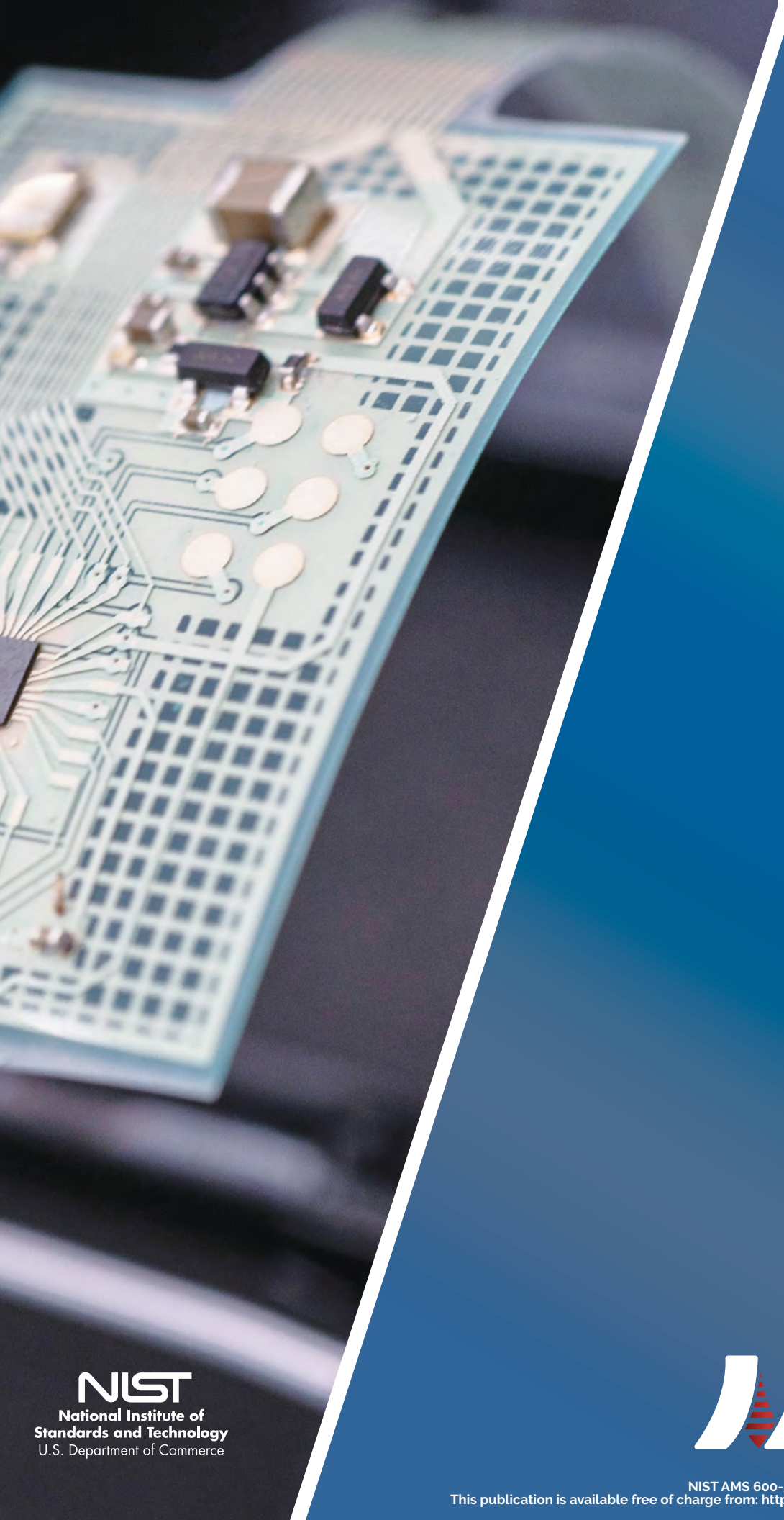


ANNUAL REPORT 2018

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

Manufacturing USA®

NIST AMS 600-5
This publication is available free of charge from: https://doi.org/10.6028/NIST.AMS.600-5

About This Document

This annual report documents the progress of the Manufacturing USA program in meeting its goals and highlights accomplishments of the federal agency-sponsored manufacturing institutes that participated in the Manufacturing USA program in fiscal year 2018.

Disclaimer Statement

Any mention of companies or commercial products within this document is for information only and does not imply recommendation or endorsement by the National Institute of Standards and Technology (NIST) or the other federal agencies participating in Manufacturing USA.

Permissions

All tables, figures, and photos in this report, unless otherwise noted, were produced by participants in the Advanced Manufacturing National Program Office's Interagency Working Team.

Any permissions required for third-party materials provided by institutes for this document are the responsibility of the reporting institutes.

Copyright

About the Cover

The NextFlex flexible Arduino® will expand the ability of innovators to create new electronics concepts based on flexible hybrid electronics. Arduino is a microcontroller-based electronics prototyping platform that utilizes versatile, easy-to-use hardware and software. It has achieved a high degree of popularity with developers, ranging from novices to seasoned experts, because it is open source, with publicly available design files and low cost. By moving Arduino to a flexible material, NextFlex has removed the design limitations of rigid circuit boards and chips, which are fragile, rigid, and bulky, and has opened an easy, inexpensive pathway for integrating Arduinos into newer sensor devices that are flexible or curved. Credit: NextFlex

Message From the Manufacturing USA Team

Manufacturing USA, through public-private partnerships, assists American manufacturing enterprises in developing new products and new production technologies needed to accelerate the pace of economic expansion. Since advancement of new technologies requires new skill sets for our workforce, the program's 14 institutes and their industrial partners collaborate with local school systems and academic institutions to promote and develop the advanced skills needed for our future manufacturing workforce to make tomorrow's products.

In fiscal year 2018, the 14 Manufacturing USA institutes, sponsored by the Departments of Commerce, Defense, and Energy, conducted nearly 500 major applied research and development projects of high priority to broad industry sectors. The participants and direct beneficiaries of these projects are Manufacturing USA institutes' 1,937 members, of which 63% are manufacturing firms, and 70% of the industry members are small manufacturing companies – key manufacturing supply chain participants. 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.

The Manufacturing USA institutes are truly innovation hubs for manufacturing, providing real value to U.S. industry and promoting innovation in academia and federal laboratories. These hubs benefit the public by outreach to local K–12 students and teachers, stimulating workforce development in new technical fields, and providing for improved job opportunities. Advancing promising technologies into U.S. production and creation of higher-paying manufacturing jobs for U.S. workers increases our Nation's economic opportunity while delivering the products needed by the nation and the world.

We are excited to collaborate with our agency partners and lead this initiative to support all the Manufacturing USA institutes, ensuring that products conceived in America are manufactured in America. Our vision is nothing less than U.S. global leadership in advanced manufacturing, as directed by the White House through the National Strategic Plan for Advanced Manufacturing.

Advanced Manufacturing National Program Office

Credit: NIST

Executive Summary

The Manufacturing USA program is a network of 14 manufacturing institutes working with participating federal agencies, including their 3 sponsoring agencies and 6 additional participating agencies. Each institute is a unique public-private partnership, jointly funded by government and private industry.

Manufacturing USA completed its fourth year since Congress authorized the program through the Revitalize American Manufacturing and Innovation Act (Public Law 113-235),[1] and this fiscal year 2018 (FY 2018) Annual Report describes the accomplishments and state of the program.

This year, the Manufacturing USA network focused on fostering manufacturing technology and avenues for technology transfer and on building education and workforce development programs. In all areas, the program has been successful, as summarized below, and has experienced significant growth in key performance metrics.

Focus Area: Manufacturing USA Network Growth

The 14 institutes grew substantially in 2018, thereby growing the Manufacturing USA network. To date, the institutes have received overall commitments of more than $3 billion, including $1 billion in federal funds matched by over $2 billion in nonfederal investments, representing the remarkable catalyzing effect of matching investment. Furthermore, state governments contributed more than $400 million to the institutes, underscoring the importance of advanced manufacturing to the future success of state and local economies. This enthusiastic reception by industry, academia, and the states confirms that the institutes serve a critical need for U.S. manufacturing, the U.S. economy, and national defense.

The total number of organizations with memberships to individual institutes grew by 50% this year to 1,937; of these, 63% are industry members. Of the industry members, 70% are small and medium-sized manufacturing companies (SMMs). Industry leads the institutes, which each includes a significant number of small manufacturers as essential members of the supply chain.

The Hollings Manufacturing Extension Partnership (MEP) program achieved its goal of embedding an MEP Center staff member in each of the institutes, strengthening the connection of smaller manufacturers across the country to the institutes. Leveraging the focus of the MEP National Network™ on SMMs, the embedding pilot projects conducted outreach to inform these companies about the opportunities available in the institutes. Through the end of FY 2018, embedding projects reported serving 62 manufacturing clients and completing 75 projects. More than 70% of the projects were related to innovation services, including technology deployment, engineering assistance, and growth services.

Focus Area: Manufacturing Technology and Technology Transfer

The institutes focus on developing a broad range of manufacturing capabilities in promising new advanced technologies that have the potential to significantly impact the economy and national security. In FY 2018, the number of active research and development projects increased by 74%, bringing the total number of manufacturing innovation projects to 476. By convening the best minds from industry, academia, and government to tackle tough manufacturing challenges, these institute-led collaborations and projects strengthen and expand the U.S. manufacturing base:

- BioFabUSA (DoD-sponsored, Manchester, NH) launched the first tissue foundry technology call with the long-term goal of building a closed and fully automated manufacturing line for engineered tissues that is modular, flexible, and compliant with good manufacturing practice.
- A CESMII (DOE-sponsored, Los Angeles, CA) technology project is developing optimized sensor networks, critical for smart manufacturing, to improve energy efficiency for discrete

[1] Consolidated and Further Continuing Appropriations Act, 2015, Pub. L. 113-235, Title Vii – Revitalize American Manufacturing Innovation Act of 2014, codified at 15 U.S.C. § 278s, http://uscode.house.gov/view.xhtml?req=(title:15 section:278s edition:prelim).

manufacturing. The project team is led by University of Connecticut (Storrs, CT) and includes industrial partner Johnson & Johnson (Raynham, MA).

- LIFT (DoD-sponsored, Detroit, MI) is leading a project that will reduce Humvee rollovers by 74%, reducing fatalities of service personnel.

- IACMI (DOE-sponsored, Knoxville, TN) members have increased the variety and understanding of materials available for the large-scale additive manufacturing of composite structures, generating significant commercial growth for multiple companies. Local Motors (Knoxville, TN) recently installed the world's largest 3D printer, made by Thermwood, at its microfactory and plans to commercially produce Olli 2.0, its first self-driving vehicle, in 2019.

- AFFOA (DoD-sponsored, Cambridge, MA) opened the Defense Fabric Discovery Center on October 27, 2017; the center is located at the MIT Lincoln Laboratory (Lexington, MA) and is suitable for applied research for defense applications, including the System in a Fiber project, which is directed at producing fibers with individually controllable and addressable devices.

- PowerAmerica (DOE-sponsored, Raleigh, NC) members United Silicon Carbide (USiC; Monmouth Junction, NJ) and X-FAB (Lubbock, TX) released 650-volt and 1200-volt silicon carbide semiconductor diodes that meet stringent international automotive qualification standards and are ideal for automotive applications. PowerAmerica funding enabled USiC to qualify the diodes fully at X-FAB.

- The enhancement of the manufacturing infrastructure that benefits all U.S. industry is exemplified by the publication by America Makes (DoD-sponsored, Youngstown, OH) of the *Standardization Roadmap for Additive Manufacturing (Version 2.0)* in conjunction with the American National Standards Institute (ANSI) and with funding from the Department of Defense. America Makes leveraged its broad network to convene 320 individuals from 175 public- and private-sector organizations to develop the roadmap.

Focus Area: Workforce Development — Education and Training

As economies evolve, new skills are needed. Ever since Henry Ford pioneered the moving assembly line, technological changes have transformed our work by increasing productivity, thereby enhancing our economy and society. The downside of this progress is that traditional manufacturing jobs are lost in sectors dependent on old technology, and if a nation does not strategically accelerate adoption of advanced manufacturing technologies, the number of manufacturing jobs can plummet. Ensuring the overall health of the economy requires strengthening the manufacturing sector by training workers for the new, higher-paying, advanced manufacturing jobs that new technologies require. This is especially important in the U.S. because manufacturing has been the cornerstone of our robust economy and a solid middle class over the last century.

Equipping workers with the new skills they will need to participate in the future U.S. manufacturing industry is therefore a priority for the Manufacturing USA network. In FY 2018, institutes continued their leadership in workforce training, increasing cross-institute collaborations and sharing of best practices. The result was tremendous growth in institute-led workforce development efforts, including educator/trainer instruction and development of science, technology, engineering, and mathematics (STEM) activities. More than 200,000 workers, students, and educators participated in institute workforce efforts.

- NIIMBL (DOC-sponsored, Newark, DE) announced the NIIMBL eXperience, developed in partnership with the National Society of Black Engineers (NSBE), which gives students completing their freshman years at historically black colleges and universities the opportunity to travel to NIIMBL member sites and federal agencies to gain insight into career opportunities in the biopharmaceutical industry.

- MxD (DoD-sponsored, Chicago, IL) created the first massive open online course on digital manufacturing and design, which it made available to the public at no cost. Within the first few months, more than 30,000 people accessed the curriculum.

- The IACMI (DOE) Internship Program hosted its largest class, with 43 interns, in 2018; every one of its graduates enrolled in a related graduate school program or secured a job at a U.S. innovation facility, including private companies, academic institutions, and national laboratories.

Moving Forward

Building on FY 2018's gains, the Manufacturing USA network will continue to focus on enhancing education and workforce development, building sustainable and effective business models, and advancing manufacturing technology.

Table of Contents

Credit: PowerAmerica

Introduction

The Federal Government's Focus on Advanced Manufacturing

The Federal Government prioritizes advanced manufacturing as critical for ensuring that the United States dominates the industries of the future. A recent summary of federal industrial priorities emphasizes that "new manufacturing technologies drive American competitiveness and enable the economy to continuously improve by increasing productivity, producing technologically superior products, and forming entirely new industries."[2]

In the face of intense global competition, the 2018 National Strategic Plan for Advanced Manufacturing focuses on defending the economy, expanding manufacturing employment, and ensuring a resilient supply chain and strong manufacturing and defense industrial base.[3] The plan describes how federal agencies, state and local governments, the full spectrum of educational institutions, large and small private industry, large and small investors, and, most importantly, our citizens can achieve a national vision of U.S. global leadership in advanced manufacturing. The plan emphasizes the inherent links between economic development and national security.

The strategic plan establishes a key goal of using public-private partnerships to develop advanced manufacturing technologies and transition them to market, train a skilled workforce, and maintain a strong and well-connected domestic supply chain. These efforts bridge the gap between domestic innovations and products manufactured here by a skilled U.S. workforce. The plan emphasizes that "[t]he establishment and growth of the Manufacturing USA institutes has been the central accomplishment under this goal."[4]

A recent report on achievements in science and technology in 2017 and 2018 highlighted the crucial role of the Manufacturing USA network: "From providing training for veterans to advancing technologies developed in the labs, the federal network of Manufacturing USA institutes convened players across the manufacturing community to address the Nation's pressing manufacturing technology and competitiveness needs."[5]

Background

A strong manufacturing base and resilient supply chains form the backbone of our nation's economy and national security and are essential to our ability to respond to emergencies and national threats.[6] Manufacturing is the country's fifth largest employer and, according to various estimates, makes up 11.6% of U.S. employment,[7] 11.4% of U.S. GDP,[8] 55.6%[9] of U.S. exports, and 67%[10] to 70%[11] of private-sector research and development (R&D) in the U.S. The quality and usefulness of manufactured products directly affects the lives and safety of every citizen.

---

[2] America Will Dominate the Industries of the Future, Executive Office of the President, Office of Science and Technology Policy (February 7, 2019). https://www.whitehouse.gov/briefings-statements/america-will-dominate-industries-future/.

[3] *Strategy for American Leadership in Advanced Manufacturing*, Executive Office of the President, National Science and Technology Council, Committee on Technology, Subcommittee on Advanced Manufacturing (October 2018). https://www.whitehouse.gov/wp-content/uploads/2018/10/Advanced-Manufacturing-Strategic-Plan-2018.pdf.

[4] Ibid., Manufacturing, p. 34.

[5] *Science & Technology Highlights in the Second Year of the Trump Administration*, Executive Office of the President, Office of Science and Technology Policy, p. 3 (February 2019). https://www.whitehouse.gov/wp-content/uploads/2019/02/Administration-2018-ST-Highlights.pdf.

[6] *National Security Strategy of the United States of America*, Executive Office of the President (December 2017). https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905-2.pdf.

[7] *Measuring America: Manufacturing in America 2018*, U.S. Census Bureau, Department of Commerce (October 1, 2018). https://www.census.gov/library/visualizations/2018/comm/manufacturing-america-2018.html.

[8] *GDP-by-industry*, U.S. Bureau of Economic Analysis. https://apps.bea.gov/iTable/index_industry_gdpIndy.cfm.

[9] *Monthly U.S. International Trade in Goods and Services*, December 2018, U.S. Census Bureau, Department of Commerce (March 6, 2019). https://www.census.gov/foreign-trade/Press-Release/2018pr/12/ft900.pdf.

[10] Businesses Spent $375 Billion on R&D Performance in the United State in 2016, Raymond M. Wolfe, InfoBriefs, National Science Foundation (September 25, 2018). https://www.nsf.gov/statistics/2018/nsf18312/.

[11] *Making It in America: Revitalizing US Manufacturing*, McKinsey Global Institute, McKinsey & Company (November 2017), p. 3. https://www.mckinsey.com/~/media/McKinsey/Global%20Themes/Americas/Making%20it%20in%20America%20Revitalizing%20US%20manufacturing/Making-it-in-America-Revitalizing-US-manufacturing-Full-report.ashx.

What Is Advanced Manufacturing?

Advanced manufacturing involves new ways to create existing products and the creation of new products emerging from the use of new technologies.[12]

Advances in manufacturing enable the economy to continuously improve as new technologies and innovations increase productivity, enable new products, and create entirely new industries. Manufacturing is one of the highest-paying sectors of the economy and has a significant impact on jobs in many other sectors. For example, one study found that the job-multiplier effect increases significantly for advanced manufacturing technologies, as each technology-intensive manufacturing job supports at least four other jobs.[13]

Productivity Growth in the Manufacturing Sector, 1990 to 2018

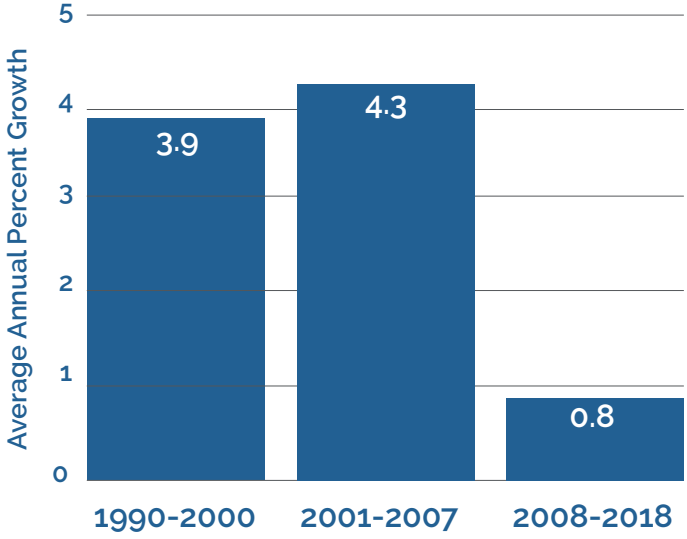


Figure 1. Productivity Growth in the Manufacturing Sector, 1990 to 2018. Productivity growth in the manufacturing sector for the years following the recession that began in December 2007 was far lower than in the years following the recessions that began in 1990.[15]

The manufacturing sector, as defined in NAICS (sectors 31, 32, and 33), consists of establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products. Advanced manufacturing, defined above, intersects and leverages many other industries (e.g., NAICS codes 51, 54, and 61); therefore, the impact of advanced manufacturing is expected to be much greater than the statistics quoted on the previous page.

Over the past 30 years, U.S. manufacturing has transformed dramatically. Manufacturing employment dropped by 5.2 million between January 1989 and January 2019. U.S. manufacturing supported 18.1 million manufacturing jobs in 1989 and bottomed out at 11.5 million jobs in 2010 before increasing to the roughly 12.8 million manufacturing jobs we see today.[14]

These losses in jobs have been compounded by reduced growth in productivity during the period since the deep recession of 2007 to 2009. In contrast to earlier periods following recessions, beginning in 2007, manufacturing productivity growth slowed (see Figure 1) and fell behind nonmanufacturing sectors. The long periods of low manufacturing employment and weak productivity growth coincided with the U.S. falling behind China (see Figure 2), which has become the largest manufacturer in the world.

[12] *National Network for Manufacturing Innovation Program Strategic Plan*, Executive Office of the President, National Science and Technology Council, Advanced Manufacturing National Program Office (February 15, 2016), p. 1. https://www.manufacturingusa.com/reports/national-network-manufacturing-innovation-nnmi-program-strategic-plan.

[13] *Advanced Technologies Initiative: Manufacturing & Innovation*, Deloitte and Council on Competitiveness, Deloitte Touche Tohmatsu Limited (2015), p. 9. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-indprod-deloitte-and-council-on-competitiveness-advanced-tech-report.pdf.

[14] All Employees: Manufacturing, Economic Research, Federal Reserve Bank of St. Louis. https://fred.stlouisfed.org/series/MANEMP.

[15] Labor Productivity for the Manufacturing Sector (Accessed August 23, 2019), Bureau of Labor Statistics. https://www.bls.gov/lpc/tables.htm

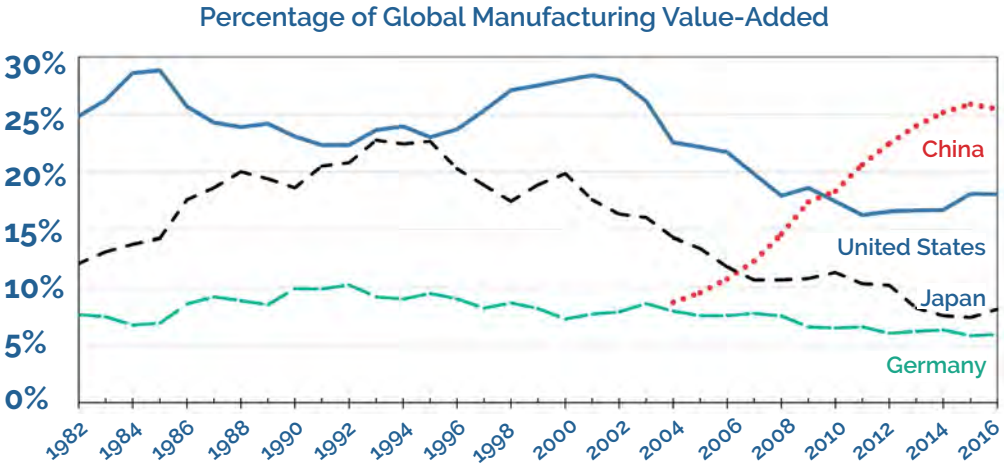


Figure 2. Manufacturing value-added by largest global manufacturers. Sources: World Bank and OECD.[16]

As shown in Figure 3, the U.S. trade balance in advanced-technology products has dramatically declined during the past 25 years. The trade deficit in advanced-technology products has worsened since 2001, reaching nearly $130 billion in 2018. The lost jobs, weakened competitiveness, and increased trade deficit demand action to ensure our nation's future prosperity.

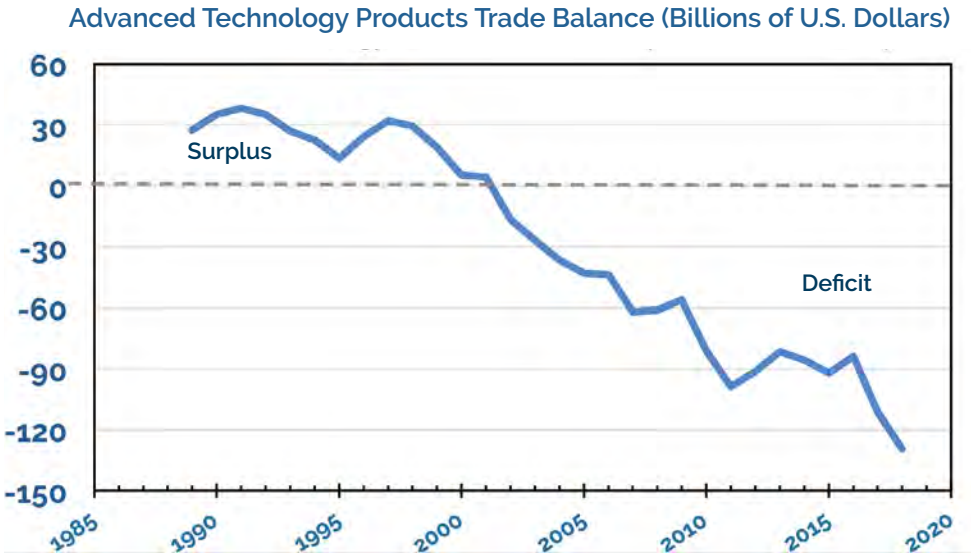


Figure 3: Foreign producers are challenging the dominance of the U.S. in advanced-technology products.[17]

[16] *Manufacturing, Value Added (Current U.S. $)*, World Bank National accounts data and OECD National Accounts data files (Accessed July 22, 2019). https://data.worldbank.org/indicator/NV.IND.MANF.CD?end=2017&locations=CN-US-JP-DE&start=1994&view=chart.

[17] Trade in Goods with Advanced Technology Products, Economic Indicator Division, U.S. Census Bureau, Department of Commerce (Accessed July 22, 2019). https://www.census.gov/foreign-trade/balance/c0007.html - 2018.

[18] *Strategy for American Leadership in Advanced Manufacturing*, Executive Office of the President, National Science and Technology Council, Committee on Technology, Subcommittee on Advanced Manufacturing (October 2018). https://www.whitehouse.gov/wp-content/uploads/2018/10/Advanced-Manufacturing-Strategic-Plan-2018.pdf.

Basis of Manufacturing USA: Advance U.S. Manufacturing

The U.S. is addressing these challenges through Manufacturing USA, a network of institutes and federal agencies working to advance manufacturing innovation.

As described in *Strategy for American Leadership in Advanced Manufacturing*, the U.S. strategic plan for advanced manufacturing, these public-private partnerships are needed to develop advanced technologies and to transition the new technologies to market, train a skilled workforce, and maintain a strong and well-connected domestic supply chain.[18] The importance of these partnerships is also emphasized in the National Security Strategy, which encourages the Federal Government to work with industry partners to strengthen U.S. competitiveness in key technologies and manufacturing capabilities.[19] For the Department of Defense (DoD) in particular, advancing next-generation manufacturing technologies enables the Department to secure the defense industrial base and place the latest innovations into the hands of our warfighters. As jobs depending on conventional technologies disappear, new high-paying jobs are being created. The institutes help ensure that the U.S. can maintain the lead in innovation and keep high-paying jobs within our country.

The bipartisan Revitalize American Manufacturing and Innovation Act of 2014 (RAMI Act) established the National Network for Manufacturing Innovation Program, now widely known as Manufacturing USA.[20] The RAMI Act also authorized the Secretary of Commerce to establish manufacturing innovation institutes and designated the Advanced Manufacturing National Program Office (AMNPO), headquartered at the National Institute of Standards and Technology (NIST), as the primary office to oversee and carry out the networking program. AMNPO is authorized by the Secretary of Commerce to collaborate with federal departments and agencies with missions that contribute to, or are affected by, advanced manufacturing. The Manufacturing USA network currently includes participation by 9 federal agencies and the 14 research and development institutes for key advanced manufacturing technologies, sponsored by the Departments of Commerce, Defense, and Energy.[21] One participating institute, America Makes, was established as a public-private partnership in 2012 by DoD to advance the latest 3D printing and additive manufacturing technologies. The success of that initial public-private partnership model set the precedent for the establishment of the other institutes as public-private partnerships.

The institutes bring together large and small manufacturers, researchers, state and local governments, and federal agencies to

- Establish manufacturing standards and best practices
- Build regional ecosystems behind particular manufacturing technologies
- Identify and address gaps in the U.S. manufacturing technology base
- Train the next generation of professionals
- Transition new manufacturing technologies and processes to the U.S. industrial base.

Additionally, the DoD-sponsored institutes work to

- Transition new manufacturing technologies and processes to the warfighter
- Secure the industrial base
- Create surge ability based on DoD's needs
- Serve as a resource for the DoD

The recent 2018 World Manufacturing Forum Report identified 10 key recommendations for the future of manufacturing,[22] shown on the next page in Figure 4. Collectively, the mission and vision of the Manufacturing USA network are well aligned with these recommendations.

---

[19] *National Security Strategy of the United States of America,* Executive Office of the President (December 2017). https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905-2.pdf.

[20] Consolidated and Further Continuing Appropriations Act, 2015, Pub. L. 113-235, Title VII – Revitalize American Manufacturing and Innovation Act of 2014, codified at 15 U.S.C. § 278s. http://uscode.house.gov/view.xhtml?req=(title:15 section:278s edition:prelim).

[21] Additional participating Federal agencies include the Departments of Education, Health and Human Services, Labor, and Agriculture,; the National Aeronautics and Space Administration; and the National Science Foundation.

[22] *2018 World Manufacturing Forum Report 2018: Recommendations for the Future of Manufacturing*, World Manufacturing Forum. https://www.worldmanufacturingforum.org/report.

Will U.S. Manufacturing Lead the Fourth Industrial Revolution?

Manufacturing has made tremendous strides since the original industrial revolution, which coincided with the period of the birth of our nation. Each such revolution has led to three dramatic changes in society: 1) improvements in productivity, 2) the loss of jobs through obsolescence, and 3) the creation of many more jobs for those nations taking the lead in new technology.

Along the way, crucial manufacturing milestones have changed the face of manufacturing history and are emblematic of past industrial revolutions. For example:

- *During the first industrial revolution, Eli Whitney's pioneering of interchangeable parts and invention of the cotton gin, which was later enhanced by steam power, greatly reduced the need for manual labor and enabled enormous productivity increases in the textile industry.*
- *During the second industrial revolution, the Technological Revolution, Henry Ford's assembly line for the manufacturing of automobiles and electrification of machinery cut the time required to assemble a car from over 12 hours to 2.5 hours.*
- *The third industrial revolution, the so-called Information Revolution, was driven by integrated circuits invented by Texas Instruments and Fairchild Semiconductor. These inventions gave rise to the internet, which grew out of a Defense Advanced Research Projects Agency project.*

The U.S.'s leadership role has increased with each industrial revolution. However, the competition is greater now during the fourth industrial revolution, which fuses mechanical and digital (cyber) capabilities. Will the U.S. maintain a leadership position? Manufacturing USA's institutes are key domestic assets that will determine the outcome of international competition during the next stage of global industrial development.

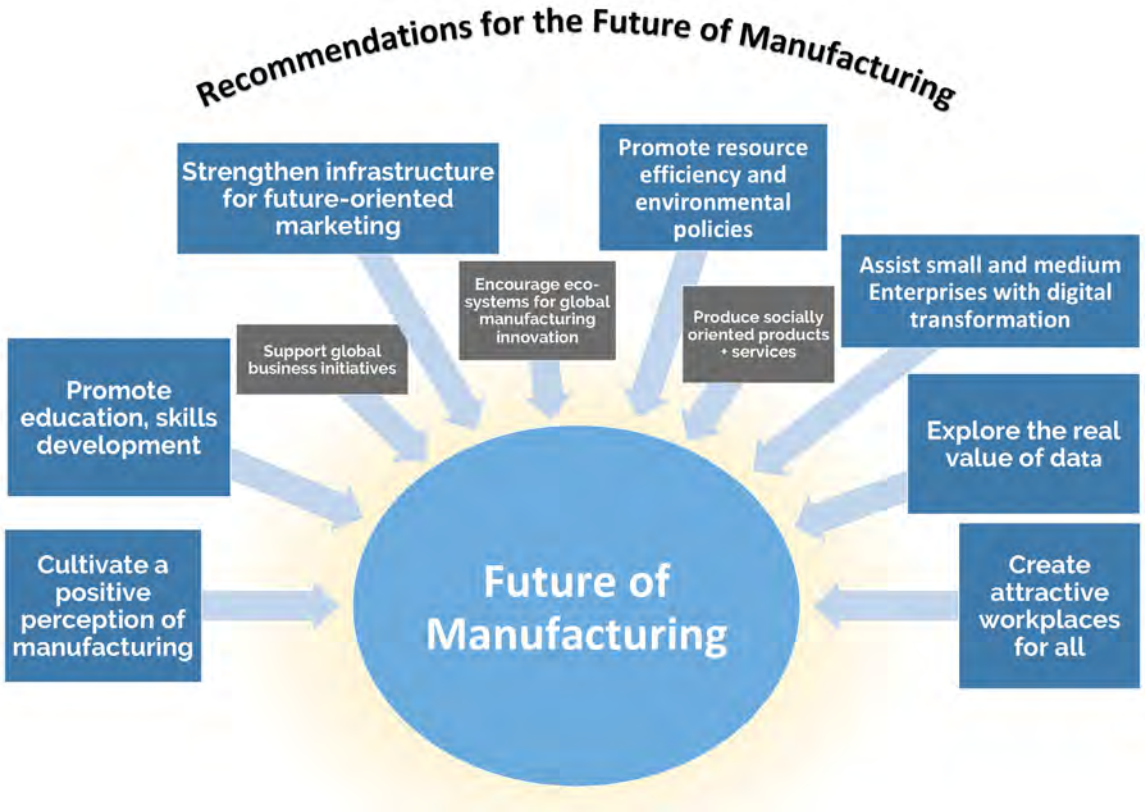


Figure 4. "Key Recommendations for the Future of Manufacturing" from the World Manufacturing Forum. Manufacturing USA's institute activities align with 7 out of 10 recommendations. Manufacturing USA's aligned activities are enlarged.

Vision, Mission, and Goals

The Manufacturing USA network works to secure U.S. global leadership in advanced manufacturing by connecting people, ideas, and technology. Manufacturing USA institutes convene business competitors, academic institutions, and other stakeholders to test applications of new technology, create new products, reduce cost and risk, and empower the manufacturing workforce with the skills of the future. These efforts help ensure that what is invented here is made here by a skilled American workforce.

The program's four goals are to

1. Increase the competitiveness of U.S. manufacturing
2. Facilitate the transition of innovative technologies into scalable, cost-effective, and high-performing domestic manufacturing capabilities
3. Accelerate the development of an advanced manufacturing workforce
4. Support business models that help the Manufacturing USA institutes become stable and sustainable after the initial federal startup funding period.[23]

The institutes are the core of the Manufacturing USA network. Each is a public-private partnership, jointly funded by the sponsoring Federal Government and private industry, focused on a unique manufacturing technology, and working toward a common goal: *securing America's future through manufacturing innovation, education, and collaboration*. The institutes connect member organizations, work on cutting-edge research and development collaboration projects to solve industry's toughest challenges, and train people on advanced manufacturing skills.

By catalyzing the collaborative, precompetitive development of promising technologies, the institutes create sustainable innovation ecosystems for advanced manufacturing through activities that include:

- Conducting (or funding) precompetitive applied research and development projects to reduce the cost, time, and technical uncertainty related to

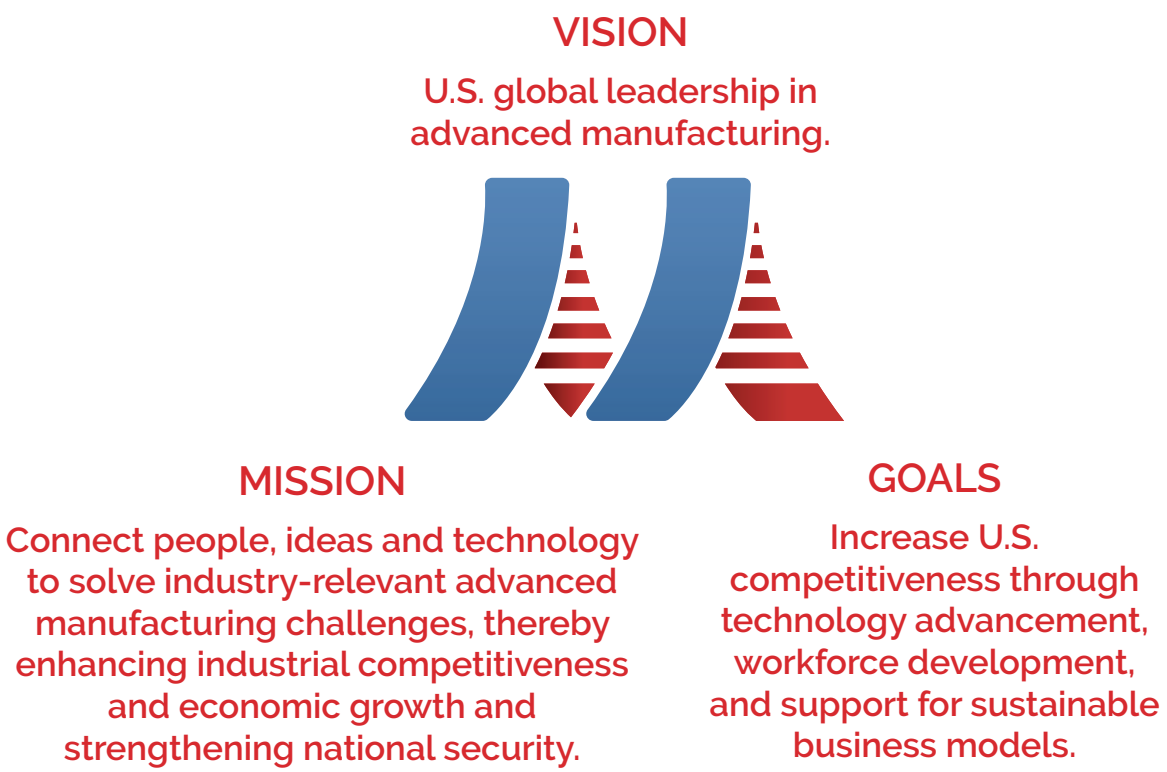


Figure 5. Manufacturing USA is guided by a vision, a mission, and four program goals.

[23] *National Network for Manufacturing Innovation Program Strategic Plan*, Executive Office of the President, National Science and Technology Council, Advanced Manufacturing National Program Office, p. 9 (February 2016). https://www.manufacturingusa.com/reports/national-network-manufacturing-innovation-nnmi-program-strategic-plan.

Figure 6. Fourteen Manufacturing USA institutes were established between 2012 and 2017 by the Departments of Commerce (NIIMBL), Defense (AFFOA, AIM Photonics, America Makes, ARM, BioFabUSA, MxD [DMDII], LIFT, and NextFlex), and Energy (CESMII, IACMI, PowerAmerica, RAPID, REMADE).

new manufacturing technologies and to improve existing technologies, processes, and products

- Developing and implementing education, training, and workforce recruitment courses, materials, and programs
- Developing new technologies, innovative methodologies, and improved practices for integrating and expanding supply chains
- Engaging with small and medium-sized manufacturers (SMMs), including woman- and minority-owned manufacturing enterprises, as well as larger manufacturing firms
- Developing or encouraging shared state-of-the-art facilities and infrastructure to reduce the cost and risk of commercializing new technologies and to address relevant manufacturing challenges on a production-level scale.

Each institute was established by a federal agency following a competition under individual agency statutory authorities and appropriations.[24] Fourteen institutes were established between FY 2012 and FY 2017, as illustrated in Figure 6, and a fifteenth, sponsored by DOE, is planned.[25]

The institutes have members in all 50 states and Puerto Rico. A complete list of the institutes, including their locations and dates of establishment, is included in Table 1 on the next page.

Reporting Period

This annual report describes the activities of the Manufacturing USA program, including institute activities and network performance, during FY 2018 (October 1, 2017, to September 30, 2018). Prior-year accomplishments or activities planned after this period are included as appropriate and are clearly referenced.

[24] The Departments of Commerce (NIIMBL), Defense (AFFOA, AIM Photonics, America Makes, ARM, BioFabUSA, MxD [DMDII], LIFT, and NextFlex), and Energy (CESMII, IACMI, PowerAmerica, RAPID, REMADE).

[25] In early FY 2019, DOE issued a notice of intent to establish the Cybersecurity Institute for Energy Efficient Manufacturing. See the Energy Efficiency and Renewable Energy Funding Opportunity Exchange. https://eere-exchange.energy.gov/default.aspx - FoaId186a868e-fd1b-4da8-bcfd-01a13cc31dee.

Table 1. Manufacturing USA Institutes Cover a Broad Range of Critical Technology Areas

Institute Name	Technology Focus Area	Establishing Agency	Headquarter Locations	Date Established
America Makes — The National Additive Manufacturing Innovation Institute	Additive manufacturing	DoD	Youngstown, Ohio	August 2012
MxD — Manufacturing times Digital[26]	Digital manufacturing and design/Cybersecurity in Manufacturing	DoD	Chicago, Illinois	February 2014
LIFT — Lightweight Innovations for Tomorrow	Lightweight materials manufacturing	DoD	Detroit, Michigan	February 2014
PowerAmerica — The Next Generation Power Electronics Manufacturing Innovation Institute	Wide bandgap power electronics manufacturing	DOE	Raleigh, North Carolina	January 2015
IACMI — Institute for Advanced Composites Manufacturing Innovation	Fiber-reinforced polymer composites manufacturing	DOE	Knoxville, Tennessee	June 2015
AIM Photonics — American Institute for Manufacturing Integrated Photonics	Integrated photonics manufacturing	DoD	Rochester and Albany, New York	July 2015
NextFlex — America's Flexible Hybrid Electronics Manufacturing Institute	Thin flexible electronics devices and sensors manufacturing	DoD	San Jose, California	August 2015
AFFOA — Advanced Functional Fabrics of America Institute	Sophisticated, integrated, and networked fibers, yarns, and fabric manufacturing	DoD	Cambridge, Massachusetts	April 2016
CESMII — Clean Energy Smart Manufacturing Innovation Institute	Smart manufacturing	DOE	Los Angeles, California	December 2016
BioFabUSA — Advanced Regenerative Manufacturing Institute	Engineered tissues and tissue-related manufacturing	DoD	Manchester, New Hampshire	February 2017
ARM — Advanced Robotics for Manufacturing Institute	Transformative robotic technologies and education for manufacturing	DoD	Pittsburgh, Pennsylvania	January 2017
NIIMBL — The National Institute for Innovation in Manufacturing Biopharmaceuticals	Biopharmaceutical manufacturing	DOC	Newark, Delaware	March 2017
RAPID — Rapid Advancement in Process Intensification Deployment Institute	Modular chemical-process intensification for clean manufacturing	DOE	New York, New York	March 2017
REMADE — Reducing EMbodied-energy And Decreasing Emissions	Sustainable manufacturing with clean energy and carbon-emission reduction	DOE	Rochester, New York	May 2017

[26] On February 28, 2019, DMDII — the Digital Manufacturing and Design Innovation Institute (DMDII) was renamed MxD — Manufacturing times Digital, with a mission to drive the digital future of manufacturing and increase cybersecurity within U.S. manufacturing facilities.

Organization and Management

Functions, Governance, and Coordination

Manufacturing USA's four governance operating principles, outlined in its network charter, include:[27]

1. The Manufacturing USA network supports member institutes in meeting the goals of the program and creates a collective impact greater than the sum of constituent parts. Individual institute governance is the purview of the lead funding agency and respective institute members. Legislatively mandated reporting on individual institute performance is the responsibility of the respective lead funding agencies.

2. Network governance is a shared responsibility among the network membership of Manufacturing USA. Mechanisms and structures are necessary to collect inputs of key stakeholders, including the private sector.

3. Decisions concerning inter-institute issues in the network should be made at the lowest responsibility level. In resolving issues, there should be a general preference toward empowering action at the institute level.

4. The AMNPO, headquartered at NIST, is responsible for supporting the network functions of Manufacturing USA.

The Network Charter also established that the AMNPO, working with its federal agency partners, is responsible for reporting to Congress on the Manufacturing USA program and related institutes. The AMNPO also plays a key role in facilitating peer-to-peer collaboration and serves as an information clearinghouse for internal and external communications.

Collaboration is key for effective management and coordination of the Manufacturing USA network. Federal agency members meet monthly to discuss policy decisions for defining and improving the network functions.

The nine federal agencies[28] supporting Manufacturing USA coordinate their efforts through the AMNPO in support of the program's national purposes, as described in the RAMI Act, and in recognition that those national purposes are best realized by an integrated whole-of-government effort.

The lead agencies embrace this unified effort, while ensuring that the value delivered by their respective institutes remains closely aligned with their agencies' statutory requirements. Maintaining this balance between Manufacturing USA's national programmatic goals and each agency's needs helps ensure that all major stakeholder base requirements are addressed.

Collaboration is also important to the institute directors, who share best practices through their Institute Directors Council meetings. Formalized in the Charter of the Institute Directors Council: Manufacturing USA,[29] the council directly supports the goals of the Manufacturing USA program and facilitates cooperation and collaboration among the institutes with advice, as needed, from the federal institute sponsors, agencies providing additional support to the institutes, and the AMNPO, which also provides financial and staff support for the council.

Manufacturing USA has developed a powerful network brand and iconic logo to foster awareness of the institutes as individual applied-technology centers that belong to a larger network. The logo helps create instant awareness when furthering the cause of advanced manufacturing to nonmember industries and academia, as well as to the media and public.

---

[27] *Network Charter: Manufacturing USA Program*, Advanced Manufacturing Series (NIST AMS) - 600-2, Section D, Network Operating Principles, Department of Commerce, National Institute of Standards and Technology. https://www.manufacturingusa.com/resources/network-charter-manufacturing-usa-program.

[28] The Departments of Commerce, Defense, Education, Energy, Health and Human Services, and Labor; the National Aeronautics and Space Administration; the National Science Foundation; and the U.S. Department of Agriculture.

[29] *Charter of the Institute Directors Council: Manufacturing USA*, NIST Advanced Manufacturing Series (NIST AMS) - 600-1, C. Blue, L. Brown, Y. Fink, N. Justice, M. Liehr, E. Morris, p. 3 (2016). https://www.nist.gov/publications/charter-institute-directors-council-manufacturing-usa.

Public Clearinghouse of Information

The AMNPO communicates with key stakeholders through a variety of means, including Manufacturing USA's website (ManufacturingUSA.com) and social media (LinkedIn and Twitter). Through public materials and industry events, the office shares stories and information about the Manufacturing USA network and the work of the institutes and their members to develop advanced manufacturing technologies and a skilled workforce.

Manufacturing USA Secure Collaboration Site

The AMNPO has developed, maintains, and continually improves a secure Manufacturing USA web-based portal for intra-network collaboration. The site facilitates communication among all institute and agency partners and supports program activities by providing information and resources to members.

Figure 7. The ManufacturingUSA.com website contains news and information about the institutes, guidance on how to participate in the network, links to funding opportunities and reports, and listings of upcoming events. Credit: AMNPO

Institute Performance

The quantitative and qualitative performance of the manufacturing institutes were assessed for FY 2018. Twelve quantitative measures in four program objective categories were used. Qualitative outcomes from individual institutes were included within each category to illustrate specific examples of institute performance. FY 2018 is the third year in which similar quantitative metrics have been reported, offering opportunities to assess trends from previous years.

As described in the strategic plan, the evaluation strategy for Manufacturing USA and its components is anchored by the following principles and best practices:[30]

- Establish or leverage existing data infrastructures that can manage information needed to address the extent to which Manufacturing USA is meeting its mission and purposes.
- Focus data collection on areas that can best provide rigorous and repeatable analysis.
- Leverage lessons learned from evaluation efforts underway within individual institutes and from other similar programs and related interagency groups.
- Provide a trusted measure of Manufacturing USA's performance that is broad enough to support process-improvement analysis for the future design and activities of Manufacturing USA.
- Leverage partnerships to improve data quality (e.g., linking Manufacturing USA to external sources where appropriate) and to building a community of practice for evaluation.

As Manufacturing USA grows and matures, additional evaluation metrics will evolve. While this evolution may complicate the comparison of certain metrics over time, Manufacturing USA's leadership is committed to their continuous improvement so that the program can be properly assessed over the long term. One area of continuous improvement may be establishing targets for key metrics to evaluate the institutes' progress toward sustainability. In addition, each of the lead funding agencies tracks the metrics of the institutes they fund relative to the agency's unique mission-specific requirements.

Measuring Overall Performance of the Manufacturing USA Program

In FY 2018, the Department of Commerce (DOC) operated the first Manufacturing USA institute established under the authority of the Revitalize American Manufacturing and Innovation Act (the RAMI Act), the Department of Defense (DoD) operated eight institutes under the Manufacturing Technology Program authority, and the Department of Energy (DOE) operated five institutes.

Through the AMNPO, the DOC, the DoD, and the DOE expanded their coordination with other federal agencies and cooperated in a wide range of support activities, based on recognition that Manufacturing USA's national goals, while well aligned with each individual agency's mission, are best realized by a whole-of-government effort that focuses broadly on increasing U.S. advanced manufacturing competitiveness.

[30] *National Network for Manufacturing Innovation Program Strategic Plan*, Executive Office of the President, National Science and Technology Council, Advanced Manufacturing National Program Office (February 15, 2016), p. 27. https://www.manufacturingusa.com/reports/national-network-manufacturing-innovation-nnmi-program-strategic-plan.

Performance Metrics

Effective quantitative performance metrics are tied to measuring progress toward validated goals and objectives. As seen in Table 2, each institute metric category described in Manufacturing USA's strategic plan provides information for tracking progress toward multiple high-level goals.[31]

The four goals in the plan are interrelated elements of a robust strategy supporting manufacturing innovation and are based primarily on the eight program purposes in the RAMI Act.[32]

Table 3 reflects an aggregation of institute-level metrics and describes the specific metrics used for each of four metrics categories.

Several specific metrics require collection and reporting of additional measures, increasing the total number of performance measures to 12. Table 4 on page 14 contains the aggregated institute metrics data (actual values), including a description of specific units of measure used to define values for each specific metric.

Table 2. Manufacturing USA Quantitative Performance Metrics Categories Mapped to the Manufacturing USA Program Goals

Institute Metric Category	Goal 1: Increase the competitiveness of U.S. manufacturing	Goal 2: Facilitate the transition of innovative technologies into scalable, cost-effective, and high-performing domestic manufacturing capabilities	Goal 3: Facilitate the development of an advanced manufacturing workforce	Goal 4: Support business models that help institutes to become stable and sustainable
Impact to U.S. Innovation Ecosystem	●	●		●
Financial Leverage		●		●
Development of an Advanced Manufacturing Workforce	●		●	
Technology Advancement	●	●		

[31] *National Network for Manufacturing Innovation Program Strategic Plan*, Executive Office of the President, National Science and Technology Council, Advanced Manufacturing National Program Office, p. 30 (February 2016). https://www.manufacturingusa.com/reports/national-network-manufacturing-innovation-nnmi-program-strategic-plan.

[32] Consolidated and Further Continuing Appropriations Act, 2015, Pub. L. 113-235, Title VII – Revitalize American Manufacturing and Innovation Act of 2014, codified at 15 U.S.C. § 278s(a)(2). http://uscode.house.gov/view.xhtml?req=(title:15 section:278s edition:prelim).

Table 3. Manufacturing USA Performance Metrics Categories and Specific Quantitative Metrics

Institute Metric Category	Specific Metric
Impact to U.S. Innovation Ecosystem	Number of partner organizations with institute membership agreements Diversity of FY 2018 members
Financial Leverage	Total FY 2018 co-investment
Technology Advancement (Development, Transfer, Commercialization, etc.)	Number and value of FY 2018 active research and development (R&D) and demonstration projects Percentage of key project technical objectives met in FY 2018
Development of an Advanced Manufacturing Workforce	FY 2018 STEM activities FY 2018 Educator/trainer engagement

Continued Growth in the U.S. Innovation Ecosystem – Institutes Have 1,937 Members

All 14 institutes report membership increases during FY 2018: Total memberships for FY 2018 increased 50% over FY 2017 and more than doubled over FY 2016. Of the 1,937 member organizations, 1,229 (63%) were manufacturers (industry), and 858 (70%) of those manufacturers were SMMs with 500 or fewer employees (see Figure 8 below). There were 474 (24%) universities, community colleges, and technical training schools, and 244 (13%) were in a broad category of other organizations that included federal laboratories, regional economic development agencies, not-for-profit organizations, and state and local governments.

Given that membership gains were made in each of the four membership categories, with an increase of 385 industry memberships from FY 2017 to FY 2018, it is clear that U.S. manufacturers are finding value in their participation and collaboration as institute members.

Examples of the impact of the Manufacturing USA institutes on the U.S. manufacturing ecosystem include the following:

- **NextFlex** (DoD-sponsored) operated the first end-to-end flexible hybrid electronics (FHE) pilot line — the nation's largest repository of FHE pilot-line tooling — with over 55 tools, mostly donated by industry. The pilot line is available to all members for prototyping and low-volume production.

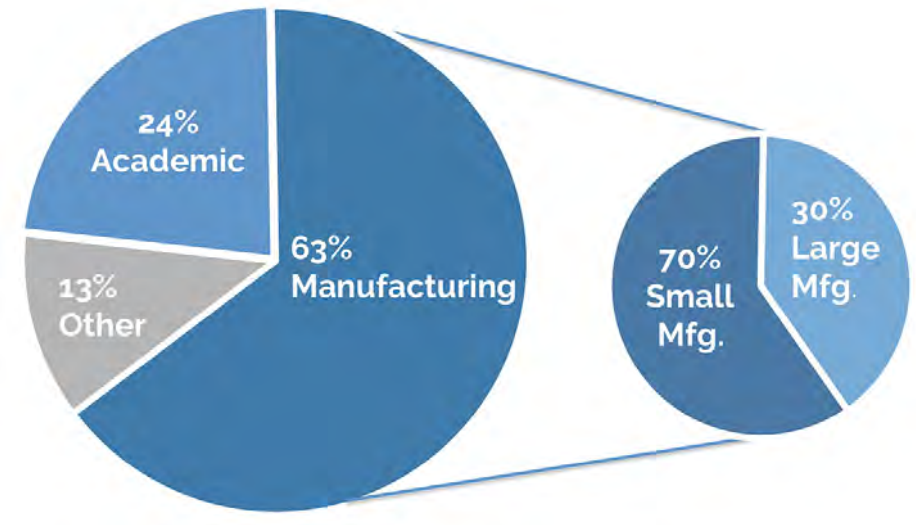


Figure 8. Institute membership demographics.

Table 4. Aggregated Institute Performance Metrics Values

Institute Metric Category	Specific Metric	Unit(s) of Measure	FY 2016	FY 2017	FY 2018
Impact to U.S. Innovation Ecosystem	Number of partner organizations with institute membership agreements	Total number of memberships	830	1,291	1,937
	Diversity of members	Number of large manufacturers (more than 500 employees)	187	295	371
		Number of small manufacturers (500 or fewer employees)	361	549	858
		Number of academic members (universities, community colleges, etc.)	177	297	474
		Number of other entities (government members, government laboratories, not-for-profit organizations, etc.)	105	150	244
Financial Leverage	Total co-investment in each fiscal year	Amount of cost share expended in each fiscal year and any federal funding not part of the base federal funding	$218.9M	$177.8M	$313.5M
Technology Advancement	Number and value of active research and development projects	Number of projects ongoing in each fiscal year (projects completed, started, and spanning each fiscal year)	191	273	476
		Total institute expenditures in the fiscal year	$333.8M	$298.5M	$496.9M
	Percentage of key project technical objectives met in each fiscal year	Percentage of key milestones met in each fiscal year	82%	79%	82%
Development of an Advanced Manufacturing Workforce	STEM activities	Number of students participating in institute projects or institute internship programs/training	23,560	185,425	200,169*
		Number of individuals in the workforce completing a certificate, apprenticeship, or training program led by the institutes	3,386	4,302	2,630**
	Educator/trainer engagement	Number of teachers or trainers participating in institute-led training	1,023	1,299	2,455

* Lightweight Innovations for Tomorrow (LIFT), whose education and workforce initiatives have leveraged online platforms to reach students across the country, was responsible for 93% of participating students.

** For FY 2018, the definition of a credential was changed to a higher standard from previous years; this figure does not include an additional 3,680 participants from the current workforce who are not pursuing an industry-recognized credential. Under the previous definition, the total would be 6,310.

- **MxD** (DoD) executed a model-based-enterprise assessment of Rock Island Arsenal (Rock Island, IL) that provides U.S. Army leadership with a roadmap for leveraging digital manufacturing technologies that could increase technical workforce productivity 40% to 45% and reduce maintenance downtime by 30% to 50%.

- **America Makes** (DoD) published the *Standardization Roadmap for Additive Manufacturing (Version 2.0)* in conjunction with the American National Standards Institute (ANSI) and with funding from the DoD.[33] The institute leveraged its broad network to convene 320 individuals from 175 public- and private-sector organizations to develop the roadmap.

- **PowerAmerica** (DOE) funding helped Wolfspeed (Durham, NC) meet strict reliability qualifications needed for commercial production. Wolfspeed, a Cree Company, manufactures silicon carbide devices and associated packaging at two locations within the U.S., and the company has developed and qualified unique silicon carbide devices, which can be used to power applications such as rail, motor drives, and photovoltaic inverters, that it is preparing to commercialize.

- The **AIM Photonics** (DoD-sponsored, Rochester and Albany, NY) Multi Project Wafer offering established a world-class 120-day cycle time from design to completed device. This speed is critical for designers — many from DoD, academia, and small businesses — that need to test their designs quickly to accelerate innovation and product development before sending the manufacturing of their devices to foundries. The decreased cycle time was accompanied by a more robust process-design kit that contained both active and passive optical elements.

- **IACMI** (DOE) members have increased the variety and understanding of materials available for large-scale additive manufacturing, generating significant commercial growth for multiple companies. Techmer PM (Clinton, TN) has increased sales of new 3D products and expects sales to double in 2019. Local Motors recently installed the world's largest 3D printer, made by Thermwood, at its Knoxville, Tennessee, microfactory and plans to commercially produce Olli 2.0, its first self-driving vehicle, in July 2019.

- **AFFOA**, (DoD) along with the MIT Venture Mentoring Service, has selected 25 venture teams for the Advanced Fabrics Entrepreneurship Program, which aims to identify advanced fiber and textile technologies to lay the foundation for commercial launch.

Financial Leverage: Nonfederal Institute Research and Development Co-Investment Exceeded Federal Program Funds by 70%

Figure 9. Breakdown of federal program funding vs. nonfederal funding of Manufacturing USA institutes in FY 2018.

In FY 2018, as illustrated above in Figure 8, the institutes exceeded the required target of a 1-to-1 match for their funding of institute expenditures. Total institute expenditures were $496.9 million, with nonprogram matching expenditures totaling $313.5 million and federal program funds totaling $183.4 million — a match from industry, academia, and regional organizations of $1.70 for each $1 in base federal funding. These matching funds were expended for technology research and development efforts, capital-intensive efforts such as facility or manufacturing equipment purchases, institute operations, and education and workforce development programs.

[30] *Standardization Roadmap for Additive Manufacturing, (Version 2.0)*, America Makes and ANSI Additive Manufacturing Standardization Collaborative (June 2018). https://www.americamakes.us/america-makes-ansi-publish-version-2-0-standardization-roadmap-additive-manufacturing.

One Step Closer to Organs on Demand

BioFabUSA launched the first tissue foundry technology call with the long-term goal of building a closed and fully automated manufacturing line for engineered tissues that is modular, flexible, and compliant with good manufacturing practice. The technology call focused on identifying and collecting existing prototypes and off-the-shelf technologies that may be integrated into a prototype modular manufacturing system.

Initially, a prototype line will be built to highlight capability gaps, refine BioFabUSA's focus areas, and influence future technology project calls. The prototype line will include five modules that go from tissue harvesting to the final product packaging. The ultimate manufacturing line, which will form the basis for technology-transfer activities, will be utilized for process validation and early-phase clinical manufacturing.

The development of a fully functioning tissue foundry line is the first step in producing tissue products at industrial scale to accelerate deployment of key medical products and enhance the DoD's ability to treat wounded warfighters.

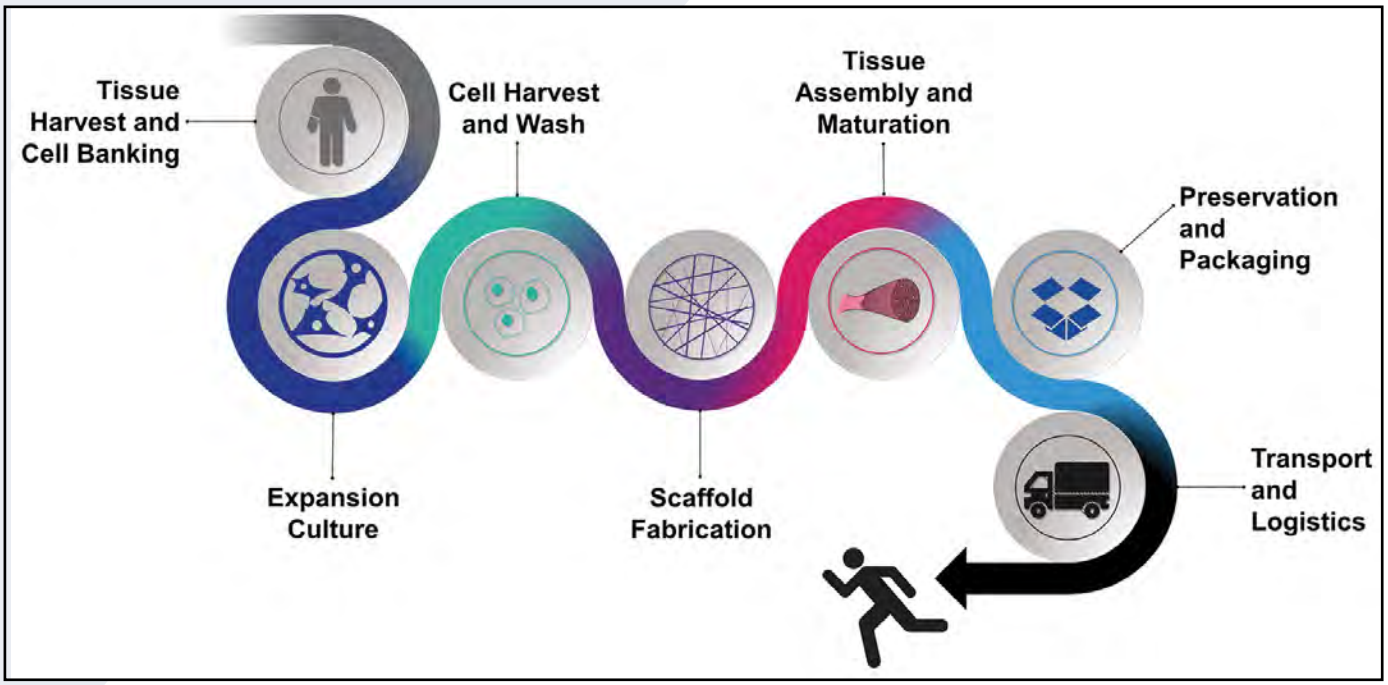


Figure 10. The BioFabUSA tissue foundry concept incorporates modular, automated, and closed processes. It uses modular manufacturing to group unit operations into five modules: cell culture and expansion, harvest and wash, scaffold fabrication, tissue assembly and maturation, and preservation and packaging.
Credit: BioFabUSA

Examples that illustrate how federal resources are being leveraged include:

- **IACMI** (DOE) has impacted the economic development and growth of the advanced composites market. Since its launch, IACMI ecosystem members in eight states have announced over 3,000 new jobs and investments of more than $400 million.
- **NextFlex** (DoD) received 30 additional DoD-directed grants and contracts for new projects worth approximately $25 million and ranging from human monitoring and secure authentication of warfighter identity to printing of sophisticated array antennas for use on aircraft wings.
- **LIFT** (DoD) and **IACMI** (DOE) shared a $50 million investment to establish a high-bay facility in Detroit, Michigan that is uniquely positioned to help revolutionize manufacturing through lightweight innovation and education, with benefits to the aerospace, defense, and automotive industries, among others.
- **CESMII's** (DOE) first request for proposals provided $16.5 million in project funding, that included a 40% cost share and allowed for a 12- to 24-month duration. These funds were for projects to create advanced methods for extrapolating and contextualizing data to improve manufacturing performance and improve and expand its Smart Manufacturing Platform™.

Technology Advancement: Advancing Technology and Improving the Innovation Ecosystem

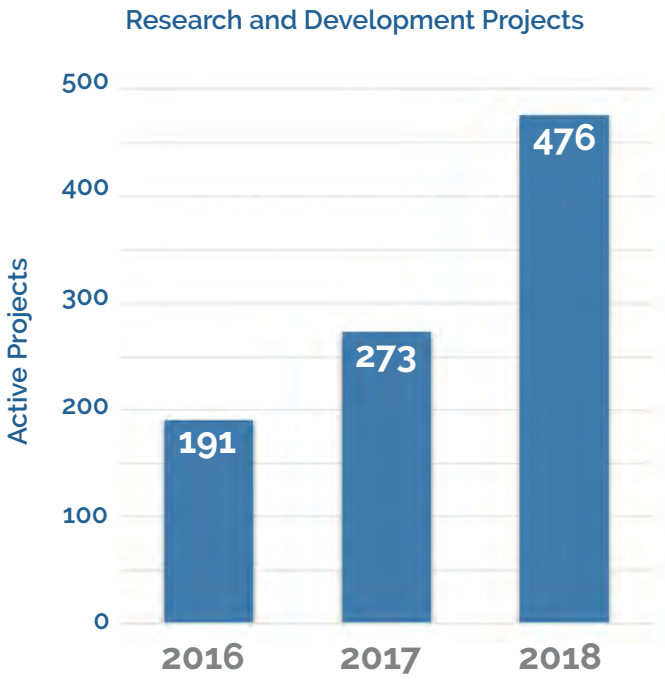


Figure 11. Number of active institute research and development projects.

During FY 2018, as shown in Figure 10 below, the institutes managed 476 technology projects that included manufacturing-process research, proof-of-concept development, early system prototyping, and manufacturing demonstrations. This represents an increase of 75% from FY 2017 and more than double the FY 2016 project totals. Although these research and development projects, like any other R&D activity, have inherent risks, an average of 82% of key technical milestones were met in FY 2018.

Critical to the institute's success is a rigorous and broadly inclusive approach to selecting project topics. Stakeholders from industry, academia, regulatory agencies, and end users develop roadmaps for key technologies and manufacturing processes. The subsequent research and development projects are selected based in part on their linkage to the roadmaps' time-based technical requirements. The transparency and wide acceptance among institute members of the role of roadmaps for establishing technical needs has helped generate highly qualified teams of industry and academic members.

Carol A. Ammon and Marie E. Pinizzotto Biopharmaceutical Innovation Center

On October 23, 2017, the University of Delaware broke ground on the new $156 million Carol A. Ammon and Marie E. Pinizzotto Biopharmaceutical Innovation Center, which will serve as the future NIIMBL headquarters and will provide a state-of-the-art facility where NIIMBL project teams can collaborate and test their ideas.

As of early 2020, NIIMBL expects to occupy approximately 25% of the six-story, 200,000-square-foot building. The NIIMBL space will feature shared laboratories, NIIMBL platform process facilities, a showcase laboratory, and workforce-training facilities.

In addition to housing NIIMBL headquarters, the building will include other university biopharmaceutical discovery and development activities, facilitating close collaboration between NIIMBL and other research and development efforts.

Credit: SmithGroupJJR

Examples of Manufacturing USA technology advancement include:

- **RAPID** (DOE-sponsored, New York, NY) initiated a new project with the University of Connecticut (Storrs, CT) to apply carbon nanotube membranes for extraction of ethanol from fermentation broths. Implementation of this concept will reduce the energy used to produce ethanol by up to 90%.
- **NIIMBL** (DOC) revealed the first technology prototype developed from a quick-start project launched in 2017. The single-use plastic cell BioSettler prototype, a device to separate cells from liquid, was a collaborative effort between Sudhin Biopharma, a small manufacturer located in Superior, Colorado, and Genentech, a world-leading biopharmaceutical company based in South San Francisco, California.
- An **America Makes** (DoD) project team successfully completed the characterization of ULTEM™ 9085 for fused deposition modeling (FDM) manufacturing. ULTEM 9085 is one of a few high-performance thermoplastic materials available for FDM with acceptable ratings for production of aircraft and other defense and industrial applications with high-strength thermoplastic requirements.

High-Volume Manufacturing of Lightweight Automotive Components

IACMI teamed with the Ford Motor Company (Dearborn, MI) and the Dow Chemical Company (Midland, MI), and core partners including Michigan State University (Lansing/Detroit, MI), Purdue University (West Lafayette, IN), the Oak Ridge National Laboratory (Oak Ridge, TN), and the University of Tennessee (Knoxville, TN), on a project to replace metal components in primary automotive body structures with aligned carbon-fiber intermediates in order to decrease overall weight and increase fuel efficiency. The project's goal is to include carbon composites in 100,000 vehicle platform units using a combination of novel carbon-fiber intermediates, production methods, and simulation tools. The Dow composite material developed through this IACMI technical project achieved part-level material performance high enough that Ford declared it acceptable for specification on future vehicle platforms.

- **PowerAmerica** (DOE) members United Silicon Carbide (USiC; Monmouth Junction, NJ) and X-FAB (Lubbock, TX) released high-voltage (650- and 1200-volt) silicon carbide semiconductor diodes that meet stringent international automotive qualification standards.
- The **AFFOA** (DoD) Defense Fabric Discovery Center is collaborating with the MIT Lincoln Laboratory (Lexington, MA) on a newly funded project titled System in a Fiber to produce fibers with individually controllable and addressable devices.
- A **CESMII** (DoD) project led by the University of Connecticut (Storrs, CT) is developing optimized sensor networks, critical for smart manufacturing, that can improve the energy efficiency of manufacturing. Johnson & Johnson (Raynham, MA) is the industrial partner.
- **LIFT** (DoD) leads a project that will reduce military Humvee rollovers by 74%, reducing service-personnel fatalities. The project will provide validation of quality retrofit installation on the Humvee fleet, including training soldiers on installation.
- A **REMADE** (DOE-sponsored, Rochester, NY) project partnering the University of Utah (Salt Lake City, UT) with EDX Magnetics (Salt Lake City, UT) uses electrodynamic sorting to improve yield, purity, and throughput when separating ferrous and nonferrous scrap metals. The technique has the potential to reduce energy consumption by 300 trillion BTU per year.
- **ARM's** (DoD-sponsored, Pittsburgh, PA) Automated Wire Harness Assembly project team, led by Wichita State University (Wichita, KS), will leverage advances in robotic manipulation, planning, and control for wire routing to develop and demonstrate an automated complex wire-harness assembly process, a labor-intensive process now completed entirely by hand.
- An **MxD** (DoD) project, led by Boeing (Chicago, IL) and the Missouri University of Science and Technology (Rolla, MO), has developed a software tool that virtually replicates a supplier's machines and verifies the supplier's ability to produce parts to required design specifications. This assurance allows equipment manufacturers to source supply chains with confidence and build a trusted network of suppliers with certified capabilities in order to save time and money.

Advanced Manufacturing Workforce: Over 200,000 Participated in Institute-Led Education and Workforce Development Training Programs

A key differentiator of the institutes is a holistic approach to U.S. manufacturing competitiveness, including the availability of a well-qualified manufacturing workforce. Since the passage of the RAMI Act in 2014, workforce issues have become increasingly important to the U.S. industrial base, evidenced by reports of a shortfall of 2.4 million workers between 2018 and 2028, worker training and availability rising to the top of Manufacturing CEO's list of needed actions, and a growing mismatch between the current worker skills and the required skills for advanced manufacturing workers.[34]

[34] *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.

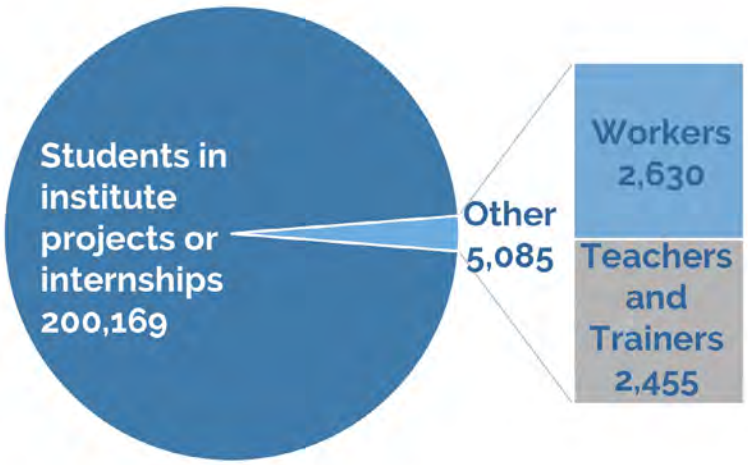


Figure 12. Number of individuals who received training in FY 2018.

Institutes develop and implement education and workforce development activities that increase or improve workforce preparedness for the advanced manufacturing jobs of the future, including technicians, digitally skilled production workers, laboratory personnel, manufacturing engineers, and scientists. Each Manufacturing USA institute supports the recruitment, development, and, in some cases, placement of advanced manufacturing workers in its particular technology area. Education and workforce activities span "K through gray" (from kindergartners to senior citizens), and projects are intended to accomplish the following:

- Use hands-on experiences to enlarge the pipeline of K–12 students aware of, or interested in, STEM and manufacturing careers.
- Support those interested in technical training, community colleges, or universities.
- Deliver advanced, just-in-time training to the existing workforce to assist upward career trajectories.
- Connect students to apprenticeships, internships, and full-time employment, both regionally and nationally.

The 205,254 individuals who participated in one of the many institute-led education and workforce activities in FY 2018 included 200,169 students involved in an educational or training program and 2,630 individuals already in the workforce who completed an institute-led certificate, apprenticeship, or training program. In addition, 2,455 teachers and trainers participated in the institutes' instructor training (see Figure 12 above). The total number of participants grew by 14,000 from FY 2017 and is seven times larger than the FY 2016 total. Examples of the institutes' impact on education and workforce development include the following:

- **MxD** (DoD) created the first massive open online course on digital manufacturing and design. More than 30,000 people have accessed the curriculum so far.
- **NIIMBL** (DOC) announced the NIIMBL eXperience, developed in partnership with the National Society of Black Engineers (NSBE), which invites students completing their freshman years at historically black colleges and universities (HBCUs) to travel to NIIMBL member sites and federal agencies to gain insight into the variety of career opportunities available in the biopharmaceutical industry.
- The first group of 11 university seniors completed the **AIM Academy's** hands-on research internship program at the Massachusetts Institute of Technology (Cambridge, MA), the State University of New York Polytechnic Institute (Utica, NY), the University of California at Santa Barbara, and the University of Arizona (Tucson, AZ). The program was designed to let students contribute to emerging photonics technologies.

IACMI's Internship Program Leads Students to Careers in Engineering and Manufacturing

"We hosted an excellent intern last year from IACMI who made a significant contribution to the experimental research work we were doing. The selection process IACMI offers provides an efficient way to find the exact candidates we need. We were excited to participate in the program this year as well and were able to select three outstanding interns who are already making a positive contribution to our work."

— Truman Bonds, President of RMX Technologies

IACMI's Internship Program hosted its largest class in 2018, and every intern who graduated received an industry job offer or was accepted into a graduate program. Forty-three interns, who worked with mentors to gain hands-on experience with composites research and production in a variety of industries, were placed at 21 innovation facilities, including private-industry facilities, academic institutions, and national laboratories across the U.S.

As the IACMI Internship Program established itself as a rewarding and meaningful learning vehicle, members embraced the opportunity to engage its elite group of students. Eight IACMI members and two regional partners hosted interns over the summer at facilities across the U.S. Industry hosts included Ford (Detroit, MI), DuPont (Troy, MI, and Wilmington, DE), Vartega (Boulder, CO), TPI Composites (Newton, IA, and Warren, RI), RMX Technologies (Knoxville, TX), Local Motors (Knoxville, TX), Michelman (Cincinnati, OH), and Arkema (King of Prussia, PA). Regional partner hosts included the Composites Prototyping Center and the Composites Recycling Technology Center.

IACMI is proud of the diversity of the program. Of this year's class, 38% are women — more than double the national average of women in engineering. By increasing the diversity of internships and candidates, IACMI is increasing and strengthening the future U.S. manufacturing workforce.

A **NextFlex** (DoD) program, FlexFactor, completed its 19th cycle of manufacturing entrepreneurship training across eight schools in six school districts in Silicon Valley. Boeing (Huntsville, AL) awarded $250,000 to fuel a local adoption of the initiative within the Alabama Community College System (Montgomery, AL) and several school districts in Alabama's greater Huntsville/Madison County region.

- **CESMII** (DOE) conducted a Smart Manufacturing Platform Overview and Approach training webinar for each of its three Regional Manufacturing Centers and their associated memberships. The webinar serves as a prerequisite for future smart-manufacturing coursework.
- The **America Makes ACADEMI** (DoD) delivered additive manufacturing technical knowledge in an accelerated course to industry professionals through a curriculum consisting of immersive experiences and skills training from multiple disciplines employed in the Design for Additive Manufacturing process.

New Metrics for Greater Understanding of the Impact of the Institutes on Education and Workforce Development

In FY 2018, an AMNPO task team, including sponsoring agencies and institute directors, explored expanding the Manufacturing USA performance metrics to gain greater understanding of program performance. By December 2018, a draft set of potential performance measures was developed in the general categories of Financial, Operations, Ecosystem, and Education and Workforce Development (EWD).

The Manufacturing USA EWD Working Group further developed and defined a set of performance measures and collected FY 2018 data from nine institutes as a pilot to determine the value of the additional information. The working group found value in the analysis but agreed on the need to refine it in future years to ensure sufficient benefit to justify the time and expense required from institutes and funding agencies to collect and analyze the data.

The EWD data presented earlier in this report includes three metrics: total number of participants, number of completed certificates, and number of teachers/trainers. As detailed in the tables below, the proposed set of expanded EWD metrics includes 21 measures in 5 categories:

- Individuals participating in institute EWD projects or institute-led EWD activities: total (as previously reported) and subdivided into three separate communities of learners (K–12 students, postsecondary students, and individuals already employed full- or part-time in the manufacturing workforce).
- Individuals completing an institute-aligned certification: total (as previously reported) and subdivided into professional certification, apprenticeship, and training programs
- Number of teachers and trainers participating in institute-led training (as previously reported)
- Number of EWD projects or activities operated by the institute: total and by funding sources
- Funding expended for EWD projects and activities operated by the institute: total and by funding sources.

The distribution of participants for the nine sample institutes by community of learning shows that 97% of participants were K–12 students, while 1% represented postsecondary students and 2% represented the current workforce. The large number of K–12 students highlights the need for recruiting students within the educational pipeline to pursue manufacturing as a career choice. The two other categories correspond to educating, credentialing, or upskilling those who have already shown interest in advanced manufacturing. Table 5 shows the distribution of participants by communities of learners.

The institute participants in the EWD Working Group report that the predominance of K–12 students is due in part to the fact that the cost per K–12 student is significantly lower than that for associate degree, bachelor's degree, or certificate students because the younger students are organized into larger groups by their schools and school districts.

The breakdown of institute education and workforce development projects by funding source for nine sample institutes is shown in Table 6 and Table 7. Table 6 shows the distribution of funding partners from five organizational groups by number of projects, and Table 7 shows the distribution of funding expenditures across the same five organizational groups. The data show that 71% of all EWD projects are funded by base institute funding, constituting 59% of expenditures. This data can be cross-referenced to draw some key observations. For example, the average funding per project is highest from nonprofit organizations or federal competitive support and lowest for projects supported by industry or state and local governments. After further evaluation, a decision will be made whether to continue this type of metrics.

Table 5. Breakdown of Education and Workforce Development Project Partners for Nine Sample Institutes

Individuals participating in institute EWD projects or institute-led EWD activities, in total and within three separate communities of learning.	**TOTAL NUMBER OF INDIVIDUAL EWD PARTICIPANTS FOR FISCAL YEAR**	**196,586**
	K-12 PARTICIPANTS: students enrolled full-time in primary or secondary schools and GED candidates not employed full-time in current workforce	**191,407**
	POST-SECONDARY PARTICIPANTS: postsecondary students (full- or part-time) not employed full-time in the current workforce, e.g., a college student or worker taking a career and technical education class to prepare for a new career	**1,499**
	MANUFACTURING WORKFORCE PARTICIPANTS: individuals employed full- or part-time in the manufacturing workforce, whether or not their participation eventually leads to a credential	**3,680**

Table 6. Breakdown of Education and Workforce Development Project Partners for Nine Sample Institutes

Number of EWD projects or activities operated by the institute in FY 2018, total and by funding source	**TOTAL NUMBER OF EWD PROJECTS AND ACTIVITIES OPERATED BY THE INSTITUTE IN FISCAL YEAR**	**162**
	BASE-FUNDED PROJECTS: resourced by institute using base Federal funding from the original cooperative agreement (CA) or technology investment agreement (TIA)	**45**
	COMMERCIAL FUNDED PROJECTS: provided from industry, regardless of membership status	**10**
	FEDERAL AGENCY FUNDED PROJECTS: resourced from Federal funding outside the base CA or TIA funding	**9**
	STATES/LOCAL FUNDED PROJECTS: resourced from state or municipal government funding	**32**
	OTHER FUNDED PROJECTS: resourced from philanthropic organizations, non-profits, foundations, or associations	**10**

Table 7. Breakdown of Education and Workforce Development Funding Sources for Nine Sample Institutes

Expenditures in FY 2018 for EWD projects and activities operated by the institute, total and by funding source	**TOTAL EXPENDITURES FOR EWD PROJECTS AND ACTIVITIES OPERATED BY THE INSTITUTE IN FISCAL YEAR**	**$ 9,032,878**
	BASE FUNDING EXPENDED: resourced by institute using base Federal funding from the original CA or TIA.	**$ 5,410,035**
	COMMERCIAL EXPENDITURES: provided from industry, regardless of membership status	**$ 66,300**
	FEDERAL AGENCY EXPENDITURES: resourced from Federal funding outside the base CA or TIA funding	**$ 1,152,223**
	STATE/LOCAL FUNDING EXPENDED: resourced from state or municipal government funding	**$ 664,317**
	OTHER EXPENDITURES: resourced from philanthropic organizations, nonprofits, foundations, or associations	**$ 1,740,003**

Manufacturing USA Coordination and Collaboration

Coordination and collaboration throughout the Manufacturing USA network has helped new institutes as they have commenced operations, existing institutes as they have expanded, and network participants as they have formed cooperative relationships. This section highlights collaborative activities enabled by Manufacturing USA, including sharing of best practices and coordination of research, technology-development activities, and education and workforce development programs. The Manufacturing USA program was complemented by the network's engagement with other government agencies and programs, such as the NIST Manufacturing Extension Partnership and by leveraging other government investments, such as those from National Science Foundation and NIST laboratory programs.

Figure 13. The April 2018 Manufacturing USA network meeting was held at NextFlex in San Jose, California. Credit: NextFlex

Network Meetings

The AMNPO, with agency partners and institute leadership, convened a Manufacturing USA network meeting in April 2018 hosted by NextFlex in San Jose, California. There, institute leaders and the lead federal agencies that support their operations came together to share experiences, generate new ideas, and identify new opportunities for cross-institute cooperation. The meeting also provided the newer institutes opportunities to learn from the experience of the more established institutes.

The 80 meeting attendees shared institute updates and participated in discussions that addressed the following topics:

- Vision and challenges for the next phase of the program
- Methods and metrics for measuring program performance
- Comparison of Manufacturing USA with similar programs in other countries
- Renewing efforts to build brand awareness, including various outreach events
- How the NIST Manufacturing Extension Partnership (MEP) Embedding Program works with institutes.

The meeting also included premeeting and parallel working sessions for specific interest groups, such as the Institute Directors Council, an executive session for institute directors and senior federal leaders and the EWD team.

Education and Workforce Development Collaboration

The Manufacturing USA EWD team was active in FY 2018, participating in monthly teleconferences and face-to-face quarterly meetings, where the team shared lessons learned from across the Manufacturing USA network and gave participants information about educational methodologies for teaching new manufacturing technologies. EWD leaders often share the same challenges, despite different technology focuses, making these meetings invaluable vehicles for collaboratively developing solutions to common roadblocks.

The network meetings encouraged communication and collaboration and provided information about outreach, funding, and partnership opportunities. Several cross-institute working groups were formed and several secured funding from the DoD's Manufacturing Engineering Education Program.

EWD team members include institute education and workforce directors, human-capital and STEM-educational experts, and representatives from seven

[35] The Departments of Commerce, Defense, Education, Energy, and Labor; the National Aeronautics and Space Administration; and the National Science Foundation.

participating federal agencies.[35] Team members from the Department of Labor's Employment and Training Administration and from the Department of Education (ED) regularly provided information about upcoming grant opportunities, grant awards, and meetings of interest to the institutes — for example, the ED's "Partnership Formation and Development in Manufacturing,"[36] a series of four interactive webinars with leaders of manufacturing speaking about improving the education-to-workforce pipeline. The team developed a common narrative presentation that institutes can use in meetings with stakeholders to highlight the importance of education and workforce development for advanced manufacturing.

At the quarterly face-to-face meetings held at RAPID (New York, NY), DC Dialogue (Washington, D.C.), NextFlex (San Jose, CA), and America Makes (Youngstown, OH), institutes shared their experiences and best methods for setting up internships and apprenticeships and discussed their importance for training next-generation technology workers. At these meetings, the EWD team heard from thought leaders in manufacturing and workforce development, including a team from the United Kingdom's High Value Manufacturing (HVM) Catapult institutes, who shared their experience benchmarking EWD efforts around the world.

Network Engagement by Government Agencies That Leverages Other Government Investments

Manufacturing USA and its associated institutes provide resources for manufacturing innovation that span the transitions from manufacturing research to advanced manufacturing technologies, business development, and market access. Coordination and alignment of the activities of the Manufacturing USA institutes with the investments of key federal agencies complements and strengthens manufacturing innovation and career development.

This alignment allows federal agencies to focus on supporting technology projects and facilities that complement the resources and expertise of the institutes and derive new resources and expertise from the institutes. As a result, the U.S. economy benefits from the translation of promising discoveries and inventions from research laboratories to the institutes and their member companies and the Nation gets the technology it needs for its defense, energy, health care, and other challenges. Agency programs also support the education of highly skilled technicians, designers, planners, researchers, engineers, and managers employed in U.S. industry. The following are examples of network engagement with NIST MEP, the manufacturing programs at the National Science Foundation (NSF), and NIST laboratory programs.

The Manufacturing Extension Partnership

More than 99% of the 291,000 factories in the U.S. are small and medium-sized manufacturers (SMMs) with fewer than 500 employees, making smaller manufacturing companies critical to U.S. supply chains and local economies.[37] These companies face significant challenges when it comes to implementing new manufacturing technologies.

The MEP National Network, which works with SMMs to help them create and retain jobs, increase profits, and save time and money, includes the MEP National Program Office (NIST MEP), 51 MEP Centers located in all 50 states and Puerto Rico, and more than 1,300 manufacturing experts at over 400 service locations, providing U.S. manufacturers with access to resources they need to succeed.[38]

To help expand the reach of the Manufacturing USA program to SMMs, the RAMI Act directed the Secretary of Commerce to ensure that AMNPO incorporates MEP into planning for the Manufacturing USA program network.[39] MEP signed memoranda of understanding with the DoD in 2015[40] and with the

[37] American FactFinder, Department of Commerce, U.S. Census Bureau. https://factfinder.census.gov/bkmk/table/1.0/en/BP/2016/00A1.

[38] About NIST MEP, Department of Commerce, National Institute of Standards and Technology. https://www.nist.gov/mep/about-nist-mep.

[39] Revitalize American Manufacturing and Innovation Act of 2014 (Pub. L. 113-235, codified in relevant part at 15 USC 278s(f)(5)).

[40] Memorandum of Understanding Between the U.S. Department of Defense, Office of the Secretary of Defense, Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy and the U.S. Department of Commerce, National Institute of Standards and Technology, Hollings Manufacturing Extension Partnership (May 2015). https://www.nist.gov/sites/default/files/documents/mep/about/MOU-NIST-OSD-Signed-Executed-2015.pdf.

The Impact of the MEP Embedding Program on Manufacturing USA

Environmental Composites Inc. *(Utica, NY), with assistance from New York MEP, continued development and testing of thermoplastic composite materials that reduce the production time for carbon-fiber-reinforced components from 2 hours to under 3 minutes. A range of material formats for transportation, consumer, and medical products have entered customer validation testing, and the developed concept and material have have been commercialized for football shoulder pads used by National Footbal League players. Further growth opportunities have been identified with the help of NY MEP, and the Tennessee MEP Center is engaging with REMADE and IACMI through a technology-driven market-intelligence effort.*

Dynamic Car *(Saginaw, MI), with assistance from Michigan MEP, connected with the Aluminum Extruders Council (Wauconda, IL), a member of LIFT, to design and develop vehicle frames with desired performance characteristics for high-performance vehicles. The frame solution has implications well beyond Dynamic Car's replica cars, suggesting similar applications for trolleys, military vehicles, ATVs, electric vehicles, and heavy-duty trucks.*

Carpe Diem Technologies Inc. *(Franklin, MA), with assistance from MassMEP and NextFlex, started a project to develop equipment for printing microstructures and electronics on flexible substrates, such as foil, paper, or plastics, which are water- and bacteria-repellent and can capture or guide photons for optics, sensors, or solar cells, as well as enhance battery performance. This effort will be further expanded though a $2.15 million capital grant the company received from the Massachusetts Manufacturing Innovation Institute thanks to the pilot study enabled by the embedding program.*

Metal Products *(Springfield, OR), with assistance from Oregon MEP and RAPID, produced special lamina for a new microchannel heat exchanger, which ensures flawless operation through daily temperature swings of more than 700 °C in the presence of hydrogen.*

DOE in 2017[41] that defined how the institutes and the MEP Centers should work together to accomplish the following:

- Facilitate awareness and outreach of the institutes' technical areas to SMMs
- Involve SMMs in institute research and development planning
- Encourage SMMs to participate in institute research and development
- Implement institute research and development results.

Since the program's establishment, institutes have coordinated with MEP Centers to engage SMMs. In early FY 2017, the MEP National Network established a formal embedding program to connect small manufacturers with technologies and resources available through Manufacturing USA institutes. Following a formal competitive process, 14 awards totaling $15.5 million were made to fund two-year pilot projects, each of which supported at least one staff member physically located at the partner institute (see Table 8 on next page).

The pilot projects conducted outreach to inform SMMs about the various opportunities available in the technology focus areas and their associated industries. Through the end of FY 2018, the embedding projects reported serving 62 manufacturing clients and completing 75 projects, more than 70% of which were related to innovation services, including technology deployment, engineering assistance, and growth services. The projects cover three categories: technology transfer from institutes, impact on supply chain, and workforce development.

[41] Memorandum of Understanding Between the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, and the U.S. Department of Commerce, National Institute of Standards and Technology, Hollings Manufacturing Extension Partnership (February 2017). https://www.nist.gov/sites/default/files/documents/2017/04/26/doe_amo-nist_mep_mfgusa_mou_-_final_-_signed.pdf.

Table 8. Manufacturing USA Institute and MEP Center Engagement

Manufacturing USA Institute	MEP Center
NextFlex	California Manufacturing Technology Center
MxD	Illinois Manufacturing Excellence Center
AIM Photonics and REMADE	New York State Department of Economic Development
PowerAmerica	North Carolina State University
IACMI	The University of Tennessee (Center for Industrial Services)
CESMII	California Manufacturing Technology Center
AFFOA	MassMEP
LIFT	Michigan Manufacturing Technology Center
America Makes	Pennsylvania Manufacturing Extension Partnership
NIIMBL	Delaware Manufacturing Extension Partnership
BioFabUSA	MassMEP
RAPID	Oregon Manufacturing Extension Partnership
ARM	Pennsylvania Manufacturing Extension Partnership

National Science Foundation

The National Science Foundation (NSF) has research and career training programs in advanced manufacturing designed to develop fundamental understanding of how materials can be transformed into products using manufacturing processes and systems. NSF research projects performed at U.S. colleges, universities, and small businesses train future U.S. advanced-technology workers as they explore new technologies beyond the cutting edge of what is possible today. As fundamental breakthroughs proceed toward application, those projects provide an upstream pipeline of new ideas for the institutes while benefiting from the knowledge, experience, and facilities the institutes and their industry members provide. In FY 2018, the NSF funded $6.8 million for projects stimulated by three Dear Colleague Letters (DCLs) that encourage researchers and educators to submit proposals that require collaboration with Manufacturing USA institutes, bringing total cumulative funding to more than $10 million.

Dear Colleague Letter 17-088: Supporting Fundamental Research to Enable Innovation in Advanced Manufacturing at Manufacturing USA Institutes:[42] This DCL encourages the submission to the NSF of proposals that align with the technical areas of the Manufacturing USA institutes. Proposals may be submitted to any NSF program or solicitation, following the instructions in the DCL. Such proposals competed in the normal review process for funding. Ten projects totaling $4.55 million were funded in FY 2018 at 11 universities to work with America Makes, ARM, IACMI, LIFT, NextFlex, NIIMBL, and RAPID.

Dear Colleague Letter 18-095: Research on Integrated Photonics Using AIM Photonics Capabilities:[43] This DCL encourages innovative exploratory and translational research by academic researchers and small businesses in all aspects of integrated photonics that utilize the current silicon-photonics capabilities resident in AIM Photonics. The organization has taken the lead in publishing a detailed protocol for submitting photonic circuit designs to AIM Photonics multiproject wafer runs for fabrication as part of proposals to the NSF. Four

[42] NSF 17-088 Dear Colleague Letter: Supporting Fundamental Research to Enable Innovation in Advanced Manufacturing at Manufacturing USA Institutes (May 25, 2017). https://www.nsf.gov/pubs/2017/nsf17088/nsf17088.pdf.

[43] NSF 18-095 Dear Colleague Letter: Research on Integrated Photonics Utilizing AIM Photonics Capabilities (July 20, 2018). https://www.nsf.gov/pubs/2018/nsf18095/nsf18095.pdf.

projects totaling $1.41 million were funded in FY 2018 at three universities and a small business to work with AIM Photonics.

Dear Colleague Letter 16-007: Advanced Technological Education (ATE) Program Support for Manufacturing Innovation Institutes (MIIs) and Investing in Manufacturing Communities Partnerships (IMCPs):[44] The ATE program focuses on the education of technicians for the high-technology fields that drive the U.S. economy, with an emphasis on two-year community and technical colleges. The program creates partnerships between academic institutions and industry to promote improvements in the education of science and engineering technicians at undergraduate institutions and secondary schools. Four projects were funded in FY 2018 with total funding of $853,000 to work with AFFOA, AIM Photonics, ARM, NIIMBL, and PowerAmerica.

To facilitate the establishment of research pipelines in manufacturing flexible hybrid electronics, the NSF sponsored the NSF-NextFlex Workshop on Accelerating Innovative Manufacturing Technology for Flexible Hybrid Electronics at NextFlex headquarters in San Jose, California, in August 2018. The workshop engaged the NSF academic-research community and the NextFlex industry community in discussions on emerging opportunities in the manufacturing of flexible hybrid electronics, with an emphasis on identifying the needs for research and education.

NIST Laboratory Programs and the Advanced Manufacturing Technology Consortium

NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve quality of life. The NIST laboratories approach this mission by working with industry to provide measurement science and standards critical to the success of the Nation's manufacturing sector. The development and effectiveness of the institutes' manufacturing innovations is enhanced through collaborations with the NIST laboratories, whose programs cover all areas of the institutes, including additive manufacturing, smart-manufacturing systems, robotics for smart manufacturing, advanced materials measurements, Standard Reference Materials, the Materials Genome Initiative, physical measurements, and biomanufacturing. The technical expertise of the NIST staff has led to productive engagement with each of the institutes, and NIST has identified a senior scientist to act as technical lead to coordinate NIST laboratory resources to support each institute.

In addition, NIST staff have active technical collaborations and advisory roles within the institutes, ranging from project collaborations and leadership roles in institute roadmapping to serving on institute technical advisory councils and executive committees. NIST also provides subject-matter experts to help other agencies develop topics for new institutes.

The NIST Advanced Manufacturing Technology Consortia (AMTech) program was a competitive grants program created to establish new — or strengthen existing — industry-driven manufacturing consortia addressing high-priority research challenges in order to grow advanced manufacturing in the U.S. Competitions were held in 2013 and 2014, and 35 awards were made in 2014 and 2015. The consortia developed technology roadmaps that guided research for members and nonmembers. The roadmaps accelerated research in promising directions while preparing U.S.-based supply chains for likely new technologies. While AMTech is not associated with the Manufacturing USA program, AmTech roadmaps contributed to the initiation of the following five Manufacturing USA institutes: AIM Photonics, MxD, LIFT, NIIMBL, and REMADE.

External Assessments

As required under the RAMI Act,[45] the Comptroller General of the Government Accountability Office (GAO) undertook a formal assessment of the Manufacturing USA program toward the end of FY 2018. The results, and the GAO's recommendations, were provided to the AMNPO in FY 2019 and will be included in the FY 2019 Manufacturing USA Annual Report. Manufacturing USA was also the subject of several congressional briefings in FY 2018 and a National Academy of Engineering workshop in early FY 2019.

[44] NSF 16-007 Dear Colleague Letter: Advanced Technological Education (ATE) Program Support for Manufacturing Innovation Institutes (MIIs) and Investing in Manufacturing Communities Partnerships (IMCPs). https://www.nsf.gov/pubs/2016/nsf16007/nsf16007.pdf.

[45] Revitalize American Manufacturing and Innovation Act of 2014 (Pub. L. 113-235, codified in relevant part at 15 USC 278s(g)(3)).

NSF Helps Small Businesses and Universities Work With AIM Photonics

AIM Photonics has taken the lead by publishing a detailed protocol that enables NSF-funded research projects to fabricate advanced photonics circuits in AIM Photonics multiproject wafer runs. In 2018, NSF support allowed three universities and a small business to make use of the world-leading fabrication facility available at AIM Photonics.

Small Business Creates State-of-the-Art Photonics Prototype

Using an NSF Phase I Small Business Innovation Research grant, Axalume (San Diego, CA), a photonic-semiconductor startup, quickly established a market presence by partnering with AIM Photonics to produce high-speed laser transmitters for high-performance computing and data center networking systems (see Figure 14 below). The company, which does not own any fabrication equipment, leveraged AIM Photonics resources to design and prototype advanced silicon circuits that combine photonics with electronics.

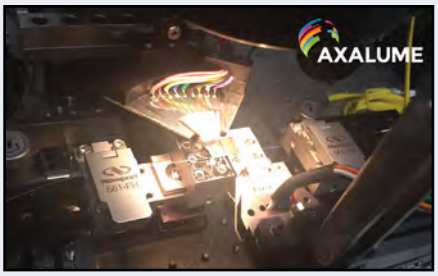


Figure 14. Laser transmitters for high-performance computing and data center networking. Credit: Ashok Krishnamoorthy, Axalume

Neuromorphic Computing Chips for Machine Learning

Researchers at the Rochester Institute of Technology (Rochester, NY) are working with AIM Photonics to prototype high-efficiency photonics-based neuromorphic computing chips for application in high-performance machine learning (see Figure 15 below). AIM Photonics' state-of-the-art photonic foundry allows rapid fabrication of novel designs with high integration density and high yields of working devices; AIM's Rochester-based Test, Assembly, and Packaging (TAP) facility packages the chips with electronics and optical fiber inputs and outputs.

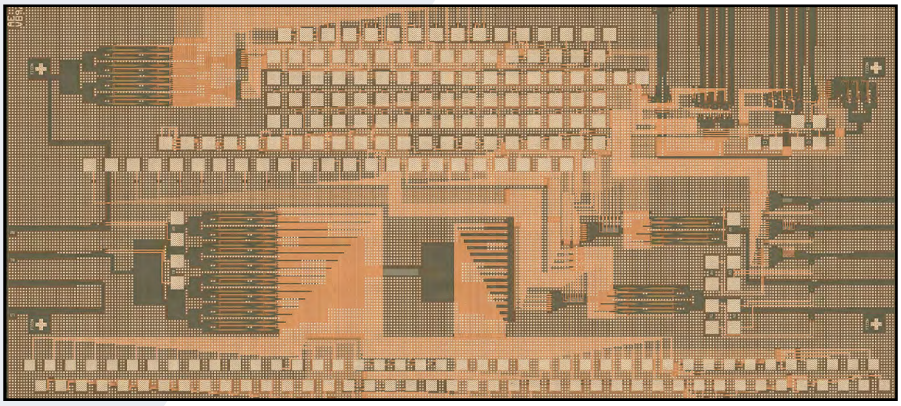
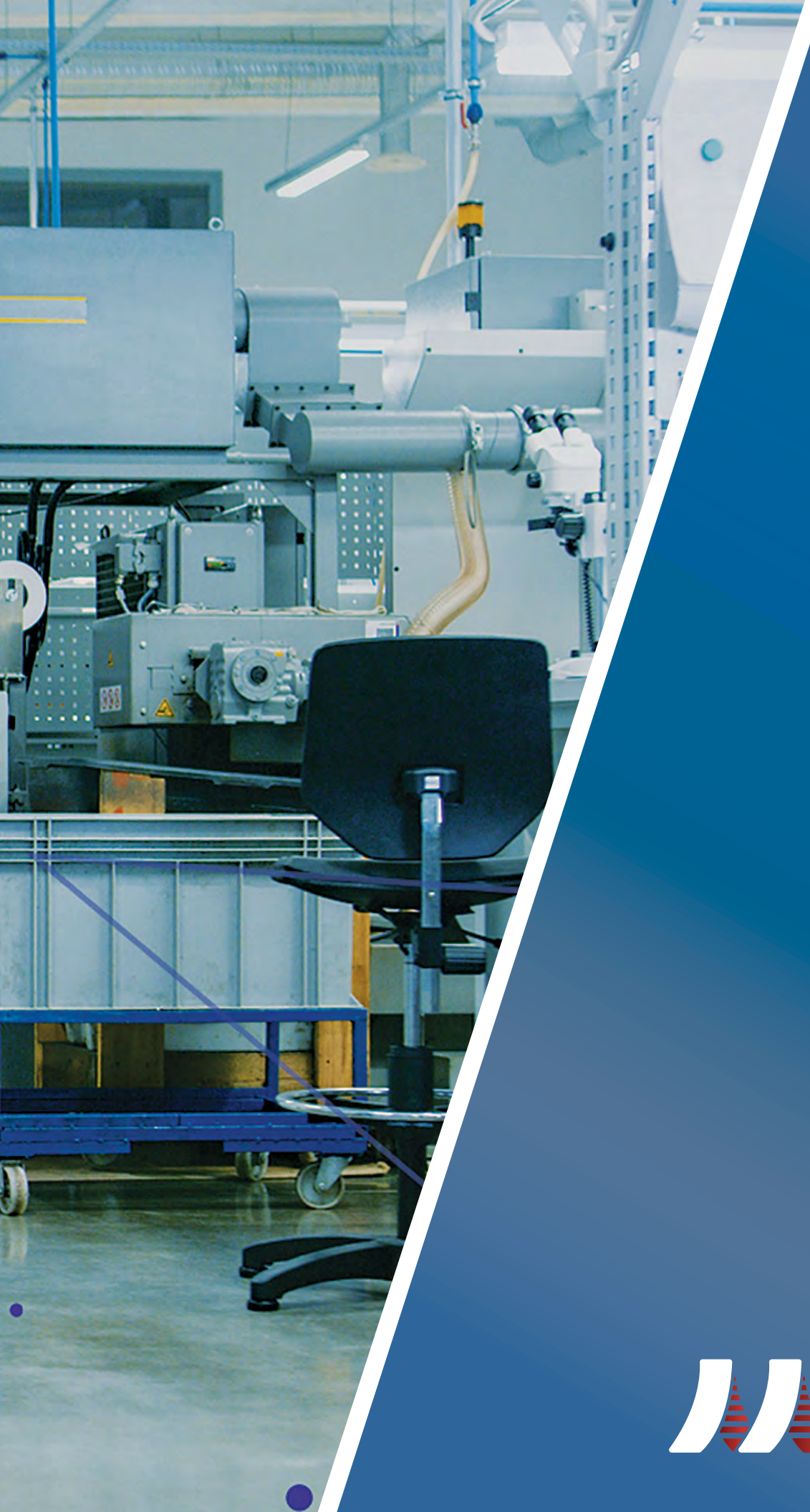


Figure 15. Neuromorphic photonic chips manufactured at AIM Photonics. Credit: Stefan Preble, Rochester Institute of Technology

Photonics-Based Circuits for Next-Generation Wireless Communications

University of Delaware (Newark, DE) researchers are working with AIM Photonics to integrate new photonic materials into the AIM Photonics fabrication facility. Advanced radio-frequency photonic chips based on those materials will enable the high-performance lasers and modulators needed for wireless 5G communications technology and beyond.

Credit: CESMII



SUMMARY OF INSTITUTE ACTIVITIES 2018

Manufacturing USA®

Department of Commerce Institute Highlights

Senator Chris Coons, Under Secretary of Commerce Walter G. Copan, and NIIMBL Director Kelvin H. Lee at the construction site for the Carol A. Ammon and Marie E. Pinizzotto Biopharmaceutical Innovation Center at the University of Delaware. This new facility will house the headquarters for NIIMBL. Credit: NIIMBL

Credit: NIIMBL

NIIMBL

The National 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

ESTABLISHED: March 2017

CONSORTIUM ORGANIZER: University of Delaware

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

MEMBERS (as of September 30, 2018): 106

NIIMBL

niimbl.org

Background

The National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL) advances the manufacturing capabilities of biopharmaceutical medicines—those made from biological sources, such as living cells—through technology innovation, workforce training, and standards development. These medicines improve and save lives by treating debilitating conditions including cancer, diabetes, autoimmune disorders, and bacterial and viral infections. NIIMBL works to improve on current manufacturing technologies and processes for existing products and develop new commercial-scale manufacturing platforms for emerging products, such as cell and gene therapies. The institute's work will enable the rapid and cost-effective manufacture of safe and effective biopharmaceuticals.

Technology Advancement

"Scientific advancements are driving the evolution of next-generation platforms, products, and methods in biologics manufacturing. NIIMBL has allowed multi-stakeholder collaborations to collectively navigate technical and regulatory hurdles, thereby fostering innovation and accelerating technology implementation."

— Audrey Chang, MilliporeSigma

New Projects Launched in FY 2018

In FY 2018, NIIMBL funded 23 projects that address key problems in biopharmaceutical manufacturing, including:

- **Getting Safe Medicines to Patients Faster:** NIIMBL members at the University of Maryland, Baltimore (Baltimore, MD) and ChromaTan (Philadelphia, PA) are pioneering a revolutionary approach to measuring contaminants in process streams that should enhance patient access to medicines by shortening the manufacturing time and thereby reducing costs. Expenses are high because current technologies rely on batch processing rather than continuous processing. Process-analytical technology that monitors manufacturing to ensure production of appropriate and safe medicines is critical to help the field achieve the benefits of continuous processing.

- **Detecting Viral and Bacterial Contaminants:** Two NIIMBL projects led by Carnegie Mellon University (Pittsburgh, PA) and Accugenomics (Wilmington, NC) focus on advanced methods for rapid detection of adventitious agents, bacterial or viral contaminants present in manufacturing processes and drug products. Standard industry methods for their detection are offline and laborious and take three weeks to complete. These projects intend to create efficiencies in the manufacturing process by allowing manufacturers to quickly identify and eliminate contaminants, ensuring an adequate supply of safe, high-quality medicines for the U.S. public.

- **Preparing for the Future: Gene Therapy Vector Production:** North Carolina State University (Raleigh, NC) and its partners are tackling the expense of gene therapy by developing a scalable platform process for production, purification, and analysis of adeno-associated virus vectors, a method to deliver DNA directly into a patient's cells. In addition to technology

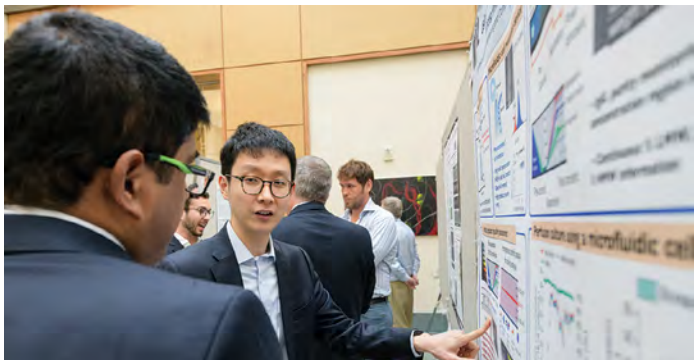


Figure 16. Researchers discuss partnership opportunities to advance readiness levels for innovative technology at the NIIMBL National Meeting in May 2018. Credit: NIIMBL

development, the project aims to strengthen workforce skills for this emerging therapy by developing new coursework and training modules for gene therapy vector production. The project includes Sudhin Biopharma Co. (Superior, CO) and the University of North Carolina at Chapel Hill.

- **Prototyping a Software and Hardware Tool for Pharmaceutical Lyophilization Scale-Up:** NIIMBL members Physical Sciences Inc. (Andover, MA), Genentech (South San Francisco, CA), Merck & Co., Inc. (Kenilworth, NJ), the University of Massachusetts Lowell, the National Institute for Pharmaceutical Technology and Education–University of Connecticut (Storrs, CT), Purdue University (West Lafayette, IN), and the Massachusetts Life Sciences Center (Waltham, MA) are developing software and hardware tools to enable better product stabilization through lyophilization, or freeze-drying. Current techniques are costly and time-consuming, but this project will help manufacturers develop higher throughput processes for more efficient and economical production of higher-quality products.

- **Establishing a Center of Excellence in Host-Cell Protein Analysis:** To ensure safe biopharmaceutical products, they should be free of host-cell proteins (HCP), impurities expressed by the host organism during manufacturing. This Center of Excellence, led by the University of Delaware (Newark, DE), will help biomanufacturers better identify and remove HCP contaminants, which will improve the product's safety and efficacy. In addition, the center will serve as a NIIMBL core facility for understanding HCPs by providing analytical services and supporting projects that rely on HCP analysis.

Workforce Development

> *"NIIMBL is enabling development of training programs related to the manufacture of important new therapeutic modalities, like gene therapy. The resulting training opportunities will benefit patients by accelerating the path of these innovative medicines to the clinic."*
>
> — Gary Gilleskie, Biomanufacturing Training and Education Center, North Carolina State University

NIIMBL is committed to workforce and training efforts to ensure that the U.S. has an adequate source of highly skilled workers to meet the domestic biopharmaceutical sector's needs. This commitment includes training and education opportunities for those new to the industry and for experienced biopharmaceutical professionals. Highlights for FY 2018 include the following:

- **Funding Workforce Development Projects:** Through the project-call process, NIIMBL elected to fund seven workforce development projects developed to enhance training and education resources for students interested in biopharmaceutical careers. One such project, led by North Carolina State University, focuses on designing automated bioprocess test beds across three sites and developing corresponding coursework that will train students on automation topics relevant to engineering, validation, operations, and quality assurance.

- **Assessing Industry Needs:** NIIMBL developed a needs-assessment survey, vetted by NIIMBL industry members for deployment in early 2019, to gain insight into the skills and competencies industry seeks in the next generation of biopharmaceutical workers. The survey results will help NIIMBL partners develop education and training programs.
- **Sharing Information About Education and Training Resources:** NIIMBL developed a new online tool to collect and categorize highly regarded biopharmaceutical training and education programs that several NIIMBL members offer to their communities. Launching in early 2019 as a feature in the NIIMBL Member Community Portal, the "Education & Training" and "Facilities & Resources" modules will allow NIIMBL members to identify and share educational resources. In addition, the tool will assess the strength of current education offerings and identify gaps for NIIMBL to address.
- **Launching the NIIMBL eXperience:** On September 17, 2018, NIIMBL announced the NIIMBL eXperience at the White House Initiative on Historically Black Colleges and Universities Conference in Washington, D.C. In partnership with the National Society of Black Engineers (NSBE), the NIIMBL eXperience enables students completing their freshman year at HBCUs to travel to NIIMBL member sites and federal agencies to gain insight into career opportunities in the biopharmaceutical industry. During their visits, starting June 2019, students will learn about each organization, network with current employees, and tour facilities.
- **Convening Conversations on the Future of the Biopharma Workforce:** NIIMBL continues to engage stakeholders in discussions about the future of the biopharmaceutical workforce. In May 2018, the NIIMBL Workforce Activities Committee held a workshop at the NIIMBL National Meeting in Washington, D.C., that focused on the workplace of tomorrow and best practices for preparing future biopharmaceutical workers.

Figure 17. Cell-culture technician at work in a NIIMBL laboratory at the Delaware Biotechnology Institute. Credit: NIIMBL

Innovation Ecosystem

"We have found our membership with NIIMBL to be incredibly valuable, as we have been afforded the opportunity to work with some amazing individuals and organizations. LumaCyte's innovative label-free single-cell analysis technology (laser force cytology) has benefited from increased exposure through this industry-led consortium, and for a small manufacturer focused on driving innovation into a market that has historically been conservative, our membership has proven to be well worth the commitment."

— Renée Hart, LumaCyte

NIIMBL brings together leading experts from across the biopharmaceutical manufacturing industry. As of September 30, 2018, NIIMBL consisted of 106 members, including large manufacturers and suppliers, small, innovative companies, and leading research institutions. Through project calls and technical workshops, NIIMBL has helped facilitate collaborative partnerships to advance new technologies. In addition, NIIMBL has engaged in a number of efforts to foster collaborations and strengthen the biopharmaceutical innovation ecosystem. These include the following:

- **Organized the Project Call Summit at the University of Maryland College Park:** Coordinated as part of the project-call process, the summit enabled 109 innovators to pitch their ideas and capabilities to an audience of NIIMBL members and federal scientists. This two-day event encouraged teams to form partnerships and discuss collaborative opportunities.
- **Engaged Organizations of All Sizes and in Varying Areas of Expertise Throughout Its Ongoing Technology Roadmapping Efforts:** This initiative invites members and nonmembers to develop guiding documents for the future of the biopharmaceutical industry. More than 40 organizations participated in 3 roadmapping workshops during FY 2018. Roadmaps on gene therapy, vaccines, and antibody-drug conjugates/biospecific antibodies will be published early in FY 2019.
- **Helped Promote and Publicize Technologies Developed by Small Companies:** NIIMBL facilitated this promotion through oral presentations and scientific poster presentations at its national meeting and technology workshops.
- **Support SMMs:** Staff from the Delaware, North Carolina, and Massachusetts MEP Centers focus on the needs of innovative small companies and regularly offer innovation showcases to connect SMMs with large companies.

NIIMBL Hosts Second National Meeting

"NIIMBL provides us the opportunity to work closely with industry, to find out what industry needs, and hopefully come up with practical technologies industry can use."

— Bruce Yu, University of Maryland, Baltimore

A spirit of innovation, collaboration, and community was prevalent at NIIMBL's second National Meeting in Washington, D.C., held on May 16–17, 2018. With an emphasis on celebrating, expanding, and strengthening the NIIMBL network, the event brought together more than 300 representatives from NIIMBL member organizations, the biopharmaceutical community, and government agencies to celebrate the organization's first-year achievements and identify future opportunities for advancing U.S. leadership in biomanufacturing.

The first day of the event, hosted by the National Academy of Sciences, featured presenters who emphasized innovation, collaboration, and new technologies and the benefits of diversity, inclusion, and mentorship. Some highlights include:

- Celgene CEO Mark Alles and MilliporeSigma CEO Udit Batra emphasized their organizations' commitment to partnering with the NIIMBL co-mmunity.
- FDA leaders Anna Abram, Janet Woodcock, and Peter Marks discussed opportunities for improved medicines and the FDA's support for NIIMBL's collaborative approach to solving industry challenges.
- Pfizer's Tim Charlebois moderated a panel discussion featuring FDA leaders, Amgen executive Patrick Swann, and Novartis executive Larry Starke that centered on innovation's impact on healthcare.

- Johnathan Holifield, Executive Director of the White House Initiative on Historically Black Colleges and Universities, and Gail Drake, a mentor with FIRST (For Inspiration and Recognition of Science and Technology) and coach of Robotics Team #1885 from ILITE (Inspiring Leaders in Technology and Education), addressed developing the next generation of professionals through diversity, inclusion, and mentorship initiatives.

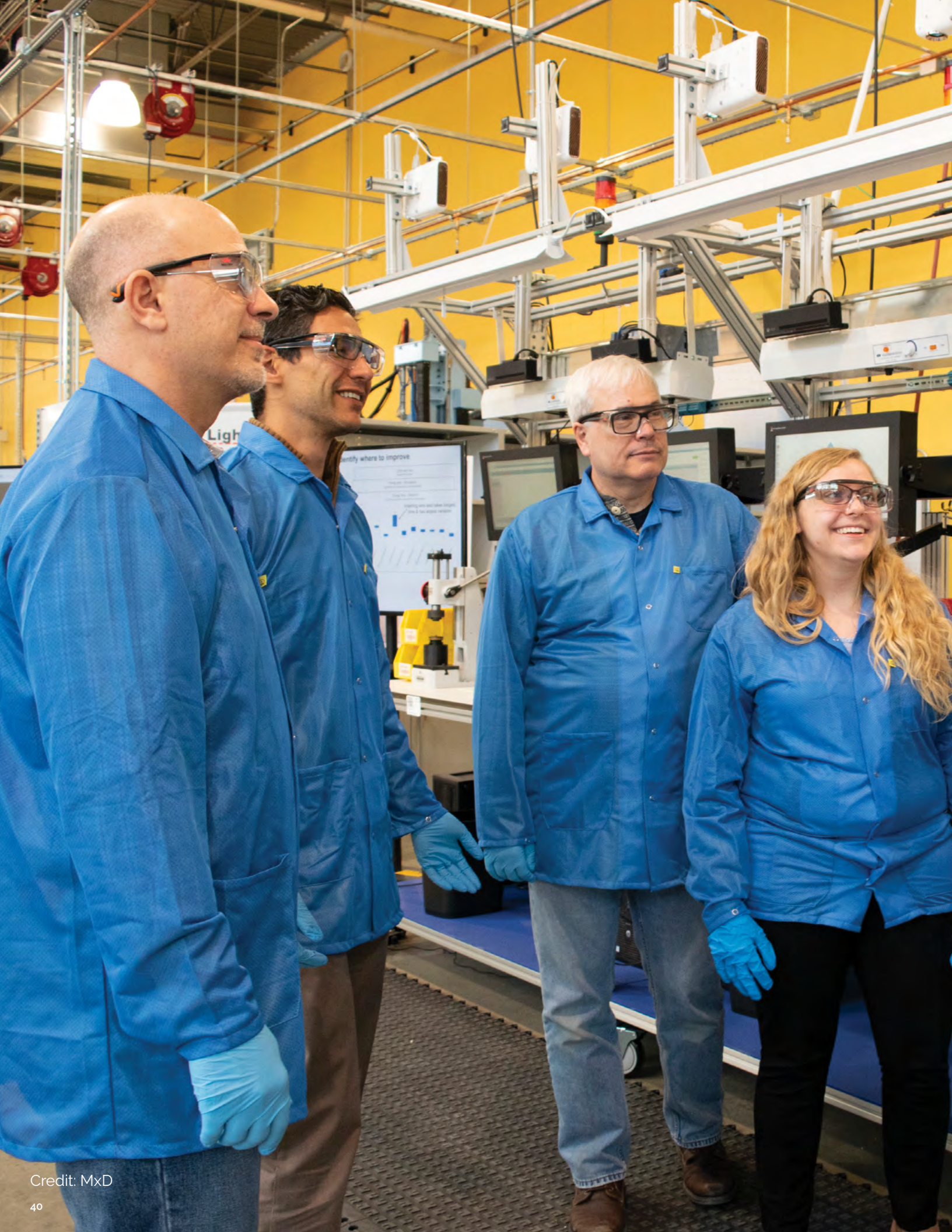
On May 17, NIIMBL members gathered at the Hyatt Regency Crystal City in Arlington, Virginia, for member activities. The agenda included workshops focused on process-analytical technologies and the biopharmaceutical workplace of the future, presentations from NIIMBL-funded project teams, a session on project-call best practices and success tips, and a town hall featuring the announcement of Project Call 2.1, NIIMBL's third call for projects, which focused on technical and workforce needs identified by industry members.

This annual meeting, along with technology workshops and teaming events throughout the year, plays a critical role in supporting partnerships that will drive the industry forward.

"NIIMBL provides a unique structure for collaboration and innovation through a network of leading researchers from industry, academic, and government institutions. Merck is excited to participate in NIIMBL, which provides an active forum to enable scientific exchange as our industry seeks to leverage expertise and capabilities to develop disruptive breakthroughs to advance bioprocess."

— David Roush, Merck & Co., Inc.

Figure 18. NIIMBL annual meeting, National Academy of Sciences. Credit: NIIMBL



Credit: MxD

Department of Defense Institute Highlights

Credit: America Makes

America Makes

The National Additive Manufacturing Innovation Institute

MISSION: Develop and grow a comprehensive and globally competitive U.S. additive manufacturing and 3D printing infrastructure consisting of: world-class domestic sources of 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 and 3D printing.

HEADQUARTERS: Youngstown, OH

SATELLITE LOCATION: The W.M. Keck Center for 3D Innovation at the University of Texas at El Paso

ESTABLISHED: August 2012

CONSORTIUM ORGANIZER: National Center for Defense Manufacturing and Machining

FUNDING: Federal, $65M including support from DoD, DOE, NSF, and NASA; Nonfederal, $68M; both planned over seven years.

Follow-on five-year cooperative agreement: $50M ceiling federal funding and $25.8M nonfederal funding

MEMBERS (as of September 30, 2018): 220

America Makes

americamakes.us

Projects Completed/Ongoing in FY 2018

"The significance of this project for the aerospace industry is tremendous. Our open collaboration with the FAA-funded effort to develop a framework for advanced polymer-based additively manufactured materials, in this case, ULTEM™ 9085, into the NCAMP process was incredibly successful. The project examined an extensive and comprehensive set of machine process controls to understand and measure variability. It yielded the creation of the first, public database of its kind to enable the widespread use of additive technologies in the production of aircraft interiors. Now, aerospace engineers have a baseline understanding of how to design for AM and specify AM as an actual manufacturing tool, as well as the assurance that the first AM part and the last AM part are indistinguishable."

— Tracy L. Albers, Ph.D., President and CTO, Rapid Prototype + Manufacturing (rp+m) LLC

- In June 2018, America Makes published version two of the *Standardization Roadmap for Additive Manufacturing* in conjunction with the American National Standards Institute (ANSI) and with funding from the DoD. The institute leveraged its broad network to convene 320 individuals from 175 public- and private-sector organizations through the Additive Manufacturing Standardization Collaborative to development the roadmap.
- America Makes entered into the third phase of the "Maturation of Advanced Manufacturing for Low-Cost Sustainment" program, funded by the Air Force Research Laboratory. The program's objective is to enhance and improve Air Force sustainment operations through the development, demonstration and transition of advanced manufacturing technologies, including additive manufacturing.
- America Makes ACADEMI delivers additive manufacturing technical knowledge in an accelerated course to industry professionals through a curriculum of immersive training experiences and skills from multiple disciplines employed in the Design for Additive Manufacturing process.
- In June 2018, an America Makes project team successfully completed a database for fused deposition modeling printing of ULTEM™ 9085. This polyetherimide, high-performance thermoplastic material is one of few such materials available for fused deposition modeling with application acceptable ratings for the production of aircraft, vehicles, and other defense and industrial applications that require high-strength thermoplastic materials (see Figure 19 on next page).

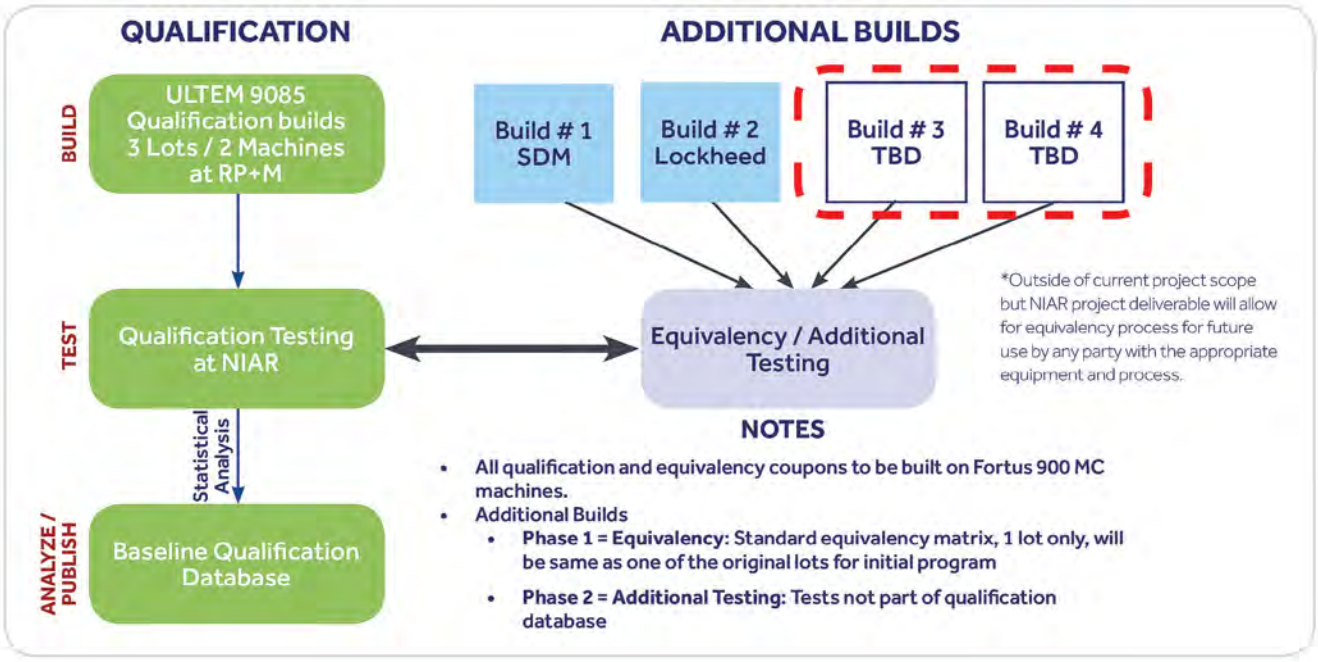
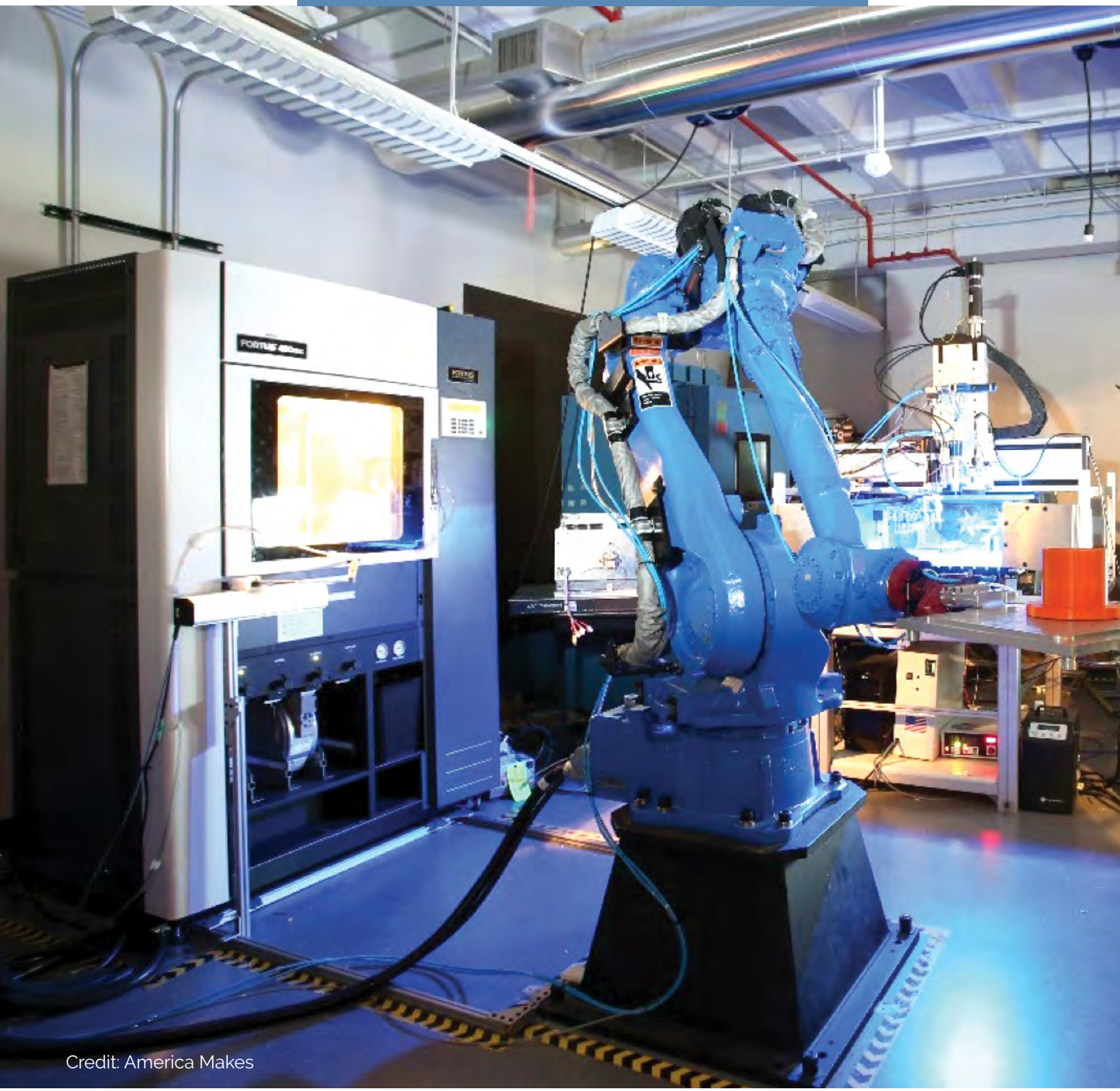


Figure 19. Overview of project plan for qualification and equivalency testing for fused deposition modeling printing of ULTEM™ 9085. Credit: America Makes

New Projects Launched in FY 2018

- America Makes launched their Advanced Curriculum in Additive Design, Engineering and Manufacturing Innovation (ACADEMI) in September 2017 to deliver additive manufacturing–based technical knowledge through an accelerated curriculum of immersive training experiences and Design for Additive Manufacturing process skills development exercises for industry professionals. In May 2018, the institute received DoD funding to build on the initial success and incorporate insights from other Manufacturing USA institutes, the U.S. Army, the U.S. Department of the Navy, OSD Systems Engineering, and the Defense Logistics Agency.
- America Makes convened a project team from Rapid Prototype + Manufacturing (rp+m) LLC, (Avon Lake, OH), Stratasys Inc. (Eden Praire, MN), Wichita State University's National Institute for Aviation Research, the National Center for Advanced Material Performance (Wichita, KS), and Lockheed Martin Missile and Fire Control to build a database which features mechanical properties, physical properties, and processing parameters. Now completed, this new resource is accessible via the America Makes Digital Storefront and enables broad dissemination of the collective knowledge for future part design and integration in various commercial and government applications.



Credit: America Makes

Credit: MxD

MxD

The Digital Manufacturing Institute

MISSION: MxD, the Digital Manufacturing Institute, provides the government and U.S. manufacturers with the digital tools and cybersecurity needed to transform American manufacturing. MxD was formerly known as the Digital Manufacturing and Design Innovation Institute (DMDII).

HEADQUARTERS: Chicago, IL

ESTABLISHED: February 2014

FUNDING: Federal, $83M; Nonfederal, $106M; both planned over five years

MEMBERS (as of September 30, 2018): 325

mxdusa.org

Projects Completed/Ongoing in FY 2018

"This project has been an important step toward digitizing and streamlining the process of getting equipment and materiel from the factory to the foxhole."

—Col. Kenneth Letcher, Commanding Officer, Rock Island Arsenal Joint Manufacturing and Technology Center.

- MxD completed a project led by Rolls-Royce (Indianapolis, IN) that reviewed, evaluated, and tested current tools for creating and transferring 3D models through the supply chain. This project identified the importance of having interoperable programs and proved the need to standardize the data within 3D models to eliminate 2D drawings. The results of this project laid the foundation for additional MxD projects, including Digitally Enabling the Supply Chain with Rolls-Royce and Creating a Model-Based Feature Information Network with Lockheed Martin.
- MxD helped to commercialize an integrated manufacturing variation management technology that was developed by Caterpillar and researchers from the Missouri University of Science and Technology (Rolla, MO) and the University of Illinois at Urbana-Champaign. The software enables the use of laser trackers and scanners to improve quality and reduce waste in manufacturing large die-cast parts to reduce a machine's volumetric error by more than 80% and detect insufficient stock 100% of the time.
- An MxD project, led by Boeing, has developed a software tool that virtually replicates a supplier's machines and verifies their ability to produce parts to the required design specifications. This assurance allows equipment manufacturers to source their supply chains with confidence and to build a trusted network of suppliers with certified capabilities to save time and money.
- MxD executed a Model Based Enterprise assessment of Rock Island Arsenal (Arsenal Island, IL) that provides Army leadership with a roadmap for leveraging digital manufacturing technologies that would increase technical workforce productivity 40% to 45% and lower maintenance downtime by 30% to 50%.

New Projects Launched in FY 2018

"The success of our company also depends on the success of our suppliers. Thousands of small businesses work with us daily, and they have to be successful for us to be successful. That has been part of the value proposition of MxD."

— Ademola Idowu, Senior Research Scientist & Innovation Program Leader, Dow

- MxD launched the National Center for Manufacturing Cybersecurity. This hub will be a testbed for the creation and adoption of new cybersecurity technologies to help secure the supply chain and the warfighters who rely on these capabilities.
- MxD's created the first massive open online course on digital manufacturing and design available to anyone online. More than 30,000 people have accessed the curriculum so far.
- A new MxD project will develop a system that 1) scours the landscape for events that could disrupt supply chains, 2) assesses the risks, and 3) suggests solutions using news sources, government agencies, social media, advanced analytics, and machine learning. The validated and benchmarked system will use secure blockchain technology in a cloud-based framework and will be able to communicate with a supply chain manager — right to his or her smartphone.
- MxD's project team assessed current operations at Rock Island Arsenal, the largest government-owned weapons manufacturing arsenal, and generated recommendations to enhance their digital capabilities, give workers instant access to the data, move away from paper models, improve return on investment and potentially serve as a model for the rest of the nation's arsenals. This project has established a foundation on which future pilots and demonstration projects for flexible and responsive warfighter readiness solutions will be built.
- MxD convened a research effort with support from the Department of the Army, Iowa State University (Ames, IA), and John Deere (Moline, IL) to reinvent the way manufacturers look at rapid prototype machining. The result is a computer numerical control (CNC) rapid prototyping software that offers substantial time savings for manufacturers. As manufacturing technologies and processes continue to evolve at a global scale, advanced research outcomes like this software are going to be essential in enabling the workforce, streamlining production and ultimately enhancing the capabilities of the U.S. manufacturing base.

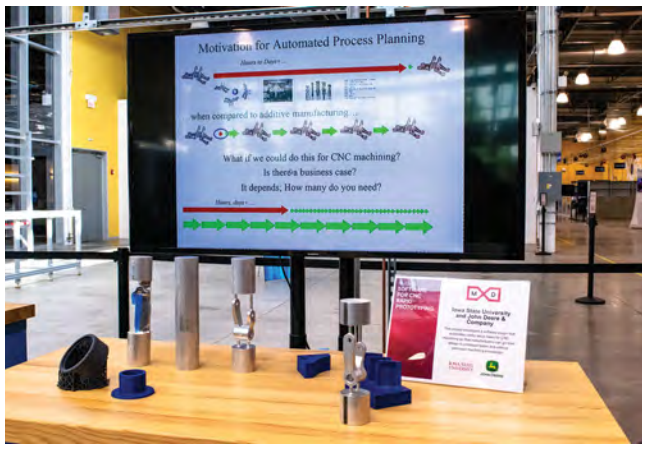


Figure 20. MxD's CNC rapid prototyping software project on display on its 22,000 square-foot manufacturing floor. Credit: MxD

Figure 21. MxD's cybersecurity wall demonstrates measures manufacturers of all sizes can take to protect their equipment and systems from cyber-attacks. Credit: MxD


Credit: MxD

Credit: LIFT

LIFT

Lightweight Innovations for Tomorrow

MISSION: To develop advanced lightweight materials manufacturing technologies and implement educational programs to train a workforce confident in deploying those technologies in defense and commercial applications.

HEADQUARTERS: Detroit, MI

SATELLITE LOCATIONS: Ann Arbor, MI; National Industrial Commons

ESTABLISHED: February 2014

CONSORTIUM ORGANIZER: American Lightweight Materials Manufacturing Innovation Institute (ALMMI)

FUNDING: Federal, $70M; Nonfederal, $78M; both planned over five years

MEMBERS (as of September 30, 2018): 104

www.lift.technology

Projects Completed/Ongoing in FY 2018

- LIFT developed a modeling method based on integrated computational materials engineering to optimize joint design and welding processes for the joining of dissimilar metals like titanium and steel. This successful project enables the utilization of an array of lighter structural materials joined with heavier structural materials to achieve high performance and efficiency in automotive, aviation, aerospace, and military vehicles, which in turn benefits the warfighter and has both practical defense and economic impacts.

- LIFT, in collaboration with Ricardo Defense Systems (Van Buren Township, MI), developed an optimized, commercial, off-the-shelf antilock braking and electronic stability control system retrofitted to High Mobility Multipurpose Wheeled Vehicles which can reduce Humvee rollovers by 74%, thus reducing fatalities of servicemen and women (see Figure 22 below). Additionally, advanced casting techniques and metal matrix parts resulted in lighter system components and improved mobility performance, fuel economy, and logistics trail, all while limiting the risk to soldiers' well-being and ensuring mission successes.

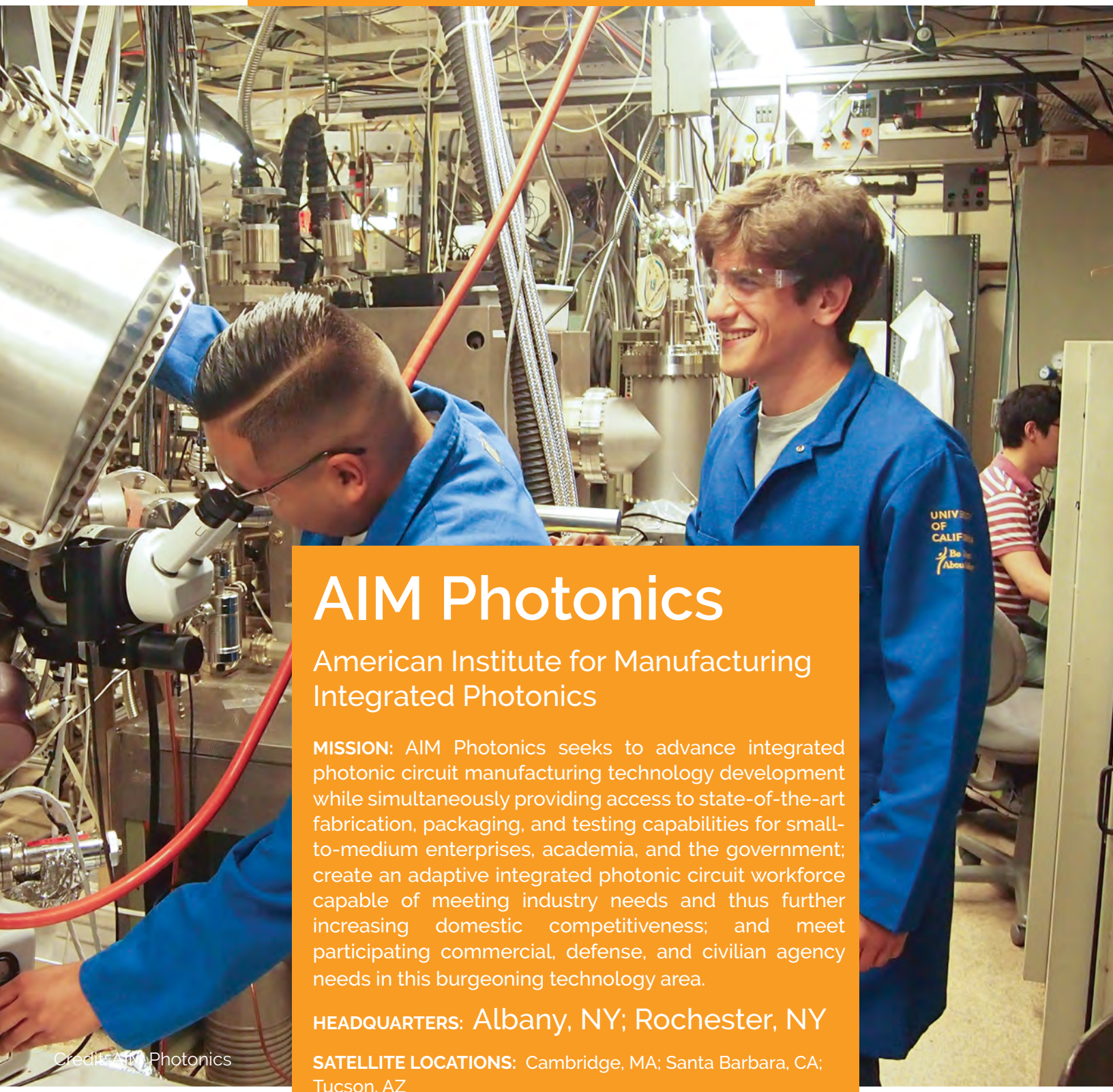
- The Detroit-based High Bay facility is a $50 million shared investment between LIFT and IACMI, uniquely positioned to help revolutionize manufacturing through lightweight innovation and education.

- LIFT's Operation Next offers a self-paced hybrid learning program combining online coursework with hands-on experience on real-world equipment. It begins while the soldiers are still on active duty within their six-month transition window. Participants get "credit" for what they already know and can do. The result is that soldiers earn nationally portable, industry-recognized National Institute for Metalworking Skills (NIMS) credentials. At Fort Campbell 14 are currently enrolled — 7 for NIMS computer numerical control (CNC) certification and 7 for NIMS Industrial Technology Maintenance (ITM) certification. As of FY 2018, forty-three have graduated, 20 with NIMS-CNC credentials and 23 with NIMS-ITM credentials. Of the 43 graduates, 21 hace accepted job offers, 3 have enrolled to continue their educations, 17 recently completed and are considering job offers, and 2 are taking time off before job searching.

New Projects Launched in FY 2018

- LIFT launched their Inorganically Bonded Sand Molds Printed at Line Speed (Melt R2-5) project to economically produce thin-wall, lightweight iron castings from inorganically bonded printed sand molds (without hard tooling). This project also aims to eliminate smoke, steam, vapor, and odors during casting to improve mold fill.

Figure 22. Ricardo Defense Systems antilock braking and electronic stability control system can reduce Humvee rollovers, reducing fatalities of servicemen and women. Credit: Ricardo Defense Systems



Credit: AIM Photonics

AIM Photonics

American Institute for Manufacturing Integrated Photonics

MISSION: AIM Photonics seeks to 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 thus further increasing domestic competitiveness; and meet participating commercial, defense, and civilian agency needs in this burgeoning technology area.

HEADQUARTERS: Albany, NY; Rochester, NY

SATELLITE LOCATIONS: Cambridge, MA; Santa Barbara, CA; Tucson, AZ

ESTABLISHED: July 2015

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

FUNDING: Federal, $110M; Nonfederal, $502M; both planned over five years

MEMBERS (as of September 30, 2018): 99

aimphotonics.com

Projects Completed/Ongoing in FY 2018

- AIM completed the High Capacity Photonic Interconnected Systems project to develop low-power, high-speed optical switching technology for datac enter applications.
- AIM's High Dynamic Range Radio Frequency Photonics for Wideband Systems project developed a radio-frequency photonics interposer design to integrate the chip laser and utilize a common photonics integrated circuit (PIC) footprint, enabling the use of different modulator and photodiode designs in the future.
- The AIM Academy program completed its first group of 11 seniors who worked in hands-on research internships at Massachusetts Institute of Technology (MIT) (Cambridge, MA), SUNY Polytechnic Institute (Albany, NY), University of California, Santa Barbara, and University of Arizona (Tucson, AZ) with the goal to contribute to emerging technologies in photonics.

Figure 23. SUNY Polytechnic's 300mm state-of-the-art advanced node microelectronic chip research facility and AIM Photonics' integrated photonic chip research headquarter in Albany, New York. Credit: AIM Photonics

New Projects Launched in FY 2018

- AIM launched a new project to develop a complementary metal-oxide semiconductor (CMOS)-compatible waveguide platform for integrating mid- and long-wavelength infrared laser sources into the AIM Photonics' foundry offering that will enable a variety of commercial and military applications. This project will support a consortium of AIM Photonics members led by University of California, Santa Barbara and includes Northrop Grumman (multiple locations in the U.S.), the U.S. Naval Research Laboratory, and SUNY Polytechnic Institute (Albany, NY).
- The recently completed Test, Assembly, and Packaging, or TAP, facility is a key component in AIM Photonics' end- to-end PIC advanced manufacturing capability. The facility features development and production process capability in key areas including wafer-scale, chip-scale, input/output attachment. It will have state of the art test and metrology capability for key functional areas.
- NSF awarded $1.2 million to Rochester Institute of Technology (Rochester, NY), University of California, San Diego, and University of Delaware (Newark, DE) to leverage AIM Photonics' world-class research, development, and foundry capabilities. The universities will use the award to realize advanced computing architecture using light, develop mobile probes for identifying specific materials, and enable improved manufacturing processes for photonic devices.

Analog Photonics (Boston, MA) expanded the comprehensive set of PIC component libraries within SUNY Polytechnic Institute's process capabilities to address the needs for O+C+L band applications. This updated PDK, combined with multi-project wafer (MPW) runs, will give AIM Photonics' members access to world-class silicon photonics components for the development of optical transceivers or systems used in all levels within data centers and high-performance computers (see Figure 24 below). The silicon photonics PDK includes design guide, design rule check deck, technology files, active and passive component documentation, abstracts, schematics, and compact models for the development of PICs. The newly combined PDK and MPW offering provides unmatched access to PIC systems for companies that desire a reduction in the time to market, product development risk, and investment. The incorporation of the design, verification, and process development within the PDK enables interested organizations to rapidly modify their designs while reducing cost.

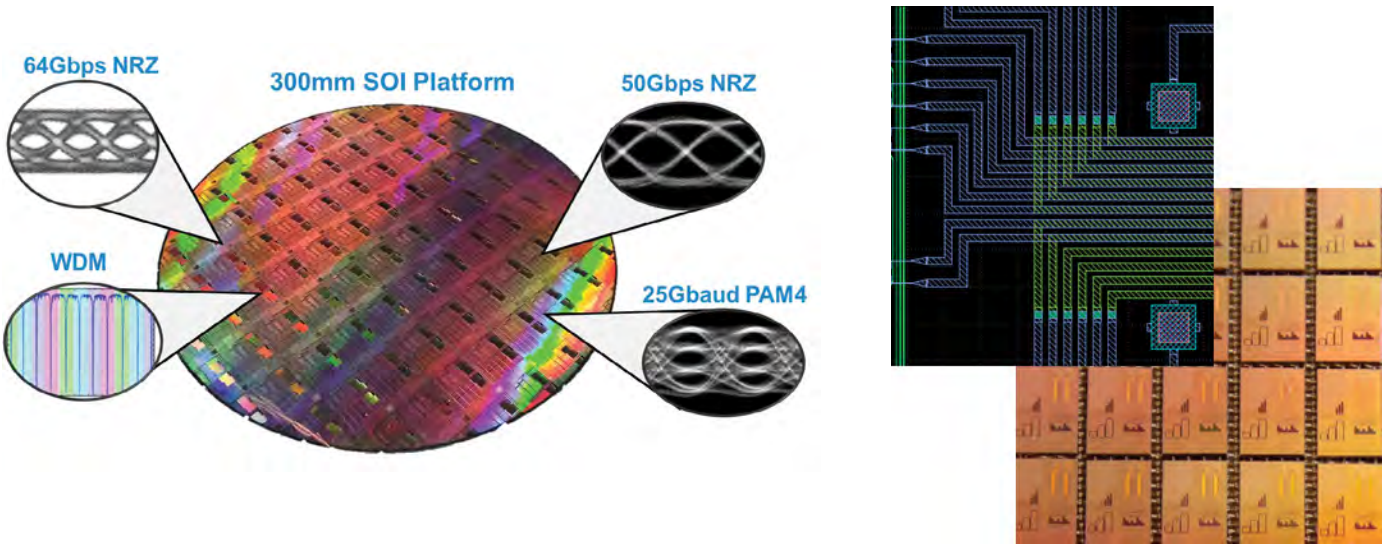
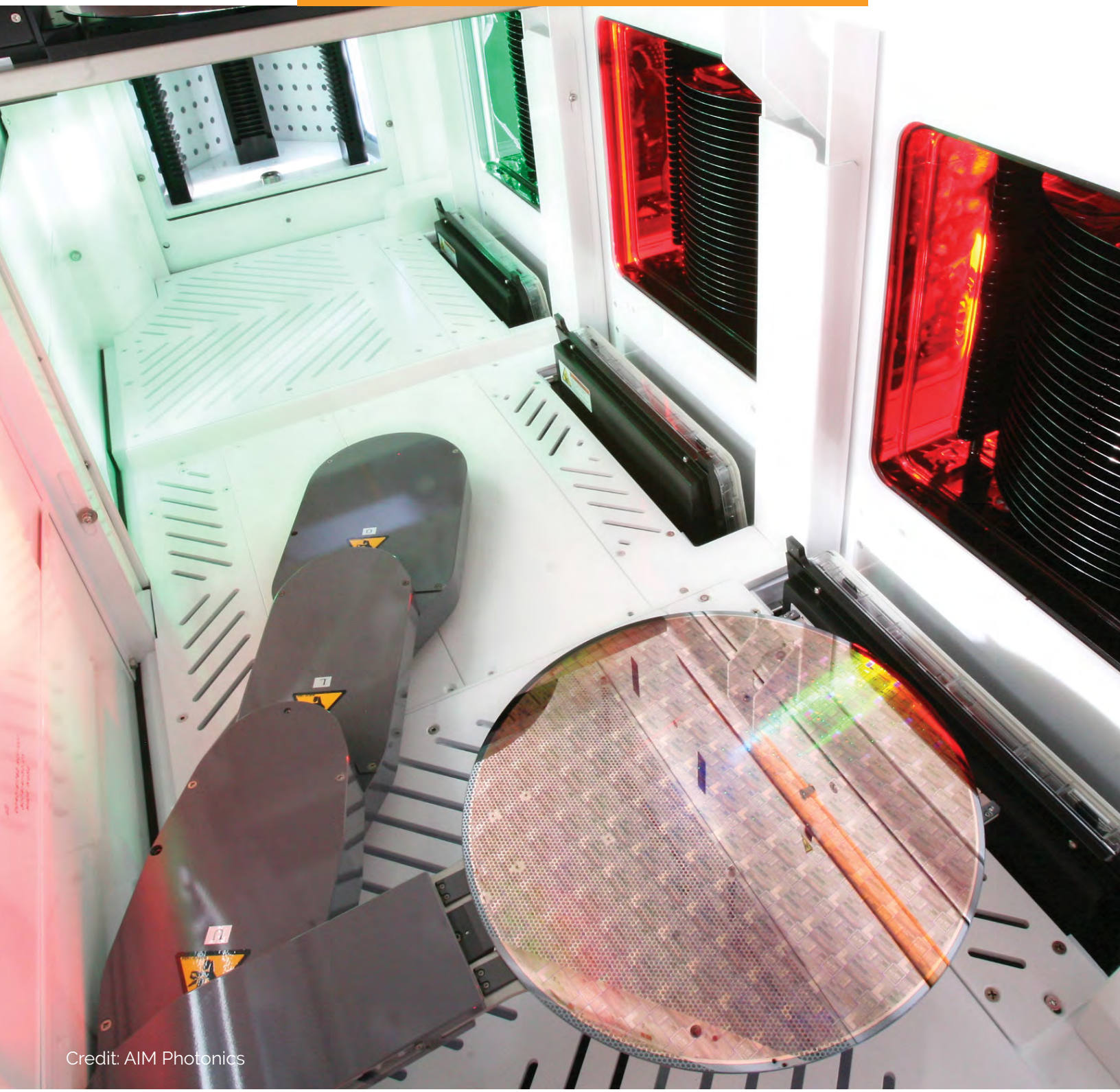


Figure 24. AIM's new Process Development Kit (PDK) – 2.5 Release. Credit: AIM Photonics



Credit: AIM Photonics

Credit: NextFlex

NextFlex

America's Flexible Hybrid Electronics Manufacturing Institute

MISSION: To pioneer flexible hybrid electronics (FHE) manufacturing to serve our nation's warfighters and the U.S. economy.

HEADQUARTERS: San Jose, CA

ESTABLISHED: August 2015

CONSORTIUM ORGANIZER: FlexTech Alliance

FUNDING: Federal, $75M; Nonfederal, $96M; both planned over five years

MEMBERS (as of September 30, 2018): 93

nextflex.us

Projects Completed/Ongoing in FY 2018

- NextFlex has generated an additional 30 agency-directed projects, worth approximately $25 million, ranging from human monitoring and secure authentication to printing of sophisticated array antennas on aircraft skin.
- NextFlex's Flex Oral Biosensing for Athletes and Warfighters project developed a sensing device to detect the threat of physical exhaustion and dehydration through a continuous-sensing system embedded in a mouth guard (see Figure 25). Printed sensors detect bioanalytes in saliva and give early warning of imminent injury or casualty among athletes and warfighters. It replaces the current generation of devices that are limited to physical signs, such as heart rate and motion. The final deliverable included Bluetooth communication, wireless charging, and a replaceable lactate sensor. The device can function for more than seven days in a simulated saliva environment with no degradation of electronic performance.

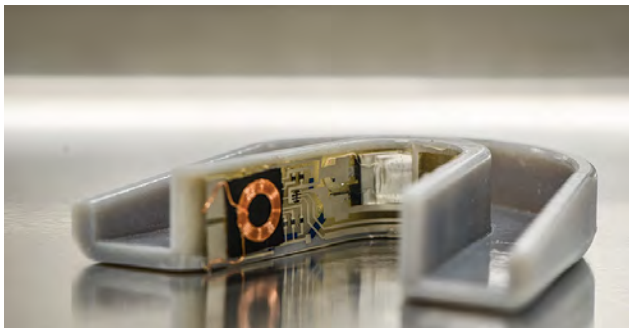


Figure 25. Mouthguard with sensor for biosensing. Credit: Palo Alto Research Center Incorporated

- The FHE X-band Antenna Arrays for the Next Generation of Deployable Antennas project team delivered 12-inch-by-12-inch deployable antennas with printed phase shifters, printed multilayer stacked patch X-band phased arrays, and low-cost commercially available transmit/receive modules (see Figure 26).

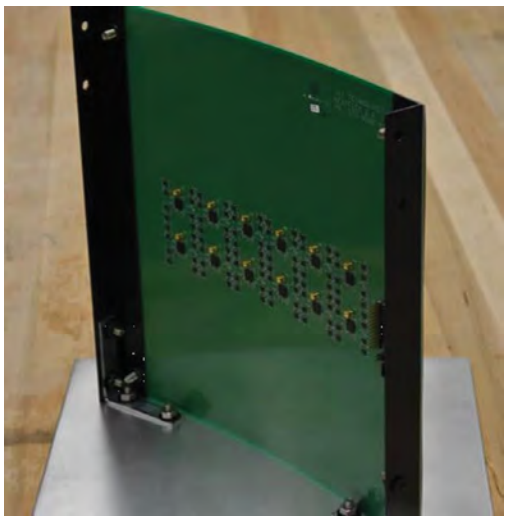


Figure 26. Deployable antenna array. Credit: NextFlex

- FlexFactor, a NextFlex program, completed its 19th cycle of manufacturing entrepreneurship training across eight schools in six school districts in Silicon Valley. During the month-long course, student teams identified a human health or performance problem, conceptualized an FHE device to solve it, and developed a business model for commercialization. Boeing (Huntsville, AL) awarded $250,000 to fuel a local adoption of the initiative within the Alabama Community College System (Montgomery, AL) and several school districts in Alabama's greater Huntsville/Madison County region.
- NextFlex operates the first end-to-end FHE pilot line with more than 55 tools, mostly donated by industry, to create the largest repository of FHE pilot tooling. The pilot line is available to all members for prototyping and low-rate production.

New Projects Launched in FY 2018

- NextFlex launched a project with Boeing (Huntsville, AL) and its partners American Semiconductor (Boise, ID), Chromera (Poway, CA), DuPont (Wilmington, DE), Imprint Energy (Alameda, CA), and Western Michigan University (Kalamazoo, MI) to develop an FHE patch with measurement systems, logic, power, and communication that can greatly reduce the time and cost of tests by eliminating wiring and simplifying logistics. This multi-sensor patch will have numerous other applications in the area of structural health monitoring (see Figure 27).

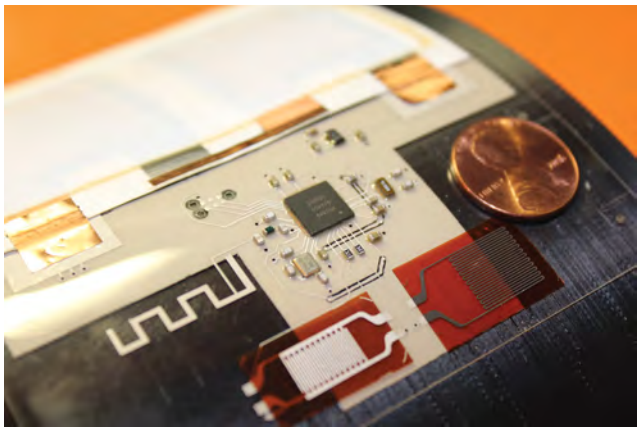
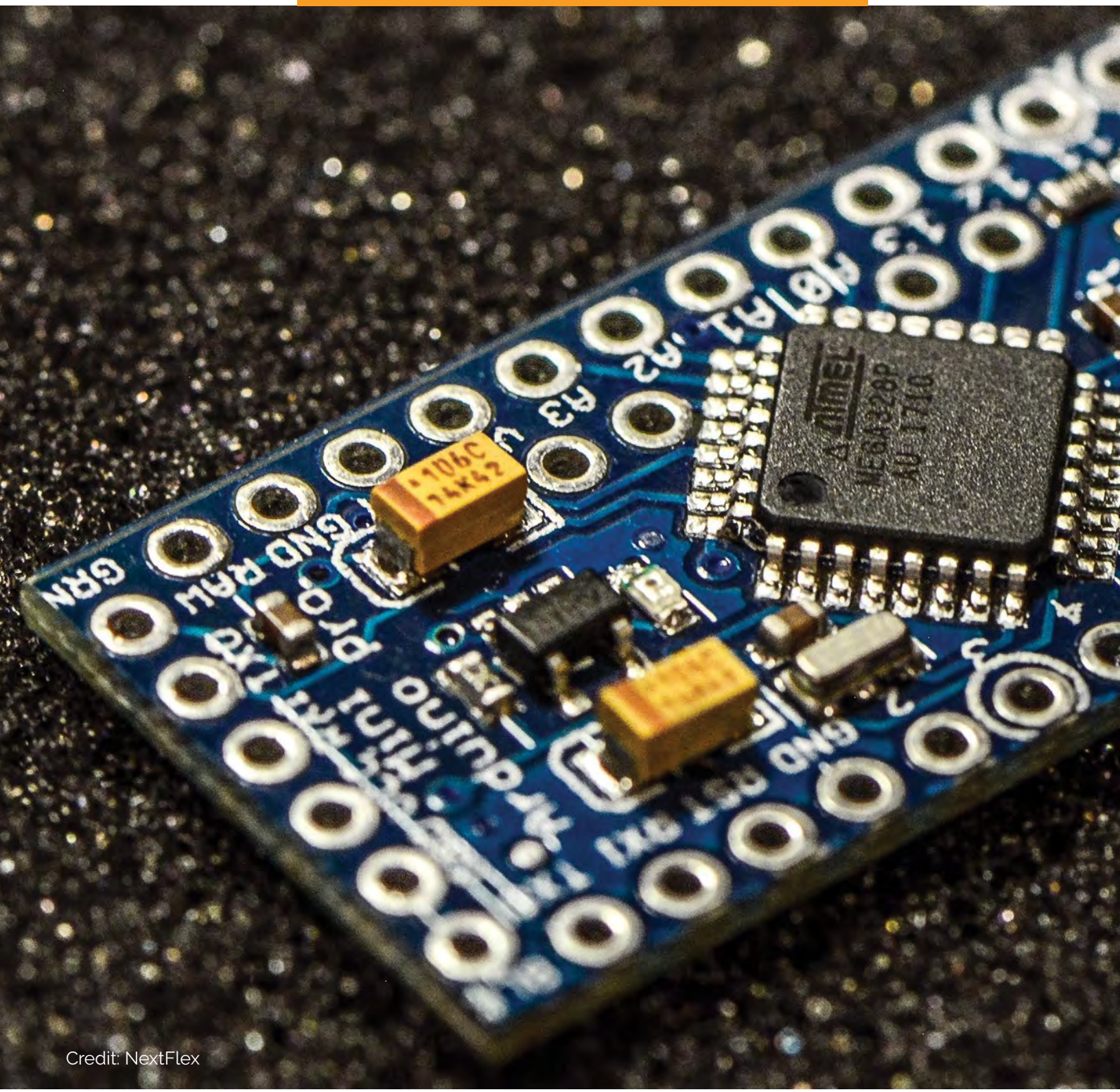


Figure 27. A NextFlex funded project is developing condition monitoring sensor tags to decrease cost and accelerate testing of large military assets, such as aircraft. Credit: Boeing



Credit: NextFlex

Credit: AFFOA

AFFOA

Advanced Functional Fabrics of America Institute

MISSION: To enable a domestic manufacturing-based revolution by transforming traditional fibers, yarns, and fabrics into highly sophisticated, integrated, and networked devices and systems.

HEADQUARTERS: Cambridge, MA

ESTABLISHED: April 2016

CONSORTIUM ORGANIZER: Massachusetts Institute of Technology

FUNDING: Federal, $75M; Nonfederal, $272M; both planned over five years

MEMBERS (as of September 30, 2018): 118

affoa.org

Projects Completed/Ongoing in FY 2018

- The grand opening of AFFOA's Fabric Discovery Center took place on October 27, 2018. The center is located at MIT Lincoln Laboratory (Lexington, MA) and is suitable for applied research for defense applications.

New Projects Launched in FY 2018

- The Defense Fabric Discovery Center is collaborating with Lincoln Laboratory on a new Lincoln Laboratory–funded project "System in a Fiber" to produce fibers with individually controllable and addressable devices.
- An AFFOA project with the University of Maine (Orono, ME) improved the strain relief of the composites by creating a transparent shrink-wrap tubing to protect the LED fibers. The result was a 100% LED yield; all LEDs worked.
- AFFOA, along with the MIT Venture Mentoring Service, has selected 25 venture teams for the Advanced Fabrics Entrepreneurship Program. The program, a one-year-long effort, is meant to identify and build value in advanced fiber and textile technologies to lay the foundation for commercial launch. Participants will have the opportunity to acquire venture-building skills, create job opportunities for themselves and others, differentiate themselves in the job market, expand their professional network, and interact with fabric technology and industry experts. Other program offerings include hands-on professional development, team-building activities, new skills development, engagement in the AFFOA member network, and ultimately, the opportunity for the entrepreneurs to create a venture in an area they find exciting.
- AFFOA advanced light fidelity (LiFi) wireless communication technology as a faster, more secure way of transmitting data using light. Using this technology, users can stand under a modulated light wearing a LiFi-enabled cap and hear an audio signal in the form of voice narration or music. The AFFOA-developed, LiFi light receiver fibers have special detectors woven into the cap that detect and convert the modulated light to audio signal which is then transmitted through an earpiece. The DoD will benefit from the first directional and secure fabric-based communication system.

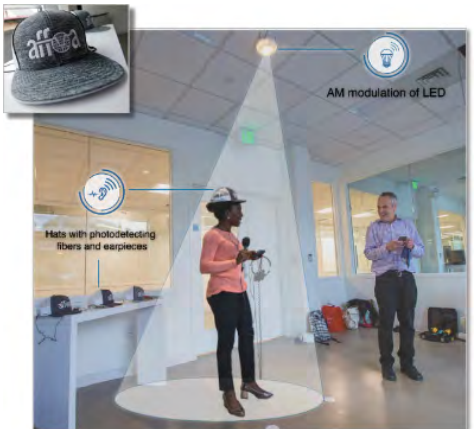


Figure 28. AFFOA-developed LiFi receivers have detectors woven into cap fibers that convert modulated light into audio signals. Credit: AFFOA

Credit: BioFabUSA

BioFabUSA

Advanced Regenerative Manufacturing Institute

MISSION: BioFabUSA seeks to make the large-scale manufacturing of engineered tissues and tissue-related technologies practical and prepare the required workforce to meet the needs of the wounded warfighter and others in need of this technology across the U.S.

HEADQUARTERS: Manchester, NH

ESTABLISHED: December 2016

CONSORTIUM ORGANIZER: Advanced Regenerative Manufacturing Institute (ARMI)

FUNDING: Federal, $80M; Nonfederal, $214M; both planned over five years

MEMBERS (as of September 30, 2018): 103

biofabusa

biofabusa.org

Projects Ongoing in FY 2018

- BioFabUSA continued a project focused on reproducible incorporation of a system of perfusable blood vessels into engineered tissues, which will enable the culture and implantation of whole tissue–engineered organs. This project is developing automated manufacturing workflow solutions for vascularized tissues suitable for clinical and commercial activities. It leverages the Advanced Solutions Life Sciences BioManufacturingBot (BMB) 6-axis robotic-based platform to fabricate prototypical vascularized liver tissue as a demonstration.

Credit: Advanced Solutions Life Sciences

- BioFabUSA made progress on a project to measure viability, a key component of living, tissue–engineered constructs. Historically, measurement of viability involves multi-step, invasive and destructive test methods. The lack of adequate non-invasive and non-destructive viability measurement inhibits the ability of manufacturers to control manufacturing processes to ensure tissue viability. Therefore, this BioFabUSA project is adapting an existing and widespread technology for viability measurements of cells in suspension to measurement of viability and growth rate of cells embedded in 3D tissues, enabling real-time quality control.

- Another BioFabUSA project involves the development of a prototype automated fluid management and culture control system meeting the specifications and compatible interfaces of bioreactors combined with control/data management systems. Current tissue manufacturing processes are labor intensive, variable, and difficult to control. The development of a scalable, modular, and automated system could serve as a central component of a large-scale tissue biofabrication system. The prototype system will manage up to 50 bioreactor units from a single reservoir of culture medium for up to 3 months, utilizing a novel, single-use cassette-based integrated pump and valve technology combined with real-time, non-invasive sensing technologies to measure/monitor the culture environment.

New Projects Launched in FY 2018

- BioFabUSA launched an education and workforce development project call directed to engaging and attracting the next generation of talent to biofabrication. There is significant evidence that career choices are being determined by students as early as middle school, and this project call highlighted hands-on activities to educate and provide insight about current and future tissue manufacturing processes. While this project call focuses on the development and testing of these hands-on activities, a long-term plan could be to integrate them into the secondary school curriculum. The intent is that these activities will provide opportunities to highlight essential manufacturing skills and processes and allow students to envision a career pathway for themselves in this emerging technology area, ultimately attracting the future workforce to the industry.

- BioFabUSA released a tissue foundry technology project call to develop the first-ever manufacturing line for engineered tissues. The development of a modular, flexible, closed, and fully automated manufacturing line with multiple bioreactors adaptable for all tissues is the ultimate goal of the technology call. The technology call focused on the identification and collection of existing prototypes and otherwise off-the-shelf technologies that may be integrated into a prototype modular manufacturing system. Initially, a prototype line will be built to highlight capability gaps, refine BioFabUSA's focus areas, and influence future technology project calls. The prototype line will included five modules including seed pool culture, cell harvest and wash, scaffold fabrication, scaffold seeding and culture, and final packaging of the product. The ultimate manufacturing line will be utilized for process validation and early phase clinical manufacturing, and will form the basis for technology transfer activities. The development of a fully functioning tissue foundry line is the first step in developing tissue products at industrial scales that will accelerate the development of key medical products and enhance the DoD's ability to treat wounded warfighters.

Credit: ARM

ARM

Advanced Robotics for Manufacturing

MISSION: ARM accelerates robotics innovation to drive U.S.-based growth in manufacturing while developing domestic robotics expertise to aid in the creation of high-value careers. By lowering economic, technical, and operational barriers, ARM ensures that enterprises of all sizes can adopt robotic solutions, while preparing the American workforce to work collaboratively with robots.

HEADQUARTERS: Pittsburgh, PA

ESTABLISHED: January 2017

CONSORTIUM ORGANIZER: Carnegie Mellon University

FUNDING: Federal, $80M; Nonfederal, $173M; both planned over five years

MEMBERS (as of September 30, 2018): 170

ARM

arminstitute.org

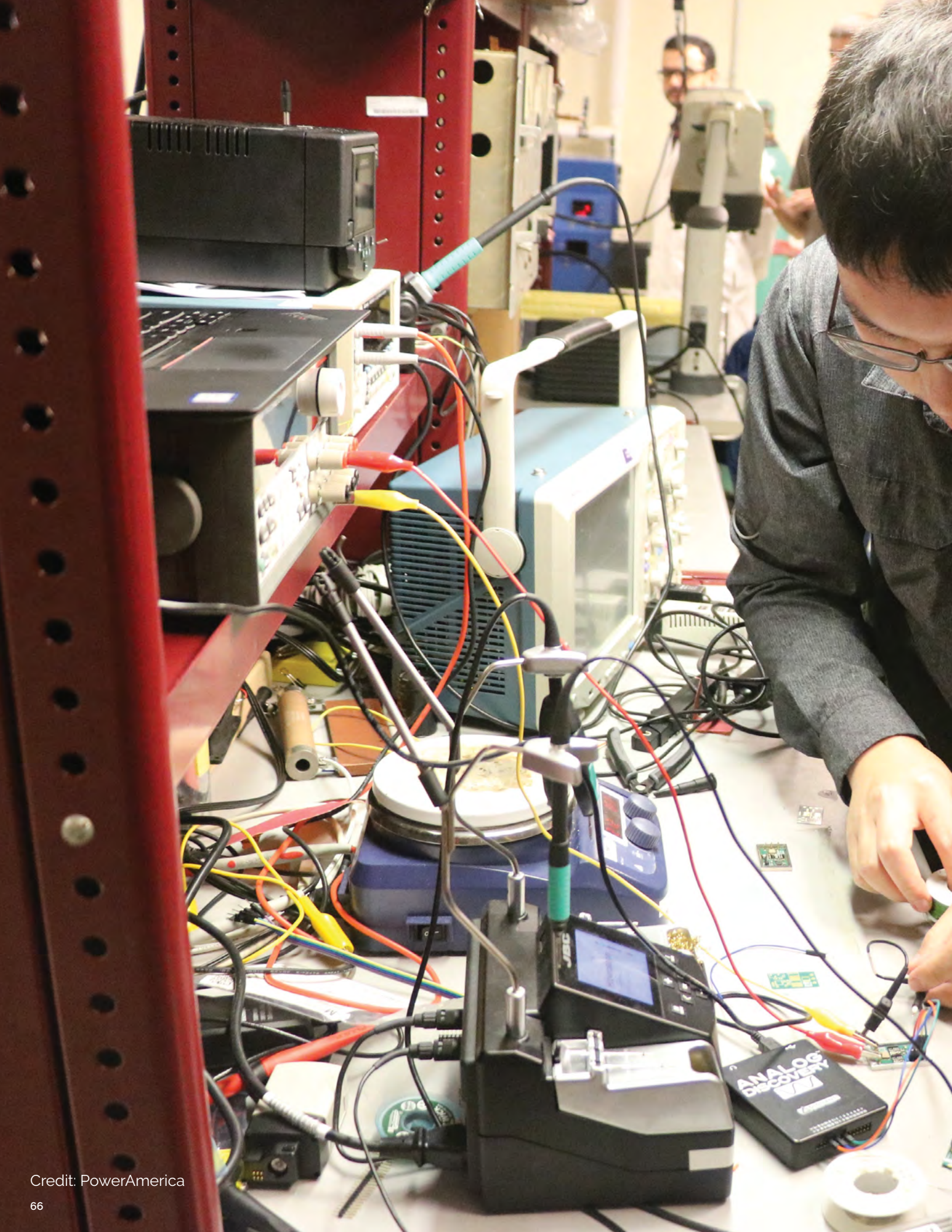
Projects Ongoing in FY 2018

- ARM's Automated Wire Harness Assembly project team, led by Wichita State University (Wichita, KS), will leverage advances in robotic manipulation, planning, and control for wire routing planning to develop and demonstrate an automated complex wire harness assembly process.

- ARM's Teach-Bot Apprentice Education and Training System, a one-year educational program, began in FY 2018 (see Figures 29 and 30). At its completion in 2019, the project team, led by the Massachusetts Institute of Technology (Cambridge, MA), hosted a culminating event at MassMEP in Worcester, Massachusetts with more than 50 attendees including SMMs, ARM leadership, robotics industry partners (such as ABB and MassRobotics), and state representatives and administrators. The event demonstrated the Teach-Bot curriculum as a promising solution to address the dire need for training a skilled robotics technician workforce. The successful outcomes will be shared with the DoD maintenance and sustainment communities for potential implementation.

Figure 29. In the Teach-Bot Apprentice Education and Training System, the robots play the role of an instructor and mentor by showing demos and executing experiments. Credit: ARM

Figure 30. The Teach-Bot program uses robots to teach industrial robotics to pre-apprentices, American workers, and SMM managers. Credit: ARM



Credit: PowerAmerica

Department of Energy Energy Institute Highlights

Credit: PowerAmerica

PowerAmerica

The Next Generation Power Electronics Manufacturing Innovation Institute

MISSION: The PowerAmerica institute at 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

ESTABLISHED: January 2015

CONSORTIUM ORGANIZER: North Carolina State University

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

MEMBERS (as of September 30, 2018): 48

PowerAmerica

www.poweramericainstitute.org

Background

PowerAmerica is working to replicate the extraordinary miniaturization and increased performance seen in silicon technology in the field of high-power electronics. The institute will accelerate development and adoption of advanced semiconductor components 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. WBG semiconductors have applications in electric power distribution, data centers, and industrial motors and in the efficient, robust power components needed for electric vehicles and trains.

Technology Advancement

"We are involved because one of the single most important things PowerAmerica is doing is changing the mind-set of the customer community. When a PowerAmerica project demonstrates a first, it gets the attention of the users."

– John Palmour, CTO, Wolfspeed, a Cree Company

Projects Completed in FY 2018

In FY 2018, 30 projects were completed. Some highlights that address the WBG semiconductor technology roadmap follow:

- **New Possibilities for Electric Vehicles:** Partners United Silicon Carbide (USiC, Monmouth Junction, NJ) and X-FAB Texas (Lubbock, TX) released high-power (650- and 1200-volt) silicon carbide semiconductor diodes, meeting stringent, international automotive qualification standards, making them ideal for automotive applications. PowerAmerica funding enabled USiC to fully qualify the diodes at X-FAB. The devices have great potential to improve efficiency in electric vehicles — including onboard chargers, converters, and fast chargers. The market for silicon carbide components for electric vehicles is expected to experience explosive growth over the next decade.
- **Enabling Smaller, More Efficient Mobile Charging:** With support from PowerAmerica, Navitas (El Segundo, CA) set out to establish a commercially compelling platform with gallium nitride integrated circuits that set an industry standard in energy efficiency, power density, and manufacturability for consumer adapters and charger application. The shift to high-density, high-efficiency adapters creates an opportunity for U.S. suppliers to capture a significant portion of this market. Navitas' technology has been adopted in the world's thinnest universal 45-watt power-delivery adapter.
- **Commercializing New Devices:** Wolfspeed, a Cree Company, has locations in Durham, North Carolina, where it manufactures silicon carbide devices, and

Figure 31. X-FAB operator in front of photolithography tool. Credit: X-FAB

Fayetteville, Arkansas, where it manufactures silicon carbide device packaging. In Durham, the company has developed and qualified, and is preparing to commercialize, high-voltage silicon carbide devices, which can revolutionize power applications such as train engines, electric motors, and solar panels. Meanwhile, the Fayetteville arm of Wolfspeed is developing specialized packaging to contain the high-voltage devices, which does not exist in the marketplace and yet will be crucial to adoption of these devices. PowerAmerica funding helped the packaging meet strict reliability qualifications necessary for commercial production.

- **A Faster, Smaller EV Charger:** Researchers at North Carolina State University (Raleigh, NC) have spent the last several years developing a silicon carbide–based electric-vehicle fast charger that is cheaper, more compact, and more efficient than its silicon-based counterparts. The charger is at least 10 times smaller than existing systems and wastes 60% less power during the charging process. The team has been working to build a version of the charger that can charge more vehicles simultaneously and more quickly. The product would meet a critical demand for the growing electric-vehicle sector, as no commercial fast chargers at this voltage level are currently on the market for passenger vehicles.

New Projects Launched in FY 2018

In FY 2018, 26 new projects were launched to address key problems in WBG power electronics manufacturing, such as the following:

- **Design and Manufacture of Advanced WBG Power Modules:** GE Aviation Systems (Pompano Beach, FL) and the National Renewable Energy Laboratory (Golden, CO) are partnering to design and produce advanced WBG power modules made with silicon carbide and gallium nitride. The goal of this project is to enable true engine-coolant temperature-grade equipment, which is required to support next-generation defense systems as well as commercial transportation, and wind and solar systems, while reducing the overall cost.
- **Develop More Energy-Efficient, Reliable Products:** Working with researchers at Ohio State University (Columbus, OH), Toshiba International Corporation (Houston, TX) will develop a silicon carbide–based, industry-level, 1-megawatt medium-voltage motor-drive system, which has applications in the oil and gas industries and for wastewater and HVAC systems. Because of the properties of silicon carbide, the system will have a smaller footprint and lighter weight, as well as higher reliability and faster switching, than systems on the market today. The company plans to manufacture the drives in Houston, TX.
- **A More Efficient Gallium Nitride-Based Power Converter:** A team at the University of Colorado Boulder will design and implement a gallium nitride–based novel converter with an increased density of 10 times that of converters on the market, with up to 3 times lower power loss. The converter, which will have fewer components, simpler implementation, and lower cost, can be used for power delivery to data centers, cellular base stations, portable applications, and defense systems.

- **A High-Efficiency, High-Speed HVAC Drive:** The United Technologies Research Center (East Hartford, CT) will create a high-efficiency, high-speed drive for HVAC systems using WBG semiconductor technology. HVAC systems today account for nearly 40% of energy use in the U.S., so helping them operate more efficiently will preserve energy and reduce overall operating costs. The company aims to have the drives installed with their first customers by 2022. Establishing an advanced manufacturing process for these systems will additionally enable cost-competitive, large-scale production of power electronics based on WBG technology.

Workforce Development

"The more I went through this program, the more I really came to believe and understand that silicon carbide has the ability to revolutionize power electronics, and technology across the board. It's been a great experience."

— Cristian Melara, graduate of PowerAmerica's Research Experience for Undergraduates, summer 2018 class

PowerAmerica continues to collaborate with industry and educational organizations to provide education and workforce development opportunities in WBG electronics. Highlights from FY 2018 include:

- Served over 130 research students; presented tutorials to more than 1,200 attendees at conferences, the annual meeting, and a summer meeting and in a short course and university projects; and presented 21 technical webinars to 800 attendees.

Figure 32. Students at a wide-bandgap workshop. Credit: PowerAmerica

- Hosted 20 undergraduates, high school students, and teachers through the Research Experience for Undergraduates, a crash course in WBG power electronics technologies featuring labs, hands-on research, and professional skills development (see Figure 32 above). The program pulls not just from four-year schools but also from community colleges in the surrounding region, reaching students who would not otherwise have access to research and labs at a large, well-funded research institution like North Carolina State University, where PowerAmerica is based.

Workforce Projects Launched in FY 2018

PowerAmerica will continue to develop a skilled workforce through a variety of projects funded in 2018, including the following:

- Development of a power electronics board with plug-and-play capability, providing undergraduates at the University of North Carolina at Charlotte with hands-on WBG experience

- Creation of the first open-source gallium nitride power-design toolkit, which will be made publicly available to students and engineers studying gallium nitride processing (Rensselaer Polytechnic Institute)

- Development of a software teaching tool on WBG technology and a universal platform for rapid prototyping of WBG applications (North Carolina State University).

Innovation Ecosystem

"PowerAmerica's program is critical toward making high-voltage silicon carbide devices like MOSFETs, competitive with traditional, widely used silicon devices. The establishment of a robust supply chain, engagement with a high-quality foundry, and the infrastructure to produce high volumes, which are enabled by PowerAmerica, allows silicon carbide MOSFETs to become competitive in the applications marketplace."

— Ranbir Singh, CEO, GeneSiC

The best example of the innovation ecosystem created with funding and support from PowerAmerica is the X-FAB Texas foundry in Lubbock, Texas — a silicon foundry that, with funding from PowerAmerica, was upfitted to produce silicon carbide wafers. The foundry operates under a collaborative model, providing silicon carbide semiconductor companies that lack their own fabrication facilities with access to a plant. Together with PowerAmerica, X-FAB is leveraging existing silicon economies of scale to fulfill the institutes' mission of utilizing small investments to reduce the cost of manufacturing silicon carbide devices and make them more accessible for wide-scale commercial adoption.

Today, X-FAB Texas serves 13 customers with 25 projects, including 9 members of PowerAmerica. X-FAB expanded its silicon carbide production in 2017, an investment the company estimates will add 50 new jobs.

PowerAmerica members using X-FAB to manufacture products include Monolith Semiconductor and GeneSiC Semiconductor. Monolith relocated its headquarters from Ithaca, New York, to be closer to X-FAB. With PowerAmerica's support and the use of X-FAB's facilities, Monolith has developed manufacturable, high-yielding 1700-volt silicon carbide Schottky diodes with best-in-class performance. These high-voltage diodes are being produced to meet the needs of next-generation, higher-power-density solar and wind-turbine inverters, as well as other applications such as data centers, industrial motor drives, and rail traction. (Monolith was fully acquired by Littelfuse, Inc. in 2018.)

GeneSiC Semiconductor, which is manufacturing its 3.3-kilovolt silicon carbide power MOSFETs (metal-oxide-semiconductor field-effect transistors) at the X-FAB foundry, leverages its international distribution and sales networks to make these devices available on a global scale — an initiative that is already attracting interest from international customers.

John Deere Moves Closer to the First All-Electric Heavy-Duty Vehicle

Since 2015, with funding support from PowerAmerica, John Deere has collaborated with researchers from the DOE's National Renewable Energy Laboratory (DOE-NREL) to develop a silicon carbide inverter that converts vehicle engine power into electrical power needed for electric motors in heavy-duty vehicles. The inverter may have industrial applications in hybrid heavy equipment and in all-electric heavy equipment. Vehicle electrification using a silicon carbide inverter has been estimated to improve fuel economy by as much as 25% when compared to conventional nonelectrified vehicles of similar payload, although silicon carbide inverters are still under development and actual fuel-economy gains may differ from the above estimates. John Deere currently manufactures and offers commercially available inverters and hybrid loaders that use semiconductor technology other than silicon carbide semiconductors.

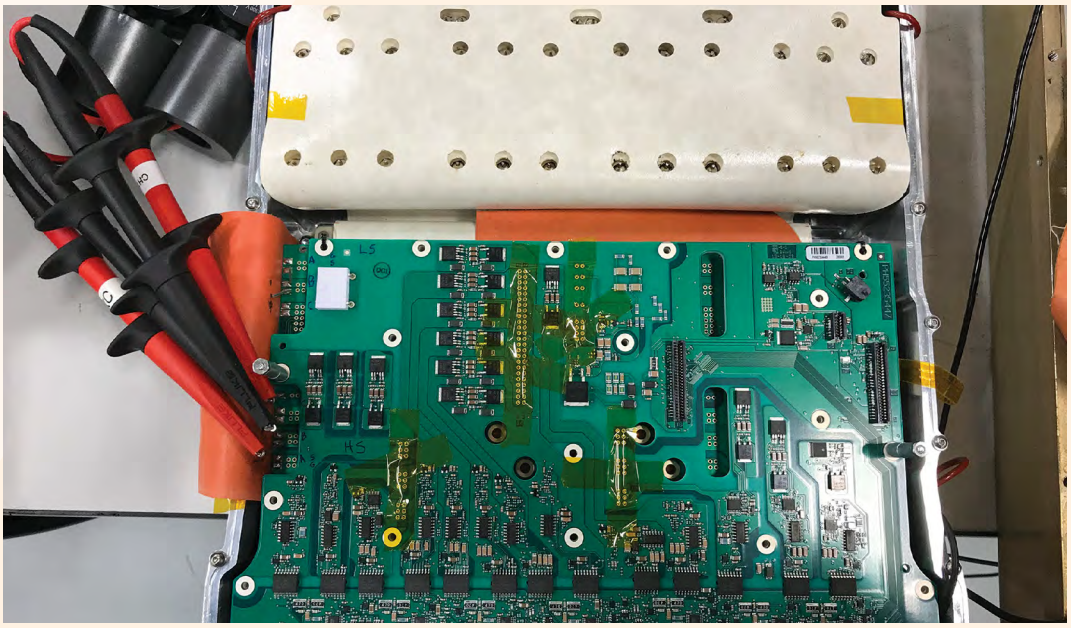


Figure 33. The power density of silicon carbide semiconductors allows components in high-power applications to be smaller and lighter than their conventional counterparts. Credit: PowerAmerica

Credit: IACMI

IACMI

Institute for Advanced Composites Manufacturing Innovation

MISSION: Create an ecosystem of innovation to drive commercial outcomes leading to economic growth 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 National Wind Technology Center (Boulder, CO); The Indiana Manufacturing Institute at Purdue University (West Lafayette, IN); The University of Tennessee's Fibers and Composites Manufacturing Facility (Knoxville, TN); Oak Ridge National Laboratory (Oak Ridge, TN); Vanderbilt University's Laboratory for Systems Integrity and Reliability (LASIR) (Nashville, TN)

ESTABLISHED: June 2015

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

FUNDING: Federal, $70M; Nonfederal, $178M; both planned over five years

MEMBERS (as of February 28, 2019): 154

The Institute for iacmi Advanced Composites Manufacturing Innovation

THE COMPOSITES INSTITUTE

iacmi.org

Background

IACMI improves U.S. security and manufacturing competitiveness by providing production-relevant environments for innovation, a supply-chain-based framework for decision-making, and workforce training in support of the needs of the advanced polymer composites industry. IACMI serves this community by uniquely and systematically connecting innovation and workforce assets across multibillion-dollar industries positioned for significant future domestic and international growth. Through implementation of new materials, faster processes, and lower life cycle costs, IACMI will make the U.S. a leader in the manufacture of these strategic materials and accelerate the growth of markets for them.

Technology Advancement

"IACMI actively connected us to the right suppliers, equipment manufacturers, and recycling companies as we built our technical project team. Ashland's participation in the project enabled us to establish networks with innovative modeling companies, leading to new business opportunities as a resin supplier for three other IACMI projects. As an IACMI member, we've had the opportunity to leverage shared funds and existing equipment at Michigan State University, Zoltek, and UDRI. By using these existing resources, we didn't have to buy the equipment and have reduced our learning curve."

— Joe Fox, Ashland

Projects Completed in FY 2018

As of FY 2018, nine projects have been completed. Highlights that address items in IACMI's advanced composites technology roadmap include:

- **Broadening Additive Manufacturing to Produce the First Self-Driving Vehicle:** The technical project led by Techmer PM (Knoxville, TN) and Local Motors (Knoxville, TN) improved the material options and printing processes for additive manufacturing (3D printing), which enables Local Motors to commercially produce its 3D-printed vehicle. By increasing the variety and understanding of materials available for additive manufacturing, this project has generated significant commercial growth for multiple companies involved in the project. Techmer PM has increased sales of new 3D products and expects to double sales in 2019. Local Motors recently installed the world's largest 3D printer, made by Thermwood, at its Knoxville, Tennessee, microfactory and plans to commercially produce Olli 2.0, its first self-driving vehicle (see Figure 34 below). Other project participants include BASF (Florham Park, NJ), Oak Ridge National Laboratory (Oak Ridge, TN), and the University of Tennessee (Knoxville, TN).

Figure 34. Additive manufacturing was used to produce Local Motors' first self-driving vehicle. Credit: IACMI

- **Making a Composite Material with Performance Characteristics for Automotive Production:** The Dow Chemical Company (Midland, MI) developed a composite material through a prominent IACMI technical project that achieved performance such that the Ford Motor Company (Dearborn, MI) is willing to declare it acceptable for specification on future vehicle platforms. Other project participants include Purdue University (West Lafayette, IN), Oak Ridge National Laboratory (Oak Ridge, TN), Vanderbilt University (Nashville, TN), Michigan State University (Lansing/Detroit, Michigan), and the University of Tennessee (Knoxville, TN).
- **Lowering Costs and Speeding up Production of Continuous-Fiber Materials:** DuPont (Wilmington, DE) led a project that demonstrated a new manufacturing process using a carbon-fiber composite that exhibited favorable characteristics when compared to traditional woven materials. The process, an ultrafast way to manufacture fabrics, is a potential method for producing lower-cost carbon fiber reinforced polymer (CFRP) materials with improved physical properties, creating opportunities for new applications in the automotive and aerospace industries as carbon-fiber composites become easier and safer to produce. Other project participants include Fibrtec (Atlanta, TX) and Purdue University (West Lafayette, IN).

New Projects Launched in FY 2018

As of 2018, IACMI has over 50 technical projects underway that address key problems in composites manufacturing. Examples include the following:

- **Cost-Effective Carbon Fiber for Vehicle Production:** Vartega (Golden, CO) leads a project to close the loop on automotive carbon fiber component manufacturing scrap by characterizing and validating materials to meet the growing demand for cost-effective carbon fiber that can be used to reduce vehicle weight — improving fuel economy, reducing emissions, and extending electric vehicle range. Vartega has plans to install its first commercial recycling system in the IACMI Scale-up Research Facility (SURF), located in Detroit, Michigan, close to the recently acquired Central Train Depot, which will act as the new centerpiece for Ford Motor Company's (Dearborn, MI) new mobility, autonomy, and electrification campus. Other project participants include Michelman (Cincinnati, OH), Oak Ridge National Laboratory (Oak Ridge, TN), the Colorado School of Mines (Golden, CO), Michigan State University (Lansing/Detroit, MI), the University of Dayton Research Institute (Dayton, OH), the University of Tennessee (Knoxville, TN), BASF (Florham Park, NJ), and Plasan Carbon Composites (Walker, MI).
- **Prototyping Textile Carbon-Fiber Applications:** While traditional carbon-fiber composites have long been touted for their weight savings in stiffness-critical automotive applications including automotive bodies, B-pillars, and other structural components, only recently have textile carbon fibers become cost-competitive with traditional, heavier materials. Textile carbon fiber has potential for significant impact in the automotive industry because of cost and weight savings. IACMI led a team that produced the first large injection-molded automotive prototype made with low-cost textile-grade carbon fiber, which yielded an estimated cost savings of 40% to 50%, compared to a 50,000-filament tow commercial counterpart. Additional trials have demonstrated the versatility of the technology using different fiber content, which has produced various prototypes, including fenders with 10% and 45% carbon-fiber content. Project participants include Techmer PM (Knoxville, TN), Oak Ridge National Laboratory (Oak Ridge, TN), and Michigan State University (Lansing/Detroit, MI).
- **Carbon-Fiber Pressure Vessels for Transportation Applications:** Steelhead Composites (Golden, CO) is leading a project to develop structurally predictable, low-cost smart composite pressure vessels without compromising safety by employing integrated, reliable health monitoring. This validated technology can be used to reduce the cost of adopting composite pressure vessels in fuel-cell cars and other applications in transportation markets. Other project participants include Teijin Carbon (Rockwood, TN), Oak Ridge National Laboratory (Oak Ridge, TN), and the University of Tennessee (Knoxville, TN).

Figure 35. IACMI Scale-up Research Facility (SURF), Fender, Milacron. Credit: IACMI

Workforce Development

"The IACMI internship program is a great benefit to us. It brings students in with experience in the right technical area to support us, and they are able to do work that is valuable to us with minimal training and input. We learn from them as well as they learn from us."

— Charles Hill, Local Motors

IACMI is uniquely and systematically connecting innovation and workforce assets across multibillion-dollar industries positioned for significant future domestic and international growth. Since its founding, IACMI has placed more than 100 interns through the IACMI Internship Program, trained more than 2,000 industry workers through composites training workshops and courses, and engaged more than 9,000 K–12 students in STEM activities.

- **The IACMI Internship Program:** Every IACMI intern who has graduated has done so with a job offer in industry or has been accepted into a graduate program. Through the IACMI Internship Program, interns gain hands-on experience working in national laboratories, academic labs, and industry. Additionally, interns learn networking and professional skills through poster presentations and by attending a professional-development workshop. IACMI recognizes the importance of building well-rounded engineers and composites workers who will make strategic decisions to better their communities and organizations, and IACMI prioritizes offering students experiences that will set them on the track to becoming engaged leaders in their fields.
- **Training Workshops to Advance Composites:** Each year since its launch, IACMI has partnered with Composites One to present four composite training workshops designed to share techniques utilized in the industry with composite technicians and workers. The workshops continue to foster collaboration between composites experts and researchers working with industry to advance integration of composites into IACMI's technology areas. IACMI directly trained more than 500 composites workers through these events in 2018. Additionally, IACMI hosted deep-dive training for industry partners in techniques for repairing and creating sheet-molding compound techniques at SURF in Detroit, Michigan.
- **K–12 Student STEM Engagement:** IACMI participates in STEM engagement events such as Manufacturing Day aimed at K–12 students. To celebrate Manufacturing Day 2018, IACMI showcased manufacturing advancements in the advanced composites research and development community by hosting 50 high school students at the Local Motors microfactory in Knoxville, Tennessee, and 100 students at the IACMI and LIFT joint manufacturing facility in the Corktown neighborhood in Detroit, Michigan.

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

IACMI is creating a community within the composites supply chain of more than 150 members, of which more than 50% are SMMs. More than 60% of IACMI members are engaged in institute project activities.

IACMI is impacting economic development and growing advanced composite markets. Since its launch, IACMI ecosystem members in 8 states have announced more than 3,000 jobs and investments of over $400 million. Headlines for articles that attest to this success include:

- "Leisure Pools Anticipates Employing 1,000 at Factory in Forks of the River Industrial Park" — *Knoxville News Sentinel*
- "N12 Technologies and University of Dayton Research Institute Partner to Enable High Production Capacities of NanoStitch" — *BusinessWire*
- "The Composites Recycling Technology Center Is Now Taking Orders for the World's First Park Bench Made From Recycled Aerospace-Grade Carbon Fiber" — *CompositesWorld*

Figure 36. Wind turbines. Credit: IACMI

Figure 37. IACMI and LIFT event for Manufacturing Day. Credit: IACMI

High-Volume Manufacturing of Lightweight Automotive Components

IACMI teamed the Ford Motor Company (Dearborn, MI), the Dow Chemical Company (Midland, MI), and core partners including Michigan State University (Lansing/Detroit, MI), Purdue University (West Lafayette, IN), Oak Ridge National Laboratory (Oak Ridge, TN), and the University of Tennessee (Knoxville, TN) for a project aimed at replacing metal components in primary automotive body structures with aligned carbon-fiber intermediates in order to decrease overall weight and increase fuel efficiency. The goal of the project is to include carbon composites in 100,000 vehicle-platform units using a combination of novel carbon-fiber intermediates, production methods, and simulation tools. The Dow composite material developed through this prominent IACMI technical project achieved part-level material performance such that Ford has declared it acceptable for specification on future vehicle platforms.

Credit: IACMI

Credit: CESMII

CESMII

Clean Energy Smart Manufacturing Innovation Institute

MISSION: To accelerate development and adoption of advanced sensors, controls, platforms, and models to enable smart manufacturing to become the driving, sustainable engine that delivers real-time business improvements in U.S. manufacturing

HEADQUARTERS: Los Angeles, CA

REGIONAL MANUFACTURING CENTERS:
Western — University of California at Los Angeles
Northern — Rensselaer Polytechnic Institute (Troy, NY)
Southern — Texas A&M University (College Station, TX)
Southern Satellite — North Carolina State University (Raleigh, NC)

ESTABLISHED: January 2017

CONSORTIUM ORGANIZER: University of California at Los Angeles

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

MEMBERS (as of September 30, 2018): 102

CESMII
THE SMART MANUFACTURING INSTITUTE

www.cesmii.org

Background

The focus of CESMII, the Smart Manufacturing Institute is the democratization of strategic technologies, knowledge, and innovation processes to support the revitalization of American manufacturing and to strengthen domestic manufacturing competitiveness. This includes the development and deployment of integrated advanced sensors, platforms, and high-performance computational models to help U.S. manufacturers benefit from smart manufacturing, making them more competitive globally. By using smart-manufacturing practices, manufacturers can optimize their businesses, technologies, infrastructure, and practices using engineered systems that integrate operational technologies and information technologies (OT/IT). The institute partners with private- and public-sector organizations to develop, test, and validate these capabilities for manufacturing as well as to facilitate implementation of new manufacturing solutions (including using apps) and make them accessible and affordable.

CESMII has identified metrics for attaining objectives focused on significantly increasing U.S. energy productivity and energy efficiency, deployment cost recovery through energy savings and productivity, training a smart-manufacturing workforce, and increasing value to and participation of the smart-manufacturing supply chain.

Technology Advancement

"Smart manufacturing is an unprecedented exploitation of data into real-time actions that changes the manufacturing industry with ever-advancing data and information technologies. CESMII is at the forefront of smart manufacturing, ready to change U.S. manufacturing."

— Jim Davis, Vice Provost of Information Technology, University of California at Los Angeles, and co-founder of the Smart Manufacturing Leadership Coalition (Los Angeles, CA)

New Projects Launched in FY 2018

Ten research and development projects were selected in FY 2018 in response to CESMII's first request for proposals. These projects include 40 member institutions representing a variety of industrial settings (e.g., manufacturers of food products, steel, and cement), academia, and technology providers. The projects address critical gaps in smart-manufacturing technologies covering advanced sensing, process control, process modeling, data analytics, and platform technologies. The projects represent an investment of $16.5M, including a 40% cost share, and range from 12 to 24 months in duration. Examples include:

- **Producing Zero-Defects in Steel Continuous Casting:** The project's main objective is to improve steel-slab quality and productivity of the continuous casting process by adopting smart-manufacturing methodologies and technologies, thereby reducing the

overall energy intensity of the existing steelmaking and casting operations. Project partners include ArcelorMittal (East Chicago, IN), the Missouri University of Science & Technology (Rolla, MO), Purdue University (West Lafayette, IN), the Rensselaer Polytechnic Institute (Troy, NY), ThinkIQ (Aliso Viejo, CA), and Uptake (Chicago, IL).

- **Factory 4.0 Educational Toolkit:** Pennsylvania State University (University Park, PA), Arconic (Pittsburgh, PA), and MIT (Cambridge, MA) will build a small-scale process simulator with hardware and software components that mimic aspects of a smart-manufacturing system for educational purposes. The project will also develop a communication and data-storage architecture, optimization/machine learning algorithms and models, and educational modules and interfaces.
- **Energy Management Systems for Subtractive and Additive Precision Manufacturing:** This project aims to develop and demonstrate tangible benefits of smart-manufacturing approaches applicable to subtractive and additive precision manufacturing. It will coordinate use of systems engineering, modeling, advanced controls, data analytics, and secure communication protocols for energy-efficiency improvement in the precision machining and hybrid manufacturing of metals and alloys to support cross-industry platforms. The project team includes the University of Connecticut (Storrs, CT), CCAT (Hartford, CT), Johnson & Johnson (Raynham, MA), and the United Technology Research Center (Hartford, CT).
- **Smart Manufacturing for Chemical Processing Energy Efficiency:** Team members from the Texas A&M Experimental Station (College Station, TX), Aspen Technology (Bedford, MA), OSISoft (San Leandro, CA), Praxair (Tonawanda, NY), Process Systems Engineering (Houston, TX), the Rensselaer Polytechnic Institute (Troy, NY), and the University of Texas (Austin, TX) are working on a project to develop smart-manufacturing platform-ready tools for the reliable, profitable, and energy-efficient operation of a cryogenic air-separation unit. They will rigorously test these tools in a cyberphysical environment and deploy some of them to efficiently operate in a commercial air-separation plant.
- **Inferential Modeling for Driving Out Energy Waste:** The goal of this project is to eliminate wasted energy in manufacturing facilities through improved information technology. This project will apply new data modeling and analytics technology to significantly reduce the cost and time to implement an effective energy-optimization solution. Project participants include ThinkIQ (Aliso Viejo, CA) and General Mills (Minneapolis, MN).
- **Machine Learning and Data-Centric Analytics for Aerospace:** This project will develop technologies for data modeling, machine learning, and data-centric analytics for smart aerospace additive manufacturing. It will implement these innovations using data from working aerospace manufacturing facilities. The project team includes Honeywell (Phoenix, AZ), the Missouri University of Science & Technology (Rolla, MO), Morf3D (El Segundo, CA), the University of California at Los Angeles, the University of Southern California (Los Angeles, CA), Identify3D (San Francisco, CA), Raytheon (El Segundo, CA), Sentient Science Corporation (Buffalo, NY), and Stratonics Inc. (Lake Forest, CA).

The Smart Manufacturing Platform

In addition to the portfolio of research and development projects, CESMII developed a comprehensive vision for its Smart Manufacturing Platform, one of four strategic pillars of CESMII's integrated strategy for democratizing and accelerating the adoption of smart manufacturing by small, medium, and large manufacturers. The platform will enable seamless interoperability of manufacturing-related technologies such as sensing, control, modeling, and analytics using the core capabilities of data ingestion, data contextualization, data management, workflow-based orchestration, and a marketplace of CESMII-approved apps.

This unique, industry-driven framework will be a core strength of CESMII, and the institute will acquire, develop, and harness critical intellectual property to meet industry's growing demand for these technologies. Using existing and new assets, the platform will allow users to integrate the hardware and software components developed by members (technology providers) that are required to assemble customized smart-manufacturing systems,

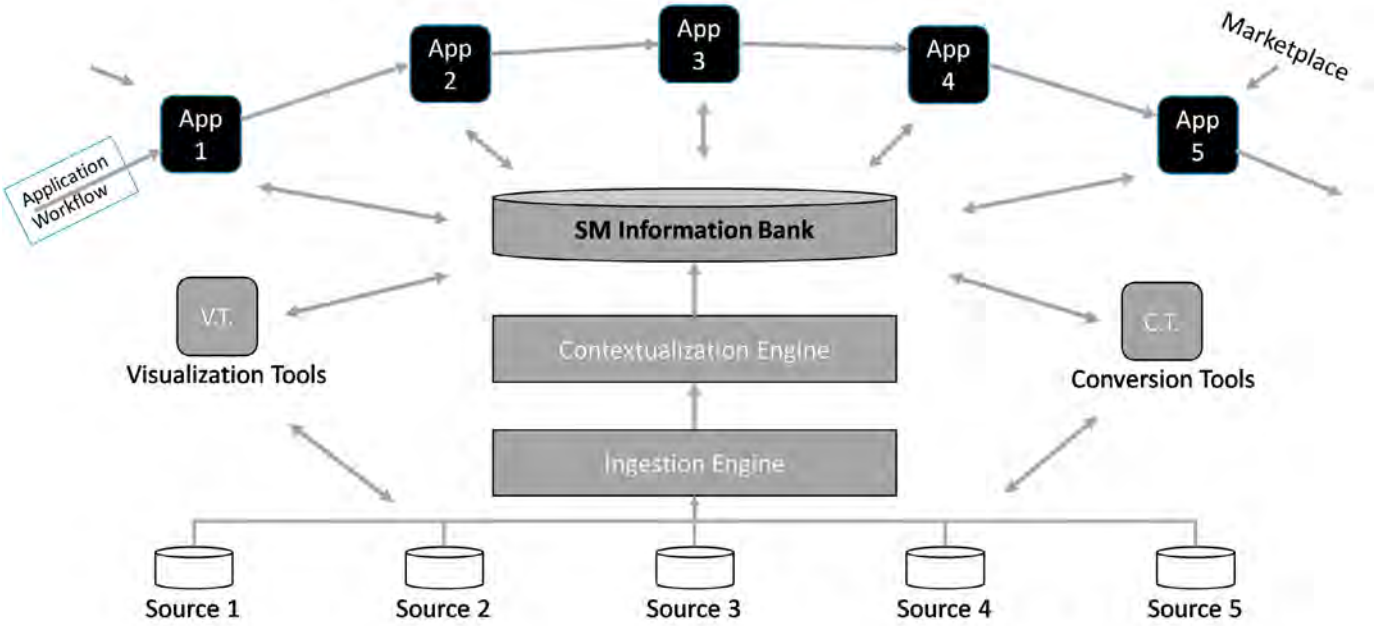


Figure 38. Core capabilities of the Smart Manufacturing Platform — providing connectivity to manufacturing assets, data-contextualization and data-management services, and open access to a marketplace of value-add applications. Credit: CESMII

proliferate their availability in the commercial market, and train the workforce. This process is designed to be user accessible and affordable regardless of an organization's size or technical acumen.

"Praxair has a long history of smart manufacturing, using new technology to reduce our cost to deliver products to our customers. We see the technology developments enabled by the partner ecosystem created by CESMII as a means to uncover the next generation of energy-saving innovations."

— Lawrence Megan, Director, Praxair Digital (Tonawanda, NY)

A collaborative approach is being undertaken to develop the platform with participation from subject-matter experts representing manufacturers, technology providers, systems integrators, and academia. The vision was documented and presented to CESMII membership (see Figure 38 above). In addition to research and development projects that contribute to platform development, a specific project addressing the core capability of data ingestion and contextualization was selected and launched.

Workforce Development

CESMII's smart-manufacturing education and workforce development efforts aim to accomplish the following:

- Engage the manufacturing/industrial ecosystem and include technical staff at facilities to address the differences in training requirements and the capacity to implement smart-manufacturing practices tailored to organizational size, especially for small manufacturers that may have limited information-technology support

- Educate through the use of programs that include training, consulting, and certification programs
- Develop education and training for students and faculty in K-12 schools, community colleges, and universities (both undergraduate and graduate), as well as for reentering workers, including veterans.

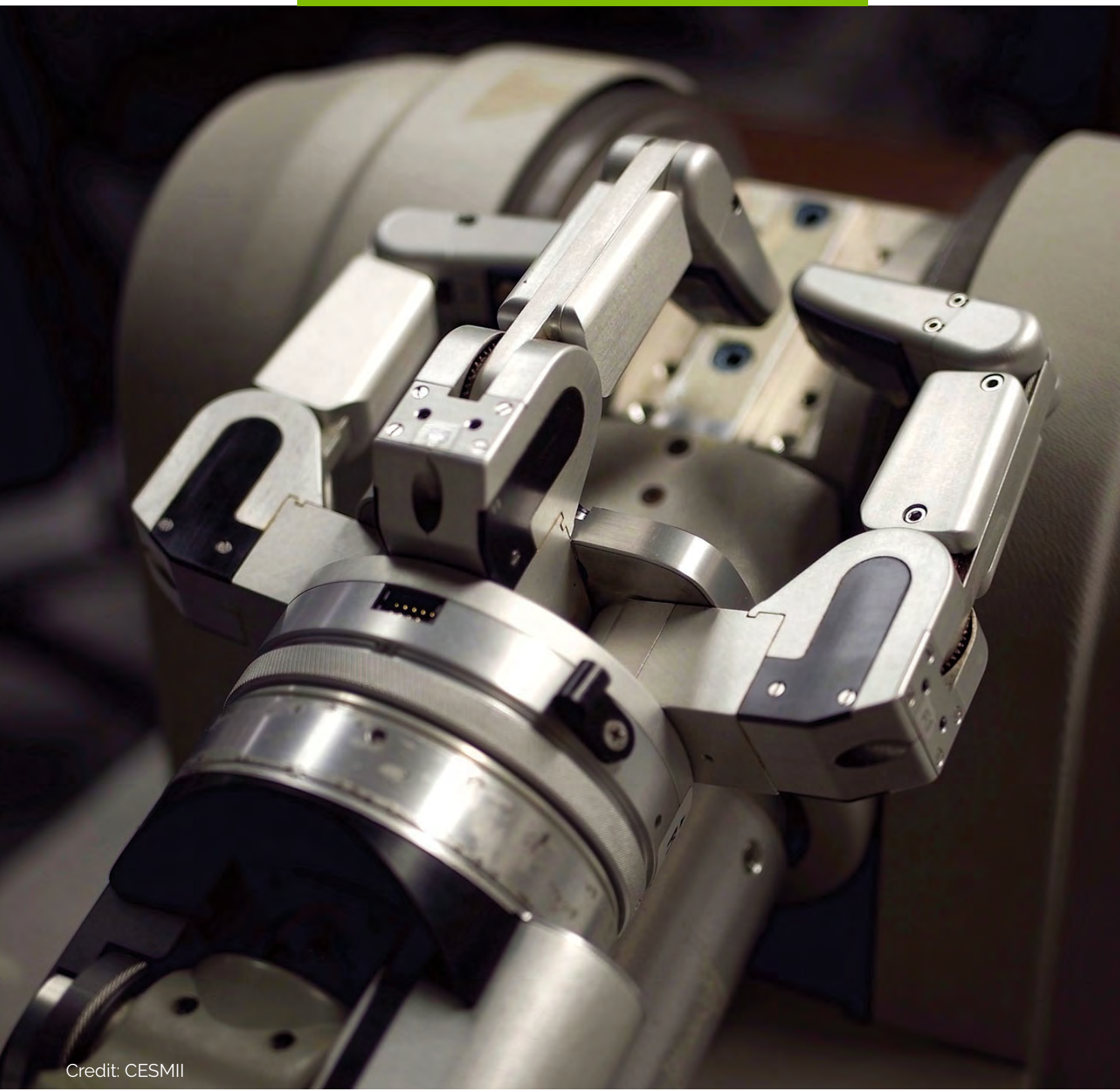
Highlights from FY 2018 include:

- Held a workshop with over 90 participants, which resulted in a cohesive training plan and the initial catalog of training modules. Additionally, CESMII has formed a standing committee with 26 members and conducted workshops with more than 340 attendees.
- Led a training webinar for using the Smart Manufacturing Platform for each of the three regional manufacturing centers and their associated memberships, which serves as a prerequisite for the future SM101 and SM201 curriculum.
- Strategically partnered with MESA International to provide and develop training content.
- Fostered partnerships with local community colleges to gather information on technical expertise within each of their regions.

Innovation Ecosystem

CESMII's Smart Manufacturing Platform will unlock the power of the raw data created by manufacturing processes, thereby unleashing the potential for innovation. A core strength of CESMII's innovative ecosystem is the diversity of its network. CESMII's 100-plus members are varied both in organizational size and product offerings. CESMII members include small, medium, and large organizations; universities and community colleges; research labs; and government agencies. Membership cuts across the spectrum of U.S. manufacturing, including producers of packaged foods, steel, lightweight metals, electronic components, innovative sensors, aerospace components and machinery, rubber, industrial gases, software, pharmaceutical and consumer products, and various service organizations, as well as educational institutions producing highly skilled professionals and next-generation manufacturing leaders.

Although highly varied in their product offerings and processes, CESMII members share many of the same significant manufacturing issues, which is the reason they became CESMII members. Although these collaborative partnerships are still novel, they continue to prove to be valuable and instrumental in furthering the smart-manufacturing journey.



Credit: CESMII

Credit: REMADE

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

ESTABLISHED: May 2017

CONSORTIUM ORGANIZER: Sustainable Manufacturing Innovation Alliance

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

MEMBERS (as of September 30, 2018): 75

remadeinstitute.org

Background

With improvements in materials production and processing, the U.S. can significantly increase manufacturing energy efficiency, yielding substantial economic savings. The Reducing EMbodied-energy And Decreasing Emissions (REMADE) institute, a Manufacturing USA institute co-funded by the DOE, was founded to help realize these opportunities.

The three primary goals of REMADE are to develop technologies capable of accomplishing the following:

- Reducing energy and emissions through a reduction in primary material consumption and an increase in secondary feedstock use in energy-intensive industries
- Achieving better than cost and energy parity for key secondary materials
- Enabling the widespread application of these new technologies across multiple industries.

In partnership with industry, academia, trade associations, and national laboratories, REMADE enables early-stage applied research and development of technologies that could dramatically reduce the embodied energy and carbon emissions associated with industrial-scale materials production and processing. The REMADE institute is particularly focused on increasing the recovery, reuse, remanufacturing, and recycling (collectively referred to as Re-X) of metals, fibers, polymers, and electronic waste (e-waste).

To achieve its mission, the REMADE institute is organized around five focus areas, or nodes, four of which align to the material lifecycle stages: Design for Re-X, Manufacturing Materials Optimization, Remanufacturing and End-of-life Reuse, and Recycling and Recovery. The fifth node, Systems Analysis and Integration, addresses systems-level issues that are broader in scope than any one particular node and that have the potential to impact all the nodes (see Figure 40 on page 89).

Since its establishment, REMADE has attracted more than 75 members, developed a technology roadmap, selected and launched projects, and conducted a national labor study that will guide the future education and workforce development activities of the institute.

Technology Advancement

"REMADE is a model public-private partnership that is solving technical challenges and making it possible to conserve and repurpose significantly more manufacturing resources. We are excited to be working with REMADE to help advance a more circular economy for plastics and help our industry meet its commitment to recycle and recover all plastic packaging in the U.S. by 2040."

— Steve Russell, Vice President, Plastics Division, American Chemistry Council

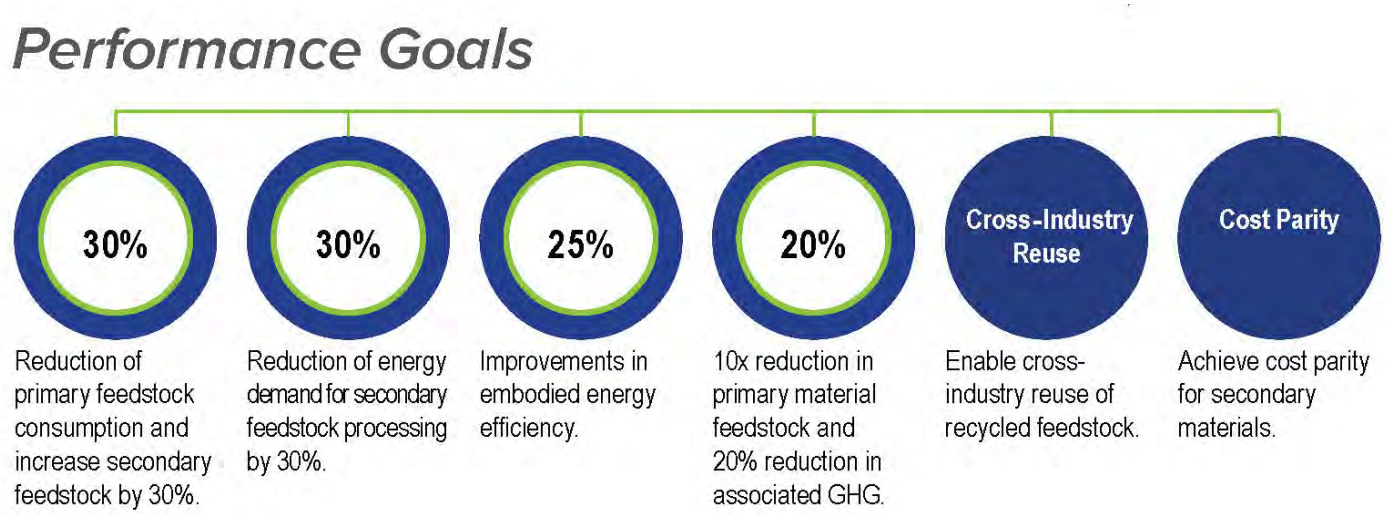


Figure 39. REMADE Performance Goals. Credit: REMADE

New Projects Launched in FY 2018

In FY 2018, the REMADE institute launched two projects focused on the recycling and recovery of paper, fibers, and e-waste. These projects marked the institute's first official step toward achieving its objective of improving sustainable manufacturing in the United States:

- **Assessing the Impact of Single-Stream Recycling on Paper Contamination in Recovery Facilities and Paper Mills:** This project will evaluate the impact of single-stream recycling on paper contamination in recovery operations and explore emerging recovery processes for minimizing fiber contamination. The benefits include the potential to reduce costs by $10 million and reduce carbon dioxide emissions. The project team includes the University of Miami (Miami, FL), the Institute of Scrap Recycling Industries (Washington, D.C.), the American Forest & Paper Association (Washington, D.C.), and Resource Recycling Systems (Ann Arbor, MI).
- **Rapid Sorting of Scrap Metals With a Solid-State Device:** The University of Utah and EDX Magnetics (Salt Lake City, UT) are partnering on this project to improve the separation of nonferrous scrap metals from other nonferrous metals using electrodynamic sorting at high throughput and with greater purity and yield. The results will enable energy reduction of 300 trillion BTU per year and reduce greenhouse gas emissions by the equivalent of 15 million tons of carbon dioxide per year.

In addition, REMADE selected 17 projects for negotiation in 2018 with a total value of $10 million. These projects leverage the expertise of 30 organizations across the diverse membership of REMADE. Examples include:

- **Develop New Cost-Effective Methods for Removing Trace Contaminants in Recycled Metals:** This project between Ohio State University (Columbus, OH), Alcoa (Pittsburgh, PA), and Computherm (Madison, WI) will experimentally evaluate the addition of scoping elements in molten aluminum to neutralize trace contaminants that would otherwise limit the recycling of aluminum.
- **Determine Material, Environmental, and Economic Efficiency of Sorting and Recycling Mixed Flexible Packaging and Plastic Wrap:** Work between the American Chemistry Council (Washington, D.C.), Resource Recycling Systems (Ann Arbor, MI), and the Idaho National Laboratory (Idaho Falls, ID) will further develop technology to recover flexible plastic film from a material-recovery facility. Market opportunities for the recovered film will be examined and the resulting economic and environmental impacts will be evaluated. The technology to be developed in the project, if implemented broadly, has the potential to capture almost 11 billion pounds of flexible plastic packaging and plastic wrap landfilled each year.

Figure 40. REMADE Nodes. Credit: REMADE

- **Demineralize Carbon Black Derived From End-of-Life Tires:** Alternative process technologies will be experimentally evaluated to upgrade carbon black recovered from end-of-life tires, in which it was used as a reinforcing filler to meet quality specifications for the carbon black market. Approximately 3.87 million tons of waste tires accrue every year in the U.S. If these tires were processed to recover the carbon black, about 1.1 million tons of carbon black could be recovered for use as a secondary feedstock. Project participants are the University of Utah (Salt Lake City, UT), OTR Wheel Engineering/Green Carbon Inc. (Rome, GA), and the Idaho National Laboratory (Idaho Falls, ID).

By the summer of 2019, REMADE expects to launch more than 30 projects with the potential to save over 1 quadrillion BTUs of energy and recover over 41 million tons of metal, plastic, fiber, and e-waste.

Workforce Development

"REMADE's partnerships and collaborations allow the institute to understand the skills and training required for a 21st-century workforce. REMADE's education and workforce development study is a foundation that will guide future investment and training development."

— Michelle Hayes, Remanufacturing Industries Council

Credit: REMADE

Figure 41. REMADE member meeting. Credit: REMADE

In FY 2018, REMADE completed a national labor study documenting relevant occupations, skills, and competencies required to successfully deploy new REMADE technologies and accelerate the transition to a circular economy. The institute also built a catalog of existing workforce training offerings in targeted sectors to identify gaps that require future REMADE workforce development activities. To date, REMADE has hosted several thought-leadership seminars addressing topics relevant to U.S. industry. Looking forward, the institute will develop a tiered certificate pathway program and associated training content designed for the incumbent and future workforce.

Innovation Ecosystem

The REMADE institute, with more than 30 industry members representing 640,000 employees, 25 academic institutions, 11 trade organizations and 4 national labs, is well positioned to develop and deliver innovative solutions that will transform the U.S. manufacturing ecosystem.

REMADE's mission has garnered interest from across the U.S. economy. In the span of a year, REMADE has assembled a diverse consortium of 75 industry, academic, national laboratory, and trade association partners who are collaboratively solving the greatest challenges in recycling, remanufacturing, and design to accelerate the transition to a more circular economy.

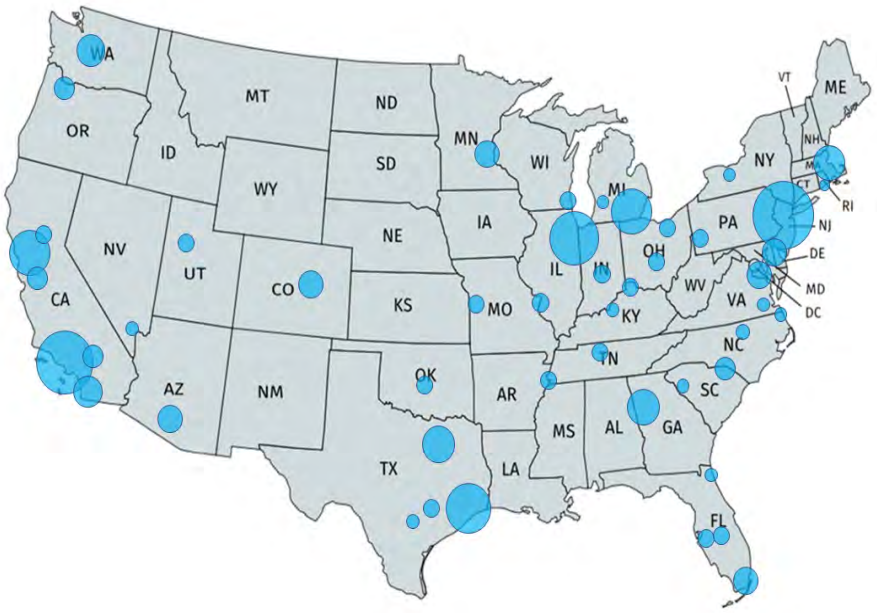
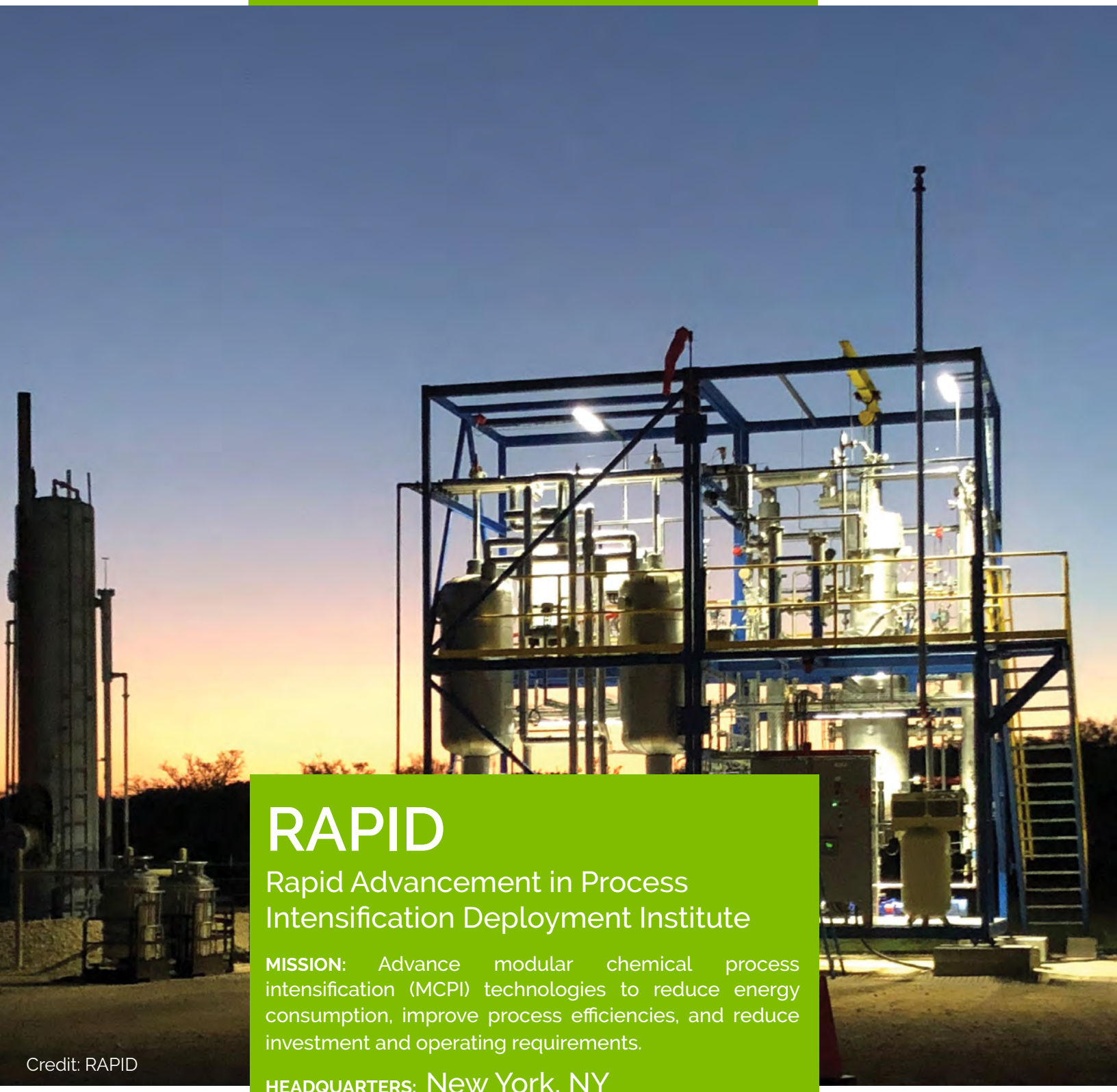


Figure 42. Regions where concentrations of the REMADE workforce have been identified, from the institute's *Workforce Profile* report. Credit: REMADE

Because SMMs make up 55% of its industry members and large corporate partners such as Nike, Caterpillar, Unilever, and Michelin are involved as well, the REMADE institute is well positioned to develop and transition technology across the U.S. manufacturing ecosystem.

Technology developed by REMADE and its members will play a central role in expanding the supply chain for secondary-material manufacturing in the U.S.



Credit: RAPID

RAPID

Rapid Advancement in Process Intensification Deployment Institute

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

HEADQUARTERS: New York, NY

ESTABLISHED: March 2017

CONSORTIUM ORGANIZER: American Institute of Chemical Engineers (AIChE)

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

MEMBERS (as of September 30, 2018): 70

RAPID
Transforming Process Industries

www.aiche.org/rapid

Background

Process intensification, which dates back to the early 1970s, involves development of new technologies or equipment that can potentially transform the process industries. The Rapid Advancement in Process Intensification Deployment Institute (RAPID) leads a national effort to research and develop high-impact modular chemical process intensification solutions for U.S. industry and operates the institute to benefit members from industry, academia, national laboratories, and other nonprofit organizations. RAPID is also committed to advancing women-owned and minority-owned businesses in the emerging field of process intensification. The institute's strength is its ability to provide members with access to process intensification resources, tools, expertise, and facilities.

RAPID is continually refining its technology roadmap, which currently focuses on six key areas:

- Chemical and commodity processing
- Natural gas upgrading
- Renewable bioproducts
- Intensified process fundamentals
- Modeling and simulation
- Module manufacturing.

As a result of its various activities, RAPID serves as a nexus between process innovation, economic development, and job creation. The technology development and educational programming RAPID supports can increase energy and operational efficiencies, enhance productivity, and improve sustainability. The institute's programming makes U.S. manufacturing in the process industries, including chemicals, oil and gas, pulp and paper, and others, more competitive in the global market.

Technology Advancement

"Membership and active participation in the RAPID manufacturing institute has been the key catalyst for introducing the concepts of process intensification into our corporation and for our successful collaboration with the University of Pittsburgh."

— Clifford Kowall, Lubrizol Corporation

New Projects Launched in FY 2018

RAPID has a robust portfolio of 34 technical projects in early stages of activity. In its mid-2018 project call, the institute selected six technical research and development projects and two education and workforce development projects. Highlights include the following:

- **On-Demand Treatment of Wastewater Using 3D-Printed Membranes:** Wastewater treatment — an area called out in RAPID technology roadmapping efforts — often involves many steps and can be energy intensive. This project between Lubrizol (Wickliffe, OH), the University of Pittsburgh (Pittsburgh, PA), and Siemens (Washington, D.C.) will work to devise a more energy-efficient process to separate contaminants from water using novel 3D-printed membranes. The results will be a first-of-its-kind proof of concept where a 3D printer is used to create unique geometries and structures in membranes to separate water and contaminants relevant to the chemical industry.

- **More Efficient, Safer Production:** RAPID members plan to use the platform technology developed by IntraMicron (Auburn, AL) to create a safer and more efficient process for production of ethylene oxide, an important organic compound used to develop many industrial chemicals. Ethylene oxide manufacturing has been identified in the target list of the DOE's Chemical Bandwidth Study of potential energy-savings opportunities in U.S. chemical manufacturing. To increase efficiency, this project will apply a microfibrous-entrapped catalyst with enhanced thermal conductivity to safely improve current ethylene-epoxidation processes.

- **High-Purity Ethanol Extraction:** The University of Connecticut (Storrs, CT) will lead a team in partnership with Mattershift (San Francisco, CA) and Fraunhofer (Plymouth, MI) to demonstrate that carbon-nanotube membranes have exceptional performance in ethanol extraction. The unique chemical and structural features of carbon nanotubes allow ethanol to selectively pass through the membranes, leaving water behind. These membranes are expected to concentrate low-purity (between 5% and 40%) ethanol solutions to more than 80% in a single pass. Application of this technology could reduce the energy used in ethanol production by up to 90%.

- **DIAMOND Treatments for Shale Gas Wastewater:** Texas A&M University (College Station, TX), the University of Pittsburgh (Pittsburgh, PA), the University of Texas at Austin, and U.S. Clean Water Technology (Los Angeles, CA) are partnering on this project to generate commercially viable design and operational strategies for treatment of water resulting from shale-gas production. The highly distributed nature and variable characteristics of shale-gas wastewater provides a unique opportunity to use modular systems for wastewater management to overcome the costs associated with developing tailored designs for each source of wastewater. This integrated project (DIAMOND, or Deploying Intensified Automated, Mobile, Operable, and Novel Designs) will accomplish the following:
    - Assess, screen, and integrate commercially viable conventional and emerging technologies for wastewater treatment
    - Develop computer-aided modeling approaches for nonrecurring engineering needed to deploy treatment systems
    - Demonstrate proof of concept via applications to a broad range of samples.

- **Developing New Approaches to Separate Liquids:** The University of Illinois (Urbana-Champaign, IL) and Carnegie Mellon University (Pittsburgh, PA) are collaborating with other RAPID members on a project to develop, test, and demonstrate the use of ultrasound for continuous-flow, scalable liquid separation of ethanol and water. This approach would avoid the heat-transfer losses and bottleneck issues of distillation. Successful deployment of ultrasound technology for high-volume liquid separation could result in significant savings in energy and capital costs and lay the groundwork for similar separations in a broad class of other systems.

Workforce Development

"Kudos to RAPID education and workforce development for getting graduate and undergraduate students excited and involved in developing technologies to double energy efficiency in process industries through process intensification and modular manufacturing. It is refreshing to see advanced process technology development making waves in chemical engineering graduate education."

— Yang Luo, Praxair

- **Modular Chemical Process Intensification Boot Camp:** Oregon State University (Corvallis, OR) will develop a four-day boot camp for professional engineers interested in advancing process intensification in the chemical industry. The boot camp is designed to expand engineers' understanding of and appreciation for the value of process intensification for use within their companies using practical and real-world applications. By demonstrating how process intensification can help advance module manufacturing through better economics through size and weight reduction of components, engineers will receive actionable insights to implement within their organizations. A pilot offering of the course is targeted for late summer 2019.
- **Integrated Course: Emerging Processes for Water Purification:** The University of Arizona (Tucson, AZ) will develop a four-day face-to-face course for professional engineers and graduate students to compare and contrast the uses of conventional versus emerging processes to purify water. Understanding the pros and cons of current and emerging technologies in wastewater treatment will provide participants with understanding of which technology is most cost- and energy-efficient. In this project-based course, attendees will brainstorm a treatment process, design and perform experiments, test hypotheses in a state-of-the-art pilot-scale wastewater-treatment facility, model the process using simulation software by Chemstations (Houston, TX), update hypotheses based on the data, and establish the practical viability of the hypotheses using available software. A pilot offering of the course is targeted for early winter 2020.

Innovation Ecosystem

"RAPID is a community where you are able to meet the best and the most creative minds from across industries, academia, and national labs . . . to partner, jointly develop, and/or provide a commercialization path for relevant innovative technologies to boost energy efficiency and reduce modular system costs to benefit U.S. manufacturing."

— Yang Luo, Praxair

As a result of membership and thought-leadership activities fostered by RAPID, a robust ecosystem revolving around innovation has been created for members. Members such as Oregon State University (Corvallis, OR) and Pacific Northwest National Laboratories (Richland, WA) can actively explore new approaches and technologies. For example, they are learning to use additive manufacturing techniques to design and build microchannel chemical reactors and heat exchangers with 5-fold to 10-fold reductions in size and weight.

Working within the Module Manufacturing Focus Area of the RAPID Manufacturing Institute, Oregon State University and Pacific Northwest National Laboratories (PNNL) are advancing a new solar thermochemical product to market in partnership with a spinout of PNNL called STARS Technology Corporation.

With support from RAPID funding, STARS will set up pilot production of its modules for proof-of-concept testing under field conditions. The STARS chemical-conversion technology supports multiple applications, including solar-powered steam methane reforming, where solar-to-chemical efficiencies greater than 70% have been demonstrated.

SUCCESS STORY

The Sweet Smell of SourCat™

In fall 2018, RAPID member IntraMicron (Auburn, AL) scheduled numerous visitor tours for industry executives and other RAPID members to their desulfurization pilot plant in Texas to demonstrate how their SourCat desulfurization technology is ideally suited to wellhead operations, landfill gas, biogas, offshore platforms, acid-gas treatment, and other process gas streams (see Figure 43 below). SourCat, unlike other gas-desulfurization systems, does not require a concrete foundation and can be easily assembled or disassembled. Most noteworthy, this technology offers an energy- and cost-efficient alternative to traditional natural gas-desulfurization approaches. SourCat enables more cost-effective production by reducing desulfurization cost from greater than $1 to less than $0.15 per thousand cubic feet of gas.

Figure 43. SourCat pilot-scale demonstration. SourCat provides an energy- and cost-efficient alternative to traditional natural gas-desulfurization approaches. Credit: IntraMicron

Additionally, Oregon state investments leveraging RAPID-funded projects are providing the opportunity to establish new supply chains both for use in components for modular chemical-process intensification and for use in future aerospace and biomedical device markets. The cumulative economic impact on these industries over time could include billions of dollars in revenue and thousands of new high-wage jobs.

Intern Intensification

Launched in June 2018, RAPID's inaugural Student Intern Program, which aimed to develop and train future leaders in process intensification by giving interns hands-on experience supporting RAPID projects, was a resounding success, as 86% of participants stated that the program had an impact on their educational goals and career aspirations.

Originally designed to support 4 interns, the program exceeded this goal due to a higher-than-anticipated level of interest, engaging 14 interns from 5 RAPID member institutions over the course of 10 weeks (see Figure 44 below). Nominating organizations were responsible for hiring the interns, providing them with technical mentors, and compensating them, with the cost of supporting an intern treated as cost-share toward RAPID projects.

RAPID created a dynamic intern experience, providing professional- and leadership-development content, feedback, and career guidance, as well as a virtual community — an online forum where interns could share perspectives on their work in the lab and outside of it.

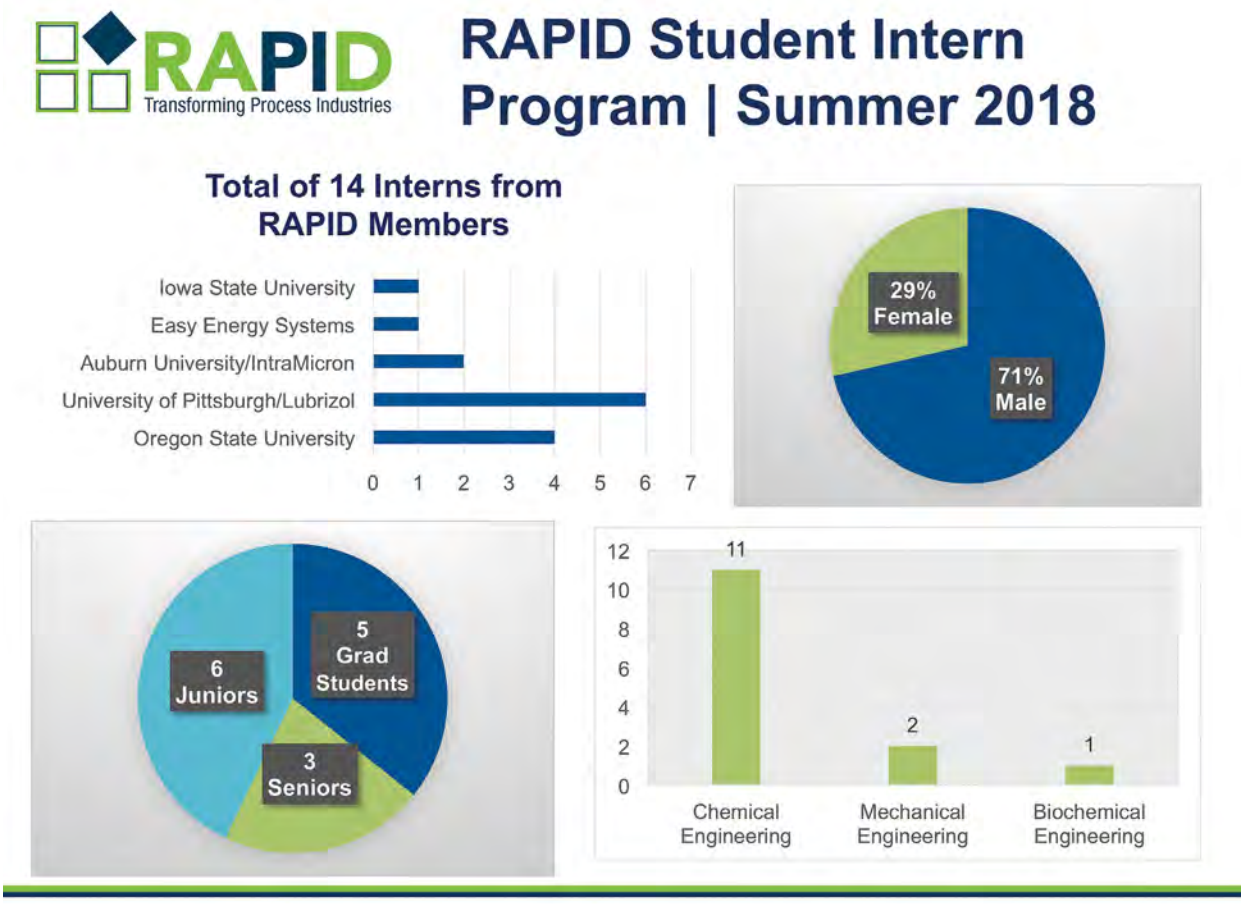


Figure 44. Fourteen students interned at RAPID in FY 2018. Credit: RAPID

Appendix A

Federal Agencies Participating in the Manufacturing USA Program

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 the Manufacturing USA program 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 the Manufacturing USA program.

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.[46] 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 is concentrated on 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.[47] Unlike the other manufacturing institutes, the DoD-sponsored manufacturing innovation institutes have

[46] 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)).

[47] Under 10 USC 2521, the DoD Manufacturing Technology Program has the authority to establish and continue the public-private partnership with the eight DoD institutes. The DoD-sponsored manufacturing innovation institutes participate in the Manufacturing USA network as national resources to further their defense-specific objectives of fostering a robust manufacturing industrial base. The authorities granted under the Revitalize American Manufacturing and Innovation Act of 2014 do not apply to the DoD-sponsored Manufacturing USA institutes.

the additional mission to develop innovative technologies that will ultimately aid the Warfighter. The DoD Manufacturing USA 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, and biotechnology, 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, domestic 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.

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 $1.27 billion Carl D. Perkins Career and Technical Education Act, the purpose of which is to develop more fully the academic and career and technical 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 and collaborates with other federal agencies in those areas that focus on the knowledge and skill needs of the economy and efforts related to student success. Technical assistance to the institutes related to education and workforce development will be offered by the ED in 2019.

Department of Energy

The mission of the U.S. Department of Energy (DOE) is to ensure the security and prosperity of the United States by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions. This includes catalyzing the timely, material, and efficient transformation of the Nation's energy system and securing U.S. leadership in energy technologies, as well as maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity. To accomplish these goals, the DOE has established multiple crosscutting innovative programs to strengthen and increase U.S. manufacturing competitiveness by boosting energy productivity and leveraging low-cost domestic-energy resources and feedstocks.

Advanced manufacturing involves the minimization of energy expenditure in the production, use, and post-use of manufactured goods, which range from fundamental commodities such as metals and chemicals to sophisticated final-use products such as automobiles and wind-turbine blades. The manufacturing sector, a subset of the industrial sector, consumes 25 exajoules (24 quads) of primary energy annually in the U.S. — about 79% of total industrial energy use. The DOE partners with private and public stakeholders to support research and development of innovative technologies that can improve U.S. competitiveness, save energy, and ensure global leadership in advanced manufacturing technologies.

The DOE uses a range of mechanisms, including Manufacturing USA institutes and Energy Innovation Hubs to develop advanced manufacturing technologies. As of the end of FY 2018, the DOE had five Manufacturing USA institutes. The first,

PowerAmerica, is focused on wide-bandgap semiconductor technologies for next-generation power electronics. The second, the Institute for Advanced Composites Manufacturing Innovation (IACMI), is focused on composite technologies for vehicles, wind-turbine blades, and compressed-gas storage tanks. The latest additions to the DOE institute portfolio include Clean Energy Smart Manufacturing Innovation (CESMII), Rapid Advancement in Process Intensification Deployment (RAPID), and the Clean Energy Manufacturing Innovation Institute for Reducing EMbodied-energy And Decreasing Emission (REMADE) in Materials Manufacturing. A competition for a sixth institute, Cybersecurity in Energy Efficient Manufacturing, will be held in FY 2019.

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. Promising technologies 5 to 10 years in the future are examined by the FDA Emerging Sciences and Technology Working Group, and existing technologies for products such as pharmaceuticals manufactured using innovative approaches can utilize the Center for Drug Evaluation and Research's Emerging Technology Program, which encourages adoption of innovative approaches.

The FDA is actively engaged with its interagency partners, the DoD and the DOC/NIST, in select Manufacturing USA institutes that intersect with FDA-regulated products—specifically, America Makes, NIIMBL, and BioFabUSA. In 2017 and 2018, the FDA worked closely with the America Makes Standards Collaborative to publish versions 1 and 2 of the *Standardization Roadmap for Additive Manufacturing*. Furthermore, the FDA, in collaboration with the HHS Assistant Secretary for Preparedness and Response (ASPR) Biomedical Advanced Research and Development Authority (BARDA), awards projects through the FDA's Broad Agency Announcement to support emerging and enabling technologies for continuous manufacturing. To better inform future federal funding and stakeholder community research and development efforts, the FDA partnered with ASPR/BARDA to sponsor a National Academies of Science, Engineering, and Medicine (NASEM) workshop on the continuous manufacturing of biologics to foster an in-depth discussion of the technical challenges and opportunities for collaboration, especially in the precompetitive space. The FDA is working closely with NIIMBL and FDA stakeholders to incorporate this feedback to support data-driven regulatory decisions.

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 Space Technology Mission Directorate (STMD) of the National Aeronautics and Space Administration (NASA) serves as the agency's principal organization supporting Manufacturing USA. The 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.

NASA's Human Exploration and Operations Mission Directorate also supports advanced-technology development through the Advanced Exploration Systems Division. The In-Space Manufacturing (ISM) program is responsible for development of 3D printing capabilities for production of components on the International Space Station (ISS) for both NASA and commercial objectives, paving the way for future factories in space.

Advanced manufacturing research and development at NASA 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.

NASA is advancing promising transformative technologies, including in-space manufacturing, on-orbit assembly, and advanced materials facilitating economic development of new commercial space sectors. NASA seeks leadership in space science and exploration through excellence in space-related manufacturing such as 3D printing for space travel to support scientists and engineers to live and work in the unique microgravity environment.

NASA is expanding its efforts to engage industry and academia on advanced manufacturing topics central to the nation's space mission through its National Center for Advanced Manufacturing, with a focus on developing manufacturing technologies that enable major advances in systems capabilities that mitigate the risk aversion of development and operations programs.

National Science Foundation

The National Science Foundation (NSF) supports fundamental advanced manufacturing research, education, and workforce training in its Directorates for Engineering, Computer and Information Science and Engineering, Mathematical and Physical Sciences, and Education and Human Resources. 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 and NIST jointly sponsor MForesight: Alliance for Manufacturing Foresight, a consortium that harnesses the expertise of the broad U.S.-based manufacturing community to forecast future advanced manufacturing technologies.

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

Worldwide, bioenergy and bioproducts are emerging as new and rapidly growing sectors of the highly productive agricultural and forest industries. Manufacturing bio-based products (e.g., biofuels, industrial chemical intermediates, performance polymers, and finished higher-value products) represent a significant opportunity for the United States to support growth of a bio-economy. Expansion of the bio-economy has the potential for the sustainable harvest and use of 1 billion tons of renewable biomass in the U.S. annually while continuing to support existing food, feed, and fiber markets, growing the current market 5-fold over the next 15 years, and adding $500 billion to the annual bio-economy while creating thousands of jobs, many in rural areas.

The U.S. Department of Agriculture (USDA) recognizes that manufacturing plays an important role in maximizing the benefits of a sustainable rural economy. Areas of interest include biomanufacturing and bioproduct development to

- Establish processes and chemical platforms leading to high-value intermediate and end-use products
- Support commercialization of products developed from basic and applied research
- Improve U.S. global competitiveness by building domestic capability for ongoing biomanufacturing and bioproducts development
- Educate and train the needed workforce.

Appendix B
Abbreviations

ACADEMI	Advanced Curriculum in Additive Design, Engineering, and Manufacturing Innovation
AFFOA	Advanced Functional Fabrics of America
AIM Academy	AIM Photonics Academy
AIM Photonics	American Institute for Manufacturing Integrated Photonics
ALMMII	American Lightweight Materials Manufacturing Innovation Institute
AMNPO	Advanced Manufacturing National Program Office
AMTech	Advanced Manufacturing Technology Consortium
ANSI	American National Standards Institute
ARM	Advanced Robotics for Manufacturing Institute
ARMI	Advanced Regenerative Manufacturing Institute
ATE	Advanced Technological Education
CESMII	Clean Energy Smart Manufacturing Innovation Institute
CFRP	carbon fiber reinforced polymer
CMOS	complementary metal-oxide semiconductor
CNC	computer numerical control
DCL	Dear Colleague Letter
DMDII	Digital Manufacturing and Design Innovation Institute
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
ED	Department of Education
DOL	Department of Labor
FHE	flexible hybrid electronics
FY	fiscal year
GaN	gallium nitride
GAO	Government Accountability Office
IACMI	Institute for Advanced Composites Manufacturing Innovation
IMCP	Investing in Manufacturing Communities Partnership
LiFi	light fidelity
LIFT	Lightweight Innovations for Tomorrow
MEP	Manufacturing Extension Partnership
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MPW	multi-project wafer
MxD	Manufacturing times Digital: The Digital Manufacturing Institute
NASA	National Aeronautics and Space Administration
NIIMBL	National Institute for Innovation in Manufacturing Biopharmaceuticals
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NSF	National Science Foundation
PIC	photonics integrated circuit
PDK	process development kit
RAMI	The Revitalize American Manufacturing and Innovation Act of 2014
RAPID	Rapid Advancement in Process Intensification Deployment Institute
REMADE	Reducing EMbodied-energy And Decreasing Emissions
SBIR	Small Business Innovation Research
SiC	silicon carbide
SMMs	small and medium-sized manufacturers
STEM	science, technology, engineering, and mathematics
STMD	Space Technology Mission Directorate (NASA)
USDA	United States Department of Agriculture
WBG	wide bandgap

Advanced Manufacturing National Program Office Interagency Working Team Participants

Advanced Manufacturing National Program Office

Michael F. Molnar (Sponsor)
Robert Rudnitsky
(Annual Report Co-Leader)
Hong Liang
(Annual Report Co-Leader)
Lisa Jean Fronczek
(Team 1 Coordinator)
Frank W. Gayle
Said Jahanmir
(Team 2 Coordinator)
Margaret Phillips
Kelley Rogers
Zahraha Brunner
Nico Thomas
Stephen Campbell
Jessica Strickler
Nicholas Stubblefield

Department of Commerce

Mary Ann Pacelli
Phillip Singerman
Ben Vickery

Department of Defense

Tracy Frost (Sponsor)
Mark Gordon
(Writing Team 2 Leader)
Abhai Kumar
(Writing Team 1 Co-Leader)
Michael Britt-Crane
Jessica Bowen
John Christensen
David Heckman
Mark Jackson
Steve Linder
MicKenzie Roberts-Lahti

Department of Education

Gregory Henschel (Sponsor)
Robin Utz

Department of Energy

Valri Lightner (Sponsor)
Natalie Rance
Andrew Steigerwald
Nebiat Solomon
Sudarsan Rachuri
(Writing Team 1 Co-Leader)

Department of Health and Human Services

James Coburn, FDA (Sponsor)
Jeff Baker, FDA

Department of Labor

Carrie Snidar (Sponsor)
Robin Fernkas
Mark Toal

National Aeronautics and Space Administration

John Vickers (Sponsor)
Frank Ledbetter

National Science Foundation

Bruce Kramer
(Sponsor and Contributor)
Andrew Wells

U.S. Department of Agriculture

World Nieh (Sponsor)
Daniel Cassidy

Advanced Manufacturing
National Program Office

ManufacturingUSA.com

NIST AMS 600-5
This publication is available free of charge from: https://doi.org/10.6028/NIST.AMS.600-5

190908