNY New Paltz model) to train students and incumbent workers in AM-relevant skills.

2.4 Roles

Each of the major stakeholders in the initiative to date—NYSERDA, Empire State Development's Division of Science, Technology & Innovation (NYSTAR), FuzeHub, and certain companies and universities—have natural roles to play in setting up first the interim entity and, potentially, catalyzing a more robust and formal organization in the future.

NYSERDA has taken a lead role by funding this initial scoping project and could consider working with NYSTAR to support the lower hanging fruit items, possibly including the newsletter, the asset mapping, and the monitoring of funding opportunities and maintenance of committees to pursue them.

FuzeHub, in addition to being available for contracted work to perform these functions, has established a Manufacturing Innovation Fund. Through this fund, Manufacturing Innovation Grants are available to fund projects in which companies work with nonprofit resources to improve their manufacturing capabilities. An eligible activity, for example, could involve a company working with the AMPrint Center and local MEP center to design an improved product to be additive manufactured. The fund may have other potential applications to advance the vision established by this scoping process.

NYSTAR funds the Additive Manufacturing and Multifunctional Printing (AMPrint) Center, which represents a significant investment in shared infrastructure. Furthermore, the Division's administration of the New York Manufacturing Extension Partnership (NY MEP) represents an opportunity for ESD-funded centers to assist in promoting AM's benefits to existing companies and assisting them and entrepreneurs with adoption. Under a grant from the National Institute of Standards and Technology, NYSTAR is supporting an 18- to 24-month NY MEP position responsible for promoting AM technologies to NYS industry. More broadly, the Division's entire network of funded centers, for example incubators and university-based research centers, represent a key network through which AM education, outreach, and technology adoption projects can be pursued. Also of note, ESD provided incentives that attracted Norway's Norsk Titanium to establish a facility in Plattsburgh that is the world's first aerospace AM plant.

SUNY recognizes it has an important role as a well-positioned player. SUNY's leadership has proposed contributing to the overall effort by better connecting AM people across all of its campuses, perhaps in an inter-campus network of excellence for materials and AM.

2.5 Funding

Below is an initial list of potential funding sources and how they could be applied to further this effort. FuzeHub or another leading stakeholder should maintain and convene committees with responsibility for monitoring and pursuing these resources.

Table 2. Funding sources and potential applications

Funding Sources	Potential Applications
National Grid	Funding for workshops/events promoting 3D adoption; potential contribution to consortium
Manufacturing USA Institutes	NYS companies and institute respond to Manufacturing USA institute project calls involving AM
National Science Foundation	Establish an NSF Engineering Research Center focused on additive
National Institute of Standards and Technology - Manufacturing Extension Partnership	Open topic grant calls starting Spring/Summer 2017 could put forward an MEP-focused initiative to engage small manufacturers and entrepreneurs re: 3D adoption Regional Innovation Strategies i6 Challenge Grants to bolster a regional innovation ecosystem with a focus on additive
Economic Development Administration	Regional Innovation Strategies i6 Challenge Grants to bolster a regional innovation ecosystem with a focus on additive
NYS agency funds	Consortium catalyst funds; shared equipment funds; challenge grant funds; etc.

3 New York State Additive Manufacturing Consortium

Addressing current challenges and opportunities in AM means harmonizing improvements across machinery, materials, and design techniques. Ultimately, this requires a level of coordination that spans the entire supply chain. The structured consortium would help to facilitate the development of an industry community that works collaboratively to find solutions.

Creating a Consortium involves the following tasks:

- defining the scope
- building the consortium structure
- pursuing funding
- setting the mission

The following sections explain each of these tasks in greater detail.

3.1 Defining the scope of additive manufacturing to be addressed by the Consortium

Additive manufacturing comprises a complex variety of potential processes, materials, and applications. For example, AM can be undertaken using a single material or multiple materials. When multiple materials are used, they may be added discreetly or in blends (i.e., composites) with progressively varying compositions of the mixture.

The type of AM material that is used (e.g., plastic, ceramics, metal, or biologic) can also present its own complexities. In addition to prototyping, AM can be used to make a final part or the tooling or molds that are then used to make a final part. Often, subsequent processing of the final part is still required (such as cut-off of support pieces, surface finishing, tempering, etc.), which potentially extends the AM supply chain.

There are also competing definitions of AM to consider:

- In its simpler form, AM is understood to be confined to the context of adding a spatial third dimension (3D) to the product of a repeating manufacturing process of piece-part production.
- A more expansive AM definition includes the addition of not only a dimension, but of specialized functions to the product (potentially in layers, or in a spatially profiled manner) so as to provide a unique combination in the piece-part of functional complexity, low cost, and manufacturing simplicity.

The Consortium will use the more expansive definition of AM, inclusive of all its complexities (i.e., all materials, prototyping and production). The scope includes functional printing as well as two-dimensional printing (2DP) to the extent that it is foundational for 3D printing.

3.2 Building the Consortium structure

The Consortium would establish a hub and spoke structure of solution providers to provide services to other Consortium members (such as manufacturers). The relationship among all members of the Consortium might be based on elements of NY-BEST as a model. Existing resources, such as the AMPrint Center, Buffalo Manufacturing Works, and other entities, would serve as the initial spokes. In turn, each of these spokes would be hubs for secondary spokes, such as remote outreach partners.

Public-private partnership is an important part of this model. The NY-BEST experience is instructive in this regard as well, as it is a working model of a consortium that is led by professional staff and consists of members spanning industry, academia, and government. NY-BEST has also shown exceptional forethought with building a coalition that is attentive to the needs of industrial enterprises of all sizes.

A third aspect of the NY-BEST model is also highly applicable: NY-BEST did not create a physical center right away, instead limiting its initial scope to the provision of services to the industry. It is recommended that by leveraging existing university-based and other assets instead of establishing a single mega-center, the Consortium can also achieve early wins, minimize administrative overhead, maximize operational efficiency, and encourage collaboration.

In the model, the following assets would be natural candidates to serve as spokes:

- Rochester Institute of Technology's AMPrint Center
- Clarkson University's Center for Advanced Materials Processing
- Cornell University's Cornell Center for Materials Research
- Stony Brook University's Department of Materials Science and Engineering
- SUNY New Paltz's Hudson Valley Advanced Manufacturing Center
- Alfred University's Center for Advanced Ceramic Technology
- Rensselaer Polytechnic Institute's Center for Automation Technologies and Systems
- Rockland Community College's 3D Printing Smart Lab
- Buffalo Manufacturing Works

3.3 Pursuing funding

The Consortium should pursue federal funding. Cost sharing is an important part of this strategy, and reflects the emphasis on collaboration rather than competition among AM assets.

Obtaining funding means establishing a unique value proposition. By focusing on materials-related research and parts testing (both prototype and production) instead of on AM equipment (some of which will inevitably be out-of-date before new spokes are launched), this effort can find its niche. The Consortium will therefore focus on federal funding opportunities that relate to innovation, commercialization, or manufacturing.

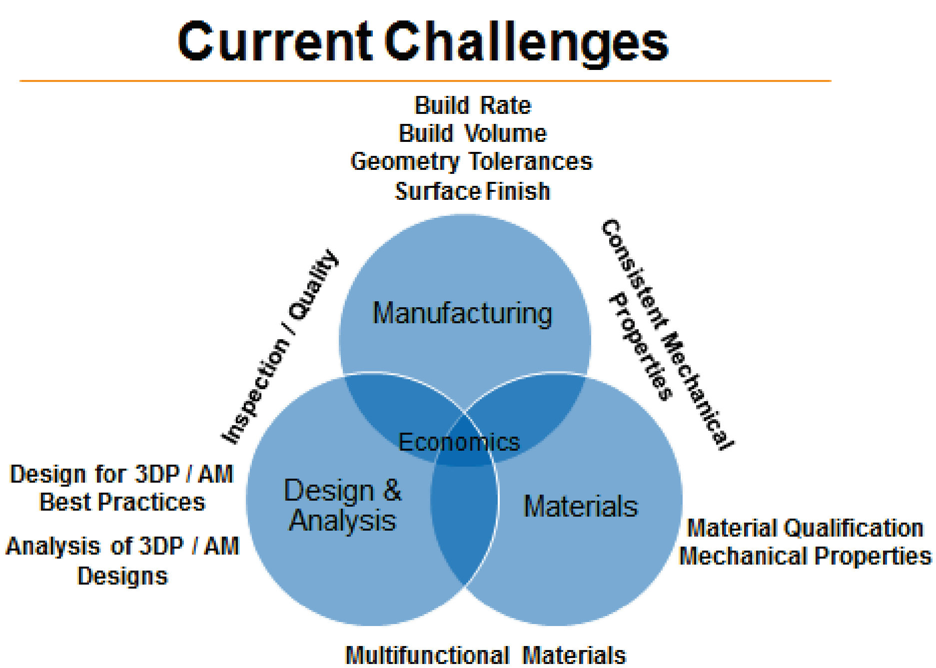
3.4 Setting the mission

The Consortium will further define its scope and mission not just for the hub, but for the expansion spokes it seeks. First, the Consortium will provide the spokes with a select group of topics on which to focus based on members' needs. This will drive early wins that are meaningful to a variety of the Consortium's members. Importantly, the Consortium will establish priorities based on areas in which NYS already has significant AM capabilities.

Second, the Consortium will attract additional members who can provide solutions at various locations along the manufacturing and support infrastructure supply chain, but who do not yet see themselves as being involved with AM. For example, a company that makes inspection tools for use in traditional manufacturing processes might be unaware of the opportunity and specifications for adapting its product for use as an inspection tool in AM. In this way, a range of NYS-based companies (such as those engaged in specialty materials, precision machinery, software, process control sensors, etc.) can thus expand their markets and become suppliers to the AM sector. Prioritization will be driven by a methodology to help companies self-identify with a current business line that is applicable to AM.

Finally, the mission will involve promoting manufacturers' adoption of proven, production-ready AM materials and processes. This may be especially applicable to the State's many small machine shops, which could begin to incorporate AM as one of the techniques that they use to produce parts for clients. The mission will be focused on the most impactful opportunities to address identified challenges, as illustrated below.

Figure 1. Current challenges (reprinted with permission of Fred Herman of Advanced Additive Manufacturing)



4 Consortium Startup Phase

Creating the hub requires a phased approach with startup and expansion phases. This section describes the envisioned focus areas within the startup phase:

- part quality
- outreach and education
- workforce training

4.1 Part quality

4.1.1 Issue

Repeatability, reliability, and robustness are the three Rs that need to be conquered in order for a more wide adoption of AM. Exacting precision is required for industrial-scale repeatable production of complex, high-value parts, such as components used in aerospace applications or equipment used in the energy sector. This degree of repeatability within tight tolerances has not been historically needed for early-adopter uses of AM, such as the production of a single iteration of a concept prototype or artisanal products such as jewelry where slight variations between items can be tolerated and in fact celebrated by proclaiming that each item is a one of a kind.

Consequently, commercially-mature AM equipment, design and control software, consumable raw materials, and real-time in-process monitoring sensors—the integrated overall system—is currently poorly suited for the economically-important transition to use in industrial-scale production. Experience shows that, too frequently, repetitive production runs yield unacceptable products with too much part-to-part deviation even when all major variables remain fixed (i.e., a single operator producing repetitions of a part through multiple runs on a single machine the same day using raw materials from the identical supply batch).

The components of repeatability issues must be fully understood and solved in order to enable growth that will eventually entail production by numerous operators using numerous machines using consumable raw materials that are procured in successive batches. Robustness isn't just about achieving dimensional tolerances, rather, it's about ensuring that a part performs as required. This is especially important for use of AM in full production runs (as opposed to just prototyping).

4.1.2 Challenges

This is a holistic challenge requiring an integrated business-to-business solution that encompasses all the variables attributable to the equipment, design and control software, consumable raw materials, and real-time, in-process monitoring sensors. A robust, supply chain-scale research and development effort is necessary to address this challenge, and to identify and implement processes, materials standards and monitoring capabilities.

4.1.3 Solutions

Work in this area can involve deeper studies of machine-to-machine variability, defining process conditions and assessing variability and capability. Fabricating parts via AM is much more than just the creation of a file to load into the machines; aspects of particle geometry, laser parameters, dispensing, curing, and cleaning all have implications for product performance, many of which cannot be inspected, but require destructive testing.

The Hub's role would not be to define state-level standards, which would be of limited value compared to national and/or industry standards. The hub and spokes can inform the standards-making process, however, and will do so particularly during the expansion phase.

4.1.4 Benefits

Understanding the component-level challenges to quality issues will help drive uniformity and consistency in part fabrication across the industry, thereby enabling the use of AM for a greater number of parts and in particular for more complex, higher-value parts.

4.1.5 Government role

NYS, through the framework of the Consortium, can act as a convener to bring together vendors, users, and researchers to work toward these solutions.

4.2 Outreach and education

4.2.1 Issue

The systems currently available for AM can have immediate applicability in numerous sectors without requiring further research and development efforts. Many manufacturers could benefit from incorporating AM into their production or prototyping.

In order to leverage these opportunities, simplified yes/no flowchart-style decision trees are needed to help companies self-identify and opt-in when and where AM might make sense, such as pre-emption of expensive custom tooling for small-quantity production runs, production of custom jigs and fixturing, production-on-demand as opposed to maintaining an extensive variety of spare parts in inventory, etc.

4.2.2 Challenges

The cost structure and processing of AM is very different than conventional manufacturing methods. Work on establishing the bounds of where conventional methods will dominate, vs. where AM is a key enabler, is important for the industry to help understand which manufacturing methods are best for which applications. In some cases, a combination of conventional manufacturing and AM will be the most desirable methodology.

4.2.3 Solutions

4.2.3.1 Process mapping and best practices documentation

The hub and spokes will leverage their relationships with the Consortium's industry partners to build process maps that describe drivers for selecting AM instead of other manufacturing methods, and that provide guidance and best practices for specific use cases (e.g., when to use a specific material).

4.2.3.2 Regional partners

As part of the hub and spoke model, allied facilities will be enlisted through relationships[6] with technology-oriented educational and economic development partners. Each spoke will have some basic equipment as well as in-house consulting and training services, and can make referrals to either the hub or other spokes (e.g., university-based assets) when necessary.

6 As a model, see the successful SUNY Strategic Partnership for Industrial Resurgence program, and the SUNY Network of Excellence in Materials and Advanced Manufacturing program.

Here, comparisons with the New York State Centers for Advanced Technology (CAT) system are important. Although the focus of each CAT is nominally statewide, in practice its impact has a regional dimension because, at a practical level, a CAT's reach is limited by geography. The Consortium model accepts these geographic realities, and will integrate spokes by recognizing a regional focus for each. Different spokes may have different technological capabilities, however, so geography alone may not determine where specific activities occur.

4.2.3.3 State and federal partners

The hub and spokes will also work with the National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP) system. In 2016, ESD's Division of Science, Technology and Innovation received a five-year re-designation from NIST to serve as the MEP center for New York State; ESD in turn designated eleven sub-recipients, including one for each of the state's ten regions, to deliver services to small manufacturers.

The hub and spokes will leverage the power of this New York MEP system, which constitutes a boots on the ground organizational presence in each region with longstanding relationships with small manufacturers and relevant associations. The partnership between the Manufacturing and Technology Enterprise Center (MTEC, the New York MEP regional center for the Mid-Hudson) and SUNY New Paltz, through which multiple companies have received assistance related to AM, provides a particularly strong model. Sponsoring a conference between universities and NY MEP Centers could provide an early win for outreach.

4.2.3.4 Small, medium, and large businesses

Industries of all sizes will drive AM needs identification. The hub and spokes will participate in active outreach efforts rather than waiting passively for industry inquiries. Like AMPrint, each component of the hub and spokes will target medium-sized to large companies.

However, some components of the hub and spokes will also approach small mom and pop shops that have ideas for new products or perhaps an AM side business. These budding entrepreneurs are distinct from the small companies found at business incubators, to whom the hub and spokes will also appeal.

Smaller machine shops, molding and tooling companies, etc. have been reluctant to try AM, but the hub and spokes will try to reach them. These businesses have thin profit margins, so losing work to AM performed by others could have significant consequences (this can be counteracted by expanding to use AM in-house when appropriate). Hobbyists, although they are increasingly users of AM, are not a target of this Consortium's model.

4.2.3.5 Service bureaus

Components of the hub and spokes should not function on a fee-for-service parts production basis in order to avoid taking business away from commercial service bureaus. Rather, the hub and spokes can promote the development of service bureaus by helping NYS manufacturers to test and troubleshoot AM prototypes, offering advice about materials, etc.

As a service, on-demand 3D printing represents a huge market due to its flexibility for numerous and varied parts, acceleration of time-to-market, and improvements in productivity and cost structure. Manufacturers need to acquire greater familiarity with AM and confidence that their technological transitions can be profitable.

4.2.4 Benefits

Outreach and education efforts to established manufacturers should avoid promoting AM methods in scenarios where the ability to outperform traditional manufacturing methods cannot currently be achieved. Instead, outreach and education efforts can be structured to focus on scenarios where AM can fill a gap or opportunity area in which AM can bring cost savings or competitive advantages, such as those noted in Section 4.2.1.

4.2.4.1 Government role

The State and federal partnerships noted in section 4.2.3.3 constitute an important component of the network needed for sustained outreach and education, and ESD is positioned to ensure coordination and consistency in this effort.

4.3 Workforce training

4.3.1 Issue

There is an opportunity for extensive job growth involving operators of AM equipment, maintenance staff for repair and routine calibration of AM equipment, and those who design and produce parts. Additionally, NYS needs a stronger pipeline of materials scientists.

4.3.2 Challenges

The marketplace is evolving at a rapid pace, and curricula and training tools will need to be developed and frequently updated and expanded. Multi-disciplinary training is critical because the emerging performance requirements of AM drive a need to tailor and balance a wide array of increasingly difficult-to-combine material properties, and thus, the talent pool must be cognizant of interactions over many technologies in order to apply a systems approach to solve these key material design optimization challenges.

4.3.3 Solutions

Designing for AM is a departure from classic part design methodology. Critical skills in evaluating material and special needs, as well as in evaluating designs based upon this newer manufacturing method versus classic machine design, are critical to enable the value that AM brings. This requires a special set of skills in 3D visualization and design for manufacturing (and in particular, design for AM).

The Consortium's hub should do the following:

- Act as an intermediary with America Makes and other resources to create and embed curriculum into universities, including specifying and supporting the acquisition of teaching kits.
- Facilitate the creation of an Integrative Graduate Education and Research Training Program (IGERT),[7] with Consortium members offering curriculum at technical universities and extended internships at industrial partners. Engineers are needed (with skills involving running and understanding processes, rather than the more basic capabilities of a CAD designer).
- Collaborate with the network of community colleges to develop and roll-out a curriculum specifically to train the technician workforce.

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7 As a model, see the successful IGERT program in Fuel Cells which is housed at RPI.

The IGERT model requires further discussion. There are merits to the IGERT approach, but the focus must not exclude other levels of higher education. Specifically, there is a role both for community colleges (technician-level training for workers who will use and/or maintain AM equipment) and for four-year colleges (experimental education for engineers who design parts that are produced with AM equipment).

These two types of training are very different, and the outreach efforts will account for this fact. Initiatives at the State and federal level that address four-year colleges are underway, and will be connected to the outreach efforts described in this document. A continued emphasis on STEM at the high school level is also critical as a talent feeder.

It's also important to note there's a difference in receiving a Certificate in Additive Manufacturing (something that the American Society of Mechanical Engineers already provides) and being certified in AM. It's necessary for Educational institutions to know what industries need without being told what their curriculum should be. The Northeast Advanced Technological Education Center offers a model, specifically, to provide programs that prepare students for jobs in advanced technology. This includes coordinating student recruitment, researching workforce trends and training needs, and creating employment opportunities. Critically, all programs under this model should utilize student feedback, interviewing students who return to campus from internships to garner the information needed to update programs.

4.3.4 Benefits

Fostering these necessary skills will enable a talent pool that is critical for the future success of the industry. Already these resources are in limited supply and highly sought after across the country. The northeastern United States is distinguished with a preeminent higher education sector, and an effort to expand these capabilities to offer a continuum of training for AM will enhance the value and attraction of educational institutions in NYS.

4.3.5 Government role

Government roles in this area include the encouragement of robust industry-education partnerships and ensuring coordination among the State's private and public education sectors in addressing curriculum and credentialing needs.

5 Consortium Expansion Phase

The Expansion Phase will focus on the following:

- materials-related research
- information gathering
- part testing
- technology transitions
- job creation

5.1 Materials-related research

Components of the hub and spokes will support materials-related research that is already underway at NYS universities, helping to ensure that the State maintains a leadership role in advancing AM technology development. The strategic focus is on materials research rather than equipment development and acquisition, because of the speed at which equipment can become out of date.

5.2 Information gathering

Organizations such as the American Society of Mechanical Engineers and the International Organization for Standardization maintain AM standards. It is challenging for companies to find time to participate in the standards-making process. The hub and spokes, especially the AMPrint Center, should facilitate input from NYS companies and other NYS entities into these processes.

5.3 Part testing

Appropriate components of the hub and spokes will test prototype parts, especially with regard to failure analysis. By learning why a prototype failed, companies can improve the next iteration. By providing failure analysis expertise, the Consortium can help companies become more confident in further adopting AM. Testing for final-use parts is also critical, especially in the absence of complete and comprehensive national standards.

5.4 Technology transitions

5.4.1 Issue

The Consortium's mandate should also include encouraging NYS manufacturers to design new and improved products that could not be made using conventional manufacturing techniques. Where the value proposition dictates, this will ensure market pull leading to these products with rapid development cycles and may inform gaps that can be solved through additional R&D (such as the need for a specific new material to enable a promising application).

5.4.2 Challenges

Prioritization to be driven by a methodology that will help companies self-identify that they are engaged in a market sector where a new and improved product would gain some competitive advantage by incorporating features that could only be made via AM (methodology may leverage understanding of particular sectors and/or product characteristics). In addition to addressing the who question, a methodology can be applied that addresses the how question (to help companies identify the opportunity, confirm the anticipated competitive advantage, design, and produce the new and improved product and apply the appropriate AM technique).

5.4.3 Frameworks

Appropriate components of the Consortium could engage in consultative services to coach manufacturers into dreaming big. This could be supplemented by low-cost bounded scope efforts of initial exploratory academic research into novel materials and processes associated with the needs of an industrialist who is dreaming big, with the intent to produce a characterization of various options for follow-on research that the industrialist might consider funding.

The Consortium could explore opportunities for such big wins through structured workshops with private industry, as well as by creating and promoting a library of technology demonstrators—e.g., case studies in which a company designed and manufactured a successful new product only producible using AM.

5.4.4 Benefits

This risk-sharing approach can help overcome inertia and propel a company or entrepreneur into a worthwhile collaboration with an academic research team in pursuit of novel solutions to an economically important opportunity.

5.4.5 Funding

The Consortium should identify a source of seed funds, perhaps to be partially matched by university endowment funds, and a process for awarding such seed funds on a project-by-project basis.

6 Conclusion: NYS Leadership and Job Growth

It is clear that by maintaining and strengthening leadership in the area of AM technology development, NYS will be best positioned to capitalize on the job creation potential associated with AM's growth, as companies engaged by the Consortium explore and adopt AM at a quicker pace.

There are currently a number of challenges with the adoption of AM at a broader scale. Production rates, quality of surface finish, material properties, and post-processing all factor strongly in cost and application considerations, making direct comparisons to traditional manufacturing methods difficult. A lack of industry standards hampers these comparisons. Skills in designing and building in 3D are not as prevalent as needed to drive widespread novel product solutions. All aspects of these challenges need to be addressed in order to spur growth in this technology area.

In the envisioned Consortium, the hub will receive marketplace intelligence from the spokes that will be instrumental for scouting where opportunities may exist to exploit the value of the AM approach, and help generate new market opportunities. A collaboration of the academic sector focusing on how to animate new design skills, the industrial sector helping to specify the needs for technology advances in materials/build-rates/attributes, and government helping to promote standards and safe best practices, will help build a more complete framework for driving more widespread adoption of AM methods.

Like many historical examples of technology disruptions and their attendant economic expansions, in order to reap the fullest economic potential associated with AM at this important juncture, NYS must ensure a robust and coordinated framework for ensuring and activating all these roles. The Consortium/hub and spokes model is recommended as the best framework to coalesce market actors and address the hurdles and opportunities associated with AM.

Appendix A. GE's Use of 3D Printing to Make Jet Parts

A brief article by Martin LaMonica regarding GE's use of 3D printing to make jet parts is illustrative of the potential for AM to revolutionize the way complex products are made. Titled, "Additive Manufacturing: GE, The World's Largest Manufacturer, Is On The Verge Of Using 3-D Printing To Make Jet Parts," it was published as part of the MIT Technology Review's 10 Breakthrough Technologies piece in Spring 2013, and can be accessed at http://www.technologyreview.com/featuredstory/513716/additive-manufacturing. This article tells a compelling story regarding the current evolution of Additive Manufacturing from being used as a prototyping technique to being a preferred industrial manufacturing technique for mass-production of high-value critical components.

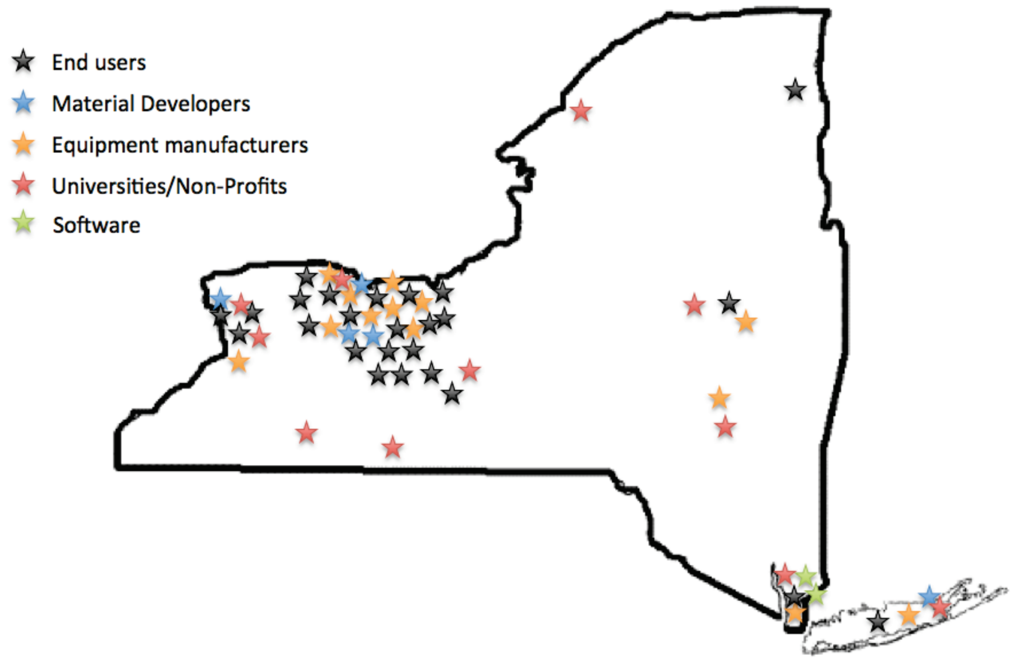
Appendix B. New York State 3DP/AM Assets

New York State is home to a significant number of companies making important contributions to the field of AM. Multinational companies Xerox, Kodak, Fisher-Price, and GE are undertaking leading research and applications in AM. New York City hosts leading manufacturers of AM equipment such as Makerbot and associated service providers such as Voodoo Manufacturing. On Long Island, Graphene 3D Lab provides powders, pellets, filaments, resins, and granules. In the Capital Region and Western New York areas, small-scale enterprises are producing custom metal powders. Other companies making notable contributions and uses of AM include Automated Dynamics, Incodema, HARBEC, Moog, Inc., ThermoAura, Ceralink, Praxair, and others who were represented at the Scoping Session (Appendix D). Small and medium-size manufacturers such as Centrotherm Eco Systems, LLC are also experimenting with three-dimensional printing (3DP)/AM not just for prototyping, but for final-use parts. Buffalo Manufacturing Works is playing an important role in assisting companies in designing AM products and adopting AM processes. Norsk Titanium recently received significant NYS state investment to establish the world's first industrial-scale aerospace AM plant in Plattsburgh.

Across the Empire State, public and private universities represent important AM resources for education, training, and product and process development. Historically, universities have partnered with industries to promote research, commercialization, and economic growth.

A non-comprehensive representation of the distribution of AM users, material developers, equipment manufacturers, universities, and software providers is provided below.

Figure B-1. Existing resources across New York State (reprinted with permission of Denis Cormier of Rochester Institute of Technology).



NYS has a strong foundation of existing university assets that could support structured, statewide NYS efforts in AM—that is, play important roles in the envisioned Consortium. These assets cover the following important areas:

- best-practices documentation and process capabilities
- multi-jet printing and development of direct contact printing for micro/nano AM applications
- metal powder-bed fusion
- research in the development of new AM modalities
- in-situ quality control and monitoring
- innovation, knowledge base, establishment of safety and materials standards for industrial and commercial processes

The following are examples of leading NYS university-based resources and expertise:

- At Rochester Institute of Technology (RIT), Denis Cormier and Ron Aman have approximately 30 years of AM experience with most commercially available processes. Both can contribute to best-practices documentation. Denis Cormier, who has been teaching 3DP/AM courses for more than 15 years, is also involved with the American Society for Testing Materials F-42 standards group, relevant to design and AM process capabilities.

- RIT is home to the Additive Manufacturing and Multifunctional Printing (AMPrint) Center, a New York State-designated Center for Advanced Technology. Affiliated RIT experts have extensive ink formulation and polymer science expertise. AMPrint also has expertise in ink synthesis and characterization capabilities (surface tension, viscosity, zeta potential, etc.). Cormier, who leads AMPrint, provides a strong focus on printed electronics.
- RIT’s Aman and Cormier each have more than 10 years of experience with laser and e-beam melting powder-bed processes. RIT has a direct metal laser sintering system from 3D Systems and is acquiring hybrid laser cladding capabilities. In addition, RIT has binder jet printing and stereolithography (SLA) equipment. Again, the use of this 3DP/AM equipment is supported by faculty members with approximately 30 years of experience combined.
- RIT has versions of most of the commercial processes, including the major direct-write processes (e.g., Optomec and nScrypt) and ExOne hardware for ceramics 3DP. RIT is also acquiring a Hybrid Manufacturing Technologies hybrid system.
- As stated above, RIT has versions of most of the commercial processes. These include SLA, selective laser sintering, selective laser melting, hybrid, and direct-write systems.
- The State University of New York (SUNY) at New Paltz has industrial-level fused deposition modeling printers: Stratasys Dimension 1200ES and Fortus 400mc. SUNY New Paltz also has full-color powder print equipment (3DS ProJet 660) as well as a large array of desktop printers that are useful for lower-cost projects. In addition, the university plans to add a high-resolution polyjet-type printer soon. Given this equipment set, SUNY New Paltz can meet almost all of the applications for which 3D printing is used currently. This includes molds, jigs, fixtures, prototypes, and final-use parts. SUNY New Paltz is already collaborating with companies in the Hudson Valley. SUNY New Paltz also has expertise with 3D printers and CAD expertise for both art and engineering.
- Other SUNY campuses with deep R&D capabilities in AM include Stony Brook University and its Department of Materials Science and Engineering; the University at Buffalo; and SUNY Polytechnic Institute. Together with SUNY New Paltz, academics at these institutions are key members of SUNY’s Network of Excellence in Materials and Advanced Manufacturing, which provides support toward groundbreaking projects in digital and AM. Capabilities and projects have included those such as 3D printing of cartilage; 3D printing of flexible sensors; and various projects related to testing and exploring new AM materials and applications.
- Clarkson University’s Center for Advanced Materials Processing performs applied research in the area of advanced metal AM.
- Rensselaer Polytechnic Institute’s Center for Automation Technologies and Systems houses an Additive Manufacturing Lab and leading metal AM researchers.
- Alfred University's Center for Advanced Ceramic Technology is the premier capability in the State for R&D concerning ceramics and AM.
- Cornell University has been home to leading AM researchers and start-ups creating novel AM machines and AM-designed products.

Appendix C. The Leading National Effort Underway to Promote Additive Manufacturing

America Makes (https://americamakes.us/about/overview) is the institute dedicated to AM within the Manufacturing USA network, formerly known as the National Network for Manufacturing Innovation (NNMI). There is an opportunity for NYS to engage the national effort of America Makes as a State Affiliate in order to influence the agenda to emphasize issues of value to stakeholders in NYS. Currently, its leading partnerships within New York State include Rochester Institute of Technology, Binghamton University, and Edison Welding Institute's Buffalo Manufacturing Works.

As the national accelerator for AM and 3D printing (3DP), America Makes is the nation's leading and collaborative partner in AM and 3DP technology research, discovery, creation, and innovation. Structured as a public-private partnership with member organizations from industry, academia, government, non-government agencies, and workforce and economic development resources, America Makes is working together to innovate and accelerate AM and 3DP to increase our nation's global manufacturing competitiveness in the following ways:

- Fostering a highly collaborative infrastructure for the open exchange of AM information and research.
- Facilitating the development, evaluation, and deployment of efficient and flexible AM technologies.
- Engaging with educational institutions and companies to supply education and training in AM technologies to create an adaptive, leading workforce.
- Serving as a national Institute with regional and national impact on AM capabilities.
- Linking and integrating U.S. companies with existing public, private, or not-for-profit industrial and economic development resources, and business incubators, with an emphasis on assisting small- and medium-sized enterprises and early-stage companies (start-ups).

Established in 2012 and based in Youngstown, Ohio, America Makes was the first institute established under the Manufacturing USA initiative and is administered by the National Center for Defense Manufacturing and Machining. America Makes offers three membership categories, each with varying financial and benefit levels. Membership fees can be met with a combination of cash and contribution of services or products. Members also receive other significant benefits, including access to valuable intellectual property, technical presentations, and project calls.

Currently, no single AM organization has the resources or the partnerships to develop the standards, tools, education, and research required to accelerate the U.S. manufacturing industry into a dominant, global economic force. America Makes' mission is to foster a balanced member community of diverse organizations with enough pooled resources to accomplish this goal. It should be noted that certain aspects of America Makes' funding are set to cease after five years of operation.

Appendix D. Stakeholders Involved in This Process

In performing the research for this report and developing the strategies herein, FuzeHub was guided by the Steering Committee listed in the Acknowledgements section as well as numerous other experts and stakeholders. Most are represented in the participant list from the June 2016 Scoping Session held at GE Global Research. That list is provided along with the agenda.

New York State Additive Manufacturing Scoping Session
GE Global Research – June 10, 2016
AGENDA

8:00–8:30 Arrivals and Breakfast

8:30–9:00 Introduction/Welcomes

- Santokh Badesha (Xerox Corporation Fellow and Manager of Open Innovation, Xerox Corp.)
- Steve Duclos (Chief Scientist for Material Systems and Nanotechnology, GE Global Research)
- Howard Zemsky (President & CEO, Empire State Development; and Commissioner, NYS Department of Economic Development)

9:00–10:15 Keynote Addresses

- Kevin Creehan (Deputy Director of Technology Transition, America Makes)
- Philip DeSimone (Vice President for Business Development, Carbon3D)
- Facilitated by Prabhjot Singh (Additive Manufacturing Lab Manager, GE Global Research)

10:15–10:30 Background on New York State Additive Manufacturing Initiative

- Dana Levy (Program Manager for On-site Power Applications, NYSERDA)

10:30–12:00 Panel: Sector Impacts: Enablers, Barriers, and Opportunities

- Energy-related products: Ajit Achuthan (Associate Professor, Clarkson University) and Cameron Smith (Computational Scientist, Rensselaer Polytechnic Institute)
- Metal and ceramic processing: Matthew Hall (Director, Center for Advanced Ceramic Technology, Alfred University)

- Healthcare and biomedical applications: David Corr (Associate Professor, Department of Biomedical Engineering, Rensselaer Polytechnic Institute) and Janet Paluh (Associate Professor in Nanobioscience, SUNY Polytechnic Institute)
- Expanding the manufacturing toolbox: Scott Volk (Director of Additive Manufacturing,
- Incodema3D) and Bob Bechtold (President, HARBEC)
- Facilitated by: Gary Halada (Associate Professor, Department of Materials Science and Engineering, Stony Brook University); and Steve Rock (Senior Research Scientist, NYS Center for Automation Technologies and Systems, Rensselaer Polytechnic Institute)

12:00–1:00 Lunch and Electronic Poster Session

1:00–1:15 Keynote Remarks from Dave Cranmer (Deputy Director, Hollings Manufacturing Extension Partnership, National Institute of Standards and Technology)

- Introduced by: Matt Watson (Director, Division of Science, Technology & Innovation, Empire State Development)

1:15–2:00 Panel: Pervasive Ecosystem Impact

- Dave Cranmer (Deputy Director, Hollings Manufacturing Extension Partnership, National Institute of Standards and Technology)
- Daniel Freedman (Dean, School of Science and Engineering, SUNY New Paltz)
- Karl Dueland (Vice President and General Manager of Digital Manufacturing, Xerox Corp.)
- Facilitated by Terry Ott (Director, Applied Processes for Manufacturing, Corning Incorporated) and Cumar Sreekumar (Director, Advanced Technology Group and Vice President, Intellectual Property Solutions Division, Eastman Kodak)

2:00–3:30 Sustaining the Momentum: Organizing the NYS Ecosystem

- Denis Cormier (Earl W. Brinkman Professor and Director, NYS Center for Advanced Technology in Additive Manufacturing and Functional Printing (AMPrint), Rochester Institute of Technology)
- Steve Levesque (Operations Manager for New York, EWI)
- Dave Hauber (Vice President of Engineering, Automated Dynamics)
- Rajesh Mehta (Program Director, National Science Foundation; and manager of the advanced manufacturing and nanotechnology portfolio for the NSF's SBIR program)
- Kevin Harding (Principal Engineer for Optics, GE Global Research)
- Bill Acker (Executive Director, NY-BEST)
- Facilitated by Dana Levy (NYSERDA)

3:30–3:45 Closing Remarks from Alexander Cartwright (State University of New York Provost and Executive Vice Chancellor)

- Introduced by Santokh Badesha (Xerox Corp.)

3:45–4:00 Next Steps and Adjournment

4:00–4:30 Networking

PARTICIPANTS

**Member of the New York State Additive Manufacturing Advisory Committee.*

- Ajit Achuthan* – Associate Professor, Clarkson University
- Bill Acker – Executive Director, NY-BEST
- Shawn Allan – Owner, Materials Engineer, Allan Materials Inc.
- Ronald Aman – Assistant Professor, Rochester Institute of Technology
- Santokh Badesha* – Xerox Fellow and Manager of Open Innovation, Xerox Corp.
- Jason Bassi – Strategic Account Executive, Stratasys
- Robert Bechtold* – President, HARBEC
- Thomas Bell – Project Director, Center for Economic Growth
- Stephan Biller – Chief Scientist for Manufacturing, GE Global Research
- Alex Cartwright – Provost and Executive Vice Chancellor, State University of New York
- Joe Cesarano – President and Founder, Robocasting Enterprises LLC
- Denis Cormier* – Director, AMPrint Center, Rochester Institute of Technology
- David Corr – Associate Professor, Department of Biomedical Engineering, Rensselaer Polytechnic Institute
- David Cranmer – Deputy Director, Hollings Manufacturing Extension Partnership, National Inst. for Standards and Technology
- Kevin Creehan – Deputy Director, Technology Transition, America Makes
- Paul Dellaneve – Vice President, Corporate Development, Moog Inc.
- Philip DeSimone – Vice President, Business Development, Carbon3D
- Peter DiLaura – President, CADimensions, Inc.
- Raymond Dromms – Director/Current Product Engineer/Triage, Welch Allyn/ Hill-Rom
- Steve Duclos – Chief Scientist for Material Systems and Nanotechnology, GE Global Research
- Karl Dueland – Vice President and General Manager of Digital Manufacturing, Xerox Corp.
- Scott Fisher – Technology Director, Application Technology, SABIC
- Arthur Fisher – Business Development, UL
- Daniel Freedman* – Dean, School of Science and Engineering, SUNY New Paltz
- Elena Garuc* – Executive Director, FuzeHub
- Gary Halada* – Associate Professor, Department of Materials Science and Engineering, Stony Brook University
- Matthew Hall* – Director, Center for Advanced Ceramic Technology, Alfred University

- Kevin Harding – Principal Engineer for Optics, GE Global Research
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- Luke Kelly – Vice President of Finance, Carbon3D
- Shawn Kelly, Oerlikon Metco
- Andrew Kennedy – President and CEO, Center for Economic Growth
- Scott Laundry – Senior Project Manager, Central New York Technology Development Organization
- Mike Lefebvre – Executive Vice President for Public Policy, Planning & Incentives, Empire State Development
- Steve Levesque* – Operations Manager for New York, EWI
- Dana Levy* – Program Manager, On-Site Power Production, NYSERDA
- Jessica Longobardo, MPI Inc.
- Wendy MacPherson – Senior Project Manager, Industrial and Agriculture, NYSERDA
- Tammy Malone – Office Manager, On-Site Power Production, NYSERDA
- Brian Marks, Consultant to Carbon3D
- Rajesh Mehta – Program Director, National Science Foundation
- Rutvik J. Mehta* – President, ThermoAura Inc.
- Stephen Melito – Matching Specialist and Technical Writer, FuzeHub
- Scott Miller – Manager, Nanostructures and Surfaces Laboratory, GE Global Research
- Michael Morse – Vice President, Strategic Business Development, Empire State Development
- Arun Natarajan – Senior Chemist, GE Global Research
- Terry Ott* – Director, Applied Processes for Manufacturing, Corning Incorporated
- Janet Paluh – Associate Professor in Nanobioscience, SUNY Polytechnic Institute
- Thomas Phillips – Executive Director, Hudson Valley Technology Development Center
- Rahul Rai – Associate Professor, University at Buffalo
- Stephen Rock* – Senior Research Scientist, NYS Center for Automation Technologies & Systems, Rensselaer Polytechnic Institute
- Megan Rooney – Marketing Assistant, FuzeHub
- Timothy Scholz, Central New York Technology Development Organization
- Holly Shulman – President, Materials Scientist, Ceralink Inc.
- Prabhjot Singh* – Additive Manufacturing Lab Manager, GE Global Research
- John Sinnott* – Industrial Partnerships Manager, Cornell Center for Materials Research
- John Sirman – Director of Emerging and External Technologies, Praxair
- Alyson Slack – Manager, Manufacturing Strategic Initiatives, FuzeHub
- Cameron Smith – Computational Scientist, Rensselaer Polytechnic Institute

- Cumar Sreekumar* – Director, Advanced Technology Group and VP, Intellectual Property Solutions Div., Eastman Kodak
- Davetta Thacher – Project Manager, On-Site Power Production, NYSERDA
- Cheryl Thierfelder – Business Development, Praxair
- Mark Torpey – Director, Technology and Business Innovation, NYSERDA
- Richard Tower – Senior Director, Operations, Marchon Eyewear, Inc.
- Stuart Uram – President, Core Cast LLC
- Scott Volk* – Director of Additive Manufacturing, Incodema3D
- Daniel Walczyk – Professor and Director, Center for Automation Technologies and Systems, Rensselaer Polytechnic Institute
- Matthew Watson* – Director, Division of Science, Technology and Innovation, Empire State Development
- Spencer Wright – Vice President of Product, nTopology
- Michael Yevoli, Capital Regional Director, Empire State Development
- Daniel Young – Business Development, Alfred University
- Howard Zemsky – President and CEO, Empire State Development and Commissioner, NYS Department of Economic Development
- Chi Zhou – Assistant Professor, University at Buffalo

Appendix E. Scoping Session Output

The following is a record of the presentations and discussions at the June 2016 Scoping Session held at GE Global Research. Please refer to Appendix D for the agenda. PowerPoint presentation decks from the event have been provided to NYSERDA separately.

E.1 Morning keynote addresses

E.1.1 Phil DeSimone, Vice President for Business Development, Carbon3D

DeSimone posed the question of why 3DP has failed to transform manufacturing to date, and offered that the reason is slow speed, low quality of 3DP parts, and limited choices in material. The underlying cause of this failure is that mechanical engineers have been trying to solve material science problems.

Carbon3D technology consists of a projector, z-stage, and window. Features include advanced speeds and consistent mechanical properties. This latter point is key for the FDA and other regulatory approvals. Unlike other SLA machines, Carbon 3D delivers thermoplastic properties at a great speed.

DeSimone shared some 3D printed parts with the audience, including one for BMW automobiles. He noted that the behavior is identical to injection-molded polypropylene. This is important because materials for automotive and aerospace applications must often withstand higher temperature. The company also developed an elastomeric material for an athletic shoemaker using thermoplastic polyurethane.

DeSimone recommended that NYS direct its AM investments toward education, particularly the education of engineers, who are currently too often taught to avoid certain things in product design. Today, engineers need to unlearn some of these rules. This will be one of the major roadblocks in the growth of 3DP. Carbon3D will address the challenge one company at a time, by solving their biggest engineering problems.

Carbon3D’s M1 build envelope is a connected device with one million data points per day. It’s loaded with sensors and provides a new experience with capital equipment. Carbon3D sends software updates (constant improvement) and provides predictive customer support.

Parts from the M1 can come with a manufacturing history. This is what's required to show that the part has been built-to-spec. The M1 also leverages network effects. When there's a problem in the field, the machine sends failed data back to Carbon3D, which can then incorporate the findings and improve the functionality. Then, Carbon3D shares the fixes with its entire customer base. They use a subscription model of three years at $40,000.

It's important to go beyond the prototyping market, but hurdles like surface finish, mechanical properties, and quality are hard to overcome. Yet with the customization of cars, manufacturers need an alternative to traditional technologies. The industry will move from moldable parts to unmoldable ones.

During the Q&A, Janet Paluh from SUNY Polytechnic Institute asked about Carbon3D's efforts to partner with universities. Paluh recommended reaching out to the individual scientists rather than the schools as a whole. DeSimone noted that Carbon3D is partnering with universities, that the individual professors are the buyers, and that they are the ones using grants to fund such partnerships.

E.1.2 Kevin Creehan, Deputy Director of Technology Transition, America Makes

Kevin Creehan began by explaining that collaboration and ecosystem are terms they hear constantly at America Makes, the institute under the National Network for Manufacturing Innovation (later renamed Manufacturing USA) dedicated to AM. That network uses a true institute model, which makes it different from Germany's Fraunhofer model.

America Makes is accelerating AM. Creehan showed a video that described the institute's place at the intersection of academia, industry, nonprofits, and government. Today, America Makes is managing $87 million in projects. Pockets of AM expertise are scattered across the United States, so American Makes sought to connect these resources in a way that accelerates the development of AM to ensure the country's competitiveness in the field. "Additive manufacturing started in the United States, but we have lost our advantage—not just in terms of innovation, but also on the technical side. We need innovation in the business model as well."

Creehan emphasized that despite America Makes' original Department of Defense funding, it should not be viewed as a defense-focused institute. It has partnerships with other federal agencies, and as an example, it currently has a strong focus on healthcare in addition to aerospace.

Creehan showed a slide with America Makes' five mission objectives, but also stated that it all boils down to three pieces: technology development, technology transition, and workforce development and outreach. He again emphasized the need for design engineers to think outside the design constraints they were originally taught. Realistically, it will be harder to get older engineers to change their way of thinking. The real breakthrough will come when the next generation of engineers joins the workforce. Nevertheless, at America Makes, "K through gray" is the focus.

AM research is important and America Makes serves as a coordinator and accelerator. The institute itself is not the researchers; rather, America Makes creates a national roadmap for 3DP development, identifying gaps and coordinating the work to address them (through projects). GE is participating and leading several projects. Regardless of geographic location, institution type, or business size, all must work together.

With regard to bridging technology development gaps, Creehan referred to the Technology Readiness Levels and Manufacturing Readiness Levels used by NASA and the Department of Defense, noting that levels 4 through 7 are where the country has struggled to advance 3DP technology. Addressing that shortcoming is key to keeping the technologies that we invent in the United States. For example, the flat screen TV was developed here, but then the student inventors took manufacturing overseas.

America Makes members at the $15,000 level receive access to the $100 million in research that was mentioned in the video Creehan played; such companies can use any R&D that's been done through the program. So even if only 1% of America Makes' portfolio is of interest to the company, that's $1 million on a $15,000 investment—a strong value proposition. America Makes has doubled its membership in the past few years and is building "the supply chain of the future." It's not too late to partner.

America Makes maintains a roadmap both for AM technology and AM workforce development/education. It doesn't create the roadmaps, but rather facilitates its development using private and public partners. The roadmaps identify gaps that are then addressed by complex teams. (He noted that GE's Prabhjot Singh has been involved in such teams.) The workforce development and education roadmap identifies gaps in existing curriculum.

America Makes understands that companies fear they will lose their intellectual property (IP) by collaborating within an institute. Creehan emphasized that companies continue to own their pre-existing IP as well as whatever they develop through the institute. In other words, America Makes doesn't own a company's IP. In fact, they do not own any IP as an institute. Rather, what they provide is IP protection. Membership agreements are signed by all institute members. If you make it, you own it. If something gets made through the institute, however, then all members have a right to the funded component. Put another way, it's important to understand that there's background IP before the program, and separately, there's IP created during the program (the shareable IP).

America Makes' innovation facility in Youngstown, Ohio is "not a grand mecca" but rather a warehouse with consigned technology for training, education, and exposure. Equipment makers have contributed equipment. It's like a "permanent tradeshow." There's also space for researchers and developers to meet.

Q&A: In response to a question from SABIC's Scott Fisher, Creehan said that a NYS collaborative of sorts could join the institute. American Makes could then filter the results of research accordingly and host events with NYS.

Q&A: GE Global Research's Prabhjot Singh asked about America Makes' new collaboration with the University of Texas at El Paso. Creehan described this first America Makes satellite center as a "hidden gem" and a regional location that advances the institute's mission. The university also has its own partners in the region. American Makes is looking for more satellite centers across the United States. The goal is not just to expand regionally to reach large population centers, but to gain exposure to new technologies and industries.

Q&A: Rensselaer Polytechnic Institute's Dan Walczyk asked about the America Makes' sustainability model in terms of what will keep companies coming back. Creehan answered that in October 2017, the $55 million that was received from the federal government will be spent. At that point, America Makes must determine a model to keep going. Creehan doesn't believe that the federal government or large private firms will end 3DP investment. A second cooperative agreement is in place with the federal government for the sole purpose of project work. (Additional private funding comes from the project teams.) Ultimately, then, the "hole" is the operations of the institute itself. They need members to sustain the institute's operations, pay salaries, etc. Again, the institute model has three tiers ($15,000, $50,000, and $200,000 per year). They accept cost sharing instead of cash for membership dollars and can predict the proportionality. America Makes needs 220 members to reach this point, and is at 174 members today. They are expanding training offerings and keeping overhead down by not having a huge facility in Youngstown.

Q&A: In response to another questioner, Creehan noted that the value proposition for small businesses to join is "access to big players" they could not reach otherwise.

Q&A: Holly Shulman from Ceralink asked about cost-share thresholds and organizational decision making. Creehan answered that high-level members have access to the commercialization of the IP. There's also a governance board that's made of gold and platinum members—this is the organization's steering committee. However, even platinum members can sometimes achieve their dues entirely through cost share.

E.1.3 Dana Levy, Program Manager for On-Site Power Applications, NYSERDA

Dana Levy thanked DeSimone and Creehan for their presentations and shared that this project has catalogued the landscape of AM in NYS and begun to calibrate its economic potential. He noted the remainder of the day will help inform the questions: "How can we grow this? What are the opportunities and barriers?"

E.2 Panel: Sector impacts

E.2.1 Energy-related products

- Ajit Achuthan, Associate Professor, Clarkson University
- Cameron Smith, Computational Scientist, Rensselaer Polytechnic Institute

Achuthan said that we need to look at the current state of energy generation and energy consumption. It's also important to consider design enhancement, capabilities, and quality. Eliminating tooling reduces cost. It also means less mass and less energy. On the energy consumption side, look at GE's LEAP engine nozzle. The advantages aren't just that it's lighter and more durable; there's a significant increase in the speed of production, too, because using one part instead of 28 means less tooling. There's a dramatic decrease in emissions. Achuthan also discussed an impeller in a pump system. With AM, there are prototyping cost reductions, decreased lead-time per lot, and increased energy efficiency. A third example involves seatbelt brackets for airplanes. Because of their lighter weight, energy usage is decreased. There's a total energy savings across the production life cycle since there is no tooling to be manufactured.

We need to utilize the unique capabilities of AM. There are opportunities in green energy and renewable energy as well as repairs, since you can produce layer by layer.

There are barriers, however. These include the technological limitations of speed, volume, and part size. AM design also requires new ways of thinking. Engineers have been taught that geometries are simple, but limited (e.g., I-beams). We've also learned that materials are homogenous with uniform material properties such as yield strength. So we lack evaluative tools and resources.

Cameron Smith said there is value in high-performance computing for modeling at both the macro and micro levels. Plus, modeling costs less than tooling. Adaptive tools for modeling selective laser melting processes (adaptive mesh) is a current Small Business Innovation Research project at the New York State-supported high-performance computing consortium that Rensselaer Polytechnic Institute participates in.

Q&A: Carbon3D's Luke Kelly asked about differences in design issues between metals and plastics. Achuthan answered that there are similar design issues with both.

Q&A: Steve Duclos of GE Global Research asked about the challenge of interfacing the surfaces of old welds and new materials. Achuthan agreed that this remains a challenge. Duclos asked about vision systems and suggested there is a need for them.

Q&A: Janet Paluh from SUNY Polytechnic Institute asked about shortening warranty and manufacturing times as manufacturing large pieces of composites are a big challenge. Achuthan deferred to Rensselaer Polytechnic Institute's Steve Rock for the industry side of things and Rock answered that it's necessary to have a good understanding of the process parameters so they can be repeatable. Otherwise, you won't get the manufacturer of the original structure to buy in. Steve Duclos added this shows the importance of geometry in testing.

Q&A Steve Levesque from Buffalo Manufacturing Works asked what's changing to enable AM models since we can't manufacture some things without traditional weld modeling tools. Smith answered that the next generation systems will be more tightly coupled with the software that's being deployed (e.g., Cray, IBM) because you don't want to run a massive mesh unless you have to.

E.2.2 Metals and ceramics

- Gary Halada, Associate Professor, Stony Brook University Department of Materials Science & Engineering
- Matt Hall, Director, Center for Advanced Ceramic Technology, Alfred University

Hall said that with ceramics, the inability to use directed energy techniques is a huge limitation. (Lasers introduce thermal shock). "So binder jet technology is used instead. Thermal and mechanical post-processed is used. We want to eliminate this. It's true for ceramics and also for metals."

He talked about future directions and opportunities. Their focus is on the powder, not the printing technology. There is some particle-size distribution and morphology to consider. "We are interested in hybrid manufacturing processes—that is, introducing more than one material simultaneously for variant properties. On the ceramics side, there's the idea of reactive atmospheres."

Hall also spoke about how they're beginning to develop process maps for ceramics and glasses. Today, we are largely limited to off-the-shelf materials. Importantly, some existing powders are incompatible with existing 3DP technologies. There is not a lot of capability out there for manufacturing custom powders in small quantities. It's a problem that the piece you get out of the printer still has to be fired. This can lead to issues, as noted previously (i.e., directed energy issues). He then talked about what would help. “There has been a massive erosion of traditional disciplines in the last 20 years. Specifically, this is material science and metallurgy. There are only two programs left for ceramic engineering degrees and ten for metallurgy. We very much need more engineers who understand the materials for 3DP applications. We don’t have the workforce at the technician level either.”

Halada said he has been involved in curriculum development along the entire K-12 pipeline. He then talked about the metals being used. How does the 3DP process itself affect the chemistry of the metals? What you start with may change because of this processing. The value of 3DP is in the design flexibility, savings, etc. He also talked about hybrid manufacturing and compared 3DP to CNC machining. Certain types of materials are especially challenging—specifically, maintaining the chemistry from source to finished build is a challenge. There is value in eliminating post-processing steps. “We need reliable source materials all the way to recycling. Can we use AM to create new alloys, functional devices based on material properties? Can we get to lower costs? Toxicity and hazards are also important to consider since some metal powders can be explosive. If you need a $50,000 vacuum cleaner, that’s an issue.”

Q&A: Joe Cesarano of Robocasting Enterprises questioned the assertion that ceramic 3DP isn’t viable. They’re doing it with large production runs.

Q&A: Terry Ott from Corning Incorporated wanted to talk more about the “wish list.” Halada answered that with more online training, there could more opportunities. He said that their program had been focused on metals for years, but then plastics took over. Now everyone is into composites. With advancements in educational technologies however, there can be more active learning processes.

E.2.3 Healthcare and biomedical applications

- David Corr, Associate Professor, Department of Biomedical Engineering, Rensselaer Polytechnic Institute
- Janet Paluh, Associate Professor in Nanobioscience, SUNY Polytechnic Institute

Corr spoke about the difference between cellular and acellular models. It’s about understanding the interaction of polymers, metals, and other materials with soft tissues and hard tissues. 3DP medical devices can support the biological, or involve printing the biologics themselves (bioprinting). Based on current technology, the public’s expectations for what we can do are unrealistic. The printing of a heart is 30 years away or longer.

“So what can we do? We can print cells in 2D and 3D to make cellular structures. We can print stem cells and maintain their characteristics, something that has huge potential for regenerative medicine. We can also make tissue constructs and print at the single cell level. Going forward, we can have a huge impact with in vitro diagnostics.”

Paluh addressed the self-assembly side of things. Specifically, she talked about machines building machines. AM can be used to help assemble some of the cells first, and the cells also know how to self-assemble. “We’re learning how this works, but we have a long way to go. There are applications in stem cell biology, Alzheimer’s research, spinal cord injuries, and traumatic brain injuries. What it comes down to is cell interactions with materials. Questions to ask are: Do you want it to be inside or outside the body? Is it designed for short-term or long-term use?”

Some of the challenges are integrating probes with cells and the issue of seating or cells vs. bacterial pathogens. Despite these problems, self-assembly is the future. Paluh sees AM as an industrial revolution in this regard. “Today, we can create functional cartilage for nose and ear replacements. These are just passive structures. The geometry drives it. At the next level, can we make a functioning part or tissue?”

One emerging area is leveraging the replicability of manufacturing. Automation is also important. There must be biocompatibility during manufacturing (i.e., can’t damage the cells). Things must also be biocompatible when they are finished being produced. Paluh added that organs would need biomechanical training. Force must be applied them. They must be flexible and not static. There may be a need for multi-layer signaling with prosthetics, too.

Personalized medicine is also important. The military could print in the field. Patients could print at home. If medical expertise isn’t available, the military could create on-demand structures. They must be able to handle harsh environments, however. Personalized prosthetics could be an emphasis for at-home manufacturing.

Corr spoke about the barriers. Is multi-scale fabrication akin to hybrid manufacturing? Size is an issue. Techniques that are great at the macro level aren’t so great at the micro level. Also, if you are printing cells, the environment must be sterile and carefully controlled.

Long-term, tracking is important. “We need age-accelerated testing for new products that can’t compete with well-established materials. Miniaturization is an additional challenge, especially because of the regulatory environment. Money is needed for basic research and private investment. Strong collaborations can help engineers to understand the medical applications."

E.2.4 Expanding the manufacturing toolbox

- Scott Volk, Director of Additive Manufacturing, Incodema
- Bob Bechtold, President, HARBEC

Bechtold explained that AM is a complement to HARBEC's tools room. They try to find new ways to use it in their everyday approach. He also talked about the intersection of additive and subtractive manufacturing. The additively manufactured injection mold he discussed was made for low- to mid-volume production. It's cheaper than hard steel tooling produced via subtractive methods.

"With FDA testing, you must submit 50 units. They can do that by growing the mold overnight and then manufacturing the parts. Metal molds need to be cooled during production. Historically, this was done by drilling holes, but now we can build the molds including the holes (conformal cooling). The more we can use conformal cooling, the more we can enhance the tooling and the process. A toolmaker can program the additive metal machine to make the mold. Meanwhile, he can set up the CNC machine to do the finishing. Drilled holes that are close to the edge—a delicate thin-wall situation—are more expensive than the holes in 3D parts, which are free."

Volk talked about new metals and polymers and the blending of these materials are part of the future. "We see improvements in topology and in things that are stronger, lighter, and cost less, letting us do more with less." He then spoke about how Incodema is a production facility that is part of the START-UP NY program. They started as a service bureau and became mainly an aerospace supplier with 60,000 sq. ft. of space and up to 15 machines. Their products get compared to metal casting and CNC machined parts. 3DP is more expensive, which is a barrier.

Volk is in charge of hiring. The hardest thing for him is the lack of knowledge among engineers and technicians. Under the START-UP NY program, they have to hire 60 employees, either off the street or from other employers, which is not good for NYS overall since it's just transferring the skills gap from one employer to another. The cost of equipment is also challenging. It's hard to get people to embrace the technology when they hear the cost is high.

Q&A: Janet Paluh of SUNY Polytechnic Institute said her institution is graduating people who could do this work for Incodema, "We just need to connect them with you. They will need some training, but it's limited. Ultimately, they just don't know that you need them."

Q&A: In response to a questioner concerned about the lack of knowledge in the workforce, the presenters noted that as 3DP software improves, it becomes easier to set up parts for SLA. There's automatic file support, and operators don't need the understanding of the support structures. But when there's more reliance on operators instead of programmers, there's knowledge loss about how the machines actually work, which is a problem when production does not go according to plan.

Q&A: Gary Halada from Stony Brook University noted that higher education institutions have industry advisory boards. This would be a way to surface internships. We need people from the private sector who are willing to help the universities develop the programs.

Q&A: Cumar Sreekumar of Kodak said that the newest 3DP system by HP is an open material platform. Is there an opportunity for NYS? Could NYS organize businesses small and large as suppliers?

E.3 Afternoon keynote address: Dave Cranmer, Deputy Director, Hollings Manufacturing Extension Partnership, National Institute of Standards and Technology

Cranmer explained that NIST's mission is to promote U.S. innovation and industrial competitiveness. "Regulatory agencies hate variability, so it's our job to eliminate it. We have the American Society for Testing Materials F-42 committee looking at materials, processes, equipment, modeling, etc. There is one map done and one underway. The finished one (polymers) will be released soon."

NIST hosts the Advanced Manufacturing National Program Office, which coordinates the network of advanced manufacturing institutes (NNMI or Manufacturing USA), but does not fund the majority of them. NIST-supported Manufacturing Extension Partnership (MEP) centers are physically located in all 50 states. In NYS, Empire State Development's Division of Science, Technology and Innovation (NYSTAR) is the MEP center, and it in turn designated eleven sub-recipients to deliver services to small manufacturers throughout the State.

Cranmer described a forthcoming pilot project to enhance coordination between the MEP and NNMI networks by embedding MEP personnel in the institutes. This idea is derived from an MOU between NIST and the Department of Defense that notes the importance of getting small companies to participate in the institutes, adopt their new technologies, etc. The challenge is that small manufacturers often lack awareness and the ability to invest, and often also have limited workforces with limited design skills.

One of Cranmer's key points was that he had not yet heard at today's session anything regarding the timely creation of sites and infrastructures. "If NYS is going to proceed with AM, this is critical. We also need community college involvement, workforce development, local economic development, and related technologies such as links to digital/smart manufacturing and the materials genome project." He does worry about how the industrial base can invest in all of these new technologies at once.

Q&A: Dana Levy from NYSERDA asked about recommended organization and infrastructure for a potential NYS collaboration. Cranmer's answer was to establish joint working sessions among relevant players to provide the foundation for collaboration. He offered an analogy at the federal levels, where there is a joint working group of all of the agencies spending money on manufacturing.

E.4 Panel: Pervasive ecosystem impact

- Terry Ott, Director, Applied Processes for Manufacturing, Corning Inc.
- Cumar Sreekumar, Director, Advanced Technology Group and VP, Intellectual Property Solutions Division, Eastman Kodak
- Daniel Freedman, Dean, School of Science & Engineering, SUNY New Paltz
- Karl Dueland, VP/GM, Digital Manufacturing, Xerox Corp.

Ott introduced Freedman, who introduced SUNY New Paltz's 3DP initiatives. We are a comprehensive college and one of only 12 such institutions across the state. We focus on teaching, so the research includes undergraduates. Science and engineering at New Paltz has doubled in the last five years. This is important because it fills a big void in the science and engineering workforce in the mid-Hudson Valley.

SUNY New Paltz's Hudson Valley Advanced Manufacturing Center has one of the most sophisticated AM labs in the country and is part of the campus's START-UP NY project. It's where manufacturers go who don't understand a technology, but feel that it may be useful for their application. Partner Stratasys supplied much of the equipment in the lab, which is open to the entire campus and broader community. "Everyone should learn to use this technology—not just artists and engineers," Freedman says. There will be 75-minute short courses for any student or community members.

SUNY New Paltz also has a materials course that's based on AM. There's a hard core design course, too. He would like to see some business students take it. They will also train teachers, some of whom will teach public school students how to use 3D printers.

There are workforce development issues. Community colleges need to do this, but they must have access to the technology—and an interest. SUNY New Paltz has five community colleges within easy driving distance, yet none are interested. It would be a perfect add-on to their machining or CAD programs.

"We have to teach more people to use CAD. Otherwise, 3DP is useless. It's like having a laser printer if you can't write. The media doesn't convey our enthusiasm for the parts we can make with 3DP that can't be made by other methods. They see just another cheap plastic part." Freedman is on the Stratasys Educational Advisory Board. He says that many people don't know they have an application for 3DP yet. Yet Stratasys hit a wall because they want everyone to go to 3DP. First, however, they must learn how to design parts and use CAD.

Q&A: Janet Paluh from SUNY Polytechnic Institute asked about the workforce gap in the biomedical area. Could SUNY New Paltz work with them to fill it? Freedman answered that it's a good idea to get more students to do more internships as well as graduate work in the SUNY system.

Kodak's Cumar Sreekumar introduced Xerox's Karl Dueland, whose presentation centered on his assertion that innovation in business models and business objectives is just as important as design and manufacturing. Xerox manages over a million devices. His business in digital manufacturing at Xerox is to find the business cases (if any) for all of their inventions, patents, etc. There are many ways to make money in this space. They range from consulting and design to becoming a provider of end-use parts to software. "The 2D printers are uniform in performance. There is a great deal of variability with 3DP printers. Another difference is that 3DP service agreements aren't as good. You might get a call back in a day. With a 2D print job, 80% is good enough. With 3DP, you have to trash the part unless you get a perfect 100%."

Sreekumar also stated, "3DP requires finishing processes that 2DP does not. We have found that this post-production processing takes as long as or longer than the time to make the actual parts. This is problematic. Also, 2DP is for offices and graphics designers. 3DP is for engineers and product designers. The ability to get to zero landfill matter will be a key future consideration with 3DP."

"In addition to the challenge of the commercial model, businesses want to know how to train technicians completely but cost-effectively. How much can be monitored remotely, too? In the 2D world, the click model is by page. We don't have one in the 3D world yet because part sizes differ so much. There are questions of IP. Today, the IP mainly concerns materials. But what if my 3D printer makes pill and there's a jam. Whose problem is it?"

Q&A: David Corr from Rensselaer Polytechnic Institute warned that we need to avoid overselling 3DP. It's just another tool in the toolbox. Figuring out where the right opportunities are is key.

Q&A: Santokh Badesha from Xerox suggested looking at what the competitors are doing that works and doesn't work. Find the right pathway to build upon your capabilities.

E.5 Sustaining the momentum: Organizing the NYS ecosystem

E.5.1 Denis Cormier, Director, AMPrint Center, Rochester Institute of Technology

Cormier explained the AMPrint Center's role as a newly designated New York State Center for Advanced Technology. Three key areas to the advancement of AM technology are functional materials, AM process development, and novel AM apps/devices. Most 3DP creates a part that serves a mechanical or structural function. But there's also an optical function, an electronic function, heater and heat exchangers (thermal), batteries (chemical), and biological applications with tissues. He noted the vast potential for thinking beyond just more mechanical applications.

Also, what infrastructures are available? The invention of the selective laser sintering process at the University of Texas has led to the creation of many companies there. They have the premier additive research conference in the world now, too. So RIT, which also has a New York State Center of Excellence in sustainable manufacturing, is organizing a symposium for 3DP as well. We hope to attract industry and eventually have a five-course minor in AM. They are even planning an on-demand business competition.

Q&A: NYSERDA's Dana Levy noted that this is an important and narrow moment for NYS to separate itself from the rest of the pack in terms of 3DP. We have 3DP knowledge to take advantage of, including Rochester-area ink specialists and print engineers.

Q&A: Tom Bell from the Center for Economic Growth asked about how to overcome resistance from the aerospace, biomedical, and automotive industries regarding applications there. Material properties are very important to them, and it's hard to get retrofits qualified. "The cost of requalifying on the bill of material is too high," he said. You have to go back and requalify the part if the vendor changes the software. Cormier responded that these factors should be increasingly mitigated over time, leading to more opportunities for the use of AM in these industries' supply chains.

E.5.2 Steve Levesque, Operations Manager for New York, EWI

EWI (Edison Welding Institute) is a non-profit that's dedicated to advanced manufacturing. Additive goes with their welding expertise. Their main focus, including at the company's Buffalo Manufacturing Works facility, is on the AM of large metal parts.

Laminated object manufacturing is a technology that they've developed. They have a small learning lab and do mostly printing. They may push the design further next year by adding CAD.

In additional to "big metal AM", EWI is working with the electron beam process and investigating hybrid processes.

Their typical model is membership- based. Members can ask unlimited questions of EWI's advisors. Our services end when we have to put safety glasses on. We will do the design technical reviews. EWI is looking for project work to be done on their machines by their engineers and technicians.

E.5.3 Dave Hauber, Vice President of Engineering, Automated Dynamics

Hauber invented directed printing 30 years ago. His company was a spin-off of Rensselaer Polytechnic Institute's Center for Automation Technologies and Systems. He specializes in thermoplastics. Now he's interested in high-performance composite structures. By weight, carbon fiber reinforced materials are stronger than steel—and that's not just with fused deposition modeling.

He's produced a part for the largest helicopter in the United States. It's a driveshaft that's 30% lighter, yet also the highest performance part that's available. He is also involved with the Composite Prototyping Center on Long Island, which has two AM machines for public use and a work cell that was developed with help from NYSERDA and uses a high power laser.

E.5.4 Rajesh Mehta, Program Director, National Science Foundation

Mehta stressed the importance of the Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) programs as serving as "America's Seed Fund." The focus is on commercialization. He's helped 400 companies get funding.

The real job creators aren't necessarily small businesses, he noted, but "young businesses." These job creators need to be part of the right ecosystem so that they have the energy and resources to pursue an idea.

Almost 90% of the companies that the National Science Foundation provides SBIR/STTR funding to were established within the last five years. Almost 25% of the companies that they've funded don't have a PhD on staff.

Massachusetts and California are the states that have benefited the most from National Science Foundation funds. Development of the right ecosystem attracts federal dollars in terms of support for the idea, job development, etc.

SBIR winners get money in two tranches. If you're successful in Phase 1, you can get even more money in Phase 2. It's a grant and not a contract; the agency doesn't buy anything. The only goal is your commercial success. We are "public interest investors." We want to see you create jobs, generate tax revenues, and provide societal benefits. Both major political parties like the program, which promotes its continuance.

The National Science Foundation processes 10,000 SBIR/STTR proposals every six months, and about 10% get funding. There are two solicitations each year: June and December. Three NYS stories in this space are ThermoAura, Robocasting, and Ceralink. He shared that his agency also just funded a company called Modern Metal that's trying to create 3DP houses.

E.5.5 Kevin Harding, Principal Engineer for Optics, GE Global Research

Harding belongs to SPIE (the professional society for optics and photonics technology; acronym is now the full name) and says that optics is an interdisciplinary activity used for everything from in-vitro activities to making rockets. Optics and photonics in advanced manufacturing are strong areas of NYS activity. It's a multi-trillion dollar industry, and many additive systems have lasers or other optical components.

There is room for improvement with fiber lasers. The rate which things are written in a power bed could get faster.

The potential for non-destructive testing is key. We need to know about cracks and porosity.

The AIM Photonics institute in Rochester, he noted, could be a positive contributor to AM advancement in NYS. You can even additively manufacture optical systems. Harding recommends talking to AIM Photonics about the intersection of these technologies: Of the 140 manufacturers in their group, how many use AM?

There is an NYS company that makes injection-molded plastic lenses for the auto industry.

E.5.6 Bill Acker, Executive Director, NY-BEST

NY-BEST is a potential model for an AM consortium. There are some important similarities. Both are undergoing rapid growth. Energy storage is transforming transportation and the grid.

NY-BEST is an industry trade group. It's not part of NYS. There are 150 member companies.
Our mission is to grow and catalyze the energy storage industry AND to make NYS a leader in energy storage.

He emphasized that such a consortium can be and may need to be catalyzed by the state, but that it must be driven by industry.

He offered four things that an AM consortium can do to show value.

- Be a resource. Put out news and information. Send newsletters, use social media, and become a clearinghouse to the world. Run conferences. Target four major events each year, including one multi-day event. These events are good for collaboration. NY-BEST gets high ratings on this metric. So have a general conference, a technology conference, a markets conference, and an investments conference. Also, do a lot of work at helping startups. One-third of NY-BEST's 160 member companies are start-ups.
- Accelerate commercialization. We saw that credible testing of larger systems was key. RIT has a battery prototyping center to make batteries. Kodak has a commercialization facility, too. We are also putting in manufacturing capabilities, working with California on batteries, and working with Brookhaven National Lab.

- Accelerate education. Lobby policymakers to change regulations.
- Workforce and economic development. Most of NY-BEST consists of members companies, but there are universities involved as well.

Importantly, over time, NY-BEST has shifted its emphasis from research to business development.

Q&A: Janet Paluh from SUNY Polytechnic Institute suggested that a center with higher-end printers would be more attractive and help protect IP better than a center with “cheap $800 printers.” She suggested a need to make industrial-level equipment available rather than printers more suited to hobbyists.

Q&A: Scott Fisher from SABIC asked how machine access could be provided in a way that keeps the momentum moving forward. Who has what in terms of equipment and capabilities? NYSERDA’s Dana Levy noted that a maintained inventory of NYS assets would be useful. Acker noted that NY-BEST, for example, maintains a resource database on their website that shows who is where and what they have.

Q&A: Steve Rock from Rensselaer Polytechnic Institute noted that along with equipment, NYS needs expertise to run it. You can’t just buy it and drop it in a center. It might not be well-maintained. What happens when it’s out-of-date?

Q&A: NYSERDA’s Dana Levy asked all participants what the most critical thing the Scoping Session organizers should focus on is. Key takeaways, as recorded by NYSERDA’s Tammy Malone, were the following:

- Invest in one location with three top printers
- Provide access to existing, smaller facilities with equipment and make their locations known; create a database of these resources like NY-BEST’s
- Such facilities need to dedicate resources to keeping equipment current and properly maintained and managed
- A key strategic area of focus should be promoting awareness of “today’s opportunities” for applying AM

E.6 Closing remarks: Alexander Cartwright, Provost and Executive Vice Chancellor, State University of New York

Santokh Badesha introduced Cartwright, who began with: "What do you next? That's the question."

Cartwright noted there is significant expertise across the State in terms of university resources and publicly-funded initiatives. SUNY is "uniquely positioned" to help here. He cited NYS's under-performance in garnering National Science Foundation SBIR funds as an area in which more can be done.

Cartwright has been at SUNY for 20 years. As the Vice President of Research, he thought about how to connect people across campuses. They created communities of excellence and to collaborate on interdisciplinary research. He suggested intercampus networks of excellence for AM and materials. "It takes a long time for people to get to know each other," he explained. "Teams are built when people get to trust each other, which means they have to get together more than just once. There has to be something in it for everybody. There has to be compromise, too."

He advised the group to remember the conversation about IP from the America Makes presentation. If someone wants to make an artificial organ, can we connect them with someone that can bio-print the materials? If so, we have to get these groups together and get them talking.

SUNY has 65 campuses and 600,000 students. How do we get them to communicate? The SUNY Materials and Advanced Manufacturing network had 60 direct faculty involved, and there were even more at secondary levels. It's about breaking down barriers among institutions, even among campuses that compete.

There are three key agenda items at SUNY relevant to AM:

- Student completion and student success. This is relevant to the AM discussion because there is a correlation between degree attainment and the ecosystem for innovation. Employers need employees. We have to get students going in the right direction. We at SUNY need to work with industry to provide the workforce that you need. It's not just about STEM, however: How do we infuse the arts and humanities into what we are doing in the STEM fields? Some students are interested in the arts and humanities, of course. Could they bring this perspective to STEM fields and jobs? This is the future of the curriculum.
- Diversity, equity, and inclusion. Our goal is to be the most inclusive university system in the world. It's the "union of the unlike" that leads to progress. It's what makes the United States strong and what will make NYS strong.

- Impact. Higher education impacts society in so many ways, from professional education to basic research, etc. We are committed to growing our research expenditures by 25% by 2025. We believe that the future of higher education is to open doors to industry. SUNY has been actively involved in START-UP NY. We want companies to interact with us.

Cartwright told the audience: “You just need to come and ask us and we will find the people. Let us know the issues and we will help you.”

Q&A: Dan Walczyk from Rensselaer Polytechnic Institute asked how to ensure that there is cooperation between the SUNY network and the private universities. The answer, Cartwright said, is that we “go federal.” As an example, he described an initiative involving the human brain that involves Cornell University, SUNY, the City University of New York, and others. “We would love to establish some real meaningful partnerships with the privates, including at the leader-to-leader level.”

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