Manufacturing USA®

2019/2020 HIGHLIGHTS REPORT








National Institute of Standards and Technology
U.S. Department of Commerce

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MANUFACTURING USA HIGHLIGHTS REPORT

A summary of accomplishments with Special COVID-19 updates

December 2020

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TABLE OF CONTENTS

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MESSAGE FROM THE INTERAGENCY TEAM

Manufacturing USA® is a network of public-private partnerships united to secure U.S. global leadership in advanced manufacturing through large scale collaboration on technology, supply chain, and workforce development. The network includes the U.S. Departments of Commerce (DOC), Defense (DoD), and Energy (DOE), their sponsored manufacturing institutes, and six other federal partner agencies – National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), Health and Human Services (HHS), and the Departments of Agriculture, Education, and Labor. Together, they work towards accomplishing national manufacturing objectives to secure America's future through manufacturing innovation, education, and collaboration.

Federal support for these institutes creates a framework that allows industry, academia, and federal laboratories to work together to take the most promising new technologies and transform them into products to be manufactured in America. In fiscal year 2019, the 14 Manufacturing USA institutes collectively conducted 561 major applied research and development projects of high priority to broad industry sectors. The participants and direct beneficiaries of these projects are the 1,920 institute member organizations, of which 61% are manufacturing firms. Of those firms, 69% are small manufacturing companies – key manufacturing supply chain participants.

The strong public-private partnerships built through the Manufacturing USA institutes also enabled the network to respond rapidly to the COVID-19 pandemic. Within only a few months, the sponsoring agencies and some institutes had mobilized to launch projects to expand the production of needed medical countermeasures, provide workforce training, increase testing capacity, and help manufacturers prepare for the country's future. Alongside the sponsoring agencies, the National Institute of Standards and Technology (NIST) used funding authorized by the Coronavirus Aid, Relief, and Economic Security (CARES) Act for Manufacturing USA institutes to support high-impact projects for pandemic response, with the first competition for COVID-related grants launched immediately after enactment. Along with CARES-funded projects, the Manufacturing USA institute members and communities have committed resources and facilitated coordination to quickly focus their programmatic efforts to respond to the pandemic crisis.

While this report focuses on success stories from fiscal year 2019, a special insert is included with some preliminary success stories on the network's response to COVID-19. This by no means captures the whole of the agencies' and institutes' efforts and offers a preview of good things to come from our continued collaborations. As always, our vision remains nothing less than U.S. global leadership in advanced manufacturing.

We are proud to share these highlights from Manufacturing USA.

On behalf of the entire interagency team,

Michael F. Molnar, Director
Advanced Manufacturing National Program Office

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AMERICAN ECONOMIC COMPETITIVENESS: TODAY AND INTO THE FUTURE

A strong manufacturing base and resilient supply chains form the backbone of our economy and national security and are essential to effectively respond to emergencies and national threats – including COVID-19. Manufacturing accounts for 11% of U.S. GDP[1] and 68% of U.S. exports of goods.[2] Advances in manufacturing technology and innovation enable the U.S. economy to grow, increase productivity, develop new products, and create entirely new industries. Manufacturing – especially advanced manufacturing – is also one of the highest-paying sectors of the economy and has an enormous multiplier effect on other sectors. For every dollar spent in manufacturing, an additional $2.74 is added to the economy.[3]

Over the past three decades, the U.S. and global manufacturing sectors have been transformed, resulting in new challenges and risks as well as progress and opportunities. U.S. manufacturing employment has declined by 27% from 1990 to 2019,[4] in part because China and other countries substantially expanded their share of global manufacturing value-added. These same trends drove supply chains for personal protective equipment (PPE) and other medical products overseas. However, the employment decline over the last three decades also reflects increased productivity as companies apply new technologies and process improvement methodologies. In fact, manufacturing labor productivity more than doubled from 1990 to 2019[5] and manufacturing employment has modestly but consistently *increased* since 2010, representing the longest continuous post-war expansion of manufacturing employment.

Manufacturing accounts for 11% of U.S. GDP and 68% of U.S. exports of goods.

The U.S. continues to be a leader in basic research and technological innovation. In fact, the U.S. climbed to first globally in university-industry research collaborations and third globally on the Global Innovation Index rankings (behind only Switzerland and Sweden).[6] Still, the manufacturing sector continues to face challenges in translating technical innovation into U.S.-based production, and, as production has migrated overseas, research and development (R&D) and technical skills have sometimes followed. One symptom of this challenge is the U.S. trade balance in advanced-technology products which has declined from a $35 billion trade surplus in 1990 to a $133 billion deficit in 2019.[7]

The U.S. innovative engine can stall for a variety of reasons as technology advances from basic research and proof-of-concept through applied R&D, such as when the promising technology is not sufficiently developed to be viable or cost-effective, or entails too much risk for the private sector to invest, scale up, and bring the technology to market. The result of this is missed opportunities for our country's competitiveness.

[1] U.S. Bureau of Economic Analysis
[2] U.S. Census Bureau, International Trade in Goods and Services
[3] https://www.nam.org/facts-about-manufacturing/, retrieved 09-23-2020
[4] U.S. Bureau of Labor Statistics
[5] U.S. Bureau of Labor Statistics, manufacturing sector annual time series
[6] Global Innovation Index 2019, Cornell SC Johnson College of Business, INSEAD, WIPO
[7] https://www.census.gov/foreign-trade/balance/c0007.html#2020

Our Mission: Connecting people, ideas, and technology to

- solve industry-relevant advanced manufacturing challenges
- enhance industrial competitiveness and economic growth
- strengthen our national security

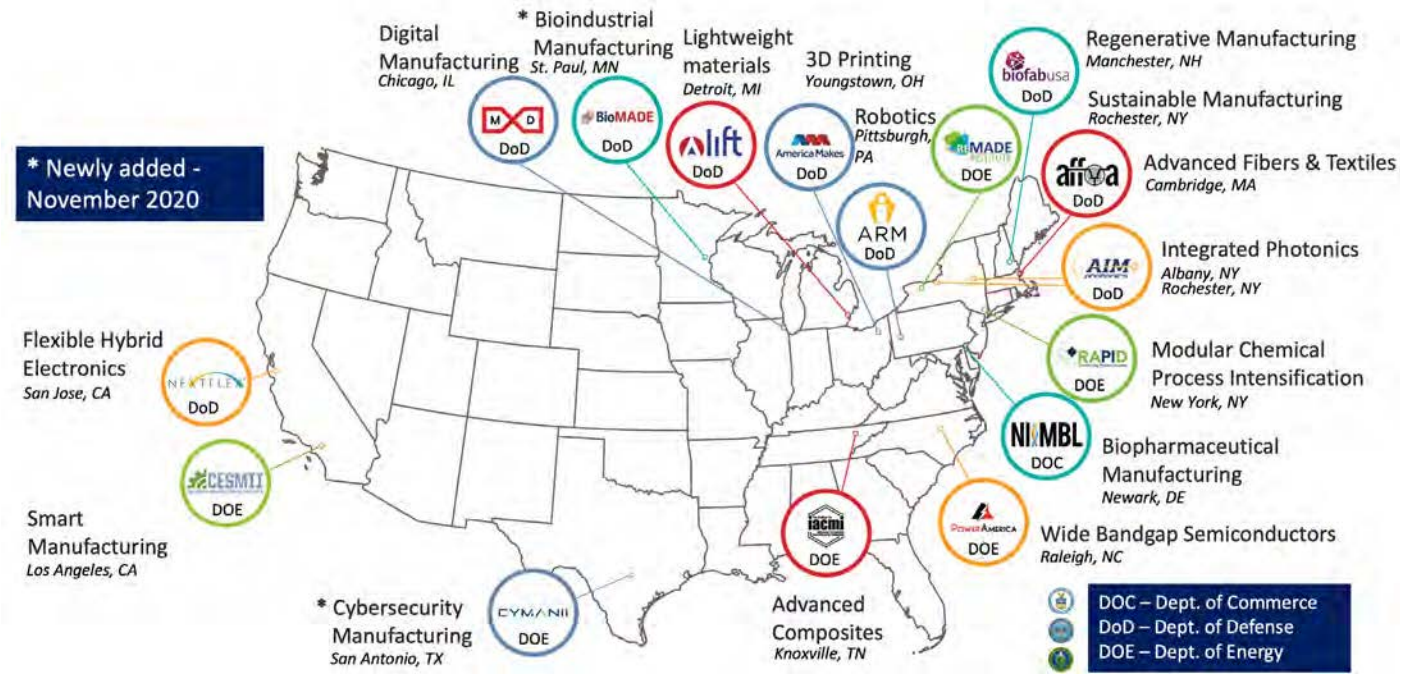
Finally, technology change also creates new requirements for the manufacturing workforce. Manufacturing has faced skill shortages in recent years, and companies report that this is in large part due to new skills necessary for advanced technology and automation.[8]

While the US manufacturing sector remains strong, we face critical challenges in maintaining technical leadership, increasing US production, and enhancing the skills of the manufacturing workforce. Working to address these challenges and opportunities requires large-scale collaboration among the public and private sectors.

A Whole-of-Government Approach

Manufacturing USA was created in 2014 to secure U.S. global leadership in advanced manufacturing. The participating agencies and their institutes play a critical role in achieving this goal. Each institute's public-private partnership unites industry, academia, and federal partners to develop technologies and opportunities that directly impact U.S. manufacturing competitiveness, promote a robust and sustainable national manufacturing R&D infrastructure, and create a skilled workforce.

In 2019, there were 14 institutes in the Manufacturing USA network: the Department of Commerce sponsors one, the Department of Defense sponsors eight, and Department of Energy sponsors five. Two additional institutes were announced in 2020, increasing the number of institutes to 16. The Advanced Manufacturing



The Manufacturing USA institutes, including the Bioindustrial (DoD) and Cybersecurity (DOE) institutes announced in 2020. Credit: NIST.

[8] 2018 Deloitte and The Manufacturing Institute skills gap and future of work in manufacturing

For every dollar spent in manufacturing, an additional $2.74 is added to the economy.

National Program Office at DOC's NIST oversees the coordinated activities and national branding of Manufacturing USA. In addition, the Departments of Education, HHS, Labor, and Agriculture as well as the NASA and NSF all participate in key aspects of the Manufacturing USA initiative. This brings together vast resources and expertise from across the U.S. government to collaborate on supporting and strengthening U.S. manufacturing.

The members of each institute collaboratively engage in the pre-competitive development of technologies within their specific field of focus. They test applications for the technology, share capital-intensive infrastructure, and develop a workforce with the skills needed for today's manufacturing. And they answer the call to meet our country's most pressing challenges, such as the current COVID-19 pandemic.

Developing Today to Ensure a Competitive Tomorrow

Last year, the institutes made significant strides in American competitiveness in many ways. For example, BioFabUSA demonstrated the first-ever Tissue Foundry – a scalable, modular, automated, and closed tissue manufacturing system. The modular design allows BioFabUSA to reconfigure the Tissue Foundry to facilitate the manufacture of any type of tissue product. In addition, the Advanced Robotics for Manufacturing (ARM) institute is attacking the challenges of robotic sewing. One such project, led by Siemens Corporate Technology in partnership with University of California, Berkeley, Sewbo, Inc., and Bluewater Defense, Inc., leverages advanced robotics technology to assemble and sew parts of military uniforms, making garment production in the U.S. an economically cost-effective reality.

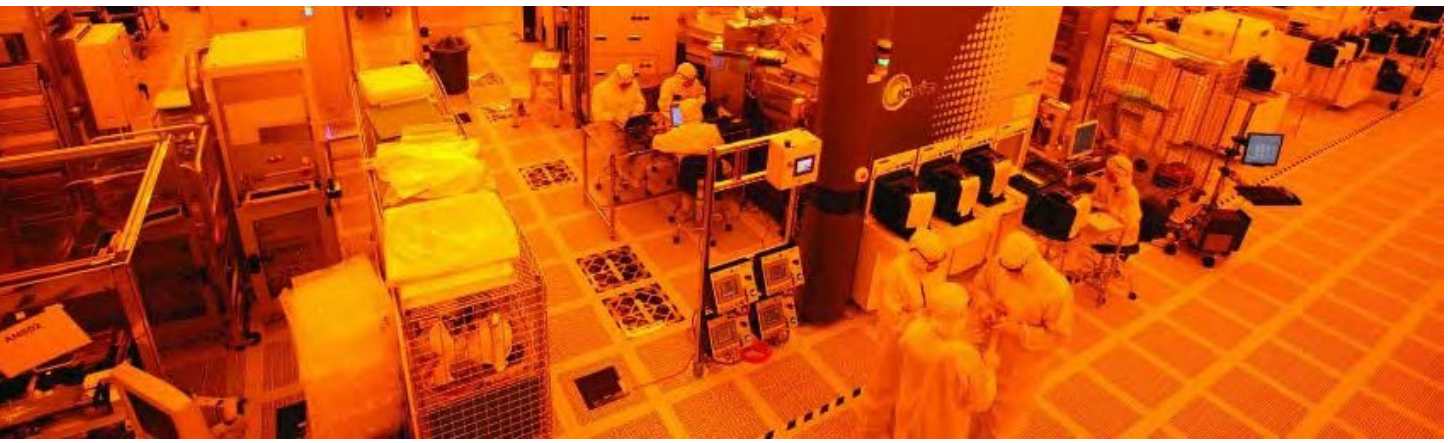
Credit: istock.

FORTIFYING THE NATION'S MANUFACTURING SUPPLY CHAINS

As the current pandemic has demonstrated, stable and secure supply chains are essential, especially in critical technological areas related to medical supplies and equipment, pharmaceutical production, and similar essential services. The vulnerability and impact of supply disruptions has directly affected the health and well-being of the citizens of the U.S. and around the world. Supply chain weaknesses are now headline news.

Stabilizing the nation's supply chains against future disruptions is critical to preparedness and an important facet of the work of Manufacturing USA, the agencies, and their institutes. In 2019 and 2020, Manufacturing USA institutes continued to develop technologies and approaches that will help secure the nation's manufacturing and supply chain. Examples include:

- **NIIMBL** members are collaborating on integrating process analytical data for quality decisions based in real-time manufacturing data and more rapid end-product testing methods. These approaches will speed the delivery of emerging treatments such as cellular and gene-therapies for cancer patients, where traditional end-product test methods can cause weeks-long delays in treating patients.
- **AIM Photonics** built the world's first open access 300 mm silicon wafer facility for integrated silicon photonics testing, assembly, and packaging (TAP). This state-of-the-art TAP facility is a key component in AIM Photonics' end- to-end advanced manufacturing capability for photonic integrated circuits and is now supporting several member programs, including Lockheed Martin, University of Rochester, and Ortho-Clinical Diagnostics.
- **America Makes** worked with DoD to create the first open platform that simplifies sharing 3D model data across the military services. The platform was delivered to the Defense Logistics Agency in late 2019 and has been deployed for military use.
- At the Biomanufacturing Training and Education Center at North Carolina State University, project team members integrated **CESMII** – The Smart Manufacturing Institute's developed technology (the CESMII SM Innovation Platform™) onto biomanufacturing assets to manage applications from multiple vendors in a way not previously possible in industry.



AIM's silicon wafer facility. Credit: AIM.

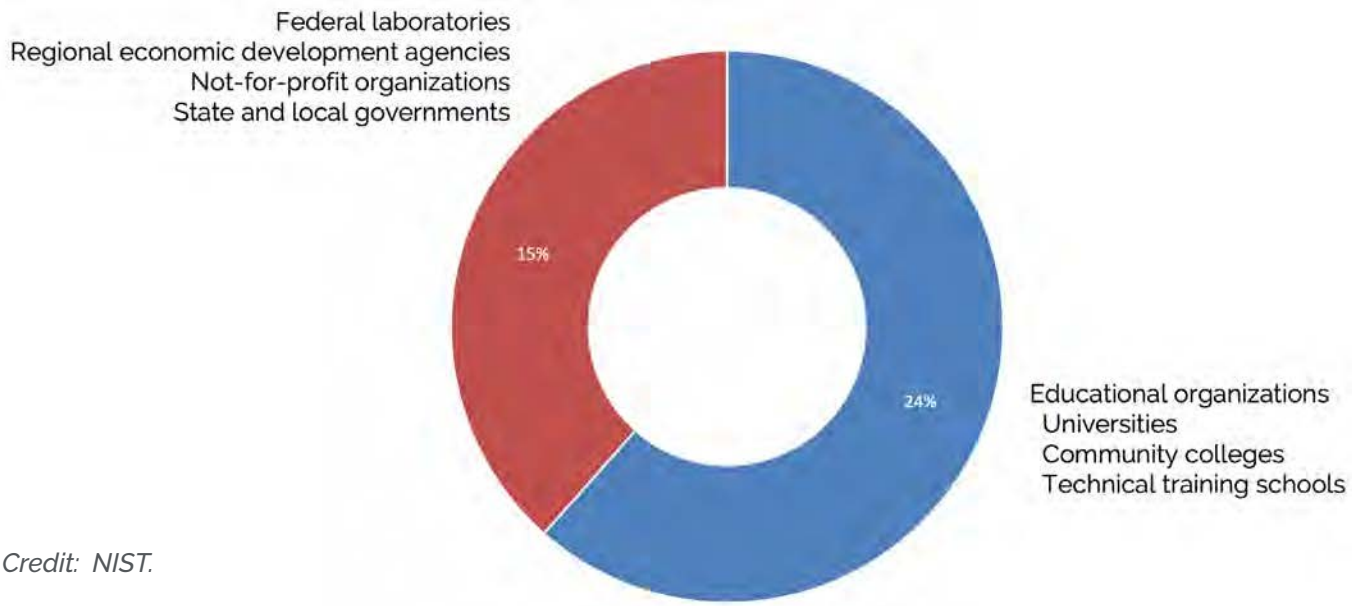
BUILDING INNOVATION ECOSYSTEMS

American manufacturing plays an out sized role in the U.S. innovation ecosystem, employing nearly two-thirds of all scientists and engineers and averaging 70% of all U.S. patents awarded annually to U.S. entities. While the U.S. continues to excel in discovery and innovation, the applied research necessary to translate new emerging technologies into products remains a huge challenge for individual companies. This challenge has only increased with increased global competition and foreign subsidies directed at their advanced manufacturing sectors. Manufacturing USA helps to address this challenge while retaining the freedom and dynamic nature of the free-market approach by creating effective collaboration ecosystems for manufacturers.

Effective collaborative R&D enables rapid advances in manufacturing technologies, such as additive manufacturing, robotics, and nanotechnologies for the development of new product capabilities including flexible circuits, integrated composites, and Internet of Things (IoT) product features. Staying competitive requires a whole-of-America approach, involving every manufacturer, a secure supply chain from raw material to finished product, and a smooth progression from innovation to deployment.

The public-private partnerships and other initiatives launched by the agencies address these needs by engaging all parts of the national industrial base. With institute and satellite locations in over a third of the states and member organizations across the nation, the Manufacturing USA Institutes provide the foundation to build a strong, robust, and competitive manufacturing ecosystem. Encompassing more than 1,900 member organizations, the institutes partner with large and small manufacturers, community colleges, research universities, and state, local, and tribal economic development entities. Of these, 61% are manufacturers, and nearly 70% of those manufacturers are small and medium manufacturers (SMMs) with 500 or fewer employees.

Educational organizations—universities, community colleges, and technical training schools—comprise 24% of members, and 15%



Credit: NIST.

of members are federal laboratories, regional economic development agencies, not-for-profit organizations, and state and local governments.

The institutes work to turn U.S.-based inventions using advanced manufacturing technologies into products, made here by a skilled American workforce. The value that the institutes bring to American manufacturers can be measured through the continued investments made towards each institute's projects.

The institutes attract investment that significantly exceeds the required one-to-one matching for their base federal funding. Total institute expenditures in FY 2019 were $488 million; $133 million in base federal program funds and $355 million in institute generated funds from industry, academia, economic development, state government, and competitive federal funding. This is a remarkable 2.7 to 1 investment ratio in matching to base federal funding. These matching funds are invested in technology R&D efforts, capital-intensive efforts such as facility or manufacturing equipment purchases, institute operations, and education and workforce development programs.

1,900 member organizations, 61% are manufacturers, 70% are small and medium manufacturers with 500 or fewer employees

Credit: istock.

2019 NETWORK IMPACTS

1,920 Institute Member Organizations

2/3rds from manufacturers

561 Major R&D Projects

18% growth from last year

$488M State, Private and Federal Funds

$2.70 institute generated funds for every $1 of base federal funds

Thousands of Students, Workers, and Teachers Participated in Institute-Led Advanced Manufacturing Workforce Development and Training

IMPACTS

EMPOWERING THE CURRENT AND NEXT-GENERATION WORKFORCE

Deploying the technological advancements within today's manufacturing environment requires a robust and highly skilled workforce, with a pipeline that encompasses both existing and future technical workers. Unfortunately, while it is anticipated that 4.6 million manufacturing jobs will be needed over the next decade, it is expected that roughly 2.4 million of those jobs will go unfilled[9] largely due to a lack of skilled workers. In addition, if automation is rapid, as many as one-third of American workers may need to change occupations and acquire new skills by 2030, according to an estimate by McKinsey Global Institute.[10] Considering this, worker training and availability are of great concern among manufacturing CEOs, and actions are needed to address the growing mismatch between current worker skills and the required skills for advanced manufacturing work.

Education and workforce development activities at the institutes span a broad spectrum of needs from up skilling current employees in advanced manufacturing technologies to providing a pipeline of newly trained workers for the future. The complexity of new manufacturing technologies requires training beyond the classroom and must include opportunities such as participation in R&D projects, completion of technical certifications, and hands-on field-based apprenticeships. However, before this can be accomplished, establishing a highly trained workforce relies on developing skilled educators well-versed in these technologies.

Last year, more than 32,000 workers and students participated in education and workforce development activities of the institutes. Examples include:

Credit: NIST.

[9] *2018 Deloitte and The Manufacturing Institute skills gap and future of work study*, Deloitte Development LLC, Member of Deloitte Touche Tohmatsu Limited (2018), p. 3. https://documents.deloitte.com/insights/2018DeloitteSkillsGapFoWManufacturing

[10] McKinsey Global Institute. November 2017 Report. "Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation"

32,000 workers and students participated in education & workforce development

NIIMBL launched the first NIIMBL eXperience, a week-long program introducing underrepresented students to the biopharma industry. College students from Historically Black Colleges and Universities spent a week visiting biopharmaceutical companies and federal agencies to learn about the industry and the important role it plays in patient health and well-being.

BioFabUSA developed a hands-on bio-fabrication experience for students in grades 6-12 to learn about current and future tissue manufacturing processes. The institute piloted the activities at the 2019 FIRST Robotics Championship with more than 5,000 students.

Penn State University and Massachusetts Institute of Technology partnered with **CESMII** to develop the Factory 4.0 Toolkit. This instrumented, small-scale fiber extrusion kit models real-world practical manufacturing scenarios along with smart manufacturing software applications and supporting educational modules adaptable in a broad range of engineering, non-engineering, and cross-discipline educational programs.

MxD has engaged nearly 1,500 individuals in workforce development and education efforts. Other efforts have brought in 80 high school students through the Catapult entrepreneurship program and Chicago's neighborhood summer program, as well as hosting faculty from the National Institute for the Deaf to assist with the development and launch of their digital manufacturing curriculum.

NextFlex continues to grow FlexFactor® which combines advanced manufacturing concepts with a basic business model framework. An initial class of 26 in 2017 has grown to more than 4,500 students to-date with planned expansion to over 6,200 per year by 2022.

Virtual Internship Program is a structured, 10-week program for engineering interns at **RAPID** member organizations. Participants join a virtual community and receive online safety, technical, and leadership training, as well as professional development and mentorship. The program gives smaller organizations access to interns nationwide and enables their student interns to join a broad virtual network across the U.S.

Credit: RAPID.

PARTNERING TO RAISE AWARENESS

The agencies and institutes engage in myriad outreach and communications to educate the public about advanced manufacturing and the rewarding careers it offers. Through ManufacturingUSA.com, social media, articles, and industry events, AMNPO serves as a clearinghouse of information about Manufacturing USA and the work of the participating agencies and their institutes and members.

The Manufacturing USA network actively participates in national Manufacturing Day each year. Held the first Friday in October, Manufacturing Day is coordinated by the National Association of Manufacturers. It serves as a celebration of manufacturing and a key way to raise awareness about modern manufacturing and available careers . Through openhouse events, tours, and outreach activities, students, parents, and educators learn about different types of career opportunities and educational pathways available. Agencies and institutes also engage in activities throughout the entire month of October in recognition of Manufacturing Day. In addition to engaging in Manufacturing Day activities in their industries and states, below are just two examples of activities designed to spark interest in today's manufacturing and the careers it offers.

Engaging Historically Black Colleges and Universities

Credit: NIST.

To facilitate the participation of Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs) in Manufacturing USA, the NSF and NIST jointly sponsored the Workshop on Promoting Participation of HBCUs/MSIs in Advanced Manufacturing R&D at NSF Headquarters on November 6 – 8, 2019. The workshop was organized by Morgan State University, and representatives of 31 HBCUs and MSIs participated. Faculty from 24 universities presented 33 posters for discussion with representatives from the Manufacturing USA institutes and sponsoring agencies.

Rethinking Manufacturing Documentary Receives Regional Emmys

Rethinking Manufacturing, a short documentary featuring **America Makes** – a DoD-sponsored Manufacturing USA institute – and two young engineers in Youngstown, Ohio, won three awards during the 2020 Lower Great Lakes Chapter of the National Academy of Television Arts & Science's regional Emmy Awards. The video production involved close collaboration between NIST, DoD, and America Makes. With support from America Makes, Youngstown State University, and the Youngstown Business Incubator, the short documentary illustrates how these young professionals and their peers are rethinking manufacturing and career choices, and how we build and revitalize communities. It dramatically demonstrates the changes underway in communities across the nation due to new opportunities associated with advanced manufacturing.

Credit: Academy of Televison Arts & Sciences.

INVESTING IN THE FUTURE, IMPROVING OUR WAY OF LIFE

During FY 2019, the institutes managed 561 technology projects that included manufacturing-process research, proof-of-concept development, early system prototyping, and manufacturing demonstrations. Each project furthers innovations that could enhance our lives, strengthen our economy, and ensure our national security. Critical to each institute's success with these innovations is a rigorous and inclusive approach to selecting project topics. Stakeholders from industry, academia, regulatory agencies, and end users develop roadmaps for key technologies and manufacturing processes. Examples of projects include:

- **AFFOA** and members developed the first-of-its-kind advanced functional fiber with embedded optical receivers and transmitters that enable optical communication across air-water interfaces and between undersea assets.

Credit: AFFOA.

- An **IACMI** recycled mixed-stream composites project utilizes the inherent energy in composites for fuel and preserves the structural value of glass fiber and carbon fiber for reuse.

Credit: IACMI.

Credit: LIFT.

- **LIFT** successfully aided Lifeline Firehose with a state-of-the-art technology that enables a firehose to simultaneously deliver both breathable air and water or foam. The technology allows firefighters to battle fires longer while getting critically needed air to downed personnel and victims.

- **PowerAmerica** members Texas Tech University and Group NIRE Renewable Energy (Lubbock, TX) established an independent, confidential, third-party testing facility, demonstrating long-term performance and enhancing end-user confidence in the reliability of wide-bandgap devices and accelerating the adoption of these technologies.

Credit: RAPID.

- Through **RAPID**, Iowa State University (Ames, IA) is developing an autothermal process for thermochemical conversion of woody and agricultural biomass to fermentable sugars and other value-added products. This new process uses less heat than existing processes and is expected to double energy productivity. The process is also well suited for distributed processing in modular units designed to fit in standard shipping containers.
- Non-destructive methods to measure mechanical damage in metals prior to products failing do not currently exist. **REMADE** members Rochester Institute of Technology, the University of Illinois at Urbana-Champaign, and Caterpillar, Inc. are collaborating to develop ways to reliably detect features associated with early-stage fatigue damage, allowing prediction of the remaining useful life of the metal part.

Credit: istock.

RESPONDING TO A NATION IN NEED: MANUFACTURING USA'S EARLY COVID RESPONSE

As the pandemic became an increasing threat to the health, economic stability, and security of the nation, institutes and their sponsoring agencies quickly ramped up to support the nation's response. In addition, the Coronavirus Aid, Relief, and Economic Security (CARES) Act allowed NIST to provide funding to five institutes to augment Manufacturing USA efforts in fighting COVID. These are described below.

Commerce Secretary Wilbur Ross July 2020 tour of America Makes and July 2020 announcement of Manufacturing USA CARES Act funding for COVID-19 pandemic response. Credit: America Makes.

Enabling a Rapid COVID Response

With funding from the CARES Act, NIST competitively awarded $12.4 million in grants to 13 high-impact projects at five Manufacturing USA institutes for pandemic response.

"I am pleased we have quickly provided these CARES Act funds to support the innovative projects contributing to our COVID-19 response efforts at the public-private Manufacturing USA institutes," said Secretary of Commerce Wilbur Ross. "When we operate at the 'speed of business' and work collaboratively across the government in partnership with the private sector, we achieve great things for our nation."

"The collaborative programs these institutes have built have allowed them to rapidly respond to the current pandemic with projects to expand production of needed medical countermeasures, provide workforce training, increase testing capacity, and help manufacturers prepare for the future," said Under Secretary of Commerce for Standards and Technology and NIST Director Walter G. Copan.

Along with Manufacturing USA CARES Act funded projects, the institutes and their sponsoring agencies have committed resources and facilitated coordination among their members and communities to quickly pivot and augment their programmatic efforts in response to the pandemic. For example, the DoD has sponsored an additional $60.7M in CARES Act projects for 13 COVID-19 response projects at the DoD institutes. Those projects and additional successes will be highlighted in future reports.

Leveraging Biopharmaceutical Innovations to Strengthen U.S. Agility

NIIMBL's CARES Act funding has spurred partnerships to deploy biopharmaceutical innovations to address the challenges of the pandemic through efforts such as:

- Scaling up production of materials used in COVID-19 exposure testing and screening of recovered patients to identify appropriate donors of convalescent plasma to treat critically ill patients.
- Developing flexible manufacturing capabilities to position the pharmaceutical industry for greater agility in scale-up production of biologic therapies and essential medical products.
- Accelerating deployment of Next-Generation Sequencing to detect adventitious-agent contaminants in biomanufactured products. Industry's adoption of this technology would allow rapid release of vaccines, therapeutic proteins, and cell and gene therapy products.

Project partners for these efforts include: Wadsworth Center, New York State Department of Health (Albany, NY), University of Delaware (Newark, DE), North Carolina State University (Raleigh, NC), Texas A&M University (College Station, TX), Johns Hopkins University (Baltimore, MD), and PMT LLC (Longmont, CO).

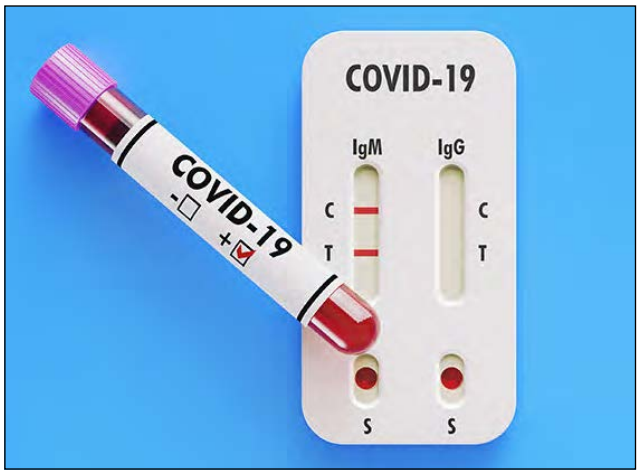
Building Partnerships to Increase Production of Medical Equipment

A $1.4 million award to **America Makes**, in partnership with fellow Manufacturing USA institute **MxD**, allows for the expansion of the production of medical countermeasure components such as personal protective equipment (PPE) using additive and digital manufacturing technologies. The effort builds on the Advanced Manufacturing Crisis Production Response project, launched in March 2020 with the U.S. Food and Drug Administration, National Institutes of Health, and Department of Veterans Affairs. The project provides a central place for health care providers to request equipment,

Credit: istock.

for manufacturers to offer capability, and for designers to upload product designs. This award will enable the team to bring in more collaborators; develop a strategic road map to prioritize and address select COVID-19 crisis needs; extend manufacturing capabilities and impact; and develop a virtual workforce training program.

In addition, **NIIMBL** partners, including North Carolina State University at the Nonwovens Institute, accelerated development of an easily manufactured filter process to produce surgical masks or N95 respirators that are potentially re-usable. This new higher-throughput process has allowed domestic manufacturers to increase production of this critical PPE.



Credit: istock.

Increasing Testing Availability

ARM received more than $600,000 to develop a safe method to use collaborative robots to automate much of the COVID-19 testing process. Current testing capacity is limited by the number of technicians in the U.S. By augmenting the limited labor force with robots, the project seeks to increase the number of tests conducted at hospital and university labs and minimize exposure to medical personnel. Wilder Systems will work with ARM on the project.

NIIMBL worked with the local hospital system, the University of Delaware, and Christiana Care Health System to develop and validate an in-house diagnostic testing capability for COVID-19 to decrease turnaround time for testing for patients and health care workers.

Addressing Education and Training Gaps

With its $1 million award, **LIFT** is training 250 workers in the Pittsburgh and Detroit areas in computer numerical control [CNC] machine operations, industrial technology maintenance, welding, and robotics. Leveraging a successful program that trains separating military personnel, LIFT's new online training will re-skill/upskill civilian workers impacted by the pandemic. It will also provide resources and support to their manufacturing employers as they manage their pandemic recovery.

The project will engage small and medium manufacturers through Catalyst Connection, part of the Pennsylvania Manufacturing Extension Partnership, and the Workforce Intelligence Network for Southeast Michigan.

Finding New Pathways

BioFabUSA received $400,000 to develop and share a road map for organizations to follow for pandemic response and recovery. The road map will identify and prioritize key needs, including those related to: supply chain issues to enable increased production of PPE, test kits, and vaccines; manufacturing production to decrease times for vaccine manufacturing; and rapid delivery of test kits and vaccines. BioFabUSA will partner with federal, private sector, and academic organizations and publicly release the road map in three months.

NIIMBL partner PMT (USA) is validating protocols for the use of vapor-phase hydrogen peroxide to rapidly decontaminate clinical and public spaces. This technology, currently used in pharmaceutical manufacturing suites, would provide a clean, simple, and fast method to ensure that high-risk public environments can be disinfected routinely overnight.

Credit: istock all images.

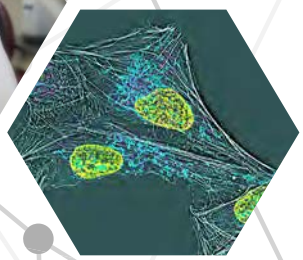
SUMMARY OF INSTITUTE ACTIVITIES

Manufacturing USA®

Credit: BTEC © North Carolina State University.

DEPARTMENT OF COMMERCE INSTITUTE HIGHLIGHTS

Credit: left, istock, right, NIIMBL.



NIIMBL

Institute for Innovation in Manufacturing Biopharmaceuticals

MISSION: Accelerate biopharmaceutical manufacturing innovation, support development of standards that enable more efficient and rapid manufacturing capabilities and educate and train a world-leading biopharmaceutical manufacturing workforce, fundamentally advancing U.S. competitiveness in this industry.

HEADQUARTERS: Newark, DE

CONSORTIUM ORGANIZER: University of Delaware

ESTABLISHED: March 2017

FUNDING: Federal, $70M; Nonfederal, $129M; both planned over five years

MEMBERS (AS OF SEPTEMBER 30, 2019): 126

NIIMBL

niimbl.org

Institute Overview

NIIMBL advances the capability to manufacture biopharmaceutical medicines through technology innovation, workforce training, and standards development. Biopharmaceuticals are medicines made from biological sources such as therapeutic proteins, vaccines, and cell and gene therapies. These medicines improve and save lives by treating debilitating conditions including cancer, diabetes, autoimmune disorders, and bacterial and viral infections untreatable with conventional pharmaceuticals. The institute's work will enable the rapid and cost-effective manufacture of safe and efficacious biopharmaceutical products, ultimately improving health outcomes and saving lives.

NIIMBL's new headquarters, the Ammon Pinizzotto Biopharmaceutical Innovation Center at the University of Delaware, opened February 2020. Credit: NIIMBL

Credit Opposite page: left University of Delaware/Evan Krape, right and bottom, NIIMBL.

Technology Advancement

> *"NIIMBL has helped Genentech to provide more shots on goal for innovative ideas and concepts that we can bring into the way we manufacture, release, and test our products"*
>
> — Eric Fallon, Genentech

In FY 2019, the institute engaged in 26 projects, of which 18 were newly launched. These projects address key challenges and opportunities facing the industry and include:

- **Buffer Stock Blending System** - NIIMBL collaborated with BioPhorum Operations Group to build a portable, flexible system for buffer stock preparation, estimated to reduce manufacturing floor footprint by 61%[11] , save $20M per facility built, and reduce buffer preparation time by approximately 30%[12]. NIIMBL members Merck & Co. (Kenilworth, NJ), MilliporeSigma (Burlington, MA), Sanofi (Bridgewater Township, NJ), GlaxoSmithKline (King of Prussia, PA), and Janssen (Raritan, NJ), as well as other leading companies from the biopharmaceutical industry are collaborating to minimize risks of the system so that these significant impacts can be realized. The system is an open source unit available for testing at

[11] Biophorum Operations Group. *An Economic Evaluation of Buffer Preparation Philosophies for the Biopharmaceutical Industry*, December 2019.

[12] Biophorum Operations Group. *NIIMBL-Biophorum Buffer Stock Blending System: A More Advanced Concept for Buffer Manufacturing*, December 2019.

the NIIMBL headquarters at the University of Delaware or onsite at member locations.

- **New Efficiencies in Product Quality Testing** – NIIMBL member 908 Devices (Boston, MA) developed a table-top mass spectrometry instrument to efficiently analyze cells during the biomanufacturing process. The equipment is 10-times smaller than traditional mass spectrometry instruments and significantly easier to use. It does not require the extensive technical training needed to use traditional mass spectrometry machines, allowing a shift in staffing toward operators and enabling advanced technical experts to focus their efforts in other areas of need. Project participants include Bristol-Myers Squibb (Summit, NJ), MilliporeSigma (Burlington, MA), University of North Carolina Chapel Hill (Chapel Hill, NC), and North Carolina State University (Raleigh, NC).
- **Optimizing Growth Rates of CAR-T Cells** – CAR-T cells are the foundation for a promising and rapidly emerging cell therapy treatment for certain types of cancers when other treatment options have failed. Villanova University (Philadelphia, PA) is advancing this type of cell therapy by developing a new approach to reduce the number of failed CAR-T cell manufacturing batches. This approach uses mathematical models to select the cells with the best metabolic performance profile in microbioreactors. Currently, the manufacturing cost is approximately $500K per treatment for CAR-T cell therapy. Preventing batches from failing protocol growth specifications could eliminate significant cost waste for manufacturers and ensure that critically ill patients get the treatment needed. Project participants include Merck & Co. (Kenilworth, NJ) and Redbud Labs (Chapel Hill, NC).

Technicians work at NIIMBL's new headquarters, the Ammon Pinizzotto Biopharmaceutical Innovation Center at the University of Delaware. Credit: University of Delaware.

Workforce Development

> *"Participants in the Door-to-Floor program have been able to advance their careers with several receiving internships or employment at leading biomanufacturers, such as BMS and Merck, as well as innovative start-ups."*
>
> — Jenny Ligon, Texas A&M University

Technicians work at NIIMBL's new headquarters, the Ammon Pinizzotto Biopharmaceutical Innovation Center at the University of Delaware.
Credit: University of Delaware.

NIIMBL builds national capacity of skilled talent to meet the acquisition, training, and workforce development needs of the biopharmaceutical manufacturing ecosystem. Through industry and academic collaboration, NIIMBL has established a diverse portfolio of projects and programs aimed to build a world-leading biopharmaceutical workforce.

- **Improving the Readiness of New Hires** – Texas A&M University (College Station, TX) created and launched its Door-to-Floor training program with 47 students receiving an advanced certificate in biopharmaceutical manufacturing. The program combines online and hands-on training and can be completed in half the time that it would take for a company to on-board a new employee. Other project participants included Akron Biotechnology LLC (Boca Raton, FL) and Vericel Corporation (Cambridge, MA).
- **Supporting the Next-Generation Biopharma Workforce** – In June 2019, NIIMBL piloted the first NIIMBL eXperience, a week-long program aimed to introduce underrepresented students to the exciting biopharma industry. Five talented students traveled to leading biomanufacturers, built connections with industry professionals and participated in career development workshops, facility tours and hands-on lab demonstrations. Hosts included AstraZeneca, Amgen, Merck, and RoosterBio, and NIST.
- **Planning for the Future** – North Carolina State University (Raleigh, NC) developed a scalable platform process and training course focused on vector production for the emerging area of gene therapy, meeting a critical industry need for workforce training for this revolutionary new treatment. Approximately36 students have participated in the four-day course, with additional offerings planned later in 2020. Sudhin Biopharma (Superior, CO) also participated in the project.
- **Sharpening the Skills of New Biotech Employees** – The University of Maryland (College Park, MD) partnered with Merck & Co. (Kenilworth, NJ) to develop and launch e-learning content targeted at new biotech employees or employees in cross-functional teams. The program includes 24 modules, each approximately 7 to 9 minutes, so employees can complete sections in brief time availabilities. After a successful pilot with 23 subject matter experts, Merck has implemented the training in its onboarding program. In addition, it is available for other biomanufacturers to add to their new employee process.

Researchers work in the fermentation lab at the Biomanufacturing Training and Education Center at North Carolina State University. Credit: BTEC © North Carolina State University.

Innovation Ecosystem

> *"There is so much more benefit with NIIMBL beyond having a project selected. The connections we have made and the value those relationships have brought to our business is invaluable."*
>
> – Lena Wu, Intabio

Collaboration is the foundation upon which NIIMBL is built. Through projects, events, workshops, working groups, and committees, NIIMBL brings together experts from across the biopharma ecosystem to solve manufacturing challenges and bring innovation to life. NIIMBL members are committed to the mission with 89% of member organizations participating in NIIMBL activities and projects, leading to countless new connections and relationships. These connections help NIIMBL members find ways to implement their technologies toward the institute's mission. For example, Intabio, a small company in Newark, CA, was able to expand the Early Access Program for its Blaze™ Microchip technology from 3 to 20 companies as a result of joining NIIMBL. Boston-based 908 Devices credits the connections it made through NIIMBL with bringing its Rebel® at-line media analyzer to market faster.

COVID-19 Pandemic Response

> *"Never in our lifetime have we experienced a global public health crisis of this magnitude. It presents a significant challenge but also an opportunity — one that I believe we are positioned to help overcome."*
>
> – Kelvin Lee, NIIMBL Institute Director

With a mission focused on biopharmaceutical manufacturing innovation, NIIMBL is uniquely positioned to assist with pandemic response by leveraging the expertise of global biomanufacturers and suppliers, small companies, and academic and federal scientists. In April 2020, NIIMBL put out a call for proposals for innovative project ideas to support pandemic prevention, response, and preparedness efforts related to COVID-19. As a result of this call, the institute awarded nine projects with funding from the Coronavirus Aid, Relief, and Economic Security (CARES) Act.

These funded projects aim to:

- Provide virus proteins and improve blood testing capabilities;
- Assist regional hospital systems with validation of rapid in-house diagnostic testing capabilities;
- Identify alternative domestic supply chains to reduce dependence on foreign suppliers for respirators and masks to protect health care workers;
- Validate decontamination approaches for clinical spaces; and
- Accelerate the development of flexible manufacturing capabilities for biologic therapies and rapid release testing to position the nation for faster medical product scale-up in response to pandemics.

More than 400 representatives from industry, academia, non-profits, and government gathered in Washington, D.C. in June 2019 for the NIIMBL National Meeting. Credit: NIIMBL.

SUCCESS STORY

Leveraging the Power of the Community to Validate New Technologies

Intabio's (Newark, CA) innovative technology, Blaze™ Microchip System, measures the Critical Quality Attributes of biopharmaceutical products in real-time, significantly reducing time and costs. Intabio partnered with Merck and Co., Bristol-Myers Squibb, and MilliporeSigma on a NIIMBL project to test their technology on cells supplied by these large biopharmaceutical companies to validate efficiencies and improve market access.

The results: dramatic reductions in testing times and labor. Traditional testing timelines ranged from days to weeks per sample and required several hands-on steps. **Only 3 to 5 samples could be tested at one time. Blaze™ eliminates manual steps and reduces testing times to only 15 minutes per sample, with the ability to test up to 25 samples over the course of a single day.** In addition, the cost of testing decreased from $23,000 per sample to approximately $65 per sample. The success of this project is a major step forward in getting safe products to patients faster.

Not only was the project a technical success, it also serves as a prime example of the power of the NIIMBL community. Through connections and relationships built within the NIIMBL membership, Intabio was able to increase the number of companies in its Early Access Program from 3 to 20.

"We want to build something that really makes a difference. One of the things that NIIMBL does is to identify the key issues in biomanufacturing and to me that was the equivalent value of having a large marketing group that I don't have. This helped us focus and direct our business and development with solid industry credibility," said Lena Wu, Intabio CEO & President, Co-founder.

Credit: NIST

SUCCESS STORY

Developing the Future Biopharmaceutical Workforce

Sometimes the best way to gain a true understanding of something is to immerse oneself in it. That's exactly what five talented scientists did during the first NIIMBL eXperience in June 2019. **The program aims to help college students from Historically Black Colleges and Universities and underrepresented student populations at NIIMBL member institutions to uncover career opportunities in the biopharmaceutical industry.** The mutually beneficial program provides students with visibility and career options that may shape their future educational path in the biopharmaceutical industry, while connecting companies with promising young talent for internships and future workforce needs.

Students were selected through a competitive application process. These students spent a week visiting biopharmaceutical companies and federal agencies to learn about the industry and the important role it plays in patient health and well-being.

Laurryn Sells, a 2019 eXperience participant and student at Howard University found the program to beneficial and enlightening. "The entire eXperience program was extremely rewarding. When I first applied for the program, I was eager to learn how I could apply my chemical engineering studies to an industry that is dedicated to improving lives. During eXperience week, I toured various company facilities, sat in on panels, and spoke one-on-one with industry professionals. I even got the chance to speak with the CEO of RoosterBio! Overall, my major takeaway was that everyone's career pathway will not look the same, but that reality is what makes each story incredible."

The program inspired Laurryn to continue her exploration of the biopharmaceutical industry by participating in the Door-to-Floor course, a NIIMBL-funded training program led by Texas A&M University.

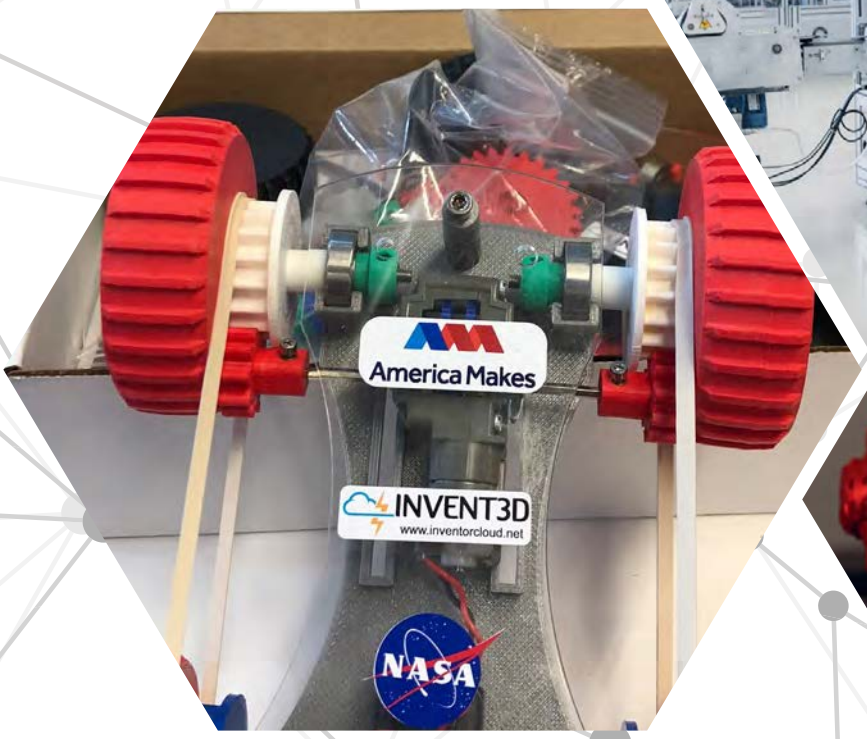
Credit: NIST

Credit: NIIMBL.

Credit: AFFOA.

DEPARTMENT OF DEFENSE INSTITUTE HIGHLIGHTS

Credit: left, MxD, right, AIM.



America Makes

The National Additive Manufacturing Innovation Institute

MISSION: Develop and grow a comprehensive and globally competitive U.S. additive manufacturing infrastructure comprised of world-class domestic sources of technology, equipment, and support; a robust domestic supply chain of high-quality materials and services; and a highly-skilled workforce capable of executing and exploiting the capabilities and advantages of additive manufacturing.

HEADQUARTERS: Youngstown, OH

SATELLITE LOCATION: The W.M. Keck Center for 3D Innovation, University of Texas at El Paso
Texas A&M Engineering Experiment Station, Texas A&M University (College Station)
National Institute for Aviation Research, Wichita State University (Wichita, KS)

ESTABLISHED: August 2012

CONSORTIUM ORGANIZER: National Center for Defense Manufacturing & Machining (NCDMM)

FUNDING: Federal, $61M; Non-Federal, $100.8 M (includes follow-on agreement with DoD)
DoD-directed project funding outside of original commitment: $97.5 M

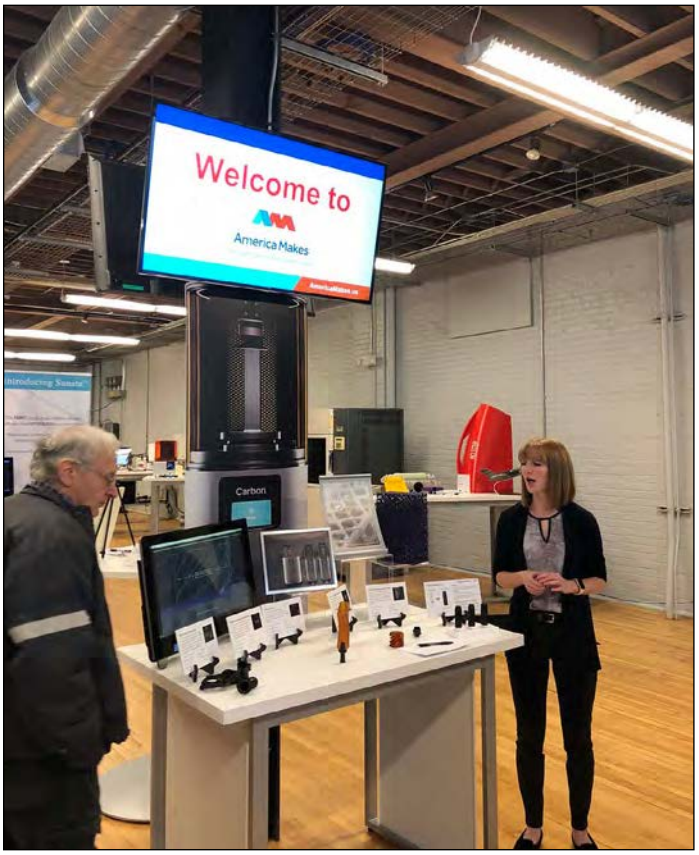
MEMBERS (as of September 30, 2019): 231

America Makes

americamakes.us

Institute Overview

America Makes is the nation's leading public-private partnership for additive manufacturing technology (AM) and education. America Makes members from industry, academia, government, workforce, and economic development organizations, work together to accelerate the adoption of AM and the nation's global manufacturing competitiveness focusing on three areas developing additive manufacturing technology, developing an additive workforce, and maintaining a collaborative ecosystem.



America Makes facility.. Credit: America Makes

Credit Opposite page: America Makes.

Technology Advancement

> *"The opportunities to engage and build relationships around the technology [that America Makes forges] with companies of all sizes has accelerated our own application of the technology and greatly enhanced our ability to coach other small companies as they evaluate the best application paths for additive."*
>
> — Susan Moehring, TechSolve

America Makes convenes technical expertise to build teams with broader capability beyond that of any single organization to address the specific needs of DoD. By fostering this collaborative mindset, America Makes accelerates the development and deployment of additive manufacturing solutions to enhance military readiness, strengthen alliances, and improve business performance and overall manufacturing affordability.

- **Maturation of Advanced Manufacturing for Low-Cost Sustainment** – This collaborative effort among 40 organizations is taking on 45 projects with $27M

in funding that will impact more than a dozen platforms. Phase 1 resulted in 1300+ pages of deliverables available for all America Makes members: best practices, new manufacturing processes, implementation options, business case examples, and knowledge on additive manufacturing (AM) and other advanced manufacturing topics. Included is a demonstration of an AM approach for composite sandwich panels that leads to production of aircraft semi-structural fairings without extensive tooling and reducing time by 50% and cost by as much as 75%.

- **Additive Manufacturing Heat Exchanger Design** – This project demonstrated improvements in thermal efficiency via heat exchanger AM capability, demonstrated process repeatability, product efficiency, and potential fuel savings. The AM product design can be used in engine precoolers and offers the potential to increase cooling capacity by 29% and reduce fuel burn by 0.6% compared to

America Makes was awarded the Defense Manufacturing Technology (ManTech) Achievement Award at the 2019 Defense Manufacturing Conference for its additive manufacturing three-phase "Maturation of Advanced Manufacturing for Low-Cost Sustainment (MAMLS)" program, which was funded by the Air Force Research Laboratory (AFRL), Materials and Manufacturing Directorate, Manufacturing and Industrial Base Technology Division. Credit: America Makes.

- **Qualification and Certification of Additive Manufacturing Metals** – Two projects in this series are assessing the merits of post-processing AM materials and quantifying the influence of design and manufacturing on important aerospace nickel alloys. Results of these projects will impact the quality, readiness, and cost for many DoD and US Air Force relevant products. Other related projects address technology gaps on the products, including fatigue, wear, and corrosion. These studies will contribute to the development of advanced tools for rapid qualification of AM materials.
- **Next Generation Multi-Laser Additive Manufacturing for Metal Components** – This project leveraged from intellectual property as well as learnings from prior projects aims to develop an open framework multi-laser powder bed fusion machine which will offer expanded manufacturing capability, improved product quality, and increased productivity for larger components which may not be available via traditional methods.

In March 2019, Dr. M. Katherine Banks and then-America Makes executive director Rob Gorham announced the Texas A&M Engineering Experiment Station partnership with America Makes to establish an America Makes satellite center on the campus of Texas A&M University in College Station. Credit: America Makes.

Workforce Development

"Education in advanced manufacturing is essential to maintain U.S. competitiveness and grow U.S. manufacturing in emergent, fast-growing 21st-century technologies such as additive manufacturing, automation, and advanced insight and analytics. The education work that America Makes is facilitating though efforts such as 3D Veterans, ACADEMI and training at their innovation factory is directly targeted at developing the skills that employees need to successfully compete in an advanced manufacturing world."

— Dr. Kirk Rogers, General Electric Center for Additive Technology Advancement

The America Makes portfolio of education and workforce development programs includes a wide range of activities from K-12 engagement to post-secondary programming to warfighter training. Training also reaches separating veterans and includes formal programs around apprenticeships and industry-recognized credential building. The institute's advisory committee supports these efforts through setting strategy, identifying and creating programs, and establishing best practices. In FY 19, America Makes engaged more than 6,000 people in workforce-related programs.

- **Warfighter training** – Customized training utilizes best practice existing curricula as well as newly created custom courses to meet new DoD requirements. Training is deployed onsite as boot camps to warfighters, engineers, technicians, and contractors. More than 500 DoD members have participated in 30 courses.
- **ACADEMI** – Focused on design specifically for additive manufacturing, the Advanced Curriculum in Additive Design, Engineering, and Manufacturing Innovation, or ACADEMI, is an immersive training experience for advanced AM, delivered in an intense, hands-on environment that integrates skills from multiple disciplines. Initially built for the Air Force, ACADEMI is currently being modified for Army, Navy, and Marines requirements.
- **Credential Development** – America Makes is developing industry-recognized credentials, standards, and pathways in AM, including an Office of Naval Research funded Manufacturing Engineering Education Program focused on updating and delivering credentials on additive fundamentals, additive technician, and certified manufacturing technologist and engineers' programs.

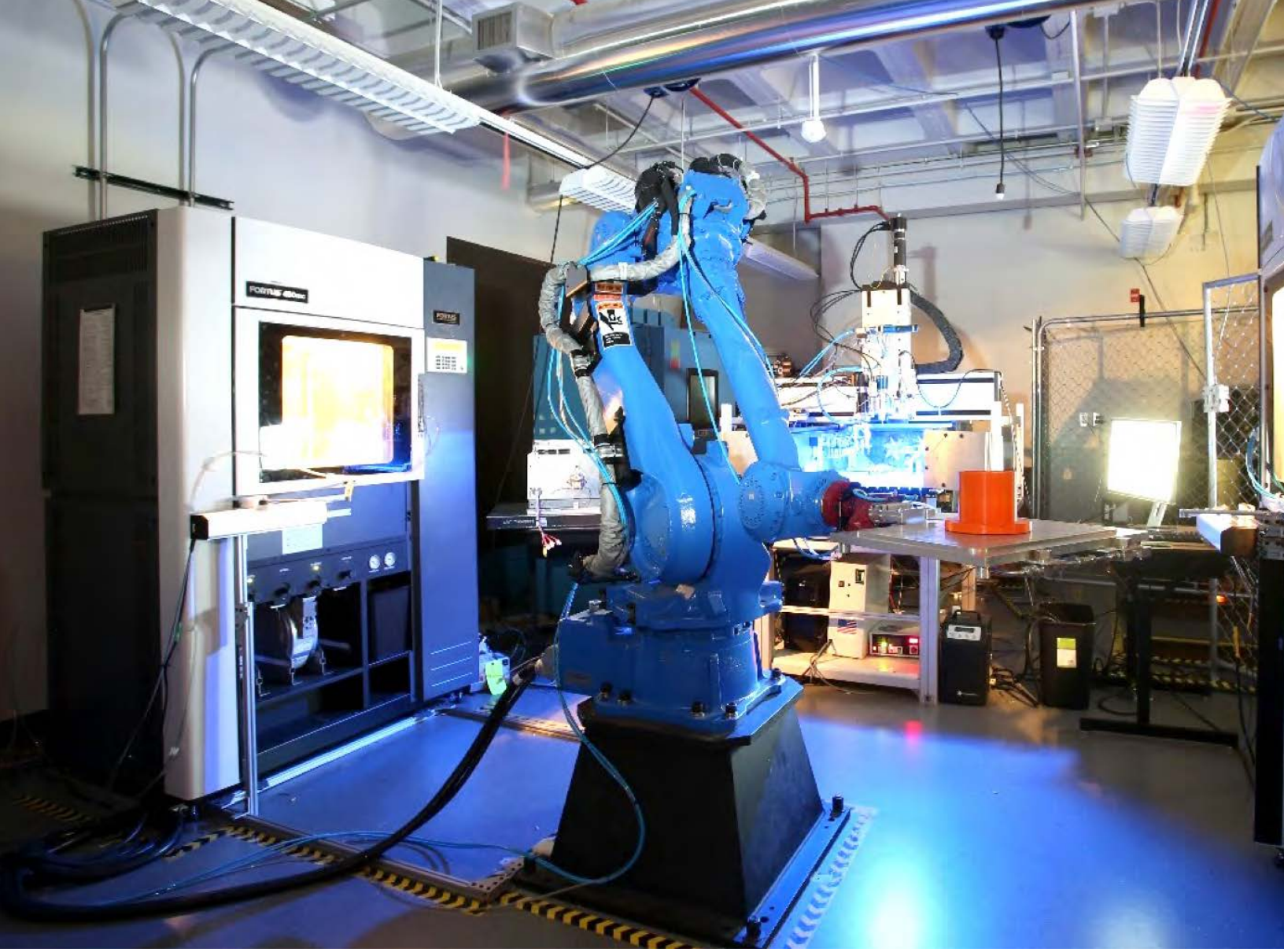
- **Innovation Factory** – This Youngstown, Ohio facility has introduced more than 800 individuals this year to AM, reaching a wide range of groups from national non-profits to Girl Scouts, and local leaders including Chambers of Commerce, Youngstown Business Incubator, and more.

Innovation Ecosystem

> *"America Makes has been absolutely key to giving the field of additive manufacturing the credibility needed to engage well-established, and often conservative, industries. The community and the networking have been very helpful to get partners engaged. The core research program has driven some important developments, from the lab to commercial practice."*
>
> – Jim McGuffin-Cawley, Senior Associate Dean, Case Western Reserve University

Through its knowledge and understanding of the needs of DoD while maintaining partnerships with industry, America Makes continues to develop and accelerate the adoption of additive manufacturing as a foundational and essential technology for the evolution of the supply chain. Important networking projects this year have included:

- **Satellite Centers** - America Makes added two new Satellite Centers in FY19 – at Texas A&M University with the Texas Engineering Experiment Station and at Wichita State University with the National Institute for Aviation Research. The intent of the institute's satellite centers is to extend the mission of the program, technology development, education and workforce development, and ecosystem creation with organizations that impact the institute's stakeholders through capability, network or ecosystem, or industry.
- **Regionalization Playbook** – Connecting small manufacturers to the Manufacturing USA institutes through the Manufacturing Extension Partnership (MEP), the Playbook was created with DoD support and outlines how to capitalize on the MEP national network and the depth of knowledge and training resources accessible through it. The Playbook can be replicated nationally for all other institute outreach and member support.
- **Safe NFL Helmet Developmen**t – A partnership with the NFL's Play Safe, Play Smart Helmet Challenge is introducing AM and America Makes members to current helmet manufacturers and NFL health and safety scientists and engineers to use new technologies like additive manufacturing and produce and test a safer helmet.
- **Stakeholder Councils** – America Makes brings the voice of the industry to the Office of the Secretary of Defense (OSD)-led Joint Additive Manufacturing Working Group and Joint Additive Manufacturing Steering Group to support cross-service coordination.
- **Additive Manufacturing Standards Collaborative** – Established in 2016 between America Makes and the American National Standards Institute, the AMSC coordinates, updates, and accelerates the development of industry-wide AM standards and specifications.
- **State Partnerships** – For example, strategic outreach with the Youngstown-Warren Regional Chamber led to $1 M in state budget allocations for the institute to work on two projects, including creation of the Ohio Education Secondary Network to foster innovation and entrepreneurship.



Credit: America Makes.

MxD

Manufacturing Times Digital

MISSION: Provide the government and U.S. manufacturers with the digital tools needed to transform American manufacturing.

HEADQUARTERS: Chicago, IL

ESTABLISHED: February 2014

FUNDING: Federal, $ 80 M; Non-Federal, $ 171.1 M (includes follow-on agreement with DoD)
DoD-directed project funding outside of original commitment: $19.7 M

MEMBERS (as of September 30, 2019): 289

mxdusa.org

Institute Overview

MxD is where innovative manufacturers forge their futures. In partnership with the Department of Defense, MxD provides manufacturers with digital tools and expertise to begin building every part better than the last. Institute members increase their productivity and win more business, powered by a workforce with the digital skills they need for a cybersecure industrial base. MxD also works with DoD manufacturers and contractors to assess and implement digital improvements throughout the industrial base.

MxD headquarters in Chicago, IL. Credit: MxD.

Credit Opposite page: MxD.

Technology Advancement

> *"MxD is taking great ideas, scaling them, and then moving them in the right direction so they can be used by industry—not only by the big companies but also by small and medium-sized companies. If my family still had their machine shop, we'd be all over it."*
>
> – Thomas R. Kurfess, Chief Manufacturing Officer, Oak Ridge National Laboratory

Ensuring the military has the most effective resources is a central driver of MxD's work. MxD partners with manufacturers to harness the power of the digital thread to drive forward advanced manufacturing technologies, while equipping the workforce (present and future) and the supply chain with the skills and cyber resiliency needed to ensure an innovative, secure, and prepared defense industrial base.

- **Docent Manufacturing Readiness Application** – MxD led a project with Ekta Flow (Chicago, IL) to develop Docent, an app for Manufacturing Readiness Level Assessment (MRA) execution, collaboration, and assessment. MRA is a standardized process to help mitigate risk and evaluate new defense acquisitions to improve outcomes. Docent provides a digital tool that offers flexibility, collaboration, and scalability across the enterprise.

- **Future Factory** – Artificial intelligence and machine learning are foundational digital technologies. The MxD future factory floor provides a real-life view of the "art of the possible" for applications of artificial intelligence/machine learning (AI/ML) and other digital technologies, and they are essential parts of many of the projects the institute pursues when it looks at using data to design and make more effective, more secure, more efficient, safer, and more economical manufactured parts.
- **Securing the Supply Chain** – MxD views a cybersecure defense industrial base and supply chain, along with a digitally skilled workforce, as essential components of DoD modernization goals for advanced manufacturing technologies, including hypersonics. MxD is developing the toolkits necessary to ensure the workforce is ready and the supply is secure to protect these innovations and optimize their potential to provide the U.S. with superior warfighting capability.

MxD helping prepare the next generation of cyber secure manufacturers. Credit: MxD.

Workforce Development

> *"Many people wonder: 'Am I still going to be able to do my job in two years, in five years?' Our ability to position them to be productive is very important. Our workforce program at MxD will help us with employee retraining and engagement."*
>
> – Ademola Idowu, Principal Research Scientist & Innovation Program Leader, Dow

- **MxD Learn** – MxD's workforce development program fosters collaboration across industry, academia, government, and non-profit leadership to ensure the current and future workforce are connected to the rules and competencies needed for digital and cybersecurity manufacturing applications.
- **Developing Skilled Workers with IGNITE** – In partnership with LIFT and America Makes, MxD launched IGNITE, a three-year high school curriculum designed to develop multi-skilled technicians. The curriculum ranges from basic information technology and employability skills to materials science and core and advanced technology. It raises awareness of career opportunities in advanced manufacturing and provides students with hands-on learning. The first two years of the curriculum focus on core competencies in advanced manufacturing while the third year, or Capstone, focuses on a particular specialty as designed by each institute. For MxD, the capstone includes a manufacturing cybersecurity component that

challenges students to design and develop an automated work cell. IGNITE is currently being piloted in three high schools across the country. The pilot managed by MxD began in Fall 2019 and involved hundreds of students.

- **Additional Programming** – MxD has engaged nearly 1,500 individuals in workforce development and education efforts. Other efforts have brought in 80 high school students through the Catapult entrepreneurship program and Chicago's neighborhood summer program, as well as hosting faculty from the National Institute for the Deaf to assist with the development and launch of their digital manufacturing curriculum.

Innovation Ecosystem

> *"We can initiate a prototype right here on the floor at MxD, apply some of the different technologies and tools from other MxD member companies, and then be able to export it out of MxD into an actual shop floor environment very quickly."*
>
> - Paul Ryznar, President and CEO, OPS Solutions

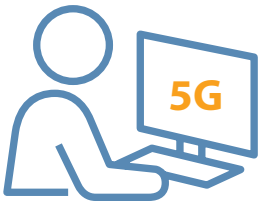
Through its robust network of partners, MxD provides U.S. manufacturing with workshops, federally-funded project opportunities, workforce development tools, and a 22,000 square-foot future factory floor innovation center to advance the digital transformation and innovation of U.S. manufacturers so they produce "every part better than the last." MxD's facility includes Autodesk's (San Rafael, CA) Generative Design Field Lab, equipped with state-of-the art machinery to design, prototype, and make products in real time. Generative design allows a user to select their preferred manufacturing processes from the beginning, so they can be sure that whichever solution they choose will be manufacturable with the equipment they have.

In March 2019, hearing the demand for a greater role in digital modernization from its member network and from across the U.S. manufacturing industry, MxD (Manufacturing x Digital) was launched, replacing the legacy DMDII (Digital Manufacturing and Design Innovation Institute) established in 2014. The launch was celebrated with an event attended by nearly 300 people including city, state, and federal government officials.

MxD's factory floor facility. Credit: MxD.

SUCCESS STORY

5G Innovation on the Factory Floor



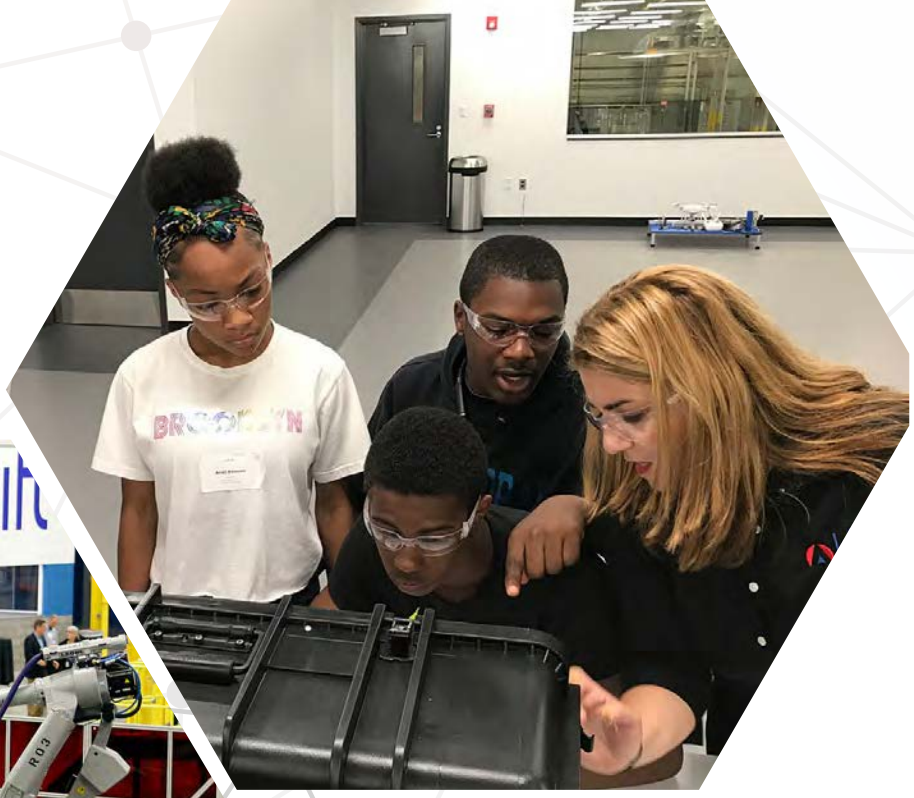
In July 2019, MxD announced a partnership with AT&T to accelerate deployment of 5G to U.S. manufacturing. **AT&T installed 5G technology and Multi-Access Edge Compute within MxD's Future Factory in Chicago to provide an active testbed to demonstrate the opportunities and benefits 5G brings to manufacturing.** In addition, MxD will utilize its active dark fiber connection to explore edge and supercomputing for specific project use cases.

MxD's partnership with AT&T also brings industry-related technologies, applications, and new collaborations to the research space to test manufacturing-related 5G use, such as Industrial Internet of Things, predictive maintenance, remote machine monitoring, autonomous robots, mixed reality training, and spatial computing.

"MxD is a premier leader in driving innovation for the manufacturing industry," said Mo Katibeh, chief marketing officer for AT&T Business. "By bringing 5G into their experiential testbed, we get to work with leading manufacturing companies to help drive new experiences and innovation not only today, but into the future."

Credit: NIST

MxD's discrete manufacturing testbed is equipped with sensors monitoring everything from ambient temperature to machine vibration. Credit: MxD.



LIFT

Operated by the American Lightweight Materials Manufacturing Innovation Institute (ALMMII)

MISSION: Advancing American Manufacturing Into the future through technology and talent development and driving rapid implementation of smarter manufacturing by connecting the materials, processes, and systems together with the talent needs of the future.

HEADQUARTERS: Detroit, MI

CONSORTIUM ORGANIZER: American Lightweight Materials Manufacturing Innovation Institute

ESTABLISHED: February 2014

FUNDING: Federal, $83M; Non-Federal, $83M
DoD-directed project funding outside of original commitment: $30.6 M

MEMBERS (as of September 30, 2019): 322

www.lift.technology

Institute Overview

LIFT solves the manufacturing equation by connecting materials, processes, systems, and talent needed to drive American manufacturing into the future.

LIFT – Leading Innovations for Tomorrow, the institute's technology program, develops and deploys new advanced materials manufacturing technologies and processes, including lightweighting, and multi-material processing in support of the industrial manufacturing base, our national defense, and the U.S. economy.

LIFT – Learning Innovations For Tomorrow, the institute's talent program, delivers a new advanced manufacturing curriculum in its immersive Learning Lab environment and to schools across the nation to address the skills gap in the U.S. workforce, providing workers with the skills, knowledge, and abilities required by new innovative technologies.

LIFT's project with Lifeline Firehose created state-of-the-art technology so firefighters can battle fires longer while providing critically needed air to downed personnel and victims. Credit: LIFT.

Credit Opposite page: LIFT.

Technology Advancement

> *"LIFT is the right organization to partner with. With both LIFT and CAR here in Southeast Michigan, the epicenter of the auto industry, it is a perfect fit to team up to advance the materials technology into the future."*
>
> – Abhay Vadhavkar, Director of Materials and Manufacturing Technology, Center for Automotive Research

LIFT is the leading lightweight materials research institute in the country and has built an ecosystem of manufacturers and educators. In 2019, LIFT updated its Fast Forge technology program, bringing large industry, small companies, and academic partners together to deliver rapid solutions to manufacturing problems across industry – resulting in 17 new projects. Other projects include:

- **Firehoses that Simultaneously Deliver Breathable Air and Water/Foam** – LIFT helped Lifeline Firehose (Lansing, MI) implement state-of-the-art technology so firefighters can battle fires longer while providing critically needed air to downed personnel and victims. The groundbreaking technology uses a patented coupler system, which LIFT engineers helped prototype, to deliver both air and fire suppressants to the end of the nozzle, using equipment firefighters are already trained on. The coupler design allows for the simultaneous

and separate flow of air and water or foam through a double-jacketed fire hose system.

- **Reducing Weight of Armor on Military Ground Vehicles** – LIFT is supporting the development of an iron-manganese-aluminum alloy for armor on military ground vehicles. The steel is expected to reduce armor weight by more than 10% while matching or exceeding the ballistic performance of conventional armor. LIFT is optimizing processing conditions to produce affordable, high-quality plate in large volumes.
- **Elevating Methods for Manufacturing Readiness** – LIFT used an Integrated Computational Materials Engineering (ICME) Approach to develop improved linear friction welding of titanium alloys for a variety of aerospace applications. LIFT built and integrated a manufacturing simulator for linear friction welding titanium components, enhancing and elevating the maturity of ICME methods with a direct impact on the manufacturing readiness of welded titanium structures within the air framing industry.
- **Optimal Joining Technologies** – This project with the Center for Automotive Research (Ann Arbor, MI) tested various joining technologies to recommend the most optimal methodologies for specific material combinations. Publication of these results will increase awareness and reduce the technology qualification barrier

Credit: LIFT.

Workforce Development

> *"One of our University Prep core values is 'Learning is Exciting,' and with our LIFT partnership, we honestly live up to those words. Innovative practices and transformational experiences are what University Prep Schools are all about, and I am beyond thrilled to see our scholars take part in this new opportunity."*
>
> – Mark Ornstein, CEO of University Prep Schools

LIFT has developed curricula and a one-of-a-kind immersive Learning Lab to educate and train the next generation of high-level advanced manufacturing technicians to help fill the existing skills gap in the U.S.

- **Operation Next** – Operation Next is an innovative manufacturing-focused training and credentialing initiative for soldiers within their last six months of active duty. As of September 2019, 101 soldiers participated, with approximately 90% accepting jobs in advanced manufacturing.
- **LIFT Learning Lab** – A state-of-the-art interactive learning facility, located at LIFT's Detroit facility, the LIFT Learning Lab provides LIFT's IGNITE: Mastering Manufacturing curriculum to 100 college prep science and math high school students. The program uses a Fundamental Skills Development Lab, Virtual Learning Lab, and Material Science Lab.

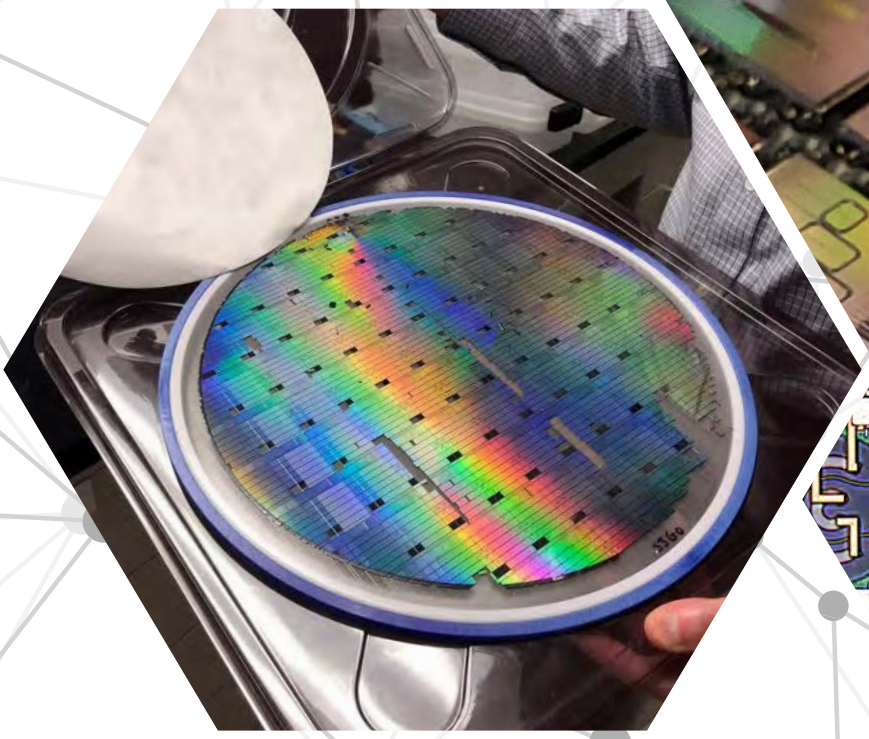
Innovation Ecosystem

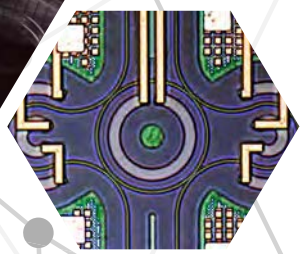
> *"LIFT is showing how partnership and inclusive ingenuity drive innovation. Their training, prototyping, and education programs create opportunities for vets, K-12 students, and the surrounding Detroit neighborhood. They truly #StandTALLforMichigan."*
>
> – Garlin Gilchrist, Lt. Governor of Michigan

LIFT headquarters in Detroit, MI. Credit: LIFT.

LIFT, with its 100,000 square-foot R&D lab in Detroit, rapidly contracts, designs, develops, prototypes, and tests innovative technologies for DoD to speed technology transition to the warfighter while building the future workforce of America. The institute also benefits the manufacturing ecosystem by convening members from across industries to learn from each other and find solutions to pervasive problems; building an ecosystem of companies of all sizes to learn and work together to advance manufacturing; and growing initial investments by attracting funding from additional federal and commercial sources to expand programming, research, and services.

LIFT has supported the community by loaning machines to Michigan Technology University; housing the Heroes' Alliance after-school STEM program for students from six high schools to collaboratively design, build, and test an electric-solar vehicle; and benefiting Detroit and the Southeast Michigan community by extending its lease of the Corktown research and development facility through at least 2025.





AIM Photonics

American Institute for Manufacturing Integrated Photonics

MISSION: Advance integrated photonic circuit manufacturing technology development while simultaneously providing access to state-of-the-art fabrication, packaging, and testing capabilities for small-to-medium enterprises, academia, and the government; create an adaptive integrated photonic circuit workforce capable of meeting industry needs and further increase domestic competitiveness; and meet participating commercial, defense, and civilian agency needs in this burgeoning technology area.

HEADQUARTERS: Albany, NY (photonic chip fabrication facility) and
Rochester, NY (photonic chip test, assembly, and packaging facility)

SATELLITE LOCATIONS: Santa Barbara, CA, Tucson, AZ

WORKFORCE LOCATION: Cambridge, MA

CONSORTIUM ORGANIZER: Research Foundation for the State University of New York

ESTABLISHED: July 2015

FUNDING: Federal, $110 M; Non-Federal, $502 M
DoD-directed project funding outside of original commitment: $6 M

MEMBERS (as of September 30, 2019): 121

www.aimphotonics.com

Institute Overview

Photonics, the use of light for applications traditionally addressed through electronics, enables significant new opportunities in a wide range of areas including telecommunications, laser-based radar, data communications, sensing, and many others. Integrated photonics dramatically improves the performance and reliability of electronic integrated circuits while significantly reducing size, weight, and power consumption.

Developing a widely accepted set of processes and protocols for the design, manufacture, and integration of photonics systems will not only advance this technology, but also present the U.S. with great economic opportunity. The Yole Silicon Photonics 2020 Market and Technology Report predicted, "Silicon photonics continues to be a very active field of innovation across many industries, with a broad range of companies and R&D labs involved worldwide. As a result, the silicon photonics market is expected to grow from $480M in 2019 to $3.9B in 2025." Integrated photonics is expected to advance established industries and enable new ones in the same way that semiconductors fostered the revolution in computing, telecommunications, and other fields over the past 40 years.

The 300 mm tools in the Albany, NY fabrication facility provide industry-leading quality and reproducibility. AIM's Si Photonics Platform was initially developed with DARPA funding, then improved and made accessible via Office of the Secretary of Defense funding under AIM Photonics. Credit: AIM Photonics.

Technology Advancement

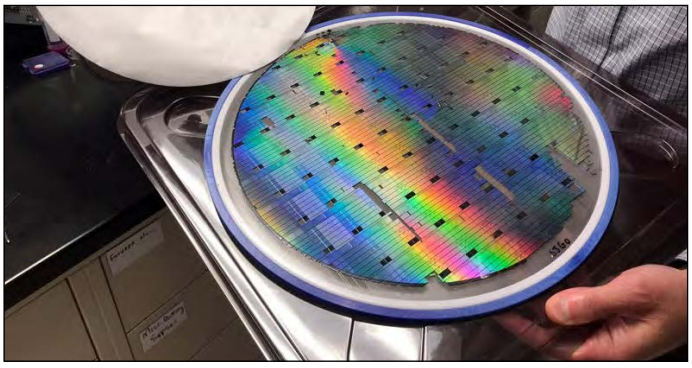
"Integrated Photonics is providing the opportunity to be more compact in how photonics fits onto our devices, saving size, weight, and power, while also delivering bandwidth capability and scalability. This gives us the ability to react to new requirements quickly and add additional optical wavelengths resulting in multiple sources of information on one fiber. Working with AIM Photonics is showing us a vision and pathway towards realizing much more compact radio frequency over fiber solutions for our platforms."

– Rick Stevens, Lockheed Martin Fellow

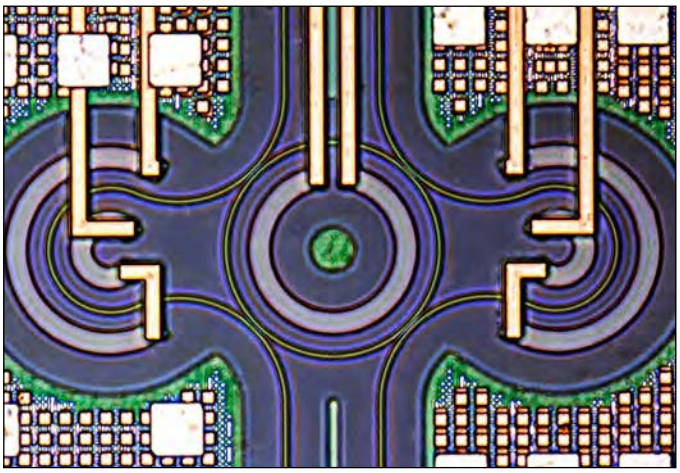
Credit Opposite page: AIM Photonics.

AIM Photonics has created a complete Photonic Integrated Chip (PIC) manufacturing ecosystem, which provides the photonics community and DoD access to advanced technology, capabilities, and resources throughout the entire product development cycle. This reduces time to market and advances national security. Institute projects address key challenges and opportunities facing the industry and include:

- **Biomedical Photonic Sensors** – Ortho-Clinical Diagnostics (Raritan, NJ), University of Rochester, Syntec Optics (Rochester, NY), and SUNY Polytechnic Institute (Albany, NY) have validated advanced low-cost point-of-care biomedical photonic sensors, which will reduce analysis and detection times from days to minutes and aid in improving and saving lives.
- **Fully Integrated Quantum Photonics Wafer** – AIM has produced the first-ever quantum photonics wafer for the DoD in a program led by the Air Force Research Laboratory and Rochester Institute of Technology. The wafer includes designs from the project leads and from collaborators at MIT (Cambridge, MA), Purdue University (West Lafayette, IN), Oak Ridge National Laboratory (Oak Ridge, TN), Army Research Laboratory (Adelphi, MD), and Rensselaer Polytechnic Institute (Troy, NY). The microchips produced by this wafer will help to explore how photonics can be used to develop



Integrated photonics COVID-19 sensors on 300 mm wafer fabricated at AIM Photonics. Credit: AIM Photonics.



Quantum silicon photonics circuit fabricated at AIM Photonics. Credit: AIM Photonics.

- **Radio Frequency over Fiber** – Warfighters communicate via electrical cabling, wiring, and electronic signals. Replacing these with fiber optics and integrated photonics significantly reduces weight and power consumption, which will ultimately lead to many benefits, including less fueling and increased mobility, speed, and performance. Member company Lockheed Martin has been working on radio frequency over fiber solutions to achieve these results and is currently in product validation and on path to delivering a key product for future DoD warfighters.
- **Developing Advanced 100 Gigabit per second Transceivers** – Multiple data communication customers have developed advanced 100G transceivers using the silicon photonics baseline, and research continues toward 800G and beyond to benefit networked communications and 5G cellular networks. In addition, manufacturable quantum dot lasers have been developed in conjunction with AIM Photonics West Coast headquarters at the University of California, Santa Barbara, to provide a fully integrated laser solution for photonic integrated circuits and significantly reduce power consumption in current transceiver technology.

Workforce Development

> *"Lockheed Martin has been committed to sending engineers and managers to AIM's Summer/ Winter Academy and supporting the Internship Matching Program. Feedback for both has been very positive and the team looks forward to leveraging opportunities offered by AIM Academy in the future."*
>
> – Nick Rhenwrick, AIM Photonics Program Manager, Lockheed Martin

AIM Photonics Academy spearheads education and workforce development initiatives in integrated photonics at every level of technical expertise, with programs including:

- **AIM Summer Academy** – In July 2019, AIM Photonics ran its fourth week-long academy. The four academies together reached 210 students. At this fourth academy, 35 students enrolled in two tracks, one in fundamentals of integrated photonics, and a second in design software tools. Representatives from software tool companies donated their time to provide students one week of dedicated hands-on training.

In July 2019, AIM Photonics ran its fourth week-long academy. Credit: AIM Photonics.

- **EdX Course "Fabless Design of Photonic Integrated Circuits within the AIM Foundry Ecosystem"** – AIM Academy launched this online course, which attracted nearly 2,000 students and resulted in 136 chip designs submitted. New York State contributed funding for submitters to process their designs, and MIT contributed funding for the course creation. The course introduced students to AIM Foundry's capabilities and delivered more trained photonic integrated circuit designers for the industry. Ninety-eight percent of survey respondents said their experience in the course was positive. An industry design contest awarded 52 students the use of AIM's $1B foundry to fabricate their designs.

Erica Graham, a graduate of the AIM Summer Academy, has been hired at AIM Photonics in Albany. Credit: AIM Photonics.

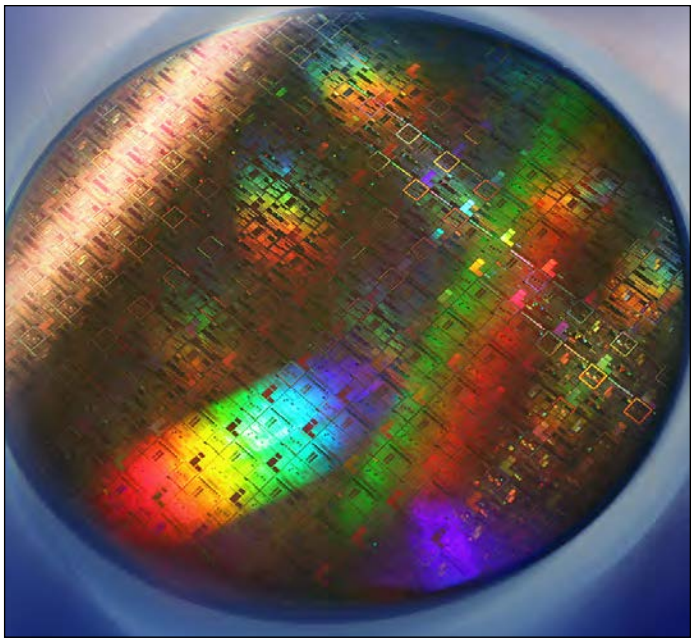
Innovation Ecosystem

"The advanced node microelectronic chip facility, where AIM Photonics PIC research takes place, has provided significant capabilities and access at very reasonable costs. This type of access is critical to ensure the continuation of advanced sensor-based technologies for DoD and commercial applications."

– Dr. Benjamin Miller, Professor of Biomedical Engineering, University of Rochester Medical Center

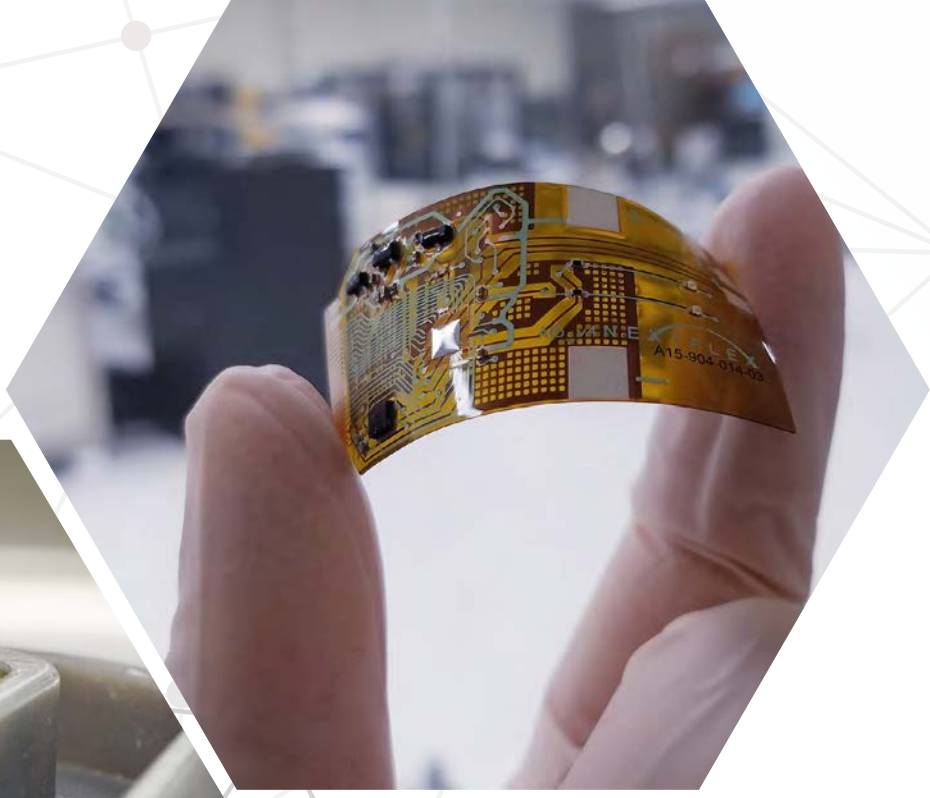
Credit: AIM Photonics.

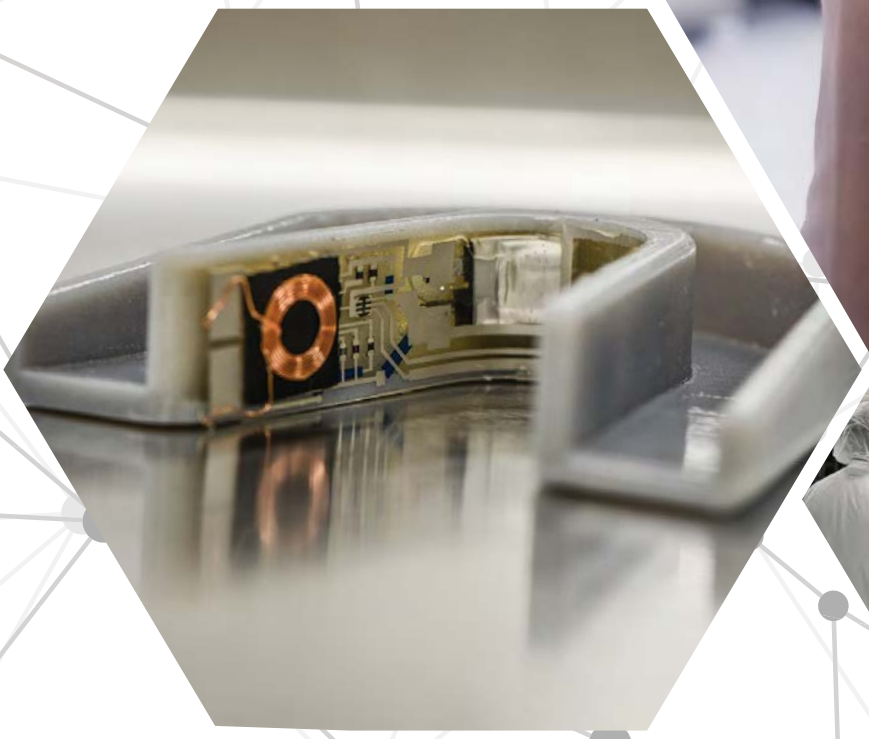
Integrated Photonics is approaching a high growth phase in key technologies and AIM Photonics has established manufacturing methods supporting these key technologies to ensure the needs of the market are addressed. The institute opened the world's first open 300 mm state-of-the-art advanced ecosystem for integrated silicon photonics test, assembly, and packaging in late 2019. The Rochester Test, Assembly, and Packaging facility is a key component in the institute's end-to-end advanced manufacturing capability for photonic integrated circuits. It has development and production process capability and will offer state-of-the-art test and metrology capability as well.



Credit: AIM Photonics.

Credit: AIM Photonics.





NextFlex

America's Flexible Hybrid Electronics Manufacturing Institute

MISSION: Pioneer flexible hybrid electronics manufacturing to serve our nation's warfighters and the U.S. economy.

HEADQUARTERS: San Jose, CA

CONSORTIUM ORGANIZER: FlexTech Alliance

ESTABLISHED: August 2015

FUNDING: Federal, $75 M; Non-Federal, $96 M
DoD-directed project funding outside of original commitment: $38.4 M

MEMBERS (as of September 30, 2019): 100

nextflex.us

Institute Overview

NextFlex facilitates the development of flexible hybrid electronics (FHE) technology that integrates low-cost printed electronics with the processing power of thin semiconductors to create a new category of stretchable, bendable, conformable, and flexible electronic devices. The low cost, small size, and lighter weight of FHE devices delivers the long-promised "Internet of Everything." The NextFlex flexible circuit board is produced in fewer than half the process steps of traditional rigid circuit boards, making it cheaper and faster to market through digital design and manufacturing.

NextFlex focuses on five areas of FHE-enabled technologies: human health and performance monitoring, structural health (bridges, buildings, aircraft wings, etc.) and asset monitoring, soft robotics, flexible power, and integrated antenna arrays. NextFlex convenes institute members to collaboratively identify and overcome manufacturing challenges in commercializing novel FHE-enabled systems and devices. Before the institute, there was no comparable facility for FHE anywhere in the world.

Technology Advancement

> *"Rather than managing development across multiple R&D and manufacturing facilities, we found a single place at NextFlex's Technology Hub, where we could develop our solution in very short time and have the right conversations to move our reader design toward production at scale."*
>
> – Ben Hwang, CEO, Profusa

NextFlex is designing, developing, prototyping, and pilot-scale manufacturing FHE for a range of military and civilian applications at a single facility. Projects include:

- **Wearable Soldier Authentication Device** – NextFlex developed and demonstrated a proof-of-concept wearable soldier authentication device that would improve security while simultaneously simplifying soldiers' access to critical systems. The device combines near-field communication and Bluetooth authentication for the U.S. Army divisions and supports the Tactical Identity and Access Management program.

Credit Opposite page: Nextflex.

- **Automated Programming and Testing** – NextFlex successfully initiated a project to automate the programming and testing of FHE using a combination of a four-axis robotic arm and vision system. The automation was subsequently adapted for visual recognition, inspection, adhesive dispense, and pick-and-place as part of a medical device build.
- **Integrating Systems to Improve Electronics** – To investigate manufacturing processes needed for flexible substrates, NextFlex is integrating micro-electromechanical systems onto FHE devices. This process would add critical capabilities for FHE devices, including measurements for navigation, precise timing, microfluidic biological measurements, and more. NextFlex has been working with partners to investigate the effects of integrating these devices into the FHE manufacturing process, including testing of failure modes, evaluating existing attach options, and testing for survivability when exposed to harsh environmental conditions.
- **Soft Robotic Knee Exoskeleton** – Development is underway for a soft robotic knee exoskeleton that is controlled using FHE-based sensors to measure the body's electrical impulses to the muscles, as well as the impacts of skin temperature and impedance. Led by Lockheed Martin and the Georgia Institute of Technology, the project's results will benefit soldiers and industrial workers by augmenting natural human performance and improving mobility for veterans and injured people with walking disabilities. Systems with these FHE control systems are expected to be more natural to use, adapt better to the user's physical state, and have greater benefit than alternatives based on more conventional designs and control systems.

A NextFlex project is underway to develop a soft robotic knee exoskeleton that is controlled using FHE-based sensors. Credit: istock.

- **FDA-Compliant Medical Device Manufacturing** – NextFlex stood up a Quality Management System and now has the ability to provide manufacturing services in the Technology Hub that comply with FDA standards. This led to the start of a build of over 1,000 medical devices complete with the required documentation.

Participants in NextFlex's FLEX PRO Professional Development Program. Credit: NextFlex.

Workforce Development

"By showcasing the ways next-generation technologies are changing the world, we attract a larger group of students into the talent pipeline, inspiring them to pursue education pathways that will bring them back to us as future hires."

– Dan Gamota, Vice President Manufacturing Technology, Jabil

Innovation Ecosystem

"NextFlex has become the focal point of the FHE ecosystem by facilitating much of the discussion around this evolving technology and drawing together a diverse community of subject matter experts that are driving advancements at a rapid pace."

- Joseph Kunze, Founder, President and CEO, SI2 Technologies, Inc.

NextFlex facilitates the development of the skills needed by our industry partners over time through such projects as:

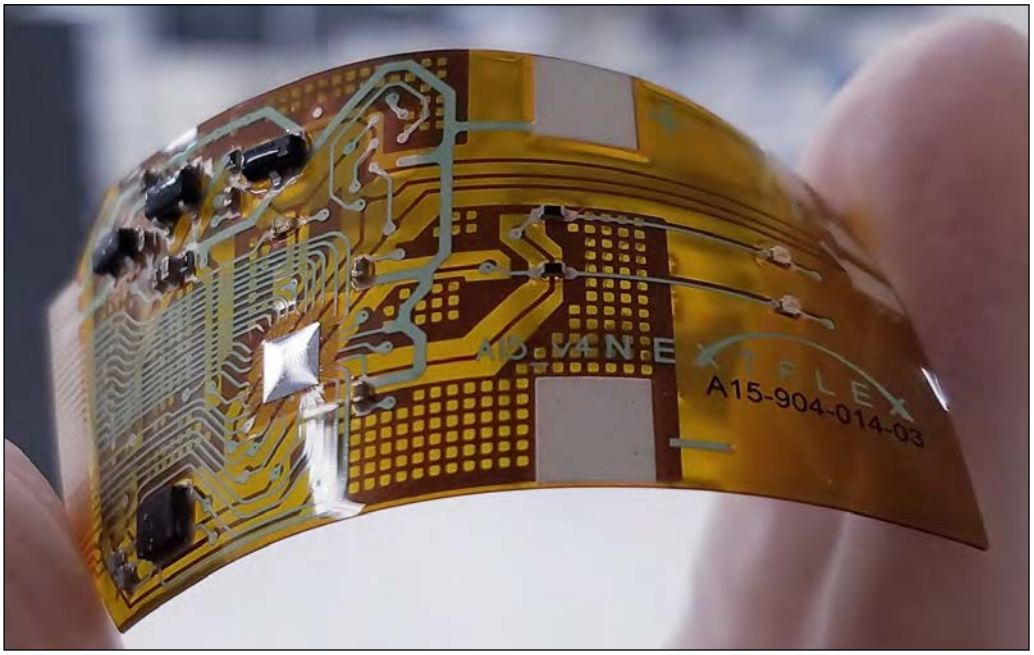
- **FLEX PRO Professional Development Program** – Designed for working engineers and product developers, these instructional and immersion modules help increase participant awareness and knowledge of FHE-related applications, engineering, and manufacturing processes. Program partners include Lockheed Martin and Boeing, and the program is poised to expand nationally from pilots in San Jose, CA and Seattle, WA.
- **Expanding FlexFactor to More K-12 Students** – This outreach program helps inform, inspire, attract, and recruit students into advanced manufacturing education and career paths. The program layers on to existing classes and challenges young people to develop a hardware device solution and build a business model around it to solve a real-world problem that they care about. Piloted in San Jose, CA, the program has since expanded to Elyria, OH, and Huntsville, AL, in partnership with regional community colleges and industry members including Jabil, DuPont, Boeing, and others.

NextFlex convenes the U.S. FHE ecosystem to align technical advances to application-driven needs from industry and government, ensuring rapid transition into manufacturing and American FHE global competitiveness. To support this work, NextFlex convenes workshops for ecosystem members, addressing such topics as "FHE for Defense Applications," "FHE Applications for Aerospace," and "Scalable Manufacturing Methods for Flexible Hybrid Electronics." Workshop partners have included Lockheed Martin (Alexandria, VA), Boeing (Seattle, WA), and University of Massachusetts Amherst.

Working with state partners in New York and Massachusetts, NextFlex also facilitates formal and informal regional networks for the industry, to convene practitioners and support supply chains and regional economic development. Both of these NextFlex Nodes are partially funded by the respective state.

Developing More Applications for Flexible Arduino®

In 2018, NextFlex and partners introduced a prototype Arduino®-compatible microcontroller board and demonstrated the power of flexible hybrid electronics. Since then, NextFlex has continued to develop a family of devices with each one adding more and more capability as well as developing the manufacturing infrastructure.



NextFlex and partners' prototype Arduino®-compatible microcontroller board. Credit: NextFlex.

One of these devices was used to exercise NextFlex manufacturing capability, where as many as 2,000 print layers can be produced per hour. This effort has now developed into a microcontroller platform where complete functioning products are being developed with multiple sensors, wireless communication, and on-board power.

SUCCESS STORY

Credit: NextFlex.

AFFOA

Advanced Functional Fabrics of America Institute (AFFOA)

MISSION: Rekindle the domestic textiles industry by leading a nationwide enterprise for advanced fiber and fabric technology development and manufacturing, enabling revolutionary system capabilities for national security and commercial markets.

HEADQUARTERS: Cambridge, MA

SATELLITE LOCATIONS (FABRIC DISCOVERY CENTERS): Cambridge, MA, Lexington, MA, Lowell, MA, Philadelphia, PA

CONSORTIUM ORGANIZER: Massachusetts Institute of Technology

ESTABLISHED: April 2016

FUNDING: Federal, $75 M; Non-Federal, $242 M
DoD-directed project funding outside of original commitment: $12.4 M

MEMBERS (as of September 30, 2019): 118

affoa.org

Institute Overview

AFFOA's vision is a globally competitive domestic supply chain in advanced fibers and fabrics. The institute delivers breakthrough capabilities and innovations for national security through mitigating risk of university technologies, non-traditional defense contractor participation, and the development of advanced textile systems. AFFOA centralizes the revolutionary fiber and fabric technology capabilities of startups, manufacturers, industry, and academia and organizes them to produce and manufacture advanced textile systems for the DoD and commercial markets.

AFFOA addresses the spectrum of manufacturing challenges associated with developing and scaling advanced fibers and textiles from design through pilot production, helping to transition innovative technologies. The institute's Fabric Innovation Network of member companies enables the development and commercialization of textile products that can see, hear, sense, communicate, store energy, regulate temperature, monitor health, and change color while delivering the conventional qualities of fabrics to benefit the commercial consumer and warfighter.

Teufelberger successfully integrated AFFOA's advanced LED and photodiode fibers into a commercial rope prototype using production equipment. Credit: AFFOA.

Technology Advancement

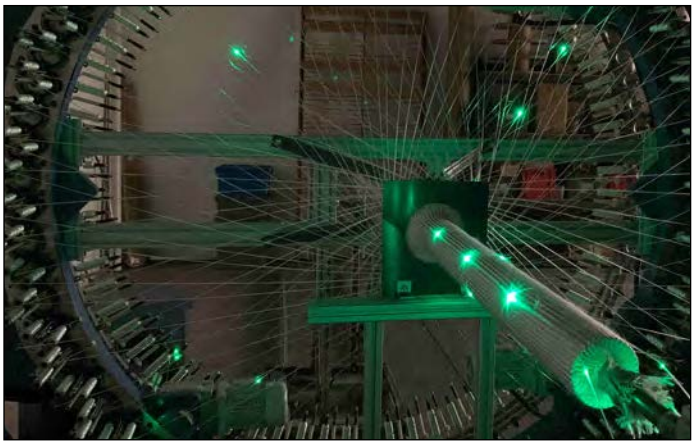
> *"Our partnership with AFFOA has allowed us to explore the possibilities of fabric and technology. They have opened our eyes to the endless possibilities of fiber technology. Working with the AFFOA team has been a true collaboration and eye-opening experience."*
>
> – '47 Brand

At the heart of AFFOA's mission is creating highly functional textile systems that will drive demand and growth of the industrial textile base while simultaneously delivering new capabilities. Projects include

- **Advanced Functional Fibers for Optical Communication** – AFFOA developed the first-of-its-kind advanced functional fiber with embedded optical receivers and transmitters to enable underwater communications. AFFOA issued a MicroAward to seventh-generation, family-owned Teufelberger (Fall River, MA) to integrate this technology into commercial ropes, paving the way for various other applications including safety, fire rescue, and optical communication.

Credit Opposite page: NIST.

- **Fabrics That Heal** – AFFOA project lead, Nufabrx (Conover, NC) in partnership with Manufacturing Solutions Center (Conover, NC) achieved commercial market penetration of their proprietary, active ingredient-releasing fibers. The yarns, infused with capsaicin and knitted into compression socks, aid in pain relief and reduce edema. The company has several strategic partnerships with other brands who are leveraging the technology in their own products.
- **Bridge Health Monitoring** – Teams from University of Massachusetts, Lowell and Saint-Gobain (Malvern, PA) installed fiber-optic sensing textiles for bridge health monitoring in partnership with the American Railway Engineering Association. The technology focuses on integrating fiber optic strain sensors directly into fabrics, enabling multi-dimensional stress-strain measurements.
- **Self-Powered Fabric** – Supercapacitor fibers were connected directly to light-emitting fibers and a fabric-embedded microprocessor to transmit digital data through light. This was the first demonstration of a completely integrated functional fabric system as well as a systems-level demonstration of supercapacitor fibers powering electronic devices.



AFFOA member company Revolution Composites integrated LED fibers in their fiberglass reinforced epoxy composites through a braiding and resin transfer molding process. Credit: Revolution Composites.

- **LOOks in Action** - In FY19, AFFOA partnered with Augmented World Expo (AWE), the world's largest augmented/virtual reality conference, to provide the official 10th anniversary conference bag and app leveraging AFFOA's LOOks technology (fabric that communicates). One of AWE's primary goals is to help attendees find and connect with like-minded people and the advanced fabric technology enabled conference goers to connect and engage with other attendees and exhibitors. This high-profile engagement resulted in the development of two different bag designs, 209 exhibitor booth decals, and a fully connected conference app. The event was a success with, among other things, 2,700 LOOks bags distributed, 3,600 app downloads, and 24,000 augmented reality avatar views.

AFFOA's connected LOOks bags showing AR capabilities and content in action at the 2019 AWE USA Conference. Credit: AFFOA.

Workforce Development

> *"The support and collaboration in building a community of academics and industry, as well as demonstrating the value of bringing together design, science, business, and technology to build a workforce of the future, has been very successful."*
>
> – Joanne Arbuckle, Fashion Institute of Technology

AFFOA is focused on creating educational and workforce development programming and partnerships to inspire, prepare, and grow the domestic textile industry's workforce to meet the current and future needs of the advanced fiber and fabric industry. Projects include:

- **Advanced Functional Fabrics Curriculum for Technical High Schools** – AFFOA worked with Greater Lawrence Technical School's STEAM Innovation Team (Lawrence, MA) and MIT Edgerton Center to develop an introductory Advanced Functional Fabrics career pathway curriculum at the technical high school level. By exposing students to the technical skills required to manufacture advanced fibers and fabrics, the program begins to develop the next generation of skilled workers needed for Industry 4.0. Students engaged in design and prototyping challenges to brainstorm products that solve user needs using fabric technology. They also visited AFFOA headquarters to learn about current technologies and meet with industry experts to pitch and refine ideas. In 2019, the team expanded upon the previous year's pilot and developed six additional units and 80+ lessons to include such elements as: how advanced functional fabrics are made; coursework for students to design and prototype new product and market applications that lead to societal benefits; and the expansion of students' capacity to see an idea through the necessary stages of commercialization and testing.
- **Advanced Fiber and Fabrics Workshop for Undergraduates** – In partnership with MIT and the Fashion Institute of Technology (FIT), AFFOA developed a workshop to build awareness among undergraduate students, particularly engineers and fashion designers, of the benefits and opportunities of a transdisciplinary approach to the design and application of advanced fibers and fabrics. The curriculum aims to demonstrate new ideas, technologies, and opportunities in advanced fibers and fabrics, and inform and inspire students interested in design, engineering, and business. Students are exposed to textile innovations and advancements, learn about production techniques, interact with students from different backgrounds and disciplines, and use their learning to develop prototypes in response to an industry product design challenge. Typical curriculum topics include multi-material fibers and their development, biomaterials, knitting, weaving, 3-D printing, prototyping, and applicable software, all within a transdisciplinary environment. In June 2019, an online curriculum was piloted that combined elements of onsite training and project experience with online information delivery.

Students put together a product prototype using fabrics and electronic components in response to the workshop industry challenge. Credit: Courtesy of FIT.

Innovation Ecosystem

> *"Your innovation in fostering collaboration is already sowing seeds for technology advancement, to the benefit of society."*
>
> – Shandon Hart, Corning

AFFOA established the Advanced Fabric Entrepreneurship Program (AFEP) which engages stakeholders across the ecosystem (students, entrepreneurs, universities, start-ups, manufacturers, industry, DoD) to introduce innovations that can be scaled to meet commercial and military needs. AFEP was created in partnership with MIT-Venture Mentoring Services to drive new product development and business/job creation. The year-long program supported entrepreneurs interested in advanced fabrics with access to resources to build commercial value, including access to AFFOA's advanced fabric innovation ecosystem, experienced mentors, technical experts, prototyping resources, equipment, customer insights, team building, and more to prepare them to launch their companies. The program leveraged the National Science Foundation i-Corps curriculum to develop key skills for customer discovery and product market fit evaluation. Twenty venture teams completed the program, and AFFOA supported nine in prototyping needs. More than half of the ventures formed companies, two applied for SBIR funding to focus on DoD work, and 63% plan to launch a commercial product or service in the near future.

Fabric Discovery Center (FDC) Highlights: AFFOA has three additional Fabric Discovery Center locations which are critical elements of its innovation ecosystem. Each has unique capabilities and focus areas relating to the advanced fiber and fabrics space.

- **Defense Fabric Discovery Center (DFDC):** A collaborative enterprise between MIT Lincoln Laboratory and U.S. Army Combat Capabilities Development Command - Soldier Center, DFDC has made significant progress in executing high-impact DoD programs, including for physiological status monitoring, chemical sensing and optical communications. The DFDC also started new programs expanding fiber functionality and laid the foundation for additional new programs. With DARPA support, DFDC developed a new way to embed discrete devices into fibers at predetermined locations along the fibers, contacted by metal wires for power and communication. This process provides a powerful platform for multiple applications. DFDC also started an Army-funded program to apply technologies to fibers to actively change the color of fabric. Finally, DFDC continued to build the infrastructure for drawing silica fibers which may provide groundbreaking capabilities for national security applications, such as directed energy.

- **University of Massachusetts Lowell FDC (UML FDC):** The UML FDC is the first and only site in the nation that brings together opportunities from three institutes (AFFOA, NextFlex and ARM) under one roof. This integration has enabled, for example, the expansion of an AFFOA-funded project on optical sensors for civil infrastructure monitoring with Saint Gobain to a NextFlex project with Boeing, Saint Gobain and CCDC on smart textile-based sensors for aircraft. During FY19, the UML FDC also expanded the innovation ecosystem by initiating six distinct projects ranging from fiber based photovoltaic devices (with the Department of Homeland Security) to multicomponent fiber retardant yarns (CCDC SC) and evaluation of exoskeletons in the affiliated New England Robotic Validation & Evaluation Center. These projects involved 16 companies, and many graduate students, researchers, engineers, and scientists from industry, academia and government. In addition, the UML FDC hosted workforce development activities with MassMEP and a backpack hackathon utilizing the Fashion Maker Space, sponsored by Wenger Victorinox Swiss Army.
- **Pennsylvania FDC at Drexel University:** In September 2018, Drexel University began construction on the Center for Functional Fabrics' new facility which now hosts the Pennsylvania Fabric Discovery Center (PA FDC), a mixed-use manufacturing, training, and event space. The Center, made possible by a $1.5 million equipment grant from the Commonwealth of Pennsylvania, is now outfitted with textile machinery dedicated to research and development of functional fabrics. The Center's research includes textile integration of LED fibers and further development of the Capacitive Touch Sensor. On September 25, 2019, the Center officially opened its doors with notable guests such as President John Fry of Drexel University, Philadelphia Mayor John Kenney, Pennsylvania Governor Tom Wolf and representatives from the DoD Office of Manufacturing and Industrial Base Policy.

Credit: NIST.

SUCCESS STORY

LOOks Technology Provides Sensing and Tracking Through Fabric

Active LOOks technology embeds microelectronic devices into the advanced fibers of fabric. Layering sensing data onto infrared strobes is a technology currently deployed on the battlefield for improved situational awareness, enhanced battle tracking capabilities, training monitoring, field authentication, and more. AFFOA demonstrated this capability through prototyping in military vests, pants, and caps, as well as composites. In one SOCOM demonstration, an Active LOOks cap was paired with an Apple watch to collect a user's physiological data and optically transmit that information to a third party, who accessed the information through an app reader in real-time. AFFOA was asked to produce 100 caps within a short time period, demonstrating the ability to rapidly source, build a supply chain, and prototype at pilot scale.

IR Active LOOks cap that collects a wearer's physiological data through an Apple watch, and optically transmits that information to a third party in real-time. Credit: AFFOA.

In May 2019, AFFOA showcased this technology during a National Security Innovation Network (NSIN) hackathon focused on communications in austere environments. AFFOA and its collaborators were selected as winners of the hackathon using capabilities derived from the caps described above. Of greater significance, the technology captured the attention of United States Special Operations Command (SOCOM) operators as a new way to visualize information on the battlefield. Currently, troops use various strobes to communicate their identity and positions to overhead assets. This technology could be added to helmet systems to prevent friendly fire and to provide commanders with enhanced situational awareness on the battlefield—essentially creating a digital overlay for command. As a follow up, AFFOA has been in contact with members of the military community to create a demonstrator project based on this idea.


LOOKS
@LOOKSbyAFFOA // www.LOOKsPack.com
The world's first progra mable, digitally
connected, mixed reali / backpack.
AF065

Credit: NIST.

BioFabUSA

Advanced Regenerative Manufacturing Institute

MISSION: Make practical the scalable, consistent, and cost-effective manufacturing of engineered tissues and tissue-related technologies, to benefit existing industries and grow new ones.

HEADQUARTERS: Manchester, NH

CONSORTIUM ORGANIZER: Advanced Regenerative Manufacturing Institute (ARMI)

ESTABLISHED: December 2016

FUNDING: Federal, $80 M; Non-Federal, $214 M
DoD-directed project funding outside of original commitment: $4.5 M

MEMBERS (as of September 30, 2019): 162

biofabusa

biofabusa.org

Institute Overview

Significant breakthroughs in cell biology, biofabrication, and materials science in the last decade have laid the foundation for large-scale manufacturing and commercialization of engineered tissues and tissue-related technologies. BioFabUSA has targeted the raw material, equipment, measurement, automation, logistics, and big data analytics challenges that hinder scalable, consistent, and cost-effective manufacturing. The development of tissue engineered medical products on an industrial scale enables the DoD to accelerate creation of numerous medical products for our wounded warfighters which support force readiness and save lives on the battlefield.

Technology Advancement

"This is literally a life-changing approach and adds a new chapter to medicine. To apply technology across multiple disciplines to help people live longer, healthier lives—there's going to be nothing but more interest in that as the population ages and the technology becomes more capable."

– Blake Moret, CEO, Rockwell Automation

BioFabUSA is integrating innovative cell and tissue cultures with advances in biofabrication, automation, robotics, and analytical technologies to create research and development tools and FDA-compliant volume manufacturing processes

BioFabUSA's tissue foundry. Credit: BioFabUSA.

Credit Opposite page: BioFabUSA.

that can accelerate medical products to improve human health and save lives.

- **First-Ever Tissue Foundry** – BioFabUSA launched a Tissue Foundry composed of a series of subsystems, each representing a different stage of the tissue engineered medical products (TEMPs) manufacturing process. Modularity allows the platform to be scaled-up and reconfigured to facilitate the manufacture of any TEMP. Modular, automated, and closed manufacturing will ensure that our nation has access to sufficient numbers of effective, consistent, affordable TEMPs.
- **Replacing Damaged Ligaments through Technology** – BioFabUSA is using the Tissue Foundry in work with STEL Technologies (Ann Arbor, MI) to automate its manual process. STEL's first product, CGEM™, is a tissue consisting of mineralized (bone) ends and a non-mineralized (ligament) middle region, generated by mesenchymal stem cells. The product is intended to replace damaged anterior cruciate ligaments (ACLs). The Tissue Foundry was initially configured to produce through automation 10 CGEM grafts from a single vial of the stem cells.
- **Growing New Muscle Tissue** – To demonstrate the adaptability of the Tissue Foundry, it will be reconfigured to produce skeletal muscle units, a technology in development at the University of Virginia, intended to maximize function for return to duty or civilian life following muscle loss.

BioFabUSA's biofabrication learning kit in action. Credit: BioFabUSA.

Workforce Development

> *"Through internships and class projects, students can gain hands-on experience and be prepared to fill some of the jobs that will be created because of the work spearheaded by BioFabUSA."*
>
> – Matt Cookson, Executive Director, New Hampshire High Tech Council

BioFabUSA is preparing the workforce to meet the needs of this developing industry across the U.S. through projects such as:

- **Grade 6-12 Hands-On Biofabrication Learning Kit** – BioFabUSA piloted a curriculum for current and future tissue manufacturing processes at the 2019 FIRST Robotics Championship with more than 5,000 students, and is now packaging the activities for teachers. The kits will include complete instructions, lab supplies, questions aligned to the Next Generation Science Standards, Common Core Standards, and a framework for K-12 science education.
- **Curricula, Science Camps, and Girl Scout Badges** – Education modules were created for grades K-12 to allow teachers to integrate lessons into their curricula. Hands-on activities for science center summer camps and field trip experiences allow students to investigate the science behind biofabrication. A digital BioFab Explorer tool kit showcases BioFabUSA members and allows students to envision themselves in high-impact careers. Girl Scouts will soon be able to earn a BioFab patch by participating in activities that represent the multi-disciplinary nature of biofabrication technology.

Innovation Ecosystem

"BioFabUSA has developed the first automated system that takes a set of cells, matures those cells in a closed, no-touch system, and via an automated production line manufactures a bone-ligament-bone graft. Think about the data available in that process; data necessary to understand environmental conditions to reliably achieve the same results. BioFabUSA is doing the foundational work to characterize cells and tissues, leveraging the power of data analytics that will lead to reproducible results, lower costs – and replacement organs for the hundreds of thousands of people currently on organ-donor waiting lists."

– Jim Weinstein, Senior VP, Microsoft Healthcare

Prior to the establishment of BioFabUSA, the tissue engineering field was fragmented and lacked a mechanism with which to turn laboratory breakthroughs into manufactured products. BioFabUSA has filled a critical need by creating and convening this community.

- BioFabUSA hosts a semi-annual conference for the tissue engineering ecosystem. The Meeting in the Millyard focused on each stage in tissue manufacturing processes, highlighting technical challenges, recent technical advancements, and applicable lessons from other industries. The fall event included strategies for workforce development, regulatory approval, and reimbursement.
- The institute drives the development of two industry roadmaps annually: 1) a technical roadmap outlining consensus-based priorities for technology development tasks supporting a vision for scalable, consistent, and cost-effective manufacturing of TEMPs; and 2) a roadmap for education and workforce development activities to generate broad interest in tissue engineering and to develop education, training, and certification programs that align with biofabrication job responsibilities.
- BioFabUSA received $3.2M in DoD funding to support the development of a Deep Tissue Characterization Center. The center will use an integrated system of analytical instrumentation to support in-depth analysis of cells, culture media, and engineered tissues, which will be correlated with successful production runs and positive clinical trial results to determine critical process parameters for the automated control of tissue manufacturing.

ARM

Advanced Robotics for Manufacturing Institute

MISSION: Accelerate the development and adoption of robotics technologies that are the foundation of every advanced manufacturing activity today and in the future. The institute leverages a unique, robust and diverse ecosystem of partners across industry, academia, and government to make robotics, autonomy, and artificial intelligence more accessible to U.S. manufacturers large and small, train and empower the manufacturing workforce, strengthen the U.S. economy and global competitiveness, and elevate the nation's security and resilience.

HEADQUARTERS: Pittsburgh, PA

CONSORTIUM ORGANIZER: Carnegie Mellon University

ESTABLISHED: January 2017

FUNDING: Federal, $80 M; Non-Federal, $173 M

MEMBERS (as of September 30, 2019): 210

ARM

arminstitute.org

Institute Overview

ARM is a nationwide collaborative with members spanning industry, advanced technology, academia, and government organizations. ARM integrates diverse industry best practices and institutional knowledge about robotics technologies across many disciplines to realize the promise of a robust manufacturing innovation ecosystem. Key focus areas include human-robot interaction, interoperability, artificial intelligence, agile and flexible robotics systems, and adoption and risk reduction. In workforce development, ARM's goal is to expand the size, diversity, and skill set of the United States robotic work force to meet Industry 4.0 and robotics career pathways.

Credit: ARM.

Technology Advancement

> *"ARM connects our company with leading manufacturers that need automation, and with top research facilities that are creating new tools and technologies for industrial robots."*
>
> – Roger Christian, Motoman Robotics Division, Yaskawa America Inc.

By leading projects related to human-robot interaction, ARM is helping DoD meet its autonomy modernization goals. ARM's projects address issues related to persistence, speed, maneuverability, and reduced risk to human life.

- **Robotic Sewing to Make Military Uniforms in the U.S.** – ARM is building prototypes that leverage advanced robotics technology to assemble and sew parts of military uniforms. The goal is to reduce DoD labor cost per garment and enable viable garment production in the U.S., thereby reducing a significant trade deficit in this sector. Partners include Siemens Corporate Technology (Princeton, NJ), University of California Berkeley, Sewbo (Seattle, WA), and Bluewater Defense (Corozal, PR).

Credit Opposite page: left, istock, right and bottom, ARM.

- **Enhancing Safety with Robots** – Sanding and surface finishing is common to all aero-structures and requires highly skilled workers who are in short supply and are susceptible to repetitive injury hazards, ergonomic issues, and exposure to airborne particulates. A team comprised of Spirit AeroSystems (Wichita, KS), Southwest Research Institute (San Antonio, TX), and Wichita State University is exploring collaborative robotics and open source solutions that would address these challenges.
- **Human-Robot Teams** – Human-robot teams may be the best solution to handle, place, and conform woven composite sheets. This idea is being explored by a project team comprised of The Boeing Company (Seattle, WA), the University of Southern California (Los Angeles, CA), and Rensselaer Polytechnic Institute (Troy, NY). The human-robot team will present a use-case in which the large size of prepreg plies, or fabric layers, would require two or more technicians to complete the manufacturing operation. The human-robot team will employ a two-armed robot to carry the plies following the lead of a human operator, where the robot will use force feedback and stereo vision to monitor tension in the sheet and the position of the human.

A demonstration of the first ROS (robotic operating system) controlled industrial sewing machine to make military uniforms in a project led by Siemens. Credit: ARM.

Workforce Development

"As a New York City-based manufacturer of underwater drones, Duro UAS requires highly specialized talent to stay competitive. ARM's workforce development leadership and support have been essential to navigating this challenge. By helping U.S. companies to compete and lead in advanced manufacturing and creating workforce programs that develop the manufacturing talent of the future, ARM is making a tangible difference in our business and across the industry."

– Brian Wilson, President, Duro UAS

By expanding the size, diversity, and skill sets of the U.S. manufacturing workforce, ARM strengthens U.S. manufacturing and its competitive position:

- **Robotics Certificates for Veterans** – A project creating curricula and program materials for robotics systems training will soon result in two robotics systems certificates for veterans focused on construction, an ideal industry for automation applications. The first certificate will focus on design and manufacture, and the second will address deployment, utilization, and repair skills for the 3Space Makers veteran workforce. The project team is led by Texas A&M University (College Station, TX).
- **Military to Manufacturing Career Pathways** – A project led by Impact Washington (Bothell, WA), a Manufacturing Extension Partnership center, leverages current manufacturing and military partnerships and develops new aspects of the Center for Advanced Manufacturing Puget Sound's (Kent, WA) Military to Manufacturing (M2M) Career Pathways Program. New aspects of the program will align with ARM's Work and Learn educational programs for transitioning military personnel, veterans, and spouses to high-value careers in manufacturing through online, classroom, and internship training.

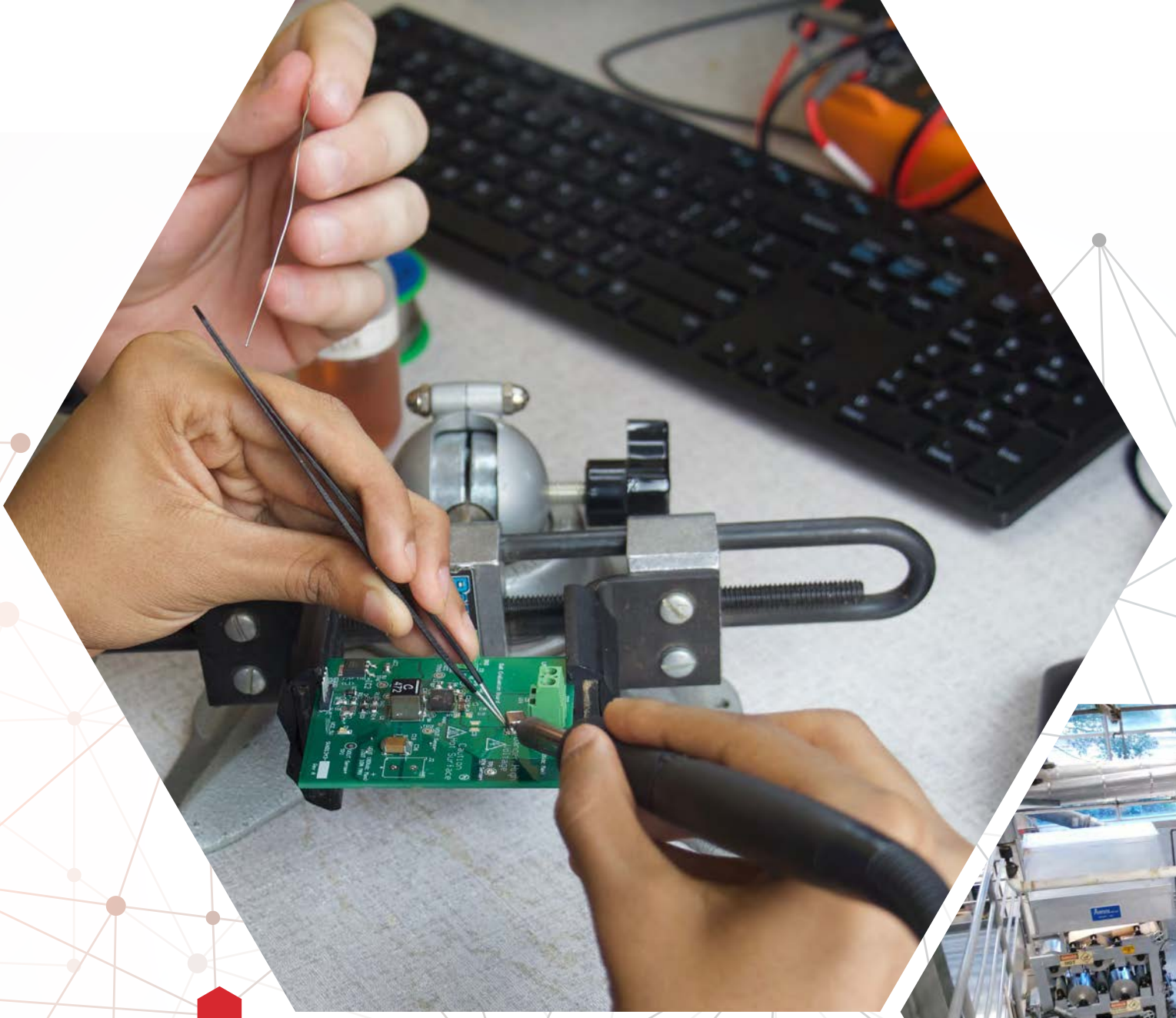
Military personnel receive training on robotic construction through a project sponsored by ARM and led by Texas A&M University (College Station, TX). Credit: ARM.

Innovation Ecosystem

> *"A key value of ARM membership is networking: bringing together members of the Institute to determine how we can collaborate with our disparate and complementary technologies to solve really hard problems and push the envelope of U.S. manufacturing."*
>
> – Jorgen Pedersen, RE2 Robotics

By lowering the barriers to the adoption and expansion of robotics for manufacturing, ARM catalyzes U.S. manufacturing competitiveness. ARM's Mill 19 facility opened in September 2019 to lead the effort. The innovative 60,000 square foot facility is co-located at and is a partnership with Carnegie Mellon University's Manufacturing Futures Initiative (Pittsburgh, PA) and MEP's Catalyst Connection. Along with supporting active projects, the facility will feature, on a rotating basis, member projects such as a robotic wire harness assembly and connector pinning work cells for manufacturers and for DoD depots that build or repair military air, land, or sea vehicles.

Other ARM initiatives have convened more than 200 members to facilitate technology project calls and matchmaking sessions to introduce members' capabilities to each other. This fosters a stronger ecosystem and facilitates partnership opportunities.



Credit: PowerAmerica.

DEPARTMENT OF ENERGY INSTITUTE HIGHLIGHTS

Credit: left, CESMII, right, REMADE.

PowerAmerica

The Next Generation Power Electronics Manufacturing Innovation Institute

MISSION: The PowerAmerica institute led by North Carolina State University seeks to save energy and create U.S. manufacturing jobs by accelerating the development and large-scale adoption of wide bandgap semiconductor technology in power electronic systems.

HEADQUARTERS: Raleigh, NC

CONSORTIUM ORGANIZER: North Carolina State University

ESTABLISHED: January 2015

FUNDING: Federal, $11.8 M; Non-Federal, $12.6 M[13]

MEMBERS (as of September 30, 2019): 46

PowerAmerica

www.poweramericainstitute.org

Institute Overview

PowerAmerica was created to help ensure U.S. global leadership in the development and adoption of advanced power electronics made with silicon carbide (SiC) and gallium nitride (GaN) into a wide range of products and systems. These wide bandgap (WBG) semiconductors operate at much higher voltages, frequencies, and temperatures than conventional semiconductors and are smaller and more energy efficient than the high-power electronics widely available today.

The objective is to reduce the cost and perceived risk inherent to this new technology. PowerAmerica brings together top researchers, industry, and government to foster an exchange of knowledge and processes and provide access to an educated workforce. This enables American industry to develop more innovative power electronics products and systems.

Wide bandgap semiconductors can greatly improve energy savings in industrial processes, data centers, and consumer devices; increase electric vehicle driving range; and help integrate renewable energy onto the electric grid — all while reducing the impact on the environment.

High-temperature ovens for SiC power device accelerated stress tests at Texas Tech University. Credit: PowerAmerica.

Technology Advancement

> *"PowerAmerica was integral in demonstrating our silicon carbide technology at the X-FAB foundry. Without their help in coordinating the fabrication and securing key production materials, this technology would not have been realized."*
>
> – Woongje Sung, SUNY Polytechnic Institute

During FY 2019 and FY 2020 to date, the institute engaged in 72 projects, of which 32 were completed or ongoing, and 40 were newly launched. These projects address key challenges and opportunities facing the industry and include:

- **Commercializing Lighter, More Efficient Devices** – Researchers at Toshiba International Corporation (Houston, TX), in collaboration with PowerAmerica, developed the world's first commercial silicon-carbide-based one-megawatt, medium-voltage motor drive system, nearly doubling power conversion efficiency at close to half the weight. Toshiba plans to manufacture products incorporating this technology in the U.S., and mass production will increase the share of U.S. manufactured products in the global market.

Credit Opposite page: PowerAmerica.

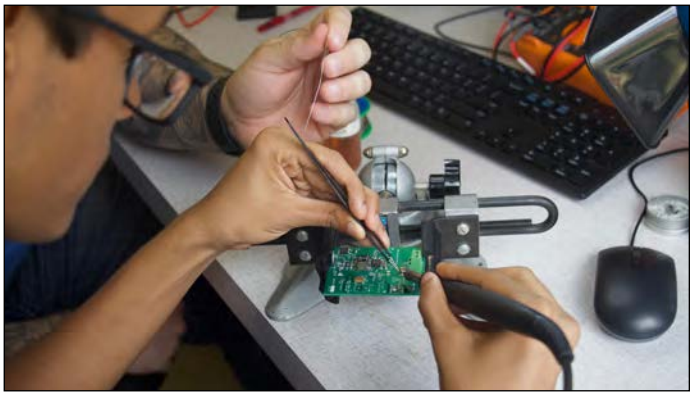
[13] Federal dollars and cost share expended by the Institute during FY 2019 are reported here. It does not reflect federal funds appropriated in FY 2019 (if any) for a given DOE Institute.

- **X-FAB Progress on Standard Process Blocks** – Silicon carbide is a more efficient semiconductor material, but it is more expensive to produce than standard silicon devices widely used in today's power electronics systems. PowerAmerica and X-FAB (Lubbock, TX) have standardized processes for manufacturers using the silicon carbide foundry, eliminating technical and logistical complexities that can occur with many different design processes. As a result, customers are experiencing shorter fabrication times, driving down overall manufacturing costs and making silicon carbide more competitive with silicon.
- **Launching a New Independent Testing Facility** – Texas Tech University (Lubbock, TX) and Group NIRE (Lubbock, TX) have established an independent, confidential, third-party testing facility, demonstrating long-term performance, enhancing end-user confidence in the reliability of wide bandgap devices, and accelerating the adoption of these technologies. Commercial stress tests have succeeded thus far and additional testing contracts are anticipated.
- **Increasing Possibilities with High-Voltage Devices** – SUNY Polytechnic (Rochester, NY) successfully produced high-voltage SiC devices at the X-FAB foundry in Lubbock, TX. Higher-voltage SiC devices are not yet widely available from commercial vendors but have substantial promise for efficient fast electric vehicle chargers, inverters for heavy-duty vehicles, medium-voltage photovoltaic inverters, medium-voltage inverters for wind applications, and more.
- **Improving Power Data Center Efficiency** – Working with Lockheed Martin, a team at the University of Colorado Boulder developed a new power delivery platform using wide bandgap semiconductor technology to greatly increase energy efficiency and power density for a growing network of power-hungry data centers and telecommunications systems. Data centers that use traditional methods of power delivery are currently estimated to account for approximately 15% of overall U.S. energy consumption.

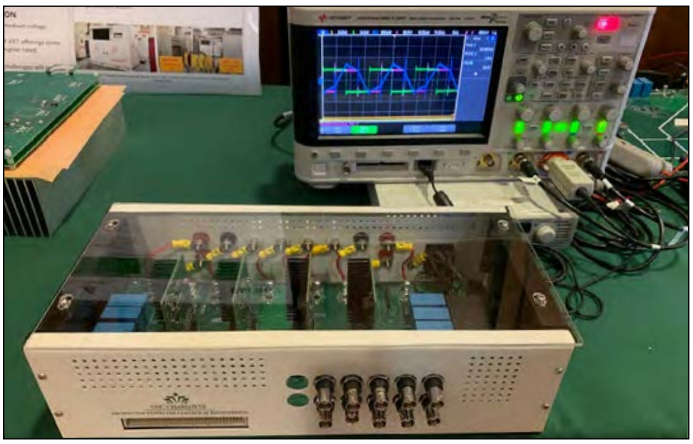
Workforce Development

"PowerAmerica accelerates our vision for democratizing power electronics education through technology and innovation. The institute's annual meetings have engaged key stakeholders with our program, and soon we will see the impact – especially on online education."

– Babak Parkideh, University of North Carolina at Charlotte



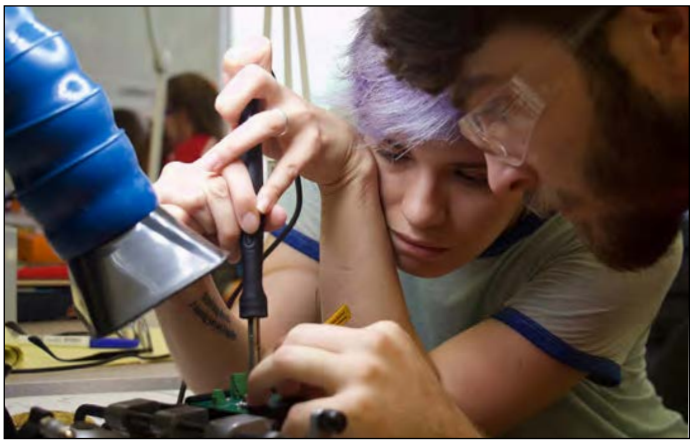
Student learning about wide-bandgap power semiconductor devices. Credit: PowerAmerica.



Plug-and-play manufacturing-ready module for training in manufacturing of high-voltage, high-frequency power electronics. Credit: PowerAmerica.

Creating a skilled workforce interested in and capable of working in this critical technology area will help strengthen U.S. manufacturing, making it a key part of PowerAmerica's mission. PowerAmerica has trained more than 400 individuals, including students engaged on more than 110 R&D projects over the lifetime of the Institute. Other examples include:

- **Wide-Bandgap Semiconductor Short Courses** – PowerAmerica held its annual short courses, attracting 50 attendees in two years. These courses draw professionals from around the country with varying degrees of experience in wide bandgap semiconductor technologies. The courses provide training in silicon carbide and gallium nitride technologies and are taught by experts in the field.
- **Universal Platform of Education, Research, and Industrial Rapid Prototyping** – Researchers at North Carolina State University (Raleigh, NC) developed a hands-on wide bandgap technology education platform with multiple experiments and testing for a range of high-power applications. The platform has reconfigurable software for various applications to save time and money compared to building dedicated hardware for separate applications.
- **Wide-Bandgap Technology Course Materials** – North Carolina State University faculty created materials and tutorials on wide-bandgap semiconductor devices and applications for undergraduate and graduate students. This will increase the workforce capable of using the technology in future low-voltage and medium-voltage power applications. Through a skilled workforce, more reliable and compact wide-bandgap products can be achieved.
- **Power Electronics Teaching Lab for Wide-Scale Availability** – Researchers at the University of North Carolina at Charlotte have developed a manufacturing-ready plug-and-play power electronics console for education. The program includes an online repository of videos, hardware design materials, and teaching lab documents to educate students and industry professionals about wide bandgap technologies. These offerings have been made available to other institutions for their students to access remotely.



Students work on a wide bandgap semiconductor device. Credit: PowerAmerica.

Innovation Ecosystem

> *"PowerAmerica does a fantastic job in getting the engagement of some of the greatest minds within the wide-bandgap semiconductor industries, including both the producers and users of these technologies."*
>
> – Ryan Kennedy, CEO, AtomPower

PowerAmerica is advancing the WBG power electronics ecosystem through collaborative innovation projects that span all aspects of the supply chain and represent important partnerships between academia, industry, and national labs. The members that form the wide-bandgap semiconductor ecosystem share best practices, connections, market opportunities, equipment, and invaluable knowledge amongst each other, which thereby extends the benefits across the industry and improves U.S. competitiveness in this important field.

- **Foundry Access** – PowerAmerica members X-FAB Texas (Lubbock, TX) and SiCamore Semi (Bend, OR) provide foundry access to other institute member companies that lack their own manufacturing facilities, such as GeneSiC (Sterling, VA), UnitedSiC (Monmouth Junction, NJ) and Sonrisa (Sante Fe, NM). University members such as SUNY Polytechnic Institute (Utica, NY) and North Carolina State University (Raleigh, NC) provide research fabrication capabilities.
- **Shared Devices** – PowerAmerica member companies such as Wolfspeed-Durham (NC) supply devices to the module divisions of companies including GE Aviation Systems (Cincinnati, OH) and Wolfspeed-Fayetteville (NC), that then lead to system insertion demonstrations at member companies such as John Deere (Moline, IL), Toshiba (Houston), ABB, and numerous universities. PowerAmerica members that manufacture gallium nitride chips, such as Transphorm (Goleta, CA), provide devices to be used in applications by companies such as Lockheed Martin
- **Knowledge Exchange** – Member-funded projects such as the third-party evaluation center of Texas Tech University and Group NIRE (both in Lubbock, TX) are an important part of the PowerAmerica ecosystem, as they provide valuable feedback to device and module manufacturers while building confidence in the reliability of wide-bandgap systems.

These and other PowerAmerica efforts facilitate the adoption of wide-bandgap technologies across the U.S., which will ultimately spur cost-lowering benefits.

Credit: PowerAmerica.

IACMI

Institute for Advanced Composites Manufacturing Innovation

MISSION: Create an ecosystem supporting innovation and workforce development to drive commercial outcomes and increase national competitiveness in the advanced-composites field.

HEADQUARTERS: Knoxville, TN

SATELLITE LOCATIONS: IACMI Scale-Up Research Facility (SURF) (Detroit, MI), Michigan State University Composites Lab (Lansing, MI), University of Dayton Research Institute's Composites Laboratory (Dayton, OH), The Composites Manufacturing Education and Technology Facility (CoMET) at the National Renewable Energy Laboratory's Flatirons Campus (Boulder, CO), The Indiana Manufacturing Institute at Purdue University (West Lafayette, IN), The University of Tennessee's Fibers and Composites Manufacturing Facility (FCMF) (Knoxville, TN, Oak Ridge National Laboratory (Oak Ridge, TN), Vanderbilt University's Laboratory for Systems Integrity and Reliability (LASIR) (Nashville, TN), The University of Kentucky Center for Advanced Energy Research (Lexington, KY)

CONSORTIUM ORGANIZER: Collaborative Composite Solutions Corporation, a not-for-profit corporation under the University of Tennessee Research Foundation

ESTABLISHED: June 2015

FUNDING: Federal, $13.2 M; Non-Federal, $ 28.8 M[14]

MEMBERS (as of September 30, 2019): 145

THE COMPOSITES INSTITUTE

IACMI.org

Institute Overview

IACMI – The Composites Institute is a 140+ member community of industry, academia, and government agencies leading innovation and workforce development initiatives to drive the adoption of advanced composites that will expand U.S. manufacturing and support national security. Advanced composites provide strength and stiffness while being very lightweight, offering advantages in transportation, energy, and infrastructure applications. Greater deployment of advanced composites can provide far-reaching benefits, such as safer, more energy-efficient vehicles.

IACMI is uniquely and systematically connecting innovation and workforce assets across multi-billion-dollar industries positioned for significant future domestic and international growth. IACMI will make the U.S. a leader in the manufacture of these strategic materials and accelerate the growth of their markets.

Credit: IACMI.

Credit Opposite page: IACMI.

Technology Advancement

> *"IACMI has proven to be a truly effective means to bring academic-led research, government labs, and industry into a collaborative environment to solve important manufacturing challenges. The recent successful demonstration of a practical method of joining thermoplastic composite assemblies may ultimately result in cost-effective technologies to fabricate wind turbine blades with entirely recoverable materials."*
>
> – Steve Nolet, TPI Composites, Inc.

During FY 2019 and FY 2020 to date, the institute engaged in 52 projects. Twenty of these projects were newly launched and 28 of the remaining 32 projects (ongoing from prior years) were completed in FY20 to date. These projects address key challenges and opportunities facing the industry and include:

[14] Federal dollars and cost share expended by the Institute during FY 2019 are reported here. It does not reflect federal funds appropriated in FY 2019 (if any) for a given DOE Institute.

- **Tools for High-Volume, High-Speed Inspection of Structures in Automotive Manufacturing** – Michigan State University (Lansing, MI) established a non-destructive evaluation cell to enable air-coupled ultrasound testing (ACUT) to efficiently evaluate composites components integrated into automotive structures. ACUT technology is currently used in the aerospace industry but has not yet been broadly adapted to high-volume products needed in the automotive industry. The ability to inspect every part with NDE will enable increased use of carbon fiber reinforced polymers in autobody structures, leading to significant lightweighting and improved strength for fuel efficiency and crashworthiness. The project is continuing to scale-up the technology. Project team members: American Chemistry Council (Troy, MI), Michigan State University (Lansing, MI), and Vanderbilt University (Nashville, TN).

- **Thermoplastic Welding of Wind Blades** – This project successfully demonstrated thermally welded wind turbine blade joints at scale, facilitating deployment of this technology on larger, multi-megawatt blades. The use of thermoplastic resin systems in the production of wind blades creates the possibility to thermally weld blade components in the factory and will reduce cost and energy, while increasing blade recyclability. Project team: Arkema Inc. (Bristol, PA), Electric Glass Fiber America, LLC (Shelby, NC), SAERTEX USA LLC (Huntersville, NC), General Electric Company (Greenville, SC), TPI Composites, Inc. (Warren, RI), University of Tennessee, Knoxville (Knoxville, TN), National Renewable Energy Laboratory (Golden, CO), and Colorado School of Mines (Golden, CO).

Testing Composite Wind Blades. Credit: IACMI.

- **Injection Overmolding of Continuous Carbon Fiber Preforms** – Automotive and aerospace industries have identified composite structural injection "overmolding" as a key technology to create low-cost, lightweight structural composite parts. Overmolding creates a close-to-final product shape and is well suited for large-scale production of complex 3D structures with excellent structural performance. This project is testing a molded bracket with a tailored fiber placement preform, ensuring the placement of continuous carbon fiber, and the team has completed injection overmolding trials. Continuous carbon fiber reinforcement provides the structural strength and stiffness needed for the automotive parts, combined with the rapid manufacturing and lower costs and cycle times achieved by injection molding. The project team consisted of Airbus Americas Inc. (Herndon, VA), Zoltek (St. Louis, MO), and University of Dayton Research Institute (Dayton, OH).

- **New Recycled Mixed-Stream Composites** – This project utilizes pyrolysis in a novel thermal composites recycling technology. Pyrolysis uses the inherent energy in composites for fuel and preserves the structural value of glass fiber and carbon fiber for reuse. The collaborative project validated and demonstrated this transformative recycling technology using composite materials such as wind blades made with glass fiber/epoxy as well as carbon fiber/epoxy, tractor parts made with a carbon-glass fiber/epoxy

hybrid, and automotive cured sheet molding compound. Further work will examine the use of the recovered fibers in various applications including sheet molding compound, injection molding, and additive manufacturing. Project team members include: HZ Technologies/ KUG (Auburn, AL), American Composites Manufacturers Association (Arlington, VA), Continental Structural Plastics (Auburn Hills, MI), Lyondell Basell (West Chicago, IL), Oak Ridge National Laboratory (Oak Ridge, TN), and University of Tennessee, Knoxville (Knoxville, TN).

Volkswagen Lift Gate. Credit: IACMI.

- **Next Generation Co-Molding of Automotive Parts** – This project involves the co-molding of various compounds to produce automotive parts, aiming to deliver the combination of materials, modeling, and molding technology necessary to cost-effectively produce a single-piece composite automotive closure panel, such as a vehicle hood. Initial trials have proven the concept and modeling will accurately predict the material behavior. A 20% to 50% reduction in the weight of an automotive hood may be achieved through new part design, reduction of part thickness, and strategic replacement of inner support panels, leading to more lightweight vehicles and increased fuel efficiency. This involved: INEOS (Dublin, OH), Volkswagen Group of America Inc. (Chattanooga, TN), Magna Exteriors, Inc. (Lansing, MI), IDI Composites International (Noblesville, IN), Michigan State University (Lansing, MI), and Purdue University (West Lafayette, IN).

Workforce Development

> *"I built upon my experiences as an IACMI intern at Purdue University and Local Motors, as well as through the graduate program at the University of Tennessee, Knoxville to prepare for this fellowship opportunity. Now my mentors are collaborators and I'm excited for this fellowship with Volkswagen. I'm looking forward to continuing my mentors' example of giving back."*
>
> **– Will Henken, IACMI intern 2016, 2018, 2019**

IACMI's workforce development initiatives train the advanced manufacturing workforce on technologies that are immediately relevant to industry and that will continue to grow in importance. IACMI's workforce development initiatives span K-12 STEM outreach, internships, and technician training opportunities. IACMI recognizes that to support national security, manufacturing must be on-shored, and IACMI is training workers to meet industry needs.

- **Sheet-Molding Compound Process Course** – In 2019, IACMI hosted its first, in-depth process course in sheet-molding compound processes at the IACMI Scale-Up Research Facility (SURF),

managed by Michigan State University. Led by industry experts, the class included detailed classroom instruction, a facility tour, observation, and a training exercise in identifying defects. Attendees included participants from a wide variety of industry members across the supply chain, including IACMI members Owens Corning and Magna Exteriors.

- **IACMI Internship Program** – IACMI sponsored 42 students hosted at 17 member and partner locations across the U.S., providing an opportunity for composites research and innovation. Students engaged in hands-on learning at IACMI member companies, national laboratories, and universities, and presented their research at the Summer 2019 IACMI Members Meeting.
- **Volkswagen Group Innovation Hub** – In 2020, Volkswagen Group of America (Herndon, VA) launched its first innovation hub in North America at the University of Tennessee Research Park at Cherokee Farm (Knoxville, TN). The facility focuses on developing lighter vehicle components made from composite materials and the electrification of vehicles, providing opportunities for students at the University of Tennessee to participate in doctoral fellowships. Several IACMI interns participated in the Volkswagen research project, with one IACMI intern selected for the first Volkswagen fellowship class.
- **Hands-On Training Workshops** – IACMI partnered with Composites One (Arlington Heights, IL) to host four workshops at four locations across the U.S.: Composites Prototyping Center (Long Island, NY), the Laboratory for Systems Integrity & Reliability at Vanderbilt University (Nashville, TN), Davis Technical College (Kaysville, UT), and Clemson University International Center for Automotive Research (Greenville, SC). More than 400 participants learned about materials and processes used in offshore wind energy production, the automotive market, aerospace, and in non-destructive evaluation methods.
- **Composites Merit Badge** – This workshop for Boy Scout Troop 516 in Elizabethton, TN introduced Scouts to composite materials and career opportunities in advanced manufacturing through a project creating carbon fiber wallets and walking sticks.

Innovation Ecosystem

> *"Our participation in IACMI allowed us to develop new technologies that have contributed to Techmer PM's growth in the additive manufacturing ecosystem."*
>
> – Tom Drye, Techmer PM

Techmer PM (New Castle, DE) and Local Motors (Phoenix, AZ) collaborated to improve material options and printing processes for additive manufacturing (3D printing) so that Local Motors could commercially produce its 3D-printed vehicles. The project increased the variety of materials available for additive manufacturing and sought to better understand 3D printed materials' properties to make reliable manufacturing decisions.

An IACMI intern presenting during the Summer Members Meeting. Credit: IACMI.

IACMI Winter Members Meeting. Credit: IAMCI.

Credit: IAMCI.

CESMII

Clean Energy Smart Manufacturing Innovation Institute

MISSION: Accelerate Smart Manufacturing (SM) adoption through the integration of advanced sensors, platforms and controls that radically impact manufacturing performance through measurable improvements in areas such as quality, throughput, costs/profitability, safety, asset reliability, and energy productivity.

HEADQUARTERS: Los Angeles, CA

CONSORTIUM ORGANIZER: University of California at Los Angeles (UCLA)

ESTABLISHED: January 2017

FUNDING: Federal, $10.9 M; Non-Federal, $11.06 M[15]

MEMBERS (as of September 30, 2019): 51

CESMII
THE SMART MANUFACTURING INSTITUTE

www.cesmii.org

Institute Overview

The Clean Energy Smart Manufacturing Innovation Institute (CESMII) is committed to applying smart manufacturing technologies to increase energy productivity and global competitiveness that will transform U.S. manufacturing. CESMII will achieve the following objectives through an integrated portfolio of roadmap projects, application projects, services, and training enabled by the Smart Manufacturing Innovation Platform™ and infrastructure:

- Research and develop smart manufacturing (SM) technology to enable cost-effective information and communication technologies for real-time management and control of energy in manufacturing processes, facilities, enterprises, and supply chains.
- Advance key enabling technologies for SM, including advanced sensors, data analytics tools, process controls, and data/information models, and building a unified Innovation Platform, marketplace, and ecosystem to scale SM to U.S. manufacturers.
- Establish a technical Education and Workforce Development program that leverages the national network of Smart Manufacturing Innovation Centers.

Technology Advancement

> *"CESMII and their efforts to build a Smart Manufacturing Innovation Platform align well with our Open Manufacturing Platform, and we are excited to partner with them to simplify the customer journey in manufacturing."*
>
> – Sam George, Head of Azure IoT, Microsoft

During FY 2019 and FY 2020, the institute launched ten R&D projects, and completed three platform technology projects. A few highlights among them:

- **New Product for Continuous Casting of Steel Slabs** – ArcelorMittal (East Chicago, IN) and Missouri University of Science & Technology (Rolla, MO) have developed sensors to measure strain and 3D displacements during continuous casting of steel. The sensors, along with predictive modeling and machine learning, will ultimately be used to improve yield from casting operations, contributing a potential 2.68 petajoule (equivalent to 2.5 billion cubic feet of natural gas) of energy savings per year for the steel industry. Other team members include Rensselaer Polytechnic Institute (Troy, NY) and Purdue University (West Lafayette, IN).

Credit Opposite page: CESMII, bottom and top right, istock.

[15] Federal dollars and cost share expended by the Institute during FY 2019 are reported here. It does not reflect federal funds appropriated in FY 2019 (if any) for a given DOE Institute.

- **Novel Physics-Based Models for Air Separation Processes** – Texas A&M (College Station, TX) has developed physics-based steady-state and dynamic models to predict the behavior of air separation units. Combined with real-time measurements and control algorithms, these models will be used to reduce energy consumption and target a 1% increase in operational efficiencies at Linde's operating locations across the country (headquarters in Bridgewater Township, NJ), worth $10M per year. Other team members include Process Systems Enterprise (Houston, TX), AspenTech (Bedford, MA), OSISoft (San Leandro, CA), Emerson (St. Louis, MO), Rensselaer Polytechnic Institute (Troy, NY), and University of Texas at Austin.
- **Thermal Models to Reduce Energy Consumption** – The University of Louisville has developed thermal models to predict the behavior of lab-based and production-scale kilns for the cement manufacturing industry. These thermal models are being coupled with chemical and fluid models to improve prediction accuracy and optimize operating temperatures, resulting in a potential 20% reduction in energy consumption across the cement industry. Argos USA (Atlanta, GA) is the industrial cement manufacturing partner that will help validate and implement the solutions.
- **Machine Learning for Additive Manufacturing** – Honeywell (Charlotte, NC) has developed data models and machine learning algorithms to detect abnormalities in additive manufacturing based on layer-based image processing. These algorithms will eventually be used to improve yield and build quality and energy productivity for aerospace additive manufacturing by as much as 5%. Other team members include Keselowski Advanced Manufacturing (Statesville, NC), University of California Los Angeles, University of Southern California (Los Angeles), Missouri Science & Technology (Rolla, MO), and Identify3D (San Francisco, CA).
- **Inferring Energy Usage in the Food Industry** – ThinkIQ (Aliso Viejo, CA) has developed predictive models to infer energy usage in food processing plants without use of meters. Leveraging the SM Innovation Platform™, the models identify and drive out energy waste from operations, targeting a 2% reduction in energy usage at two facilities. General Mills (Minneapolis, MN) is the industrial partner on the project. The first facility (a Yoplait plant in Tennessee) is connected to the CESMII platform and feeding the models data in real-time.

Workforce Development

> *"We're excited about expanding CESMII's network-of-networks and democratizing smart manufacturing, doing our part to educate everyone across the diverse U.S. manufacturing ecosystem."*
>
> – J. David Porter, Ph.D., Associate Head for Graduate Education, School of Mechanical, Industrial and Manufacturing Engineering, Oregon State University

Credit: CESMII.

SUCCESS STORY

First Integrated Demonstration Facility Launched at a Smart Manufacturing Innovation Center

At the Biomanufacturing Training and Education Center (BTEC) at North Carolina State University (Raleigh, NC), project team members integrated CESMII-developed technology (the CESMII SM Innovation Platform™, or SMIP) onto biomanufacturing assets to manage applications from multiple vendors in a way not previously possible in industry.

The system provides data collection, contextualization, and management as each independent software application provider accesses data in the SMIP to perform their dedicated functions (such as tracking material flow or triggering maintenance work processes) and reports their status back to the SMIP. Tim Shope, chief innovation officer at Avid Solutions (Morrisville, NC) said, ***"The CESMII SMIP is a gamechanger for industry. We can finally see software applications from multiple vendors bring standalone value with what they do best and, at the same time, be part of an orchestrated, optimized 'smart' system that can scale."***

CESMII project team members from Savigent Software (Bloomington, MN), ThinkIQ (Aliso Viejo, CA), Avid Solutions, and North Carolina State University have enabled this multi-vendor software system to interoperate and behave as a single, orchestrated Smart Manufacturing solution set. This Demonstration Facility sets the stage to bring industry and academia together to drive SM research, innovation, and training.

Credit: NIST

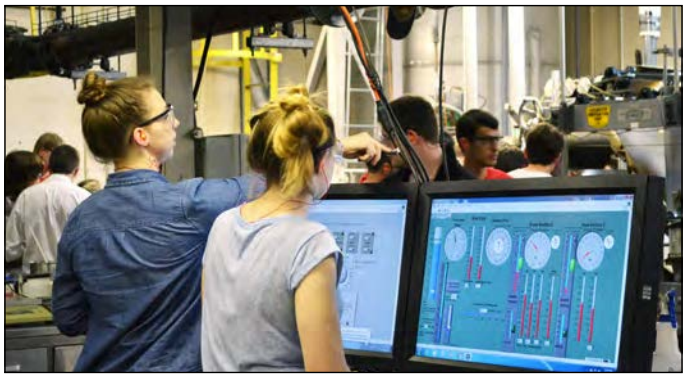
Education and Workforce Development is one of CESMII's four strategic pillars. The institute is working to make smart manufacturing accessible to everyone in U.S. manufacturing through both formal education and less-formal knowledge sharing. There are several roadmap projects in process to create hands-on tools for the education ecosystem. Other projects include:

- **Expert-Led Smart Manufacturing Training** – Workshops at CESMII Smart Manufacturing Innovation Centers engaged more than 100 members from 80+ companies in training and business transformation sessions teaching SM principles, the SM Innovation Platform™, and how business strategy connects with SM initiatives.
- **Smart Manufacturing Innovation Center Launched** – A new Innovation Center for SM at North Carolina State University will leverage their four production facilities connected to the CESMII SM Platform for test beds and education.
- **Democratization of Smart Manufacturing** – An executive-level gathering of 50+ industry and academic leaders, in collaboration with the Council on Competitiveness and UCLA, focused on the democratization of SM. The resulting Dialogue Report outlined goals, including education and workforce development, for the U.S. to meet to drive action on SM and served as the foundation for a Congressional briefing on SM in early 2020.
- **Bi-Monthly Webcast** – A series of webcasts brought together professionals of all industries with more than 300 viewers (and many more on-demand viewers later), broadcast CESMII's Annual Meeting, and delivered content online to hundreds of others collectively through regular sessions, keynotes, and workshops.

Innovation Ecosystem

> *"The Smart Manufacturing Innovation Platform will improve quality and reliability through visibility and transparency throughout supply chains, enabling scalable, more cost-effective solutions, and driving greater speed-to-market."*
>
> – Ken Creasy, Johnson & Johnson Supply Chain

CESMII, the "home of smart manufacturing," brings together a diverse ecosystem of manufacturers, systems integrators, technology vendors, and academic institutions to tackle challenges no single entity can address on its own. CESMII's Small-to-Medium Manufacturers (SMM) Affinity Group – a collaborative working group of CESMII members – gives smaller organizations a voice to shape the future of the institute's roadmap and initiatives, just as industry-focused Affinity Groups do for specific vertical markets.



NCSU Biomanufacturing Training and Education Center Credit: CESMII.

SUCCESS STORY

Factory 4.0 Toolkit Brings Smart Manufacturing Education to the Classroom

Penn State University (State College, PA) and the Massachusetts Institute of Technology (Cambridge, MA) partnered with CESMII to develop an instrumented, small-scale fiber extrusion kit that models real-world practical manufacturing scenarios along with SM software applications and supporting educational modules, such as labs, projects, and sample data sets. **This tool, designed for the classroom setting, lets students work with SM use cases and makes SM education immediately adoptable in a broad range of engineering, non-engineering, and cross-discipline educational programs.**

In this project, MIT's prior design for the equipment – a fiber extrusion device – was updated by Penn State to add power monitoring, an open-source software operating system, and an industrial control option, followed by software networks for data storage and future connectivity to CESMII's Smart Manufacturing Innovation Platform. Educational modules introduced SM Overview topics to business and engineering students and took the engineering students deeper into the industrial Internet-of-Things, data analytics, digital twins, and process optimization.

The educational toolkit will be made available to educators in the CESMII network to use in their own curricula. "The rapid pace of technology development has left educational systems scrambling to keep pace and adapt learning outcomes, inadequately preparing the manufacturing workforce at all levels," said Joseph Cuiffi, assistant teaching professor and project leader at Penn State. "Projects like this will help us change that."

Credit: NIST

REMADE

Reducing EMbodied-Energy and Decreasing Emissions

MISSION: Enable early-stage applied research and development of key industrial platform technologies that could dramatically reduce the embodied energy and carbon emissions associated with industrial-scale materials production and processing.

HEADQUARTERS: Rochester, NY

CONSORTIUM ORGANIZER: Sustainable Manufacturing Innovation Alliance

ESTABLISHED: June 2015

FUNDING: Federal, $ 2.1 M; Non-Federal, $ 2.1 M[16]

MEMBERS (as of September 30, 2019): 80

remadeinstitute.org

Institute Overview

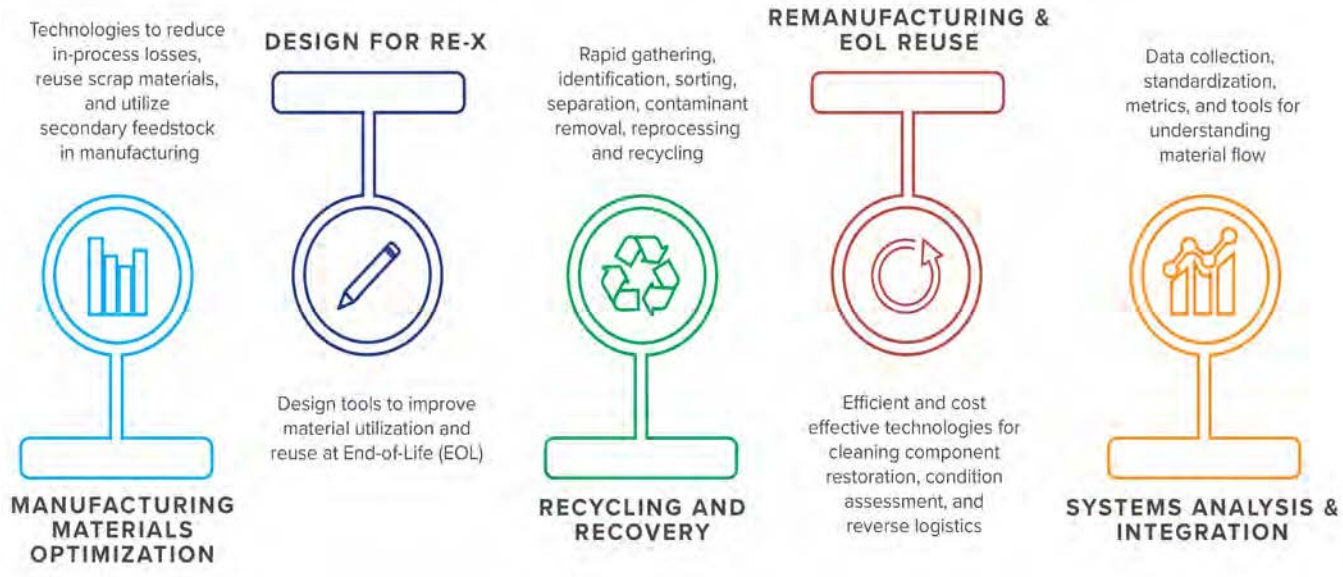
The REMADE Institute is developing technology solutions to increase the use of secondary resources in domestic manufacturing in order to significantly increase manufacturing energy efficiency. These efforts will drive substantial economic savings, energy and environmental benefits, and new jobs that will boost the competitiveness of U.S. industry.

REMADE is organized around five focus areas, or nodes (See Figure Below), designed to address cross-cutting challenges through applied research to enable increased recovery, reuse, remanufacturing, and recycling (collectively referred to as Re-X) of metals, fibers, polymers, and electronic waste (e-waste).

Technology Advancement

"Disassembly and reuse of electronics is capital intensive; by joining REMADE we have had access to some of the best and brightest minds who offer smart and economical technology solutions to such big problems."

– Adam Shine, Sunnking Inc.



REMADE Nodes with Descriptions. Credit: ©2020 Sustainable Manufacturing Innovation Alliance Corp.

Credit Opposite page: REMADE.

[16] Federal dollars and cost share expended by the institute during FY 2019 are reported here. It does not reflect federal funds appropriated in FY 2019 (if any) for a given DOE Institute. REMADE's FY19 expenditures were lower than expected and largely the result of limited response rate to RFPs. The most recent RFP was modified to increase RFP response rate.

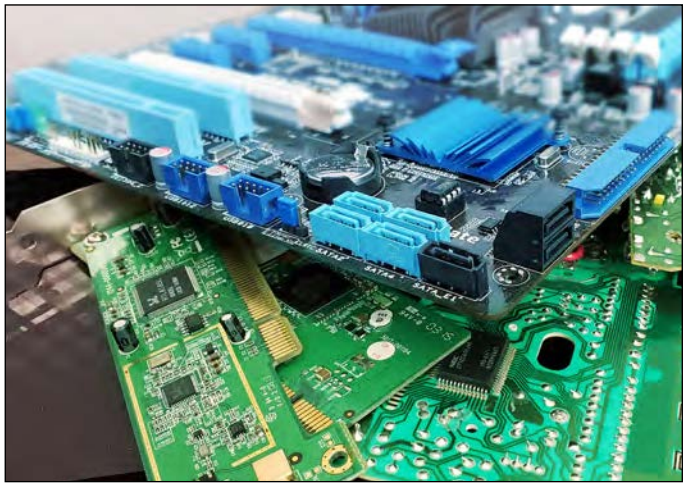
REMADE is tackling key barriers that limit recovery, reuse, remanufacturing, and recycling of metals, fibers, polymers (plastics), and e-waste across the product lifecycle from design to end of life. These challenges are in industries as diverse as automotive, consumer products, electronics, and heavy-duty equipment. Project selection is guided by the institute's Technology Roadmap and Strategic Investment Plan. The projects below show the effectiveness of collaboration between industry, universities, and federal labs.

Multilayer Plastic Packaging – Approximately 12 billion pounds of flexible packaging and plastic wraps are introduced into the U.S. market each year; however, just 1% of that material is collected for post-consumer recycling. The University of Massachusetts-Lowell, Michigan State, Unilever, National Renewable Energy Laboratory, and the American Chemistry Council are combining high-speed twin screw extrusion and catalytic depolymerization to explore cost-effective processing of these films into higher value products.

AI and Robotics in recycling Credit: ©2020 Sustainable Manufacturing Innovation Alliance Corp.

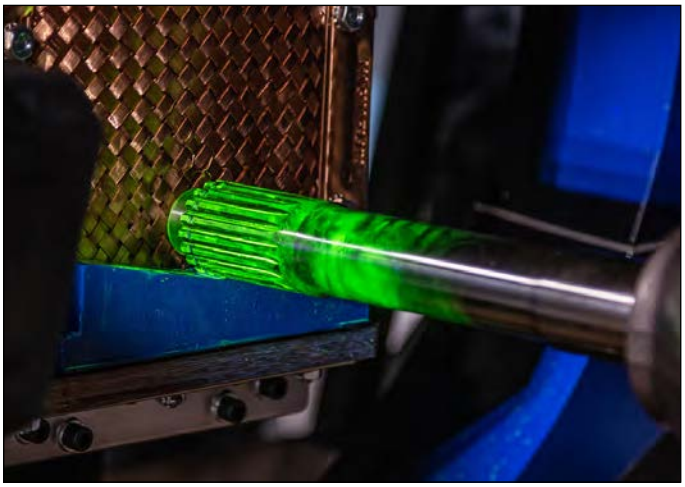
Polymers in a Global Circular Economy – The Recycling Partnership has identified an annual gap of more than 1 billion pounds between current U.S. supply and projected 2025 demand for recycled PET use in bottles. To identify approaches to close this gap, Michigan Technological University, the American Chemistry Council, and Idaho National Laboratory are developing a systems analysis framework to predict the impacts of closed-loop cycles for PET and olefin polymers. Mechanical and recycling technologies will be optimized to enhance the recovery and recycle of polymers including polyolefins and PET.

Industrially Relevant RE-SOLAR Design Framework – Solar modules are creating a major surge in e-waste because there is little design for recycling or reuse. This project provides a design framework for high-efficiency modules that can be economically recycled, recovered, remanufactured, or reused. Project participants include: University of Pittsburgh, University of California-Irvine, National Renewable Energy Laboratory (Golden, CO), and First Solar (Tempe, AZ).



Recycled electronics. Credit: ©2020 Sustainable Manufacturing Innovation Alliance Corp.

Determining Remaining Product Life – Non-destructive methods to measure mechanical damage (i.e., "fatigue") in metals prior to products failing do not currently exist. Rochester Institute of Technology, the University of Illinois at Urbana-Champaign, and Caterpillar, Inc. are working together to develop ways to reliably detect features associated with early-stage fatigue damage, allowing prediction of the remaining useful life of the metal part.



Non-Destructive evaluation for remanufacturing. Credit: Alex Tong, RIT.

Cross-Industry Use of Ground Tire Rubber for Energy Efficient Pavements – The ability to use ground tire rubber as an asphalt modifier is limited by inadequate 24-hour storage stability of rubber, which negatively affects the durability of the resulting asphalt pavement. Iowa State University, Michelin, and Lehigh Technologies (subsidiary of Michelin, Atlanta, GA) are working together to overcome this limitation. The project will mix the ground tire rubber with polydiene to provide the required storage stability and enhance pavement performance. If successful and fully adopted by the industry, the project has the potential to replace 140,000 metric tons of material with 50,000 tons of scrap polybutadiene and save the equivalent of 700,000 barrels of oil per year.

Workforce Development

REMADE is committed to providing the highest quality education opportunities targeting current and emerging engineers and technicians. This training is organized into a three-tiered certificate pathway model. The institute is working with technical experts to create new and unique REMADE relevant content, including education associated with technology developed through REMADE projects. Highlights include:

- **Training Events** – 1,500+ people attended REMADE overview and awareness webinars, short-course workshops, and on-demand training in 2019 through mid-June 2020.
- **Crash Course in Plastics Recycling** – This workshop was conducted three times totaling more than 600 participants. Now available online and on-demand.
- **Certificate Programs** – New certificate programs were developed based on industry feedback in topics such as recycling and remanufacturing technologies geared towards engineers and technicians.
- **REMADE Learning Portal** – With over 20 hours of technical content in REMADE-related technologies available online and on-demand, the portal provides awareness and in-depth understanding of concepts, technologies, and practices.

Workshops for Small Manufacturers: REMADE partnered with New York State Economic Development to deliver workshops in 2020 focused on education and training for small and medium-sized businesses. Geared towards engineers and technicians, the workshops attracted 170 attendees to participate in courses including Introduction to Plastic Recycling and Remanufacturing, Repair, and Reuse. A newly launched Remanufacturing Bootcamp has been converted to an online format and includes a five-part workshop series covering

design for remanufacturing, condition assessment, additive repair, cleaning technologies, and more.

- **75% of REMADE project teams include students** – More than 45 students in engineering- and science-related fields are working on REMADE projects, including undergraduates, graduate students, and co-op students.

February 2019 Plastics Recycling Workshop. Credit: Brian Adams Photography, Resource Recycling Inc.

Innovation Ecosystem

> *"The work being done by the Institute to drive advanced manufacturing through the prism of sustainability is helping to bring innovation to the recycling of metals, fibers, polymers, and electronics."*
>
> - Robin Wiener, Institute of Scrap Recycling Industries, Inc.

REMADE has convened organizations as diverse as the technology domains and industries the institute addresses.

- The consortium includes 80 organizations, including nearly two dozen membership-based organizations. Leveraging these trade organizations and nonprofits expands REMADE's sphere of influence to more than 4,000 entities across the U.S. and includes the Institute for Scrap Recycling, the American Beverage Association, the Sustainable Packaging Coalition, the Recycling Partnership, and the Remanufacturing Industries Council. They provide valuable input on the knowledge gaps and technology barriers faced by industry and also collaborate on many REMADE projects.
- Members establish cross-industry collaborations that simultaneously allow REMADE to fulfill its mission and help members identify synergistic solutions. As an example, Michelin and Nike have teamed up with Northwestern University on a project to increase 30-fold the amount of recycled rubber that can be incorporated into tires without degrading tire performance or impacting cost.
- The ecosystem also promotes partnerships that bring together small and medium-sized businesses like Sunnking, Inc., an electronics recycler in western New York, with the research power of organizations like Idaho National Lab.
- Small and medium-sized businesses comprise 60% of REMADE industry membership, and half of these are actively engaged in projects, enabling these companies to develop and commercialize technology to which they would not otherwise have access.

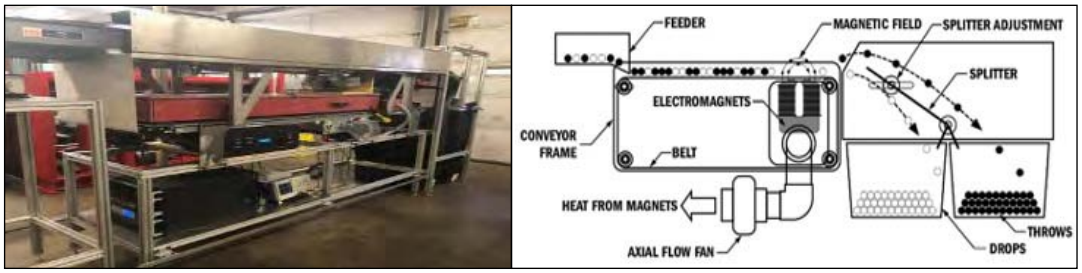
SUCCESS STORY

Advancing the Circular Economy – Recovering High-Quality Material & Reducing Energy through Advanced Sorting Technology

Researchers from the University of Utah and their industrial partner EDX Magnetics, LLC have completed the development and validation of an electrodynamic sorting technology that recovers high-quality aluminum from small-particle size (< 6 mm) mixed non-ferrous scrap. The new technology enables the recovery of high-quality aluminum scrap that was otherwise landfilled or in some cases exported for hand-sorting. Mixed non-ferrous scrap is conveyed over the electrodynamic magnet and the aluminum fraction is "tossed" from the mixed stream while the balance of the material falls off the end of the conveyor.

The electrodynamic sorting technology was developed by the University of Utah and then validated to confirm the effectiveness of the technology by processing real-world scrap. Novel magnetic cores are the heart of the new technology, demonstrated with a large-scale prototype. Other results include:

- Validation of the prototype confirmed that the technology could recover more than 90% of the aluminum content from small particle size mixed non-ferrous scrap.
- Quality of the recovered aluminum exceeded 95%.
- The new technology has the potential to enable the recovery of 180,000 metric tons per year of high-quality aluminum from commercial scrap, if fully adopted by industry. This could result in a maximum embodied energy savings of up to 33 PJ, or more than 9 billion kilowatt hours of electricity per year.
- The University of Utah is pursuing the next stage of development to enable commercial demonstration.



Prototype Electrodynamic Sorter. Credit: REMADE.

RAPID

Rapid Advancement in Process Intensification Deployment Institute

MISSION: Advance modular chemical process intensification technologies to reduce energy consumption, improve process efficiencies, and reduce investment and operating requirements.

HEADQUARTERS: New York, NY

CONSORTIUM ORGANIZER: American Institute of Chemical Engineers (AIChE)

ESTABLISHED: March 2017

FUNDING: Federal, $20.2 M; Non-Federal, $26.7 M[17]

MEMBERS (as of September 30, 2019): 79

RAPID
Transforming Process Industries

www.aiche.org/rapid

Institute Overview

For more than 100 years, chemical engineers have been developing processes based on standard unit operations and scaling those processes to build large, centralized manufacturing facilities. These principles have served the process industries well, resulting in predictable methods for designing and building low-cost, high-volume operations. Over the last several decades, scientists and engineers have been advancing new technologies that are starting to shift this paradigm. Instead of achieving economies of scale by building larger facilities, modular processes are built on standardized, smaller-scale operations and are scaled in number. Process Intensification (PI) enables new combined unit operations that are more energy- and raw-material-efficient and safer to operate.

While Modular Processing and PI, as concepts, stand on their own, combined into Modular Chemical Process Intensification (MCPI) these technologies allow manufacturers to reduce risk by building and operating smaller-footprint systems designed to produce just the amount of product needed to satisfy demand at any time, and then scale in number to meet market needs. MCPI offers manufacturers the opportunity to build a more efficient, distributed supply chain that is both sustainable and resilient. RAPID was created to lead the nation's efforts to research and develop high-impact MCPI solutions for the benefit of members from industry, academia, national laboratories, and other nonprofits.

Technology Advancement

"Through our collaborative project with RAPID, we have made key advancements toward development and scale-up of our surfactant bioproducts technology, advancements that would have otherwise been too challenging and costly for a startup to accomplish. The resources, learning materials, and network of RAPID have provided innumerable opportunities for our startup to engage with key experts and companies in our field, while networking events have provided valuable opportunities to meet colleagues in the process intensification community."

– Christoph Krumm, Sironix Renewables

Credit Opposite page: RAPID.

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During FY 2019, the institute engaged in 34 projects, of which 26 were completed or ongoing and eight were newly launched. The research and development projects were selected to address challenges in RAPID's technology roadmap focus areas:

1. Chemical and commodity processing
2. National gas upgrading
3. Renewable bioproducts
4. Intensified process fundamentals
5. Modeling and simulation
6. Module manufacturing

Additionally, each of these projects supports one or more of the institute's goals: 20% increase in energy efficiency; doubling of energy productivity; 10-fold reduction in capital cost and 20% improvement in both energy efficiency and emissions/waste; 20% reduction in module manufacturing cost; and cost-effective deployment of MCPI at scale. RAPID also works with members to refine its technology roadmap, expanding areas of interest to include MCPI solutions for pulp and paper processing, carbon capture and utilization, post-use plastics reuse and valorization, and distributed manufacturing for the fixed nitrogen value chain. Projects of note include:

- **Intensified Continuous Manufacturing of Dispersants** – University of Pittsburgh is developing the reaction kinetics and the fundamental understanding to enable continuous manufacturing of succinimide dispersants, which are used to suspend additives in engine oil. This is expected to enable conversion of the dispersant manufacturing process from batch production to continuous production, leading to as much as a 10-fold reduction in equipment size and associated capital cost, and is targeting a 20% improvement in energy efficiency and emissions/waste. Other project partners include the Lubrizol Corporation (Wickliffe, OH).
- **Conversion of Waste Biomass to Sugars and other Bioproducts** – Iowa State University (Ames, IA) is developing an autothermal process for thermochemical conversion of woody and agricultural biomass to fermentable sugars and other value-added products. The new process uses less process heat than existing processes, is expected to double energy productivity, and is well suited for distributed processing in modular units designed to fit in standard shipping containers.
- **Microchannel Devices for Efficient Separation of Chemicals** – Oregon State University (Corvallis, OR) is developing microchannel devices as a way to overcome mass transfer limitations which hamper conventional process equipment for separation of immiscible liquid droplets. The technology will enable more compact and energy efficient liquid-to-liquid extraction process, which is used in many chemical and pharmaceutical industries such as acetic acid production, biofuels production, and metal production and recovery.
- **Membrane to Reduce Water and Energy Demand in Papermaking** – Georgia Tech (Atlanta, GA) is pioneering the development of graphene oxide membranes to recover water that is produced as a byproduct of wood pulping in the papermaking process. Wood pulping is extremely energy and water intensive, and these new membranes will provide significant advantages compared to the evaporation process used commercially today. Other project partners include the Alliance for Pulp & Paper Technology Innovation (Washington, DC).
- **Microwave Chemistry for Enhancing Natural Gas** – West Virginia University (Morgantown, WV) is developing direct routes for conversion of natural gas to value-added products such as aromatic compounds using selective microwave reactor heating and catalysts. The new approach is more energy and capital efficient and could enable the conversion of U.S.

natural gas resources to easily transportable liquid products. Other project partners include the University of Pittsburgh, Shell Oil (Houston, TX), and the National Energy Technology Laboratory (Morgantown, WV).

Workforce Development

"The RAPID Virtual Internship Program is an excellent way for students to learn about industrial research with a focus on Process Intensification. The student gains personal relationships within the industry while developing the skills required to be a full-time employee. The company benefits from deeper connections to academic research and stronger relationships with students and their respective universities. I cannot think of a better way to learn how the chemical industry is tackling global sustainability through process intensification."

– Paul Witt, Dow

MCPI Boot Camp Participants. Credit: RAPID.

RAPID is working with members to create and deploy educational content that ensures a healthy pipeline of skilled engineers, operators, and technicians who are able to design, develop, and deploy modular chemical process intensification technologies. Highlights of RAPID's Education & Workforce Development activities include:

- **Virtual Internship Program** – In this structured, 10-week virtual program, engineering student interns at RAPID member organizations join a virtual community and receive online safety, technical, and leadership training, as well as professional development and mentorship. The program provides smaller organizations access to interns nationwide and invites their student interns to become part of a broad virtual network across the U.S. This creates a shared learning community and offers interns the chance to network with students at peer organizations. The combination of technical know-how and professional development gives interns the diversity of skills necessary to be successful in the workforce. After successfully piloting the program in the summer of FY2018, RAPID now continues to offer spring, summer, and fall rotations.

- **Modular Chemical Process Intensification Boot Camp** – RAPID developed and successfully piloted a four-day, face-to-face course in partnership with Oregon State University's Advanced Technology and Manufacturing Institute. The course is designed for professional engineers interested in advancing modular chemical process intensification in the processing industries, specifically through the use of "number-up" plant designs. The curriculum covers concept through to commissioning, including reexamining fundamental chemistry and physics, learning about design and advanced manufacturing of intensified process equipment that underscores that fundamental understanding, and understanding how modular chemical plants are built using intensified process equipment. RAPID continues to offer this course and is working with partners to pilot three additional courses in the near future.
- **Online Learning Content Continues to Drive Impact** – In FY2019, RAPID hosted 17 webinars on topics ranging from PI fundamentals to specific technologies such as oscillatory flow reactors and application topics such as the design, application and economics of PI. Between live offerings and archived recordings, RAPID webinars have reached more than 2,700 undergraduate engineering students and industry professionals. Additionally, RAPID's four-hour eLearning course "Fundamentals of Process Intensification" continues to be an instructional tool for faculty to assign to undergraduate students and allows for rapid incorporation of these advanced manufacturing concepts into existing engineering curricula. In FY2019, over 450 students accessed RAPID's inaugural eLearning course. RAPID plans to launch six additional eLearning courses next year.

Innovation Ecosystem

> *"Being a RAPID member has allowed M. Davis to be at the forefront of innovative ideas and part of the solution to bring them to scale. By connecting members on the research side of the solution to those on the constructability and manufacturing side, RAPID has created a synergy that benefits everyone involved."*
>
> **– Sean Boston, M. Davis & Sons, Inc.**

RAPID convenes its members quarterly to discuss institute progress and offer networking opportunities. At the American Institute of Chemical Engineers (AIChE) Annual Meeting , RAPID provided MCPI topical programming to the broader process industry community: training members to assess and address risk in scaling up their processes, sponsoring a workshop (with the NIST Manufacturing Extension Partnership) to understand the automation challenges associated with modular manufacturing, and hosting the second-annual signature Poster Session which provided networking and project information opportunities for members. During the AIChE Spring Meeting in April 2019, RAPID launched its Technology Showcase series for members to highlight their research, product, and service offerings, or problems to be solved. That event catalyzed interactions among several RAPID members, including a collaboration between Idaho National Laboratory and Starfire Energy. RAPID also hosts a Virtual Technology Showcase every six weeks and continues to create new connections among members.

SUCCESS STORY

RAPID Success Story: A RAPID Intern Spotlight

The RAPID Intern Program is an exciting opportunity for students to work with RAPID members. This virtual Principal Investigator (PI) leadership program provides student interns 20+ hours of virtual PI leadership training and professional development skill-building opportunities including networking, career discovery, and public speaking/presenting. **Last year, 26 students from a diverse set of RAPID member organizations participated in the RAPID Intern Program and all said they would recommend the program to a friend.**

Edmund Sam-Gyandoh completed the program in the fall and shared his experience:

RAPID Intern: Edmund Sam-Gyandoh, University of Pittsburgh. Credit: RAPID.

"I am a U.S. Army Veteran, a Certified Project Management Professional (PMP) and a MS Chemical Engineering student graduating in Spring 2020 from the University of Pittsburgh.

"My project focused on the transition from batch to continuous process in the specialty chemical industry, looking at modularized and intensified tubular reactor and the unconventional (largely unknown) cavitation reactor processing schemes while advancing mixing and heating techniques. My direct work involved deriving robust kinetics of a dispersant chemistry, forming the baseline milestone for the multi-step industrially/academically driven project approach.

"This program taught me leadership, teamwork, and above all, how to rethink chemical processes and communicate them effectively to solicit solutions for process intensification. As an aspiring business, engineering, and project leader, this enhanced my skill set and impacts my career by helping me to stand out as a critical thinker, value the importance of testing a hypothesis, and boost my creativity. Industry thrives on creativity and innovation and I see myself making not just a direct impact but making an impact quickly within the professional space."

SUCCESS STORY

IntraMicron Team Hits 1,000 Hour Milestone at West Texas Wellhead

Researchers from IntraMicron (Auburn, AL) and its subsidiary Sour Gas LLC have developed an energy-efficient and cost-effective alternative to traditional methods for purifying natural gas. Natural gas used by consumers is far different than the natural gas flowing from the wellhead. The wellhead product can contain impurities, such as highly toxic hydrogen sulfide, that must be removed for natural gas to be safely distributed from the processing plant to the consumer. The company's SourCat™ technology selectively recovers elemental sulfur and can process natural gas feedstocks over a wide range of purities that cannot be economically purified by traditional desulfurization approaches.

Intramicron, LLC and Sour Gas, LLC skid at a natural gas well site in TX. Credit: Incramicron, LLC.

"We have proven how effective this patented technology is and we are excited that it is now commercially available through Sour Gas LLC," said Dr. Paul Dimick, IntraMicron General Manager. "Thanks to RAPID funding, we have delivered a viable system that is exceptionally well-suited to removing hazardous hydrogen sulfide directly at the wellhead."

The project team, which also includes Auburn University and Oregon State University, reached a major milestone in their commercialization trajectory by completing a 1,000-hour pilot demonstration at a West Texas Wellhead.

Credit: RAPID.

Credit: NIST

APPENDIX A: FEDERAL AGENCIES PARTICIPATING IN MANUFACTURING USA

Department of Commerce

As part of its mission to create the conditions for economic growth and opportunity, the U.S. Department of Commerce (DOC) supports the work of Manufacturing USA by establishing networking opportunities for the manufacturing institutes. The Department hosts the Advanced Manufacturing National Program Office (AMNPO), an interagency team with participation from federal agencies that oversees planning, management, and coordination of Manufacturing USA.

Under the authority of the Revitalize American Manufacturing and Innovation Act of 2014 and as funds are available, the DOC conducts open-topic competitions for institutes, in which industry is invited to propose institutes dedicated to any advanced manufacturing area not already addressed by existing institutes.[18]

The initial competition was held in FY 2016, and in FY 2017, funds were awarded to launch the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL). This is the first institute with a focus area proposed by industry and the first funded by the DOC.

The Department more broadly increases regional and national capacity for innovative manufacturing through partnerships with state and local governments, academic institutions, and the private sector. Through its convening power, regional economic-development programs, and statistical and economic analysis, it empowers industry-driven solutions to the shortage of in-demand skills. Finally, the DOC supports research and development leading to transformative changes in technology and promotes intellectual-property policy that supports and protects innovation. By supporting public-private partnerships, such as Manufacturing USA, the DOC helps accelerate technology development and strengthen the nation's position in the global competition for new products, new markets, and new jobs.

National Institute of Standards and Technology

The DOC's National Institute of Standards and Technology (NIST) is the only research laboratory in the U.S. Government specifically focused on enhancing industrial competitiveness; its robust research portfolio includes the technical challenges associated with advanced manufacturing. In addition, the MEP National Network is a critical resource for engaging small and medium-sized manufacturers to develop new products, expand into global markets, and adopt new technologies, such as those being developed at the Manufacturing USA institutes. NIST also serves as headquarters for the AMNPO.

Department of Defense

The U.S. Department of Defense's mission is to provide the combat-credible military forces needed to deter war and protect the security of our nation. To mature and transition DoD science and technology advances into production, the Department must have access to a robust and responsive U.S. industrial base armed with advanced manufacturing technologies that deliver critical products and systems affordably and rapidly. Manufacturing innovative technologies, which enable critical capabilities, ensure that there is never a fair fight between U.S. Service members and potential adversaries.

To help develop the technology and ecosystems needed to support the Department's mission, the DoD established eight manufacturing institutes through its Defense-wide Manufacturing Science and Technology (DMS&T) program element within the DoD Manufacturing Technology (ManTech) program. Unlike the other manufacturing institutes, the DoD-sponsored manufacturing innovation institutes have the additional mission to develop innovative technologies that will ultimately aid the Warfighter.

[18] Section (d) of the Revitalize American Manufacturing and Innovation Act of 2014 (Pub. L. 113-235, codified in relevant part at 15 USC 278s(d)).).9

The DoD manufacturing innovation institutes address commercial and defense manufacturing needs within specific, defense-relevant technology areas and receive active participation and support from the military departments and defense agencies. The institutes' flexible business models and strong focus on enabling highly collaborative research and development catalyze important new organizational relationships across government, industry, and academia. Under the leadership of the Under Secretary of Defense for Research and Engineering, the Department continues to foster long-term engagement with the DoD manufacturing innovation institutes to support the DoD's modernization technology areas. Already, the institutes have shown progress in support of cybersecurity for manufacturing, micro-electronics, biotechnology, hypersonics, and automation, among other priorities.

As a key resource for the Department, the DoD intends to continue enriching their public-private partnership in order to further enable the development of defense-critical technologies into affordable, domestically produced defense products. Continued strategic and tactical engagement helps to maintain and enhance manufacturing innovation ecosystems that enable shared access to state-of-the-art equipment and facilities for small, medium, and large manufacturers alike, as well as academia. Through fostering Department engagement, these public-private partnerships help ensure domestic and defense manufacturing needs can be met while protecting intellectual property and providing overmatching technology to the warfighter first. The DoD manufacturing institutes further the Department's vision for a National Technology Innovation Base and help ensure that key advanced technologies that are invented in the U.S. are manufactured in the U.S.

In FY19, the DoD began the process of establishing a ninth institute focused on bioindustrial manufacturing. The source selection announcement occurred in Fall 2020.

Department of Education

The mission of the U.S. Department of Education (ED) is to promote student achievement and preparation for global competitiveness by fostering educational excellence and ensuring equal access. The Department administers the $1.29B Carl D. Perkins Career and Technical Education Act, the purpose of which is to develop more fully the academic and career and technical and employability skills of secondary education students and postsecondary education students who elect to enroll in career- and technical-education programs.

The Department has been active in helping develop Manufacturing USA from its formation. In the past year, the Department has been working with the Department of Defense and the National Science Foundation to lead and sponsor a series of technical assistance programs. The assistance effort is helping participating institutes to position themselves as key intermediaries between secondary and postsecondary institutions, companies of all sizes, relevant local and state governments, and other key players in the workforce education system. Such efforts are to foster next-generation career and technical education pathways for students, helping them to attain careers in advanced manufacturing. In addition to the agencies listed, the effort was supported by the Department of Commerce.

Department of Energy

The mission of the Energy Department is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

The Advanced Manufacturing Office (AMO) within the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) is the only technology development office within the DOE that is dedicated to improving the energy and material efficiency, productivity, and competitiveness of manufacturers across the industrial sector. Manufacturing accounts for 25% of total U.S. energy consumption at an annual cost typically ranging between $125B and $150B. Reducing energy costs can have a significant impact on manufacturing competitiveness, specifically improving energy affordability for manufacturers. In addition, manufacturing plays an essential role as a driver of overall economic growth, and manufactured products have a significant impact on energy use in every sector. A robust and competitive domestic manufacturing base is critical to national security because it ensures domestic supplies of key products and assures secure and reliable energy resources for U.S. citizens. To maintain

manufacturing competitiveness for future generations, the United States will need to remain a leader in the development of next-generation manufacturing technologies.

AMO brings together manufacturers, not-for-profit entities, research organizations, and institutions of higher education to identify challenges; catalyze innovations; and develop cutting-edge material, process, and information technologies needed for an efficient and competitive domestic manufacturing sector. By targeting efficient manufacturing technologies, AMO seeks to drive energy productivity improvements in the U.S. manufacturing sector, efficiently utilize abundant and available domestic energy resources, and support the manufacture of energy products with benefits extending across the economy.

DOE uses a range of partnership mechanisms, including Manufacturing USA institutes and Energy Innovation Hubs to catalyze the development of advanced manufacturing technologies. As of the end of FY 2019, DOE had five operating Manufacturing USA institutes and an open funding opportunity to establish a sixth. Each DOE Advanced Manufacturing USA Institute is designed to accelerate U.S. advanced manufacturing by catalyzing the development of new technologies, national infrastructure, educational competencies, production processes, and products via shared contributions from the public and private sectors and institutions of higher education. These partnerships create an innovation ecosystem that accelerates technology development and facilitates the transition of innovative advanced manufacturing technologies to industry. Developing these national capabilities enables future global leadership in advanced manufacturing.

Department of Health and Human Services

The mission of the U.S. Department of Health and Human Services (HHS) is to enhance and protect the health and well-being of all Americans. The Department achieves this mission by providing for effective health and human services and fostering advances in medicine, public health, and social services. The HHS considers robust manufacturing to be critical to public health security and resilience in the U.S.

The Food and Drug Administration (FDA), an operating division within the HHS, is responsible for protecting public health by ensuring the safety, efficacy, and security of human and veterinary drugs, biological products, medical devices, our nation's food supply, cosmetics, and products that emit radiation. The FDA continues to support development of new tools, standards, and approaches to evaluate the advanced manufacturing of FDA-regulated products. During the 2020 COVID-19 pandemic response, FDA collaborated with Manufacturing USA institutes, especially America Makes, to facilitate use of advanced manufacturing, where possible, for pandemic response and improvements to future responses. The FDA also has several working groups that monitor the technology landscape and work closely with Manufacturing USA Institutes. Promising technologies 5 to 10 years in the future are explored by the FDA Emerging Sciences and Technology Working Group. Technologies that are ready for implementation and adoption are considered by the FDA Advanced Manufacturing Technologies Working Group. Furthermore, the FDA awards projects through the FDA's Broad Agency Announcement to support emerging and enabling technologies for advanced manufacturing. Several of the FDA product Centers also have programs to facilitate and foster use of advanced technologies in medical products.

The HHS Biomedical Advanced Research and Development Authority (BARDA) engages regularly with manufacturing organizations through its Broad Agency Announcement for funding proposals as well as through outreach efforts. BARDA has allocated $6.5 billion in CARES Act funding to various critical manufacturing and development projects for pandemic response, including advanced manufacturing activities that will improve supply chain resilience and manufacturing efficiency.

Department of Labor

The U.S. Department of Labor's Employment and Training Administration (ETA) is the principal workforce development agency in the Federal Government. The ETA supports sustainable economic growth through leadership and a national investment portfolio that develops workforce skills necessary to support the jobs of today and is positioned to support the jobs of tomorrow, to the benefit of American job seekers

and job creators. This portfolio includes significant investments in employment and workforce development solutions.

The ETA administers a number of programs that make up the public workforce system, which contributes to strong, growing regional economies by responding to the workforce needs of job seekers and job creators, including those in advanced manufacturing, to ensure positive employment outcomes for job seekers. Partnerships at the federal, state, and regional levels connect employers, educational institutions, the public workforce system, and economic development partners. These partnerships ensure that job creators have the talent they need to grow and thrive and provide job seekers the opportunity to develop in-demand skills through work-based learning and apprenticeships and to earn industry-recognized credentials.

The ETA supports and is part of the Manufacturing USA Interagency Working Team and the Manufacturing USA Education and Workforce Subcommittee. The agency continues to engage in partnerships, share tools and resources, and identify strategies that can be leveraged to support the Manufacturing USA institutes.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) is the United States government agency responsible for U.S. space exploration, space technology, Earth and space science, and aeronautics research. The National Aeronautics and Space Act states that, "The aeronautical and space activities of the United States shall be conducted so as to contribute materially to... The preservation of the United States preeminent position in aeronautics and space through research and technology development related to associated manufacturing processes...."[19] The White House National Space Council's July 2020 policy paper, *A New Era for Deep Space Exploration and Development* further states that, "Additional efforts should broaden the scope of traditional aerospace industries to include new applications for space technologies and expand space capabilities by infusing technologies from non-traditional but promising fields, such as robotics, artificial intelligence, quantum applications, and additive manufacturing, which have much to offer the space community."[20]

The Space Technology Mission Directorate (STMD) rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies required for NASA's future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities. These collective efforts give NASA the ability to do first-of-a-kind missions and longer-term advancements in research and technology — those beyond what industry will take on and those focused on national advancement in aeronautics and space that also align with NASA's role in Manufacturing USA.

Advanced manufacturing research and development within STMD is focused in several areas, including materials for extreme environments, additive manufacturing, polymer matrix composites, metals processing/joining, robotics, computational physics-based modeling, nondestructive evaluation, and other highly specialized areas. Research and development is conducted through a combination of in-house activities at NASA centers, competitively funded research with universities and industry, and collaborations with other agencies, universities, and industry. The rapid infusion of advanced manufacturing technologies into mission applications is a major emphasis of NASA's technology-investment strategy.

National Science Foundation

The National Science Foundation (NSF) supports fundamental advanced manufacturing research, education, and workforce training in its Directorates for Engineering, Biological Sciences, Computer and Information Science and Engineering, Education and Human Resources, Mathematical and Physical Sciences and Social, Behavioral and Economic Sciences and its Offices of Integrative Activities and International Science and Engineering, most

[19] National Aeronautics and Space Act, Pub. L. No. 111–314, 124 Stat. 3328 (Dec. 18, 2010), Title 51—National and Commercial Space Programs, codified at 51 USC §20102.
https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-section20102&num=0&edition=prelim

[20] A New Era for Deep Space Exploration and Development, Executive Office of the President, National Space Council (July 23, 2020).

notably through its Advanced Manufacturing Program, and through the Future Manufacturing solicitation, first published in 2020. It also promotes advanced manufacturing innovation through a variety of translational research programs, including the Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and Grant Opportunities for Academic Liaison with Industry (GOALI) programs, and by partnering with industry, states, and other agencies.

The NSF's advanced manufacturing investment supports fundamental research leading to transformative advances in manufacturing that address size scales from nanometers to kilometers. These include process modeling, advanced sensing and control techniques, smart manufacturing using sustainable materials, chemical-reactor design and control, and manufacturing processes and enabling technology to support the biopharmaceutical, biotechnology, and bioenergy industries, with emphases on efficiency, economy, and minimal environmental impact. Advanced manufacturing is also supported through the Engineering Research Centers (ERC), Industry/University Cooperative Research Centers (I/UCRC), and Advanced Technological Education (ATE) programs. With an emphasis on two-year colleges, the ATE program focuses on the education of technicians for the high-technology fields that drive our nation's economy.

All NSF programs welcome submission of proposals to collaborate with Manufacturing USA institutes on cutting-edge research and educational projects. Awardees whose projects are funded by NSF are also encouraged to request supplemental funding to perform research and/or educational projects in collaboration with institutes. It is expected that incorporation of the resources, expertise, and experience of the institutes and their member companies will increase the competitiveness of such proposals in merit review.

U.S. Department of Agriculture

The U.S. Department of Agriculture's (USDA's) mission is to provide leadership on food, agriculture, natural resources, rural development, nutrition, and related issues based on public policy, the best available science, and effective management. USDA provides economic opportunity through innovation, helps rural America to thrive; promotes agriculture production that better nourishes Americans while also helping feed others throughout the world; and preserves our Nation's natural resources through conservation, restored forests, improved watersheds, and healthy private working lands. USDA focuses on collaborative science which aligns work in fundamental research with projects funded through extramural and intramural research programs and recognizes that manufacturing is part of value-added innovations that plays an important role in maximizing benefits of a sustainable rural economy.

Areas of interest include biomanufacturing and bioproduct development. Products made from biobased feedstocks such as forest-sourced and agricultural fibers are biological and renewable, both traits of materials of the future. Use of biobased products such as biofuels, industrial chemical intermediates, performance polymers, and finished higher-value products is growing rapidly and presents a significant opportunity for the United States. Expansion of the bio-economy has the potential for the sustainable harvest and use of substantial renewable biomass in the U.S. annually while continuing to support existing food, feed, and fiber markets and creating thousands of jobs, many in rural areas.

Advances in technology, automation, and remote sensing is a cross-cutting, macro movement in science impacting agriculture and rural communities. The Broadband ReConnect Program is focused on expanding capacity for rural areas to implement digital technologies, automate processes, increase productivity, and expand into the global market with access to reliable, high-speed broadband. Remote work capabilities allow these areas to transcend traditional geographic boundaries to attract the best and brightest minds to their operation. ReConnect furnishes loans and grants to provide funds for the costs of construction, improvement, or acquisition of facilities and equipment needed to provide broadband service in eligible rural areas.

APPENDIX B: ADVANCED MANUFACTURING NATIONAL PROGRAM OFFICE INTERAGENCY WORKING TEAM PARTICIPANTS

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