Manufacturing USA at DOE: Supporting Energy Innovation

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Market failures lead to gaps in the private sector's responses to the manufacturing and energy innovation imperative. Manufacturing USA helps fill these gaps.

Manufacturing plays an outsized role in the health of the U.S. economy because of its impact on trade and innovation and its large multiplier effect. Yet, U.S. manufacturing competitiveness has declined over the last 15 years.[1] Accelerating innovation in industrial processes that use energy—and in products used by the energy industry—would strengthen U.S. manufacturing and hasten progress toward national economic, workforce, security, and environmental goals. The Manufacturing USA innovation institutes sponsored by the U.S. Department of Energy (DOE) support U.S. manufacturers in their efforts to accelerate energy innovation. These institutes are showing promising results and deserve to be sustained.

The private sector is ultimately responsible for implementing innovations in manufacturing, and it generates and commercializes many such innovations as well. Market failures, however, lead to gaps in the private sector's responses to the manufacturing and energy innovation imperative. Manufacturing USA helps fill these gaps. Each of its 14 institutes, 5 of which are sponsored by DOE, is a consortium of large and small companies, academic and nonprofit institutions, and national laboratories that operates in a technological domain that offers significant opportunities to accelerate innovation. These members, with additional support from state governments, provide nonfederal funding that matches or exceeds the initial five-year $70 million federal investment in each institute.

This report begins by identifying the national goals that are at stake at the nexus of manufacturing and energy, and explains why federal action is necessary. It then briefly describes DOE's involvement with manufacturing—both past and present—and its links to the government-wide Manufacturing USA program.

The core of this report draws on public documents, site visits, and interviews to describe the origins of the five institutes sponsored by DOE, and the progress they have made since they were founded between 2015 and 2017:

- PowerAmerica (Next Generation Power Electronics Manufacturing Innovation Institute)
- The Institute for Advanced Composites Manufacturing Innovation (IACMI)
- The Clean Energy Smart Manufacturing Innovation Institute (CESMII)
- The Rapid Advancement in Process Intensification Deployment (RAPID) Institute
- The Reducing EMbodied-energy And Decreasing Emissions (REMADE) Institute

This report concludes with these findings and recommendations:

- DOE's Manufacturing USA institutes have the potential to accelerate technological progress toward important national goals.
- The institutes are beginning to make good on their promise, but it is too soon to make definitive judgments about them.
- It is not too early to begin taking steps to improve the performance of existing institutes and support the start-up of new ones.
- Congress should continue to fund the institutes that have already been established.
- DOE should allow the institutes greater flexibility in raising and using private-sector funding in parallel with federal funding.
- Congress and DOE should provide opportunities for the institutes to receive federal funding beyond the current limit of five years—and consider establishing a permanent program of support.
- The institutes should intensify their outreach to small and medium-sized manufacturers.
- The institutes should develop more education and training programs for technicians and other mid-skill manufacturing workers.
- DOE should better inform the public about the distinctive energy-specific mission of the DOE-sponsored Manufacturing USA institutes.

THE ENERGY INNOVATION IMPERATIVE IN MANUFACTURING

The United States must become more innovative in how it uses energy in manufacturing and develops products for use within the energy industry. This innovation imperative has economic, workforce, national security, and environmental dimensions.

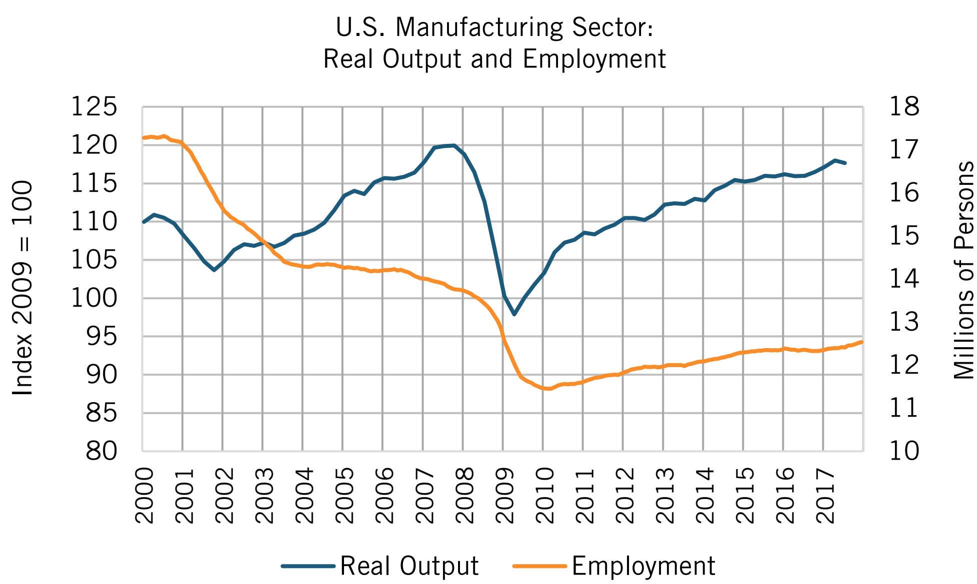
Manufacturing directly employs 12.6 million workers in the United States. Taking into account indirect effects such as supply-chain purchasing, that number more than triples to nearly 39 million jobs. Workers employed by manufacturers, particularly those without college degrees, typically earn better wages than their peers in other sectors. Workers in the most innovative manufacturing industries earn 40 to 50 percent more than their peers.[2]

Manufacturing is essential to the United States maintaining—and improving—its position in the global economy. Goods account for far more of international trade than services, and the trade in goods cannot be balanced without improving U.S. manufacturing competitiveness. Manufacturers are also at the core of U.S. innovation, contributing the bulk of R&D investment and being awarded the vast majority of patents. Innovation and productivity are key reasons why manufacturing workers earn higher wages than their peers.

Manufacturing's pivotal role in supplying the U.S. military is as old as the country itself. The Department of Defense (DOD) is required by law to monitor and "address critical issues in the industrial base relating to urgent operational needs."[3] Competition among the private-sector domestic manufacturers has helped reduce the cost of procurement and limit the nation's vulnerability to potential interruptions in foreign supplies of defense goods and services.

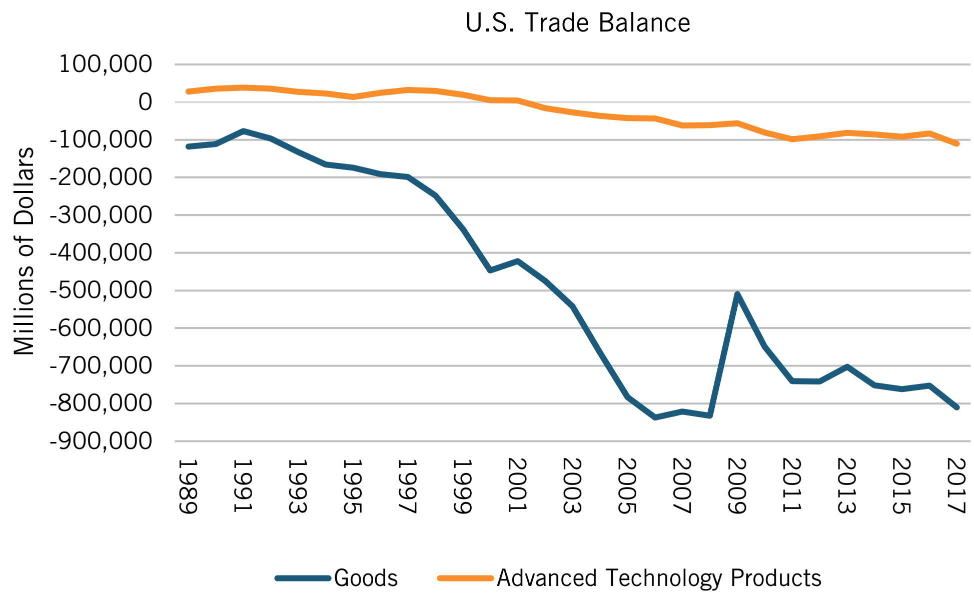
U.S. manufacturing is still recovering from the disastrous decade of the 2000s, with measured output having officially only just reached its prerecession levels. (See figure 1.) ITIF has shown these official figures to be artificially inflated due to mismeasurement of electronics and computers. Output in most manufacturing industries remains below its prerecession peak.[4] Employment remains much lower than it was in 2000—although it has crept upward from its 2010 nadir.

Figure 1: Real Output and Employment in the U.S. Manufacturing Sector[5]



The U.S. trade deficit of some $800 billion per year in manufactured goods is a key reason for the stagnation in output. Even in advanced technology products, which should be a national strength, the United States ran a deficit of over $110 billion in 2017.[6] (See figure 2.)

Figure 2: U.S. Trade Balance[7]



Energy plays several important roles in manufacturing competitiveness. For example, low energy costs have helped avert even greater losses in U.S. manufacturing over the past decade. Cheap natural gas from shale made available by hydraulic-fracturing techniques has given the nation an advantage in energy-intensive industries such as petrochemicals—although new investment sparked by this opportunity has thus far failed to significantly increase real value-added production.

The energy sector is a major consumer of manufactured goods. The demand for pipes, drilling equipment, and other supplies associated with the shale-gas boom, for instance, was a critical factor in pulling manufacturing out of the recent recession. In 2015, nearly $3 billion flowed to the manufacturing sector for pipeline construction alone, supporting about 22,000 jobs. At the same time, global competition to supply the energy sector is fierce. The rapid growth of emerging energy technologies, such as wind turbines and batteries, has only intensified this battle, as nations attempt to seize control of new supply chains. Innovative products and processes are critical to success in this race. To that end, China recently set the goal of becoming a "technologically independent energy-storage superpower."[8]

For U.S. manufacturers to become more competitive, they must increase output while reducing the approximately $130 billion they spend per year on energy. Although U.S. manufacturing as a whole has become more energy-efficient over time, the sector still wastes about one-quarter of the energy it uses—and even more in energy-intensive industries. Rapid innovation to reduce such waste could create opportunities to reduce costs in the future, as Germany, among others, has recognized.[9]

In order to improve industrial energy efficiency and innovate in energy-related manufacturing, the manufacturing workforce must become more highly skilled. For example, massive flows of data made possible by new smart-manufacturing tools will make it possible to optimize energy-and-materials flows in plants far more effectively than today. But, to use these data well, workers will have to become more digitally savvy, and continually update their training as the tools evolve.

With respect to national security, DOD is the single largest consumer of energy in the United States, requiring reliable access to energy resources for both operations and facilities. Innovations that improve energy efficiency and allow the U.S. military to take advantage of domestic energy resources can contribute to fulfilling this requirement.[10] DOE is the designated agency for domestic energy security that works closely with DOD to advance this objective.[11]

The industrial sector is responsible for about 22 percent of U.S. carbon emissions. Reducing these emissions, especially for process heat, poses some of the most difficult technical challenges for achieving a transition to low-carbon energy resources.

The close links between industrial energy use, manufacturing for the energy industry, and environmental quality are obvious. Industry consumes about a quarter of the nation's primary energy supply, depending particularly on natural gas, petroleum, and electricity. Using these inputs more efficiently would limit local air pollution near factories and power plants as well as environmental impacts upstream from drilling, mining, pipelines, and power lines. The industrial sector is responsible for about 22 percent of U.S. carbon emissions.[12] Reducing these emissions, especially for process heat, poses some of the most difficult technical challenges for achieving a transition to low-carbon energy resources.[13]

At the same time, the low-carbon energy transition is creating huge opportunities for manufacturers who supply the energy industry. Global investments worth an estimated $333.5 billion in 2017 for clean-energy goods ranging from solar panels and windmills to geothermal and biomass power equipment—not to mention upgraded systems for controlling energy flows and transporting energy carriers—are at stake.[14] Innovation will be one of the United States' key competitive advantages as these markets develop over the coming decades.

THE DEPARTMENT OF ENERGY'S ROLE IN SUPPORTING ENERGY INNOVATION IN MANUFACTURING

The private sector is responsible for implementing energy innovations in manufacturing, and it generates and commercializes many such innovations as well. Market failures, however, lead to gaps in the private-sector's response to the innovation imperative. These failures extend beyond obvious externalities that justify an active role for the federal government, such as national security and environmental protection, to include the economic and workforce dimensions of the imperative, which also call for a public response. The DOE's Advanced Manufacturing Office, including its Manufacturing USA innovation institutes, helps fill these gaps.

Economic and Workforce Market Failures in Energy Innovation in Manufacturing

The failure of markets to adequately incentivize knowledge creation is well established. Because new knowledge is hard to keep secret, and intellectual property rights are imperfect, firms that invest in knowledge creation are often forced to share the benefits of that knowledge with their competitors. They therefore end up investing less than is needed. Federal funding for research and development (R&D) at universities and government laboratories, along with tax incentives for private R&D, aims to address this market failure.[15]

However, public R&D funding in the United States is predominantly oriented to the defense and health missions and, to a lesser extent, to the creation of scientific knowledge without a specific intended use. The bulk of DOE's R&D funding, in fact, supports defense and pure science programs within its National Nuclear Security Administration and Office of Science.[16] While manufacturers may benefit from defense-, health-, and science-research investments through spillovers, the federal R&D portfolio contains relatively few programs and projects that were inspired by the potential users of new knowledge in the manufacturing and energy sectors. Yet, such "use-inspired" investments, to employ Donald Stokes's term, are often the most productive kind of federal R&D spending.[17]

Markets may also fail to support innovation among manufacturing firms across supply chains and within regions. When supplier-customer relations are determined solely by short-term price considerations, information flows that could result in learning opportunities are inhibited by the arms-length relationship required for bargaining over prices. As Josh Whitford and his colleagues have shown, more collaborative and networked relationships—that would be better able to accelerate innovation across supply chains in knowledge-intensive, complex, and rapidly changing sectors—may be blocked by intense price competition and squeezing of suppliers. Similarly, the McKinsey Global Institute calls for "deeper industry cooperation and a new level of coordination" across supply chains.[18]

At the regional level, markets may fail to adequately incentivize the creation of shared infrastructures that would strengthen industrial clusters. Regional clusters of like-minded firms were observed by the pioneering economist Alfred Marshall in the 19th century, and they remain common today—especially in manufacturing. Recent research has shown that the collective pool of industry-specific knowledge in a region is a key reason for clustering. Yet in many U.S. regions, this "industrial commons"—as management scholars Gary Pisano and Willie Shih have termed this pool of knowledge and the means for generating it—has been decimated. Often, firms that benefited from the industrial commons were unaware of their dependence on it or unable to organize effectively to strengthen the commons before it disappeared.[19]

A major contributing factor to regional hollowing out has been government-subsidized international competition. Although the United States might prefer for world trade to occur in a free market, this ideal is rarely realized. Many countries have targeted manufacturing for special treatment because of its economic-development and export potential. For instance, the big decline in U.S. manufacturing employment during the 2000s (see figure 1) was caused in significant part by, as economist David Autor, David Dorn, and Gordon Hanson put it, the "China shock" that followed that country's accession to the World Trade Organization. Although low labor costs and other market factors contributed to this shift of manufacturing activity, China's mercantilist policies, which ITIF has documented extensively, played a big part as well.[20]

The final form of market failure that points toward a role for the federal government in energy innovation in manufacturing is underinvestment in the workforce. Private investment in training is discouraged by the prospect that workers may take the knowledge and skills that they acquire on the job to another firm. Worker mobility has contributed to a decline in employer-provided training, while public expenditures on active labor-market programs have also fallen, from 0.25 percent to 0.1 percent of GDP over the last 30 years.[21] Manufacturing and energy workers, who are responsible for acquiring and maintaining the right skill sets to maximize productivity and innovation, face intimidating barriers such as large up-front costs and bewildering information about which skills and training programs are best.

DOE's Manufacturing Programs: A Brief History

The federal government's efforts to address market failures in manufacturing, including unfair international competition, go back to the dawn of the republic, when Alexander Hamilton penned a report on the topic. Centuries later, energy shortages in the 1970s, along with concerns about environmental impacts and vulnerabilities, led the federal government to create programs that targeted energy in manufacturing, which were incorporated into DOE at its inception in 1977.[22]

One such program, DOE's Industrial Assessment Centers, began conducting audits of energy efficiency and productivity at no cost to small and medium-sized manufacturers (SMMs) in 1976. DOE soon complemented plant audits with technical-assistance services and the coordination of voluntary standards for industrial energy efficiency. More recently, it has added Better Plants (a voluntary energy-efficiency challenge and information-sharing program), the ISO 50001 energy management standard, and the Superior Energy Performance certification to its offerings.[23]

DOE has also supported manufacturing R&D since its formation. Criticized by the National Research Council in the 1980s for lacking a "unifying principle," this program was rebranded in 1992 as Industries of the Future, focusing on seven energy-intensive industries: aluminum, chemicals, forest products, glass, metal casting, mining, and steel. Industry groups led the development of roadmaps, followed by public-private cost-shared research projects. The George W. Bush administration narrowed the program's portfolio and reduced its budget significantly. By 2008 its main focus was cross-cutting R&D across industrial chemical reactions and separations, sustainable manufacturing, sensors and automation, and new materials.[24]

DOE's Advanced Manufacturing Office Today

The Obama administration rebuilt the Advanced Manufacturing Office (AMO), whose appropriations reached $257 million in fiscal year 2017. AMO is housed within DOE's Office of Energy Efficiency and Renewable Energy (EERE), although it collaborates frequently with other DOE applied offices, such as the Offices of Fossil Energy and Nuclear Energy to develop next-generation materials, innovative industrial processes for carbon capture and sequestration, and advanced nuclear-power systems.[25]

AMO has articulated five goals:[26]

1. Improve the productivity and energy efficiency of U.S. manufacturing.
2. Reduce the lifecycle-energy and resource impacts of manufactured goods.
3. Leverage diverse domestic energy resources in U.S. manufacturing, while strengthening environmental stewardship.
4. Transition DOE-supported innovative technologies and practices into U.S. manufacturing capabilities.
5. Strengthen and advance the U.S. manufacturing workforce.

The AMO portfolio is divided into three subprograms: industrial technical assistance (funded at $26.5 million in FY 2017), advanced manufacturing R&D projects (a group of eight portfolios funded at $80.5 million in FY 2017), and advanced manufacturing R&D consortia (funded at $150.5 million in FY 2017)—which includes the Manufacturing Demonstration Facility and Critical Materials Hub, along with the five Manufacturing USA institutes described in detail below.[27] The Energy Policy Act of 2005 authorized DOE to establish Advanced Energy Efficiency Technology Transfer Centers out of which the manufacturing R&D consortia subprogram grew.[28] AMO's draft "Multi-Year Program Plan for Fiscal Years 2017–2021" identified fourteen technologies, five emerging and cross-cutting areas, and five targets for advanced manufacturing for energy systems AMO deemed critical to meeting its goals. (See figure 3.)

Figure 3: DOE AMO Multi-Year Program Focus Areas[29]

Figure 2.7 Diagram Showing Connections between the Fourteen Advanced Manufacturing Technology Areas (which coincide with the 2015 QTR Manufacturing Technology Assessment Topics), Energy Systems Influenced by Manufacturing, and Emerging and Crosscutting Areas.

THE MANUFACTURING USA PROGRAM

In addition to playing major roles in implementing AMO's strategy, the five DOE-supported Manufacturing USA institutes are also key components of the government-wide Manufacturing USA program. The DOD and the National Institutes of Standards and Technology (NIST) within the Department of Commerce support additional institutes, while the Departments of Agriculture, Education, Health and Human Services, and Labor, as well as the National Aeronautics and Space Administration, National Science Foundation (NSF), and Small Business Administration also participate in the program.[30] NIST hosts the multiagency Advanced Manufacturing National Program Office (AMNPO), which coordinates the program. Manufacturing USA began in 2012 with pilot institutes, was formalized with congressional authorization in 2014, and currently comprises 14 institutes.

PCAST, AMP, and the First Four Manufacturing Innovation Institutes

The first proposal for what ultimately became Manufacturing USA appeared in a June 2011 report on advanced manufacturing by the President's Council of Advisors on Science and Technology (PCAST). PCAST called for federal investments in both applied research programs and public-private partnerships to overcome market failures in areas where new technologies held high potential, industry was willing to coinvest, and the investments would strengthen domestic manufacturing capabilities.[31]

The case for federal investment was reinforced by the Advanced Manufacturing Partnership (AMP), a PCAST working group composed of industry CEOs and university presidents, and co-chaired by MIT president Susan Hockfield and Dow Chemical CEO Andrew Liveris. AMP's July 2012 report recommended a national network of manufacturing innovation institutes as a "vehicle to integrate many of [AMP's] recommendations." The report also emphasized the importance of innovation at the nexus of manufacturing and energy, stating "Any effort to reinvigorate advanced manufacturing in the United States would not be complete without an examination of energy policy."[32]

The National Additive Manufacturing Innovation Institute (now called America Makes) in Youngstown, Ohio, was created shortly after the publication of the AMP report. It was led by DOD and cofunded by DOE, NIST, and NSF on the federal side—whose contributions were matched by $50 million of coinvestment from 50 industrial partners, 28 universities and labs, and 16 other organizations. The institute's membership grew to include 180 organizations in its first five years.[33] Three additional institutes were created in 2014 using a similar coinvestment model: two sponsored by DOD (Digital Manufacturing and Design Innovation Institute (DMDII) and Lightweight Innovations for Tomorrow (LIFT)) and one by DOE (PowerAmerica). Lacking specific legislative authorization, the agencies sponsored the four institutes under their existing missions and authorities.

Revitalize American Manufacturing and Innovation (RAMI) Act

Specific authorization for Manufacturing USA was provided by Congress in the Revitalize American Manufacturing and Innovation (RAMI) Act, which passed as part of a budget package in December 2014. RAMI received an extraordinary level of bipartisan backing during a period of austerity and sharply divided government. The bill was cosponsored by 118 members of Congress, led by Roy Blunt (R-MO) and Sherrod Brown (D-OH) in the Senate and Tom Reed (R-NY) and Joe Kennedy (D-MA) in the House of Representatives.[34]

RAMI acknowledged the legitimacy of the innovation institutes that had already been set up by DOD and DOE under their existing authority and authorized NIST to oversee an open, peer-reviewed competition to award new institutes in technical areas that did not necessarily fall within the defense and energy missions. It formally established the AMNPO, and assigned NIST to support that office. Crucially, the legislation limited the duration of federal financial assistance to the NIST-supported institutes to seven years, with a maximum federal cost share of 50 percent per year, and decreases in funding after the first year.[35]

Building Out the Network, and the International Response

The sponsoring agencies moved aggressively to implement RAMI. In addition to the four additional institutes awarded by DOE, DOD set up five more between 2015 and 2017, while NIST ran an open competition that resulted in the creation of the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL) in early 2017. (See table 1.) These efforts were guided by AMP's identification of key technology areas and its emphasis on workforce development and the challenges facing SMMs that were featured in the October 2014 "AMP 2.0" report.[36]

Table 1: DOD- and NIST-Sponsored Manufacturing USA Institutes[37]

Institute Name	Headquarters Location	Month/Year Established	Sponsoring Agency
America Makes	Youngstown, OH	August 2012	DOD
Digital Manufacturing and Design Innovation Institute (DMDII)	Chicago, IL	February 2014	DOD
Lightweight Innovations For Tomorrow (LIFT)	Detroit, MI	February 2014	DOD
American Institute for Manufacturing Integrated Photonics (AIM Photonics)	Rochester, NY	July 2015	DOD
America's Flexible Hybrid Electronics Manufacturing Institute (NextFlex)	San Jose, CA	August 2015	DOD
Advanced Functional Fabrics of America (AFFOA)	Cambridge, MA	April 2016	DOD
Advanced Regenerative Manufacturing Institute (BioFabUSA)	Manchester, NH	December 2016	DOD
Advanced Robotics for Manufacturing Institute (ARM)	Pittsburgh, PA	January 2017	DOD
National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL)	Newark, DE	March 2017	NIST

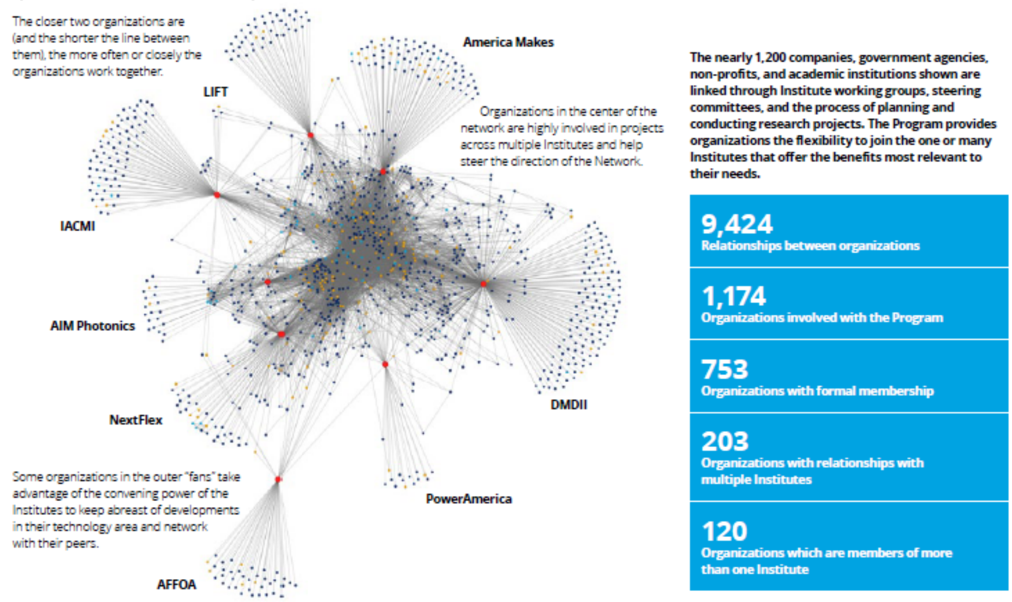
The Manufacturing USA initiative sparked an international response, even in nations that were already investing proportionally more in their manufacturing sectors than the United States. Germany, whose $2.3 billion network of Fraunhofer Institutes helped inspire the Manufacturing USA network, had already launched a national strategic initiative—Industrie 4.0—to drive forward digital manufacturing and the Internet of Things. The United Kingdom established its High-Value Manufacturing Catapult program in 2011, a network of seven public-private centers aimed at accelerating innovation in growth sectors, which received $200 million in public funding between 2012 and 2018. In 2014, South Korea announced a Manufacturing Industry Innovation 3.0 strategy that focuses on R&D projects in areas intended to accelerate Korean manufacturers' use of the Internet of Things, smart sensors, and big data. China's advanced manufacturing initiative calls for setting up 40 manufacturing innovation centers by 2025 as part of that country's larger effort to move from "Made in China" to "Created in China." Canada, Singapore, and India are among the other nations that have also recently implemented advanced manufacturing initiatives.[38]

Manufacturing USA Today

The consulting firm Deloitte carried out the first third-party evaluation of Manufacturing USA, which was released in January 2017 and covers the eight institutes in operation at that time. It concluded:

> Manufacturing USA's Institutes help spur R&D innovation and commercialization and prepare the 21st century workforce. Institutes encourage mutually beneficial collaboration to catalyze R&D investment and overcome barriers to innovation. They solve collective action problems, enable members to tap into critically valuable and synergistic stockpiles of intellectual property, and provide access to shared assets. This enables innovation to occur more efficiently.[39]

Figure 4: Manufacturing USA Network as of Late 2016[40]



Deloitte's network analysis (see figure 4) revealed that the eight institutes that it looked at engaged nearly 1,200 organizations, which in turn were associated with one another in 9,424 relationships. Jeff Wilcox, vice president for engineering and program operations at Lockheed Martin, called the network "a whole new way of doing things."[41]

These figures have undoubtedly grown substantially in the past year and a half, as the institutes studied by Deloitte have matured and the network has grown to 14 institutes. The six institutes added since Deloitte completed its analysis involved commitments from the private sector and local and state governments totaling $820 million over five years. In addition, NIST's Manufacturing Extension Partnership (MEP) began a pilot program to embed staff in all 14 institutes to aid them in connecting with SMMs nationwide.

The Government Accountability Office (GAO), Congress's watchdog agency, is tasked with reviewing Manufacturing USA every two years. Its first report on the program, released in April 2017, focused on governance. While acknowledging that RAMI did not provide the AMNPO or NIST with the authority to require action by agencies participating in the program, GAO encouraged these coordinating bodies to make a stronger effort to engage agencies that were not sponsoring institutes but had valuable expertise to contribute to the program. The GAO report has had the overall effect of strengthening the participation in Manufacturing USA of the Departments of Education and Labor.[42]

DOE'S MANUFACTURING USA INSTITUTES

The DOE-sponsored Manufacturing USA institutes are listed in table 2, with each described more fully in the subsection below the table. PowerAmerica, which focuses on wide bandgap semiconductors, was founded in January 2015 and is therefore the oldest of the five. The Institute for Advanced Composites Manufacturing Innovation (IACMI) followed a half year later. The other three institutes, Clean Energy Smart Manufacturing Innovation Institute (CESMII), Rapid Advancement in Process Intensification Deployment (RAPID) Institute, and Reducing EMbodied-energy And Decreasing Emissions (REMADE) Institute, are less than two years old.

Table 2: DOE-Sponsored Manufacturing USA Institutes[43]

Institute Name	Headquarters Location	Month/Year Established	Lead Organization	Initial Five-Year Budget (federal share/total)	Members (most recent available)
PowerAmerica	Raleigh, NC	January 2015	North Carolina State University	$70 million/ $140 million	50
Institute for Advanced Composites Manufacturing Innovation (IACMI)	Knoxville, TN	June 2015	Collaborative Composite Solutions Corporation (a subsidiary of the UT Research Foundation)	$70 million/ $189 million	170
Clean Energy Smart Manufacturing Innovation Institute (CESMII)	Los Angeles, CA	December 2016	Smart Manufacturing Leadership Coalition	$70 million/ $170 million	90
Rapid Advancement in Process Intensification Deployment (RAPID) Institute	New York, NY	March 2017	The American Institute of Chemical Engineers	$70 million/ $140 million*	57
Reducing Embodied-energy And Decreasing Emissions (REMADE) Institute	West Henrietta, NY	May 2017	Sustainable Manufacturing Innovation Alliance	$70 million/ $140 million*	43

**Based on initial institute announcement from DOE*

The institutes' topic areas emerged out of AMO's participation in AMP and DOE's 2015 Quadrennial Technology Review (QTR), and were codified in AMO's draft "Multi-Year Program Plan." (See figure 3.) In these discussions, which involved technology leaders from industry and academia as well as government, AMO sought to identify opportunities to accelerate energy innovation in manufacturing at three levels: unit operations, production systems, and supply chains. Each of these levels is represented among the institutes' topic areas; the process identified several other topic areas that could be foci for future DOE institutes.[44]

The department then undertook a competitive process to select the host institution and partners for each institute. In the case of IACMI, for instance, DOE made two public requests for information and held a full-day workshop before issuing a request for proposals, which included the end-use industries proposers were to target: wind turbines, automobiles, and compressed-gas tanks. The University of Tennessee, leading a consortium of 122 companies, universities, and national laboratories—and with the support of the state of Tennessee—won the five-year, $70 million award, which was more than matched by $189 million in private and state commitments.[45]

Key Features: Unity and Diversity

The ultimate measure of the institutes' success, according to many observers, will be domestic industry follow-on investment in the technology areas they target.

IACMI illustrates key features of all five of DOE's Manufacturing USA institutes, such as the duration of the award, nonfederal cost share, and multisectoral membership. (See table 2.) The institutes operate under cooperative agreements with DOE that specify their work must be performed in the United States and include technical milestones and deliverables. They receive funding on a reimbursable basis, and any income they earn must be used to further project objectives—which means DOE must approve spending it.[46]

Each institute is governed by a board composed of member representatives, and each has undertaken a member-led roadmapping process of setting objectives and priorities. The resulting roadmaps are embodied in project calls through which members (and sometimes prospective members as well) compete for cost-shared awards, and include plans for supporting shared infrastructures, engaging SMMs, and strengthening the workforce.

Although unified by these common features and processes, DOE's Manufacturing USA institutes are diverse in many important respects. For instance, RAPID's parent institution, the American Institute for Chemical Engineers, is a professional association, while PowerAmerica is fully embedded in North Carolina State University (NCSU). CESMII, to pick another example, is like IACMI in that it is based in a nonprofit corporation established in conjunction with the institute, but it is more geographically distributed in its operations than PowerAmerica. IACMI has funded the development of new physical facilities at five sites around the country, whereas RAPID is leveraging existing facilities owned by members. REMADE was built on a preexisting organization, while RAPID was not.

Each institute has created its own membership structure and rules for managing intellectual property. Such variations are appropriate given the differences in the manufacturing industries the institutes are serving and the technological challenges they face. However, the unique aspects of each institute have also contributed to high start-up costs. Manufacturing USA is not simply a new program, but one that requires collaboration among novel and complex configurations of players working together for the first time. Even the institutes that built on preexisting organizations had to establish new operating procedures and norms, while the newly formed organizations have been particularly challenged by the need to fund start-up activities and then seek reimbursement.

The ultimate measure of the institutes' success, according to many observers, will be domestic industry follow-on investment in the technology areas they target. This outcome cannot be fairly judged for a number of years. Product redesign and equipment purchasing typically occur in multiyear cycles, while changes to manufacturing processes that depend on reaching and educating a broad swath of manufacturers—especially SMMs—will also take time.

In the short and intermediate term, process variables such as membership and coinvestment levels must serve as proxies for such ultimate outcomes. Some observers stress the qualitative indicator of enthusiasm and excitement within industry about the institutes' program and progress. This paper touches on these metrics in the capsule descriptions of each institute that make up the next five subsections of this report.[47]

PowerAmerica (Next Generation Power Electronics Manufacturing Innovation Institute, Est. January 2015)

Semiconductors are ubiquitous in modern society. They control flows not only of information in consumer products like cell phones and computers, but increasingly of energy in capital goods like vehicles and industrial machinery—a set of applications known as "power electronics." The vast majority of semiconductors today are made from silicon, which for more than a half-century has proven to be an extraordinarily flexible material, underpinning Moore's law (the number of transistors per square inch on integrated circuits doubles every year). However, as power electronics have become more widely used, the appeal of using semiconducting materials that have a wider bandgap than silicon, such as silicon carbide (SiC) and gallium nitride (GaN), has grown. Wide bandgap semiconductors operate at higher temperatures, frequencies, and voltages than silicon semiconductors, thus allowing devices that use them to be made smaller and more efficient.

The potential gains from this family of innovations are enormous. Data centers, which are responsible for a large and growing share of U.S. energy consumption, for instance, could save an estimated 12 percent of their primary energy costs by using wide bandgap semiconductors. Electric vehicles, power transmission, and distributed energy resources in general represent another huge application area. PowerAmerica's mission is to enable the commercialization of wide bandgap semiconductors across diverse end uses by reducing both their cost and risk, which together have been holding back large-scale investment. The institute expects the market to grow from $210 million in 2015 to $3.75 billion in 2020.[48]

PowerAmerica's full integration into North Carolina State University makes it unique among the DOE Manufacturing USA institutes. Its founding CEO, Nickolas Justice, who formerly headed the U.S. Army's Research, Development, and Engineering Command, reports directly to NCSU's vice chancellor for research, and the organization relies on the university for most back-office support functions, with a staff of about 12 people. The Institute is overseen by an executive committee responsible for policy and strategic guidance, a member advisory committee, and a government advisory committee.[49]

PowerAmerica's 25 initial members matched the federal government's 5-year investment of $70 million, and by the end of 2017, the institute's membership had grown to 50 organizations. About one-third of them are relatively large firms, such as Lockheed Martin, ABB, and John Deere. Another ten are startups, and the remainder are universities and federal labs. As PowerAmerica's strategy hinges on systems-engineering solutions, it seeks a diverse membership that covers the entire supply chain, including a merchant semiconductor manufacturer (X-FAB), "fabless" semiconductor companies (such as Monolith), vertically integrated manufacturers (Wolfspeed, owned by Cree), and end users (like Lockheed Martin). Its embedded MEP staff member has focused on reaching SMMs in the supply chain who make packaging, subassemblies, boards, and the like. The institute enjoys what General Justice describes as a "seamless" relationship with North Carolina state agencies responsible for the development and growth of the state's energy economy and encouraging energy efficiency in the public sector.[50]

PowerAmerica's 25 initial members matched the federal government's 5-year investment of $70 million, and by the end of 2017, the institute's membership had grown to 50 organizations.

PowerAmerica's overarching goal is to make SiC and GaN semiconductors cost-competitive with silicon semiconductors, and increase their adoption in new markets and applications. Its roadmap toward this goal, which was developed in 2016 and released in 2017, entails a 50-percent cost reduction every two years, and focuses on improving reliability, enhancing performance, and fixing deficiencies in the "ecosystem"—such as domestic manufacturing capacity, workforce knowledge, and advanced complementary technologies. In the near term, the roadmap focuses on applications in consumer electronics, data centers, and solar power; further down the road, it anticipates energy-efficient industrial motor drives and medium-voltage drives for power plants being key end uses.[51]

Rather than develop shared facilities, PowerAmerica has worked closely with X-FAB, supporting the conversion of its 150 mm line from silicon to SiC. Conversion of an existing fab to wide bandgap semiconductor production was much cheaper and quicker than building a new one. X-FAB's merchant semiconductor business model involves producing devices according to designs and specifications provided by fabless firms; Monolith now uses X-FAB's SiC line to make its own commercial product (Schottky diode). The processes used by Monolith at X-FAB are proprietary. A more recent PowerAmerica project, led by NCSU professor B. Jayan Baliga created an open-domain SiC production process called PRESiCE, which can now be licensed by fabless companies. Adapting production to SiC at X-Fab has cost $15 million to date, and the company currently plans to spend up to an additional $50 million over the next ten years to expand capacity. PowerAmerica is working with the Dallas production facility of the semiconductor company Qorvo on GaN devices, as well as Wolfspeed on SiC. In all, PowerAmerica has awarded 87 projects through 3 calls.[52]

PowerAmerica's workforce development program focuses on graduate and undergraduate engineering. At the graduate level, eight courses in wide bandgap semiconductors have been provided by participating universities. Undergraduate and other training programs are carried out by NCSU's FREEDM Systems Center, an NSF Engineering Research Center with which PowerAmerica merged its workforce development program last year. These programs give students in diverse communities across the country an opportunity to collaborate with faculty members. A second focus under development is short courses for current industry employees. PowerAmerica held its first such course, which included a hands-on lab, on November 7-9, 2017.[53]

PowerAmerica will celebrate its five-year birthday in January 2020. Its plan for sustainability beyond that horizon depends on mobilizing NCSU engineering and research resources to secure external support, including from federal programs other than AMO as well as corporate R&D sponsors. John Deere credits PowerAmerica with advancing its wide bandgap power electronics research program by five years. The institute also expects to develop revenue streams from contract research, intellectual property licenses (like the PRESiCE process), and workforce training—although under its current cooperative agreement, expenditures of such income must be approved by DOE.[54]

Institute for Advanced Composites Manufacturing Innovation (IACMI, Est. June 2015)

Composite materials are made up of fibers embedded in a matrix; the constituent materials do not dissolve or merge, but retain their identities as they act in concert. Carbon fiber composites, for example, are stronger, lighter, and more flexible than standard metal alternatives. This combination of properties has prompted aerospace manufacturers to use composite materials. Nearly half of the airframe of the Boeing 787, for example, is made from composites, which reduces weight by approximately 20 percent compared with aluminum.[55]

Adoption of composites beyond such high-value niches has been impeded by high cost. As required by DOE's funding announcement for this institute, IACMI focuses on composites applications in the automotive, compressed-gas, and wind industries. DOE's QTR identified these industries as having the potential to save significant amounts of energy once composites become more competitive. Reducing the weight of a conventional automobile by 10 percent, for instance, would increase fuel efficiency by up to 8 percent; for an electric vehicle, such a reduction would increase range by as much as 10 percent.[56] The lack of affordable storage containers with sufficiently high tensile strength to handle extremely pressurized gas is hampering the development and commercialization of hydrogen-powered vehicles. Only when such containers can be developed will these vehicles achieve the range required by auto buyers.[57] Wind-turbine blades constructed from better composites than those used today would be lighter, stronger, and stiffer—and could therefore be larger and their support structures, less costly. A 100-meter blade made of carbon fiber instead of glass fiber, for example, would weigh about 28 percent less, enabling greater electricity generation at lower costs.[58]

IACMI is headquartered in Knoxville, Tennessee, and is managed by the independent nonprofit organization Collaborative Composite Solutions Corporation. The institute has a staff of around 15 employees. Although it has close relationships with both the University of Tennessee-Knoxville (UTK) and the Oak Ridge National Laboratory (ORNL), it does not rely on either for support services. John Hopkins, IACMI's third CEO, was previously director of strategic operations in the office of the vice president for research and economic development serving the University of Tennessee (UT) system. Dr. Craig Blue, IACMI's founding CEO, came from, and returned to, positions at ORNL when his leave from ORNL ran out. IACMI's 20-member board is chaired by Stacey Patterson, vice president for research, outreach, and economic development at UT, and Rani Richardson, a director at Dassault Systèms. IACMI's governance structure also includes a workforce advisory board, economic development council, and technical advisory board.[59]

IACMI has 170 members in 4 tiers, 91 of which are SMMs—who are permitted to make in-kind contributions to cover their dues in order to induce their participation, while also benefiting from contacts with larger member firms, federal laboratories, and universities. IACMI's membership has tripled from roughly 55 members at the time its founding in 2015. That figure, in turn, was nearly four times the size of the membership base of the Oak Ridge Carbon Fiber Composites Consortium, IACMI's precursor, when it was founded in 2011. IACMI's initial five-year budget is $175 million; the $105 million in private funding exceeds the $70 million federal award by 50 percent. IACMI receives substantial coinvestment from the five states in which it has built shared infrastructures—Colorado, Indiana, Michigan, Ohio, and Tennessee—and works closely with several MEP centers, particularly in states that already have well-established composites industries.[60]

IACMI's roadmap was finished in 2016 after, as one small business characterized it, a "very inclusive process that made an effort to incorporate SMM views." Its initial five-year objectives include cutting production costs for composite materials by 25 percent; reducing embodied energy in them by 50 percent; producing fiber-reinforced polymers at cost, performance, and speed parity equivalent to glass-fiber-reinforced polymers; and demonstrating the ability to competitively recycle or reuse 80 percent of composites by weight.[61]

In addition to the three end-use application areas, IACMI supports work in two cross-cutting areas: materials and modeling. A major focus of IACMI's first two years of operation was the creation of shared infrastructures in each of these five areas:

- Automotive: Vehicle scale up facility in Detroit, Michigan, shared with the Lightweight Innovations for Tomorrow (LIFT) Manufacturing USA institute for large-scale demonstration, including a 4,000-ton hydraulic compression press unique to North America.
- Compressed Gas: Lab space at the University of Dayton Research Institute's National Composites Center, with seven hydraulic presses, three autoclaves, injection molding equipment, and large ovens.

- Wind: Composite Manufacturing Education and Technology Facility (CoMET) in Boulder, Colorado, adjacent to the National Renewable Energy Laboratory's National Wind Technology Center, with the capacity to prototype and manufacture full-scale wind-blade components.
- Materials: Manufacturing Demonstration Facility at ORNL—a major center for additive manufacturing—housing a composites lab with equipment for induction heating, fast-cycle processing of composites, and plasma treatment for surface enhancement.
- Modeling: Indiana Manufacturing Institute at Purdue University, occupying 30,000 square feet, including the Composites Virtual Factory Hub and validation labs.[62]

Projects using these shared infrastructures are now moving forward as IACMI completes its third year.

IACMI's workforce development and education program plays a coordinating role, working closely with composites-industry trade groups like the American Composites Manufacturing Association and Composites One as well as IACMI members. The program focuses primarily on research and professional training, as composites-production technology has yet to be deployed in factories on a large scale. Through IACMI's partnerships, such as with Composites One, over 1,200 people have been trained in hands-on workshops and seminars since IACMI's launch. IACMI matches about 50 graduate and undergraduate interns per year with mentors at partner or member organizations for periods ranging from ten weeks to over a year. It has also partnered with LIFT to create an open-source educational library, which now has 151 modules up and running.[63]

IACMI's sustainability plan centers on the unique capabilities of its shared infrastructures, which are expected to generate continuing revenues from companies and other clients that want to derisk technology through demonstration, validation, and qualification. A second component of the strategy rests on the value created for members through networking and educational opportunities, and access to innovative ideas in the early stages of their development.[64]

Clean Energy Smart Manufacturing Innovation Institute (CESMII, Est. December 2016)

Information and communication technology (ICT) has had a profound impact on the U.S. economy, yet it has only just begun to transform manufacturing. "Smart manufacturing" uses advanced sensors, controls, platforms, and modeling (ASCPM), to take advantage of massive data flows. Widespread adoption of smart-manufacturing technologies and practices has the potential to reduce energy use in U.S. manufacturing by at least 15 percent, saving more than $15 billion annually and strengthening the nation's competitive position. CESMII's goal is to develop practices, technologies, and infrastructure that integrate energy productivity into manufacturing-sector objectives. Over the next five years, it seeks to demonstrate a 50-percent reduction in cost and time to deploy technologies and practices, and a 15-percent improvement in energy efficiency—and over the next ten years, a 50-percent improvement in energy productivity.[65]

CESMII is led by the Smart Manufacturing Leadership Coalition, a Washington, D.C.-based nonprofit organization founded in 2012. The institute's headquarters are currently hosted by the University of California-Los Angeles (UCLA), but will be moving to a location that is centered on a cyber-maker space for hardware and software it is codeveloping with the City of Los Angeles. Five regional manufacturing centers based mostly at universities (Northwest, California, Northeast, Southeast, and Gulf Coast) have been established in order to better reach SMMs—a process CESMII expects will evolve over time. CESMII's interim CEO, Jim Wetzel, was formerly global director of reliability at General Mills, while Haresh Malkani recently joined as CTO after serving as director of digital manufacturing and automation technologies at Arconic/Alcoa. The institute has standing member committees on business, technology, and workforce, and a platform advisory committee composed of members and outside advisors. CESMII reports to an industry-led governance board.[66]

CESMII's education and workforce development plan seeks to instill broader understanding of smart-manufacturing practices, technologies, and platform infrastructure.

CESMII has about 90 members, whose financial and cost share involvement are on track to meet DOE's goals. Over half of the members are small, medium-sized, and large manufacturers from across the supply chain. The rest comprise technology providers, universities, national labs, and other organizations. The Regional Manufacturing Centers build on preexisting capabilities at their host institutions and specialize—to some degree—in specific industries, such as oil and gas and chemicals in the Gulf Coast region. CESMII's strong relationship with a city, Los Angeles, distinguishes it from the other DOE Manufacturing USA institutes. The state of California has made a major commitment to the CESMII education and workforce development program, and each regional center is also working with its home state.[67]

CESMII's platform integrates operational technologies and information technologies (OT/IT) to provide the capability for data ingestion and contextualization, and the orchestration of software applications across vendor products and infrastructure platforms. CESMII's initial roadmap was developed through its committees, and it will be updated each year. Its first project call, based on the initial roadmap, closed in January 2018. The call encompassed collaborative projects on business practices, enabling technologies, workforce development, and platform infrastructure, as well as benchmarking studies.[68]

Rather than owning shared infrastructure, CESMII leverages the resources, products, intellectual property, and capabilities of its members, while retaining the rights to manage the platform infrastructure and application templates, and broker the "composite" IP developed from integrative projects. Additionally, each of the regional centers will establish its own demonstration facility.[69]

CESMII's education and workforce development plan seeks to instill broader understanding of smart-manufacturing practices, technologies, and platform infrastructure. The effort spans students from grade school to university as well as the existing workforce, including operators, engineers, and managers, and develops a centralized training repository and national community of practice.[70]

CESMII expects that continued reuse—and expansion—of smart-manufacturing systems configured for various industry solutions will be a key factor in its long-term sustainability. The institute will also provide such services as platform training and consulting to facilitate the development and subsequent reuse of proven application solutions. CESMII's objective is to become a trusted third party that accelerates the implementation of the next generation of smart manufacturing.[71]

Rapid Advancement in Process Intensification Deployment Institute (RAPID, Est. March 2017)

The chemical industry uses more primary energy than any other.[72] Modular chemical process intensification (MCPI) is a set of techniques that streamlines the steps in chemical manufacturing processes, while reducing capital costs and improving energy efficiency.[73] Although the concepts have been around since the 1970s, large-scale development and adoption of MCPI will require a "paradigm shift in the industry that no single firm is positioned to pursue on its own."[74] The RAPID Institute partners large and small firms from the chemical and equipment industries with academic institutions, nonprofit organizations, and DOE laboratories to design modules that will double energy productivity and cut capital costs by 90 percent compared with the current state of the art.[75]

RAPID is led by the American Institute of Chemical Engineers (AIChE), a 110-year-old nonprofit professional association in New York City.[76] In addition to the 12 experts at research institutions around the country who provide it with specialized support services on a part-time basis, RAPID employs a small staff that reports to both a governing board and a technical advisory board composed of member representatives, while relying on AIChE for back-office support and other infrastructure. Karen Fletcher, the founding CEO, was a 30-year industry veteran and former chief engineer of DuPont, and CTO James Bilenberg spent his prior career in R&D at Exxon-Mobil.[77]

RAPID's initial funding came from a five-year, $70 million award from the federal government, which was matched by the combined contributi0n of its 30 founding members. Overall membership reached 57 in its first year—and is still growing. While RAPID's anchor members include such large industrial players as Dow, Exxon, and Fluor, its other members tend to be technology providers, rather than potential innovation adopters, as is more common in other Manufacturing USA institutes. RAPID provides these members with the opportunity to showcase their technologies and build connections with potential partners and customers. Nonindustrial entities, especially universities, make up a majority of the membership. State governments do not participate directly in RAPID, although some provide cost-share funding to projects carried out at state universities. [78]

RAPID is organized around six focus areas that provide the framework for its roadmap: chemical and commodity processing, natural gas upgrading, renewable bioproducts, modeling and simulation, intensified process fundamentals, and module manufacturing.[79] Developed in the summer of 2017 by teams from member and prospective member organizations, the roadmap identified innovation gaps, which in turn helped to structure the selection of 21 R&D projects in RAPID's first round of funding.[80] These projects range in duration from 15 months to 4 years, and cost approximately $30 million. A second call for proposals is planned for the spring of 2018.[81]

RAPID does not own shared infrastructure, but rather leverages existing facilities owned by members. At the University of Texas, for instance, RAPID is contributing equipment to a dividing wall column pilot plant in exchange for member access to the facility to carry out projects. At Oregon State University, RAPID is paying for additive manufacturing equipment to be added to its technology park.[82]

RAPID has prepared an education and workforce development roadmap that calls for training current technicians, engineers, and managers as well as engineering students and faculty. The roadmap leverages the AIChE Academy to develop programs, and taps into the MEP network as well as AIChE's semiannual conferences to reach clients and prospective members.[83]

AIChE's Center for Chemical Process Safety (CCPS) may serve as a model for RAPID's long-term sustainability.[84] For example, as with CCPS, RAPID could leverage its educational services and technical tools to earn income. RAPID also intends to introduce privately funded projects as it makes its planned five-year transition away from federal funding.

Reducing EMbodied-energy And Decreasing Emissions (REMADE) Institute (Est. May 2017)

The United States consumes nearly 15 percent of all materials extracted globally—more than any other country—yet nearly half of that material winds up in landfills within a year. The energy used to process and distribute these materials in a sense winds up in landfills too. Reducing such embodied energy would lower not only the costs of production, particularly for material-intensive manufacturers, but also its environmental consequences. REMADE's goal is to cut embodied energy in the average unit of material production by 50 percent over the next 10 years by increasing recycling, recovery, remanufacturing, and reuse.[85]

REMADE is led by the Sustainable Manufacturing Innovation Alliance, an independent nonprofit organization in the Rochester, New York, area. Like IACMI, REMADE has hired its own staff, created its own policies, and carries out its own back-office functions, while maintaining a close relationship with the nearby Rochester Institute of Technology (RIT). REMADE's CEO, Nabil Nasr, is a professor, associate provost, and founding director of the Golisano Institute for Sustainability at RIT; the REMADE consortium was initially led by the Golisano Institute. Like RAPID, REMADE supports specialists on a part-time basis at academic nodes around the country to provide technical guidance.

REMADE is overseen by a governance council composed of member representatives, and is advised by strategic and technical advisory committees.[86]

REMADE's current membership comprises 69 organizations, which together will match its $70 million, five-year federal award. The relatively large proportion of trade associations among REMADE's membership makes it unique among DOE's Manufacturing USA institutes. REMADE views these members, such as the American Chemistry Council and Plastics Industry Association, as crucial avenues for dissemination of new knowledge and technologies to SMMs across a variety of manufacturing industries. Fifteen firms, including OEMs like Caterpillar and Nike, as well as vendors for specialty equipment and services, are members as well, along with a large group of universities and DOE laboratories. REMADE has received strong state support. New York committed $20 million to it, while Colorado, Utah, Florida, and Massachusetts provide support through university members.[87]

REMADE supports early-stage applied research and the development of industrial platform technologies in five domains: systems analysis and integration; design for reuse/disassembly; manufacturing material optimization; remanufacturing and reuse; and recycling and recovery. The recently finalized roadmap for the institute—developed through an interactive survey, member-site visits, an external data analysis and technology-forecasting project, and a workshop—guided the selection of nine projects to date, which were generated through a competition project call to members.[88]

REMADE plans to incorporate a number of testbeds to serve as validation resources for members to accelerate projects. These testbeds will build on members' existing resources, rather than create new facilities. The institute is currently working on a master agreement that would determine the terms of access to the testbeds for projects.[89]

REMADE has a workforce and education board composed of members. As of December 2017, the institute was in the process of hiring a director for workforce and education. Six modes of outreach, ranging from webinars to online and onsite training, are currently in the works.[90]

FINDINGS AND RECOMMENDATIONS

Manufacturing USA is a new program; PowerAmerica, the oldest DOE institute, just turned three years old, while REMADE, the youngest, is but a year old. These institutes must overcome more significant challenges than most start-up organizations because they require collaboration among novel and complex configurations of players who typically have never worked together. The institutes have also had to create organizational and sometimes physical structures, and establish operating procedures and norms. These start-up costs have now largely been paid, and the institutes are starting to execute the agendas their members created. In most cases, projects have been launched but not completed, although in some cases, results have started to materialize. Our study of these fledgling organizations has led us to several important findings.[91]

Findings

DOE's Manufacturing USA institutes have the potential to accelerate technological progress toward important national goals. These goals include economic competitiveness, high-quality jobs, national security, and environmental protection. If the institutes are successful, U.S.-based manufacturers will become more productive, grow more quickly, and export more successfully than they would in the institutes' absence. Manufacturing workers will be better-trained and more capable of contributing to cutting-edge production, thereby raising productivity. The defense industrial base will become more self-sufficient and flexible. Energy and material waste, along with pollution per unit of physical production, will decline, thus providing cost savings to the production process. Properly managed, public investment in the institutes will induce private investment and actions that "real-world" markets would not.

The institutes are beginning to make good on their promise, but it is too soon to make definitive judgments about them. Even under the best of circumstances, the full impact of the Manufacturing USA program will take years to be felt. Product redesign, equipment purchasing, and diffusion to SMMs occur slowly. Interim judgments can and should be made about the institutes' own processes, such as membership engagement and program management, after a reasonable start-up period of one to two years. But the purpose of such judgments should mainly be to improve these processes, rather than to assess their impacts on industry during each institute's first five years.

It is not too soon to take important steps that will improve the performance of existing institutes and support the start-up of new ones. The five DOE Manufacturing USA institutes are diverse in their structures and approaches. They vary, for example, in the degree to which they are centralized, how they interact with universities and national laboratories, and the extent to which they build on preexisting institutions. This diversity will provide valuable comparative insights over time.

Recommendations

Congress should continue to fund the institutes that have already been established. Proposals to establish institutes envisioned a timeline of at least five years until they were expected to be fully sustained by support from sources other than the Manufacturing USA program. The winning proposers secured private and other nonfederal commitments for matching funds to carry the institutes through this initial period. Barring obvious misconduct or failure, which have not been observed, the federal government should uphold its end of the bargain by continuing to invest in these nascent organizations. Strategic patience is appropriate for an institutional innovation of this magnitude and with such a long time horizon. U.S. manufacturing and energy policy should "lean into the wind" against short-termism driven by equity markets.

DOE should allow the institutes greater flexibility in raising and using private-sector funding in parallel with federal funding. While we argue below that the expectation of sustainability within five years should be relaxed, it is nonetheless important that private-sector and other support be expanded as the institutes mature. The institutes have a variety of strategies to develop such support—which older institutes have already begun to execute—including providing education and training services, and carrying out R&D projects whose funding comes entirely from the private sector. For instance, PowerAmerica recently held its first short course, which was fully subscribed and generated substantial revenue. However, PowerAmerica does not have the autonomy to spend this revenue as it chooses. As one program participant put it to us, DOE requires that the institutes plan to make a transition to sustainability but DOE does not yet have a plan to transition its management approach as the institutes mature.

Congress and DOE should provide opportunities for the institutes to receive federal support beyond the current limit of five years—and consider a permanent program of support. DOE has adopted a five-year window for the Manufacturing USA institutes it sponsors to transition to other funding sources. All program participants recognize that a full transition within five years will be extremely challenging—even the seven-year period specified by RAMI for NIST-sponsored institutes would likely be a stretch. Potential private supporters must become confident that their investments in these institutes will ultimately be rewarded. Small hiccups in implementation in the first year or two (which are not uncommon) may be difficult to overcome within five years. Indeed, comparable programs in other countries, such as Germany's Fraunhofer Institutes, receive core institutional funding from government on a permanent basis. Such funding could offer flexibility to institute managers and provide confidence to industry members, while limiting the influence of the largest industry members—including foreign-headquartered firms—that might otherwise dominate an institute's agenda. It would also sustain vital programs for workforce development and engagement with SMMs that might otherwise be put at risk. DOE and Congress should consider a permanent program of support for the Manufacturing USA institutes—perhaps at an ultimate level in the range of 20 to 30 percent of their budgets—to ensure the institutes remain industry-led, while maintaining incentives that they seek industry members, and evaluating them for continuation on a regular basis.

The institutes should intensify their outreach to small and medium-sized manufacturers. All of the institutes are implementing strategies that seek to engage SMMs. However, it is easier and perhaps more rewarding for the institutes to engage with entrepreneurial, technology-oriented start-ups than with existing SMMs who are already participating in supply chains. Start-ups are likely to have stronger growth prospects and to be more oriented toward innovation than existing SMMs. Many existing SMMs nonetheless have great potential to adopt innovations being developed at the institutes, and often have a greater need to do so than their younger competitors. The barriers to reach SMMs are also probably higher; the managers of SMMs are presumably older and less technologically savvy than entrepreneurs. The Manufacturing Extension Partnership's program of embedding staff within each institute is an important step toward expanding outreach to existing SMMs. It should be sustained, and we encourage the institutes to build around it. There may be additional opportunities for synergies with existing small-business programs, such as Small Business Innovation Research (SBIR) and the national labs' small business voucher pilot program. We are not arguing that the institutes limit their outreach to start-ups, rather that they match that effort with one that surmounts the substantial barriers to engagement with existing SMMs.

The institutes should develop more education and training programs for technicians and other mid-skill manufacturing workers. DOE is one of the federal government's leading funders of R&D. As such, it has a well-developed apparatus for supporting graduate students, post-docs, and, to a lesser extent, undergraduate students, through research assistantships, traineeships, and the like. It has less experience in supporting or providing training programs for workers or prospective workers without a college degree. Perhaps influenced by their sponsor, DOE's institutes' educational programs tend to emphasize engineering and research, rather than operations and maintenance activities performed by mid-skill workers. In technical areas in which innovations are still developing or have yet to diffuse widely, such an emphasis may be inevitable. However, the institutes should be encouraged to search for opportunities to provide training to mid-skill workers. The deepening engagement in Manufacturing USA of the Departments of Education and Labor, as called for by the 2017 GAO report, should aid in developing such programs. DOE's institutes may also draw on the Multi-Skilled Technician Core Competency Model the Manufacturing USA workforce team put together, and work in partnership with NSF's Advanced Technical Education (ATE) program.

DOE should better inform the public about the distinctive energy-specific mission of the DOE-sponsored Manufacturing USA institutes. DOE funds Manufacturing USA institutes to advance the department's overarching mission of powering the United States with clean, affordable, secure energy. This energy-specific mission is consistent with, but also distinct from, the broader mission of the Manufacturing USA program. Within DOE, the Manufacturing USA institutes are embedded within AMO's R&D consortia program. Key constituents, including the general public, may have difficulty perceiving the value of investments in innovation at the nexus of manufacturing and energy. At a minimum, the DOE-supported institutes seem to be more vulnerable politically than those funded by other agencies. DOE leadership should shore up the program's base of support by making a more concerted effort to explain the links between manufacturing innovation; clean, affordable, secure energy; and global competitiveness. Metrics as well as case studies that demonstrate these links should be compiled and used for this purpose. The Manufacturing USA program office should also encourage such agency-specific reporting.

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