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CONTRIBUTORS

Committee on a Vision for the Manufacturing USA Program in 2030 and 2035; Physical Sciences, Systems, and Infrastructure Program Area, Center for Advancing Science and Technology; National Academies of Sciences, Engineering, and Medicine

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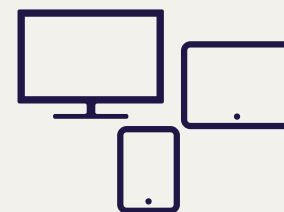
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A Vision for the Manufacturing USA Program in 2030 and 2035

Committee on a Vision for the Manufacturing
USA Program in 2030 and 2035

Physical Sciences, Systems, and
Infrastructure Program Area, Center for
Advancing Science and Technology

Consensus Study Report

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**Committee on a Vision for the Manufacturing USA Program
in 2030 and 2035**

THERESA KOTANCHEK (NAE) (*Chair*), Evolved Analytics LLC
WILLIAM B. BONVILLIAN (*Vice Chair*), Massachusetts Institute of Technology
DAVID ADLER, American Affairs
FELICIA J. BENTON-JOHNSON, Clemson University
STEPHANIE W. BUTLER, WattsButler LLC
JIAN CAO (NAE), Northwestern University
DIANNE CHONG (NAE), Boeing Research & Technology (retired)
STEPHEN R. FORREST (NAS/NAE), University of Michigan
THOMAS R. KURFESS (NAE), Georgia Institute of Technology
SUJAI SHIVAKUMAR, Center for Strategic and International Studies
CARROLL THOMAS, National Institute of Standards and Technology (retired)
CRISTINA U. THOMAS (NAE), 3M (retired)
CHARLES H. WARD, ARCTOS Technology Solutions

Study Staff

J. BRYSTOL ENGLISH, Senior Program Officer, *Study Director*
MICHELLE SCHWALBE, Senior Program Area Director, Physical Sciences, Systems, and
Infrastructure Program Area (PSSI)
ERIK SVEDBERG, Senior Scholar, PSSI
SARAH ROVITO, Senior Program Officer, Center for Advancing Science and Technology
(CAST) (*through May 2025*)
KATIE WULLERT, Program Officer, CAST (*through May 2025*)
BRITTANY SEGUNDO, Program Officer, PSSI
JOE PALMER, Senior Project Assistant, PSSI
HEATHER LOZOWSKI, Senior Finance Business Partner, PSSI
SAMANTHA KORETSKY, Research Associate, PSSI
REBECCA DEBOER, Research Associate, CAST (January 2026)
BRENT HEARD, Senior Program Officer, CAST (April 2026)

NOTE: See Appendix D, Disclosure of Unavoidable Conflicts of Interest.

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Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

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JOHN ALLISON (NAE), University of Michigan
PRITH BANERJEE, Synopsys Inc.
STEPHAN ROBERT BILLER (NAE), Purdue University
CRAIG BLUE, Oak Ridge National Laboratory
STEPHEN EZELL, Information Technology and Innovation Foundation
PHILLIP FREEMAN, The Boeing Company
MICHAEL GILROY, Center for Regional Economic Competitiveness
KATHLEEN N. KINGSCOTT, IBM Research
SHERRI MCCLEARY, The Digital Foundry at New Kinsington
PHILLIP SINGERMAN, Center for Strategic & International Studies
ERIN SPARKS, Sparks Policy Group

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by **A. Galip Ulsoy** (NAE), University of Michigan, and **Michael F. McGrath**, McGrath Analytics, LLC. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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Acronyms and Abbreviations

AFFOA	Advanced Functional Fabrics of America
AIM Photonics	American Institute for Manufacturing Integrated Photonics
AMNPO	Advanced Manufacturing National Program Office
AMRC	Advanced Manufacturing Research Centre
ARL	Adoption Readiness Level
ARM Institute	Advanced Robotics for Manufacturing Institute (ARM Institute)
ARMI	Advanced Regenerative Manufacturing Institute
ARTC	Advanced Remanufacturing and Technology Center
A*STAR	Agency for Science, Technology and Research
CESMII	Collaborative Ecosystems for Smart Manufacturing Innovation Institute
CNC	computer numerical control
DOD	Department of Defense
DOE	Department of Energy
EPIXC	Electrified Processes for Industrial eXcellence
FHE	flexible hybrid electronic
GAO	Government Accountability Office
GBP	pound sterling
GDP	gross domestic product
HVM	High Value Manufacturing
IACMI	Institute for Advanced Composites Manufacturing Innovation
IMEC	Interuniversitair Micro-Electronica Centrum VZW
INL	Idaho National Laboratory
ITIF	Information Technology and Innovation Foundation
ITRI	Industrial Technology Research Institute
LIFT	Lightweight-Metals Manufacturing Institute
LMC	large multinational corporation
MEP	Manufacturing Extension Partnership
METI	Ministry of Economy, Trade and Industry

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MRL	Manufacturing Readiness Level
MxD	Manufacturing x Digital
NIIMBL	National Institute for Innovation in Manufacturing Biopharmaceuticals
NIST	National Institute of Standards and Technology
NLR	National Laboratory of the Rockies
NSF	National Science Foundation
NSTC	National Science and Technology Council
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
RAMI	Revitalize American Manufacturing and Innovation
RAPID	Rapid Advancement in Process Intensification Deployment Institute
REMADE	Reducing EMbodied-energy And Decreasing Emissions
SME	small and medium enterprise
SMM	small and medium-sized manufacturer
SMRJ	SME Support, JAPAN / Organization for Small and Medium Enterprises and Regional Innovation, JAPAN
TRL	Technology Readiness Level
XAI	XA Investments LLC
XRL	Generalized construct encompassing TRL, MRL, and ARL

Preface

Manufacturing is critical to the nation's national security and economic well-being. The last 15 years have witnessed the rise of the techno-economic state with competitor nations practicing systematic industrial policy. Nearly all of the leading competitor nations to the United States have detailed national manufacturing strategies that are aligned with their national economic strategies. These strategies integrate industry efforts with government support at critical gaps, including for research, development, and implementation of new manufacturing technologies; for financing the scale-up of these manufacturing technologies; for regional adoption of these technologies; and for workforce development to support them. The United States has various programs along some of these lines, including the Manufacturing USA program. Overall, however, a coordinated strategy for alignment and adoption of advanced manufacturing across agencies and organizations and integrated with industry is missing. It is a critical missing ingredient. Without it, a coherent program for more rapid adoption of new manufacturing technologies into a new system for corresponding economic development is lacking. Each year that it is absent and not being implemented, U.S. production leadership erodes, affecting the nation's national security and economic well-being.

The task of this committee was to develop a new vision of where the Manufacturing USA program should be in the 2030 to 2035 time period. The report is forward looking. It notes the current challenges the program faces and then moves to much more detail on what new features and efforts the program should undertake to help meet the manufacturing challenges that the United States faces. To be most effective and productive, the Manufacturing USA needs to be a part of a formal USA industrial strategy. Therefore, key findings and recommendations center around the need for the United States to issue a formal Industrial Strategy, integrating technology development, scale-up financing, standards leadership, trade, and workforce development into a coherent national framework; to form a new governance model that enables collaboration across agencies and institutes; to better reach small and medium-sized manufacturers with new technologies and processes; to support entrepreneurial firms in bringing new technologies to manufacturing; to improve technology transfer capability through stronger in-house staff, establishing pilot production facilities, working on foundational manufacturing technologies, and

establishing business development teams; to accelerate regional growth by establishing regional development teams; and to expand the scope of manufacturing workforce education efforts.

The study was conducted over the course of 9 months. During this time, the committee held 30 public meetings and several workshops and roundtables, speaking with experts across industry, academia, and government. The committee also received input from institutes through questionnaires. The committee thanks the individuals who provided input and made contributions to this study; their input was crucial in writing the report. The committee also thanks the director of Physical Sciences, Systems and Infrastructure, Michelle Schwalbe, and senior program officer and study director, Bristol English, for their help and guidance in performing this study, and expresses special appreciation to project staff Erik Svedberg and Samantha Koretsky for their efforts in authoring this report.

Theresa Kotancsek, *Chair*

William B. Bonvillian, *Vice Chair*

Committee on A Vision for the Manufacturing USA Program in 2030 and 2035

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Summary¹

The Manufacturing USA Program, coordinated through the National Institute of Standards and Technology's Advanced Manufacturing National Program Office (AMNPO), was established in 2014 in an effort to create public–private partnerships designed to increase U.S. manufacturing competitiveness and promote a national manufacturing research and development (R&D) infrastructure.

The Manufacturing USA institutes, sponsored by the Departments of Commerce, Defense and Energy have established important manufacturing technology development programs, supported significant advanced technology R&D, embarked on innovative workforce education efforts, and most importantly, supported the growth of nascent manufacturing sectors. In Fiscal Year 2023, the 17 institutes worked with 2900+ member organizations, including 1300 small manufacturers, across 50 states and Puerto Rico.^{2,3} They facilitated the transition of innovative technologies into domestic manufacturing capabilities with over 920 applied research and development technology projects and engaged >150,000 individuals in workforce training opportunities. Collectively the institutes leveraged base federal funding of \$160.4 million to attract over \$379 million in additional funds from state, federal, and private sources. Critical to Manufacturing USA institutes success is active industry participation and engagement in defining industry roadmaps, prioritizing technology programs, and co-leading programs with institute members.

The report's authoring committee (the committee) concludes that the Manufacturing USA institutes are now a proven model that needs expanding, providing a strong foundation to build the public–private partnerships that U.S. manufacturing requires. The Manufacturing USA program is a critical policy mechanism that connects the key actors needed for advanced manufacturing: small and large industry, engineering and science expertise, state and local government, and economic development stakeholders. In the past 15 years, however, competitor

¹ This Summary does not include references. Citations for the information presented herein are provided in the main text.

² This sentence was changed after release of the report to reflect that the institutes have membership in all 50 states. They have a physical presence in more than 14 states and several have multiple offices.

³ This sentence was changed after release of the report to correct the Fiscal Year in which the data presented was collected.

nations have developed systematic industrial policies, linking the economic power of the state with industry to pursue integrated technological advances and to gain production leadership for a host of critical technologies. By comparison, the lack of an USA industrial strategy or policy has led to under-resourcing of USA manufacturing programs such as the Manufacturing USA Institute programs. This has resulted in the lack of scale-up investment, resulting in insufficient implementation of new advanced manufacturing technologies in the United States and is a primary cause of the declining rate of U.S. manufacturing productivity for the past 15 years as compared to increases for key competitor nations.

This reality presents an opportunity to reimagine the Manufacturing USA program as part of a larger Industrial Policy to create even greater impact on manufacturing in the United States. U.S. manufacturing is at a crossroads and is being systematically outcompeted. The committee concludes that now is the time for Manufacturing USA to “Go BIG.” Unless the United States accelerates its introduction of advanced manufacturing technologies and processes at scale, the nation will lack the productivity edge to compete. Upgrading the national asset of Manufacturing USA institutes is a critical means to meet that goal.

Conducted at the request of the National Institute of Standards and Technology, this report develops a new vision of where the program should be in the 2030–2035 time period.⁴ The report focuses on recommending ways to strengthen the program’s institute capabilities, cross-institute and cross-agency efforts, technology transfer and scale-up approaches, regional manufacturing ecosystems growth, and education and workforce development initiatives. Other key elements of the report are a review of federal sponsorship of institutes and international and domestic program comparisons and benchmarking.

BEST PRACTICES OF LEADING MANUFACTURING COUNTRIES

The committee considered a number of the approaches implemented by leading manufacturing nations in Europe and Asia to identify ways the Manufacturing USA institutes might evolve in the future. A significant difference in successful foreign models from Manufacturing USA is not in the details of institute design but in the broader context of these

⁴ This sentence was changed after release of the report to accurately reflect the study sponsor.

countries' emphasis on industrial strategy, with manufacturing as a national priority. Underlying their industrial policy programs are financial systems that are aligned with government directives targeting manufacturing and patient-capital financing tools which are not available in the United States. Additionally, many competitor nations have a higher number of institute-like programs that are staffed and funded at a much larger scale than the United States, including, China, which has approximately 45 Manufacturing Innovation Centers (MICs) with investments 10-100 times larger than Manufacturing USA's. China spends some \$500 billion annually in scale-up financing, and through various mechanisms about 4.6 percent of its gross domestic product (GDP). In contrast, the United States spends less than 1 percent of GDP on scale-up financing and little of that is specifically focused on manufacturing itself.

Another key difference is that competitor nations view manufacturing as a strategic sector that is crucial to their growth and economic and national security. For example, the Singapore Manufacturing 2030 vision is a strategic plan to grow manufacturing's value-add by 50 percent by 2030. In China, the government identifies critical gaps in technology and lays out a 5-year roadmap with clear milestones and timelines and then invests accordingly. Although the United States publishes a National Strategy for Advanced Manufacturing and a National Security Strategy it does not currently have an accompanying industrial strategy.⁵

On the basis of its international benchmarking review, the committee found that Manufacturing USA–equivalent organizations only achieve large-scale technology adoption and national impact when embedded within national industrial strategies. Therefore, this report makes recommendations for a U.S. Industrial strategy and the role of Manufacturing USA in that strategy.

Recommendation 2-1: In concert with the National Security Strategy, the National Economic Council, the Office of Science and Technology Policy, the Department of Commerce, Department of Defense, Department of Energy, and any other agencies supporting advanced manufacturing should convene and within the next 2 years issue a formal U.S. Industrial Strategy, integrating technology development, scale-up financing, standards leadership, trade, and workforce development to align

⁵ This sentence was changed after release of the report to include the National Strategy for Advanced Manufacturing.

resources and maximize the national impact of federal manufacturing programs, including Manufacturing USA institutes.

The report identifies several specific examples from foreign institutes that are useful models for Manufacturing USA institutes. For example, Belgium recognizes that infrastructure is key to its globally leading R&D center for microchip technology, IMEC (Interuniversitair Micro-Electronica Centrum VZW). Many U.S. companies and key suppliers to the U.S. semiconductor industry use IMEC as a critical R&D manufacturing resource. Through a distinctive R&D partnership model, corporate partners send staffers to IMEC to join teams undertaking the research.

The United Kingdom's High Value Manufacturing (HVM) Catapult was designed to bridge the same gap seen in the United Kingdom as in the United States between early-stage publicly funded basic research and later commercialization. However, unlike the Manufacturing USA institutes, it has a large in-house engineering and scientific staff of over 3,500 employees. The Catapult centers also house the UK equivalent of the National Institute of Standards and Technology's Hollings Manufacturing Extension Partnership (MEP) and have multiple formal programs for collaborating with academics, including engineering PhD students.

Germany's Fraunhofer-Gesellschaft along with Taiwan's Industrial Technology Research Institute (ITRI) are often seen as the world's leading applied research organizations. With 75 institutes and more than 30,000 scientists, engineers, and other staff, the Fraunhofer's 3.6-billion-euro budget comprises one-third from contract research, one-third from industry, and one-third from federal and state governments. However, in the broader context of the German economic model, this model is facing severe geopolitical challenges, because of its reliance on imported energy (natural gas) and markets for exports. This demonstrates that institutes need to be understood in a broader context, including a country's geopolitical strategy.

Japan's Ministry of Economy, Trade and Industry oversees four national institutions focused on industrial science and technology development. This comprehensive ecosystem of support has contributed to Japan's strong position in manufacturing. Likewise, the committee explored best practices from Singapore's Agency for Science, Technology and Research (A*STAR) Advanced Remanufacturing and Technology Centre. A*STAR is a public-private collaborative platform where industry leaders, research institutes, and government agencies co-develop and test advanced manufacturing solutions.

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Taiwan's Industrial Technology Research Institute (ITRI) provides an important example of how applied technology research institutes can be the basis for supporting the growth and launch of world-leading companies, such as the Taiwan Semiconductor Manufacturing Company (TSMC), as well as educating government officials on future technologies, such as Artificial Intelligence (AI) and potential implications to their national security and economy.

Critical Program Elements for U.S. Manufacturing Support

The U.S. financial model has led to manufacturing disinvestment. As one example, the size of the U.S. R&D tax credit lags other manufacturing nations. A 2024 Information Technology and Innovation Foundation analysis found that the United States ranked 31st out of 32 countries (28 Organisation for Economic Co-operation and Development nations and the 4 BRIC [Brazil, Russia, India, and China] economies) in their R&D tax credit support. Increasing the R&D tax credit could help incentivize the growth of domestic U.S. manufacturing (see Recommendation 2-2 and Overarching Conclusion 2-1).

Recommendation 2-2: By 2030, the United States Congress should take legislative action to define a globally competitive research and development tax credit for manufacturing processes and technologies and should actively explore expanding other tax reforms supporting manufacturing.

Other countries have pursued very different models for financing manufacturing, using multiple investment tools frequently missing in the United States, including subsidies, government-owned sovereign wealth equity funds, intellectual property-backed financing, and others (see Recommendation 2-3).

Recommendation 2-3: To address systemic capital gaps facing hardware-intensive technologies, the United States Congress, working with relevant agencies, should, within the next 2 years, authorize funding and set policy to create new federal manufacturing and financing mechanisms that include patient-capital funds, a sovereign wealth fund with a strategic focus on manufacturing, intellectual property-backed lending programs, coordinated public-private guidance funds and other mechanisms. Manufacturing USA institutes should be formally integrated as advisors to manufacturing financing bodies, providing technical due diligence, scale-

up roadmaps, readiness assessments, and first-of-a-kind validation data that de-risk future investments and inform investment decisions.

Moreover, a critical offering missing from the Manufacturing USA system versus international competitors is in-house business development (see Recommendation 5-1). Business development requires national-level, cross-institute solutions because it involves the broader scale-up and commercialization challenges facing U.S. technologies, as well as the specific challenges facing entrepreneurs. International programs also hold lessons for how the United States can close the productivity gap and improve the performance of small and medium-sized manufacturers (SMMs). A recurring feature of successful international manufacturing institutes surveyed by the committee was the capability for in-house prototyping and pilot production, as found at IMEC, the HVM Catapult, A*STAR, ITRI, and elsewhere. The underlying rationale for these shared physical facilities is that they are necessary to achieve economic competitiveness and help foster eventual commercial production of new technologies.

Additional best practices from international institutes include a focus on foundational technologies—broadly defined as technologies used for inputs in advanced technologies (see Recommendation 2-4), applied research conducted by an in-house engineering and scientific staff (see Recommendations 3-3 and 3-4), higher Technology Readiness Levels (see Recommendation 3-2), cross-disciplinary strategies (see Recommendations 4-3, 4-4 and 4-5), and a nationally aligned approach to standards (see Recommendation 2-5).

Recommendation 2-4: Manufacturing USA sponsoring agencies should immediately conduct a coordinated assessment to identify foundational manufacturing technologies in which U.S. capabilities have eroded or are in danger of erosion relative to those of international peers. Within 2 years, agencies should either (a) add foundational technology workstreams to existing institutes or (b) stand up new institutes where critical gaps exist.

Recommendation 2-5: The setting of standards is increasingly a geopolitical consideration; hence, within 2 years, Manufacturing USA institutes and the Advanced Manufacturing National Program Office should highlight the standards roadmaps that different institutes are generating, encourage the new National Institute of Standards and Technology–funded Standardization Center of

Excellence to leverage these roadmaps, and obtain funding for actual standards writing as part of the institutes' projects.

Opportunities also exist for collaboration between Manufacturing USA institutes and international institutes, particularly with those foreign institutes that have a presence in the United States and are working with U.S. companies and universities; however, collaborations with countries of concern as identified by Congress or the Federal government should be excluded. (see Recommendation 2-6).

Recommendation 2-6: With on-going sponsoring agency review and approval, starting in 2026, Manufacturing USA institutes should pursue structured collaborations with leading international manufacturing institutes in areas where complementary strengths exist. These partnerships should focus on shared research, pilot-scale demonstration, standards development, and knowledge exchange that advances domestic technology transfer and scale-up.

VISION FOR THE FUTURE OF THE MANUFACTURING USA PROGRAM

Considering best practices and other information from competitor nations, the report evaluates and makes recommendations for the Manufacturing USA program regarding technology transfer, interagency and cross-network collaboration, regional economic development, and education and workforce development, which culminates in a Vision for the Future of the Manufacturing USA program.

Strengthening Technology Transfer

Strengthening technology transfer requires a clear understanding of what the term means within the Manufacturing USA context and how the institutes operationalize it through shared definitions, coordinated road-mapping, and convening a broad range of partners around common goals (see Recommendations 3-1 and 3-2). The diversity of stakeholders within the Manufacturing USA ecosystem defines both the opportunity and the complexity of technology transfer. These stakeholders include SMM and entrepreneurial firms, large multinational corporations, national laboratories and universities, federal agencies, and state and regional economic development agencies. Because the needs of these groups differ, maintaining flexible

technology transfer mechanisms and adaptive governance structures in the Manufacturing USA network is essential.

Recommendation 3-1: Within a year, each Manufacturing USA institute should define “technology transfer” in its roadmap with measurable milestones. These should be updated annually and where possible aligned with existing Manufacturing USA performance metrics and reporting frameworks used by the Advanced Manufacturing National Program Office and sponsoring agencies.

Recommendation 3-2: Within a year, each Manufacturing USA institute should specify and clearly and consistently document its initial and target readiness levels (Technology Readiness Level [TRL], Manufacturing Readiness Level, or Adoption Readiness Level, generally expressed as, XRL) and demonstrate and document transitions to TRLs 7–9 using consistent reporting metrics coordinated through the Advanced Manufacturing National Program Office. These should be updated annually.

Additionally, institutes illustrate a variety of approaches to technology maturation. These approaches typically involve three interdependent activities including technical validation, pilot-scale demonstration, and business-case development. Furthermore, pilot-scale and scale-up facilities serve as the critical bridges between laboratory validation and industrial implementation ([see Recommendation 3-3](#)). The progression from validation to pilot-scale demonstration mirrors the capabilities embedded in international models reviewed by the committee and the workforce upskilling requirements needed for effective scale-up.

Recommendation 3-3: Manufacturing USA institutes, in conjunction with sponsoring-agency support, should begin immediate planning and initial implementation of pilot-scale and scale-up facilities, with defined milestones and early operational capability established by 2030 and full-scale operations, broadly accessible to small and medium-sized manufacturers, achieved by 2035. Implementation will require sustained federal funding and coordinated co-investment from industry and regional partners. Manufacturing USA institutes and such facilities should be supported through long-term, renewable federal

sponsorship that reflects their role as enduring national manufacturing infrastructure rather than short-term projects, with periodic performance-based review rather than assumptions of self-sufficiency within a single award cycle.

Within the Manufacturing USA network, staffing structures and levels of in-house expertise vary depending on each institute's mission, maturity, and technology domain. Institutes that maintain experienced, cross-functional teams tend to achieve faster and more reliable technology transitions. Skilled staff can identify manufacturability challenges early, anticipate barriers to adoption, and ensure that project outcomes align with industry needs. Furthermore, institutes' coordinating function, whereby they convene members and partners through activities such as technical councils, road-mapping workshops, annual meetings, and thematic working groups, enable stakeholders to align with research priorities, coordinate investments, and accelerate the transition of innovations to industrial applications.

The best innovation institutes in the USA and internationally identify the technology transfer team and include them as part of the innovation process. Dedicated individuals, small and large system installation service companies, and/or equipment/ digital tool suppliers can serve in this role. The key is to identify who will serve as the technology transfer team for every institute project, which mechanisms will be used for transfer, and to have an active role for their participation during or near the conclusion of the projects. Equally important is to have dedicated institute staff in place to enable effective Technology Transfer (see Recommendation 3-4), to establish metrics (see Recommendation 3-5) and to share best practices across Manufacturing USA (see Recommendation 3-6).

Recommendation 3-4: Within 2 years, Manufacturing USA institutes and the Advanced Manufacturing National Program Office should establish dedicated, well-staffed technology transfer teams and long-term staffing plans, leveraging existing federal technology transfer expertise and programs where appropriate.

Recommendation 3-5: Within 2 years, the Advanced Manufacturing National Program Office, with sponsoring agencies, should implement a standardized network-wide technology transfer metrics framework. If necessary, Congress should consider clarifying statutory reporting authorities to enable consistent performance metrics across all Manufacturing USA institutes.

Recommendation 3-6: Within a year, the Advanced Manufacturing National Program Office should establish a Technology Transfer Best Practices Office and formal cross-agency coordination mechanisms, building on lessons identified in previous National Academies and GAO studies of Manufacturing USA institutes.

Inconsistent engagement models and unclear membership processes can limit the ability of smaller firms and new entrants to benefit fully from institute resources and collaborations. The Advanced Manufacturing National Program Office (AMNPO) leadership and coordination are critical for ensuring that lessons learned, best practices, and performance data are shared efficiently and systematically. Although AMNPO has made significant progress in coordinating the Manufacturing USA network, opportunities remain to expand its leadership role in aligning institute practices, facilitating data sharing, and disseminating best practices to accelerate Technology Transfer.

Strengthening Interagency and Cross-Network Collaboration

The wide-ranging technical waterfront covered by the current Manufacturing USA institutes offers a number of opportunities for enhanced interagency engagement and institute networking to spur innovation. More robust national-level planning with detailed agency coordination on technology development would serve the nation better by concentrating resources and ensuring that all required stakeholders understand their roles in meeting strategy goals. Furthermore, cross-institute collaboration faces many of the same barriers to interagency engagement: differing mission focuses, administrative barriers, insufficient funding and staff, limited technical overlap, and differing maturity levels of the institutes as well as lack of incentivization. The creation of a directive body to guide strategy for integrating the institutes is needed (see Recommendation 4-1).

Recommendation 4-1: Within the next 2 years, Manufacturing USA institute-sponsoring agencies (currently the Departments of Commerce, Energy, and Defense) should create an Interagency Council as a formal, overarching directive body to set an integrated strategy for the Manufacturing USA institutes.⁶

⁶ This sentence was changed after release of the report to clarify that the recommendation applies to all institute sponsoring agencies.

Although the committee identified several best practices at various agencies and institutes, formal policies, processes, and incentives for interagency collaboration that could provide synergistic benefits with broader, national impact are not presently built into the Manufacturing USA network and are needed (see Recommendation 4-2).

Recommendation 4-2: The Advanced Manufacturing National Program Office, working with the Interagency Council and sponsoring agencies, should establish harmonized procurement, funds-transfer, intellectual-property, and data-management policies that enable seamless collaboration across agencies and institutes. This effort should be undertaken in consultation with the United States Manufacturing Innovation Council, as appropriate, and aim for harmonized policies and processes by 2030.

Limits to federal funding and adjacency of some technology areas covered by the institutes can create real or perceived competitive environments and inhibit collaboration across the Manufacturing USA network. Hence, the committee recommends a new initiative specifically focused on interagency and inter-institute collaboration to better promote innovation at the cross section of technologies (see Recommendation 4-3).

Recommendation 4-3: By 2030, Congress should appropriate funding on par with comparable international programs to the Manufacturing USA institutes to create an interagency initiative that would competitively award dedicated funds to incentivize cross-institute collaboration by addressing grand challenges in manufacturing. A project source selection team should comprise representatives from Manufacturing USA institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense) to ensure broad applicability across mission spaces and alignment with national manufacturing priorities.^{7, 8}

⁷ This recommendation was changed after release of the report to clarify that the recommendation applies to all institute sponsoring agencies.

⁸ This recommendation was changed after release of the report to clarify the budgetary reference.

The current lack of cross-institute collaboration to develop integrated packages of advanced manufacturing technologies limits the ability of institutes to provide meaningful support to SMMs, a core Manufacturing USA constituency that has been slow in adopting advanced manufacturing. Moving forward, the network could consider partnering with MEPS and regional economic development groups to coordinate this development to ensure access by SMMs to these packages (see Recommendation 4-4).

Recommendation 4-4: The Advanced Manufacturing National Program Office should work with the Manufacturing Extension Partnership (MEP) program to create a process by 2030 that ensures that these integrated packages of advanced manufacturing technologies developed by institutes are disseminated to MEPS nationwide for implementation by small and medium-sized manufacturers.

There are tremendous technological needs, integration points, and standards that are pervasive across digital-native manufacturing technologies. To address these, an integrated strategy is needed across the Manufacturing USA network to chart a path forward (see Recommendation 4-5).

Recommendation 4-5: Within the next 2 years, the Advanced Manufacturing National Program Office, in coordination with the Interagency Council, should lead an interagency effort to develop a robust strategy specifically focused on digital manufacturing across the Manufacturing USA network.

Such a focus would help clarify roles and responsibilities across the digitally focused institutes, whose technologies are also largely horizontal (i.e., Advanced Robotics for Manufacturing, Collaborative Ecosystems for Smart Manufacturing Innovation Institute (CESMII), Cybersecurity Manufacturing Innovation Institute, and Manufacturing x Digital), to promote multidisciplinary innovation across the Manufacturing USA network, broaden considerations of cybersecurity across all the institutes, and address data management policies and standards across the network and industry.⁹ When considering cross-institute collaboration, it is recommended that institutes focused on horizontal, crosscutting technologies take the leading role.

⁹ This sentence was changed after release of the report to remove references to SMART USA institute as a Manufacturing USA institute.

Likewise, collaboration with federal laboratories, which have deep technical expertise, access to world-class facilities, and long-term R&D, is underutilized for a variety of reasons including cost recovery policies, administrative barriers, and inconsistent management and operations contract terms (see Recommendations 4-6 and 4-7).

Recommendation 4-6: Within the next 2 years, the Advanced Manufacturing National Program Office, in coordination with the Interagency Council, should create a multiprong strategy that enhances use of the Manufacturing USA network’s capabilities across federal and state government agencies and small and medium-sized manufacturers (SMMs), including coordination with the Manufacturing Extension Partnership (MEP) network, and provides resources as to how agencies and SMMs can work with institutes to enhance interagency engagement.

Recommendation 4-7: Within the next 2 years, the Department of Energy (DOE) should work with national laboratories to explore modifying management and operations contractual agreements to be compatible with institute agreement terms and conditions. Additionally, DOE should make funding available to national laboratories for the specific purpose of collaborating with institutes on DOE priority projects.

Strengthening Regional Manufacturing Ecosystems

Although technology-based competition is global, ecosystems supporting manufacturing in the United States are inherently regional. To understand the Manufacturing USA institutes’ role in regional manufacturing ecosystems and economic development broadly, the committee examined the local focus of the Manufacturing USA institutes, the institutes as ecosystem integrators, and the institutes’ role in building the region’s advanced manufacturing skilled workforce, as well as its role connecting to state and other federal resources. At the regional level, new manufacturing technologies can be introduced and experimented with—providing the basis for moving toward national adoption at larger scale. The institutes’ role as ecosystem connector needs to be regional in focus because geographic distributions of capital equipment,

infrastructure, know-how, and other assets are local; connecting assets requires local cooperative networks; and local stakeholder buy-in is needed to sustain the effort.

Institutes have the potential to serve as regional economic anchors that connect and build regional ecosystems; however, the narrow focus on technical missions, lack of strategic perspective, fragmented funding structures and absence of dedicated business development expertise prevent this. Furthermore, regional coalitions and pilot-scale facilities require time to mature, align stakeholders, and deliver economic impact. Funding structures that emphasize short-term awards and frequent re-competition undermine the ability of institutes to function as stable regional anchors. Renewable, longer-term sponsorship models will improve regional planning, workforce stability, and private-sector co-investment. (See Recommendation 5-1).

Recommendation 5-1: By 2030, Congress should provide sustained dedicated funding above current appropriations to establish business development offices at each Manufacturing USA institute to support commercialization, scale-up, and regional ecosystem integration for entrepreneurs and small and medium-sized manufacturers, working in coordination with regional economic development organizations and federal manufacturing programs.

Strengthening Education and Workforce Development

Education and workforce development is a core, but underfunded, mission of the Manufacturing USA institutes. Improved workforce education is vital to advanced manufacturing because it can enable a pipeline of workers with the skills to operate, maintain, and innovate with complex emerging manufacturing technologies in such areas as robotics, data analysis, digital production, and new materials. The committee found that the most widely cited example of interagency engagement by both agencies and institute directors was in the area of education and workforce development due to its status as a core mission, being noncompetitive, and its ease of transitioning approaches across technologies. A number of best practices have been developed that create potential models for more broad-based approaches across the institutes. Recognizing this, the committee makes the following recommendations:

Recommendation 6-1: By 2030, Manufacturing USA institutes should adopt a broad range of programs to address workforce education needs in advanced

manufacturing, based on best-practice programs developed by various institutes, including to develop advanced manufacturing curricula, develop online education, create advanced manufacturing credentials, support workforce education delivery, collaborate across institutes, and broaden the manufacturing talent base. These broadened programs should be executed in collaboration with regional stakeholders, such as area companies and education institutions, and should include efforts to reach small manufacturers with workforce education advisory services and training programs.

Recommendation 6-2: Within approximately 2 years, agencies sponsoring the Manufacturing USA institutes working with the Advanced Manufacturing National Program Office should develop a unified advanced manufacturing curriculum available online that combines and unifies curricula and materials developed by institutes along with successful education and workforce development programs. Supporting this, they should develop an outcomes measurement and a credentialing system coordinated with industry and aligned with Manufacturing USA workforce metrics and programs.

Even with some of these best practices in place, education, as well as attracting and retaining manufacturing talent, remains a challenge. Skilled talent is a particular problem for SMMs considering adopting advanced manufacturing and in turn contributes to low manufacturing productivity rates compared to larger firms. To address this gap, the committee recommends implementation of Recommendations 6-3 and 6-4.

Recommendation 6-3: By 2030, Manufacturing USA institutes should implement new technologist curricula, such as the Department of Defense’s Industrial Base and Sustainment funded pilot projects. They should work toward implementing it in cooperation with regional partners in industry and community colleges and, if deemed appropriate, incorporate it into the recommended Manufacturing Academy.¹⁰

¹⁰ This recommendation was changed after release of the report to accurately reflect how programs are implemented.

Recommendation 6-4: The White House Office of Science and Technology Policy and the Domestic Policy Council should convene a cross-agency workforce education project and implement within the next 2 years a strategy to coordinate efforts across agencies to enhance Manufacturing USA institute and other agency manufacturing education programs. This would include relevant programs at the Manufacturing institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense), as well as at the Departments of Labor and Education and the National Science Foundation’s Advanced Technological Education Program.¹¹

Advanced manufacturing workforce education faces major challenges at both technical and professional levels.

For the technical manufacturing workforce, there is a major “work-learn” barrier because of the following: schools and jobs are disconnected; community colleges lack resources; most vocational education ended in the 1970s and 1980s; apprenticeships are largely missing (see Recommendation 6-5); labor markets lack an efficient information system; the Departments of Labor and Education lack programs to upskill incumbent workers; curricula in advanced manufacturing skills are limited; small manufacturers lack the skilled talent for advanced manufacturing; online workforce education is limited; and technical manufacturing workers lack solid career paths that would encourage entry.

Recommendation 6-5: Given the need for apprenticeships in manufacturing, and especially to enable the scale-up of advanced manufacturing, within the next 2 years, Manufacturing USA institutes should become active promoters and enablers of manufacturing apprenticeships as part of their regional engagements.

Equally, for engineering professionals in manufacturing, the United States has long separated engineers doing design from factory floors. Engineering curricula contain little manufacturing content, and there is limited online professional-level courseware in advanced

¹¹ This sentence was changed after release of the report to clarify that the recommendation applies to all institute sponsoring agencies.

manufacturing. To address these challenges, the committee makes the following

Recommendation 6-6:

Recommendation 6-6: A collaboration across Manufacturing USA institutes enabled by the proposed Interagency Council and the National Institute of Standards and Technology’s Advanced Manufacturing National Program Office should build out a robust online Manufacturing Academy portal of advanced manufacturing online courses and programs. By 2030, the online portal should include simulations, virtual reality, and augmented reality material, developed by Manufacturing USA institutes. The online portal should include materials and links from other verified sources, as well as new material.

Together, these critical elements and recommendations support a Vision for the Future of the Manufacturing USA Program in 2030 and 2035. It describes a new vision and the work ahead for the institutes to “go bigger” by reaching SMMs with new technologies and processes, supporting entrepreneurship in manufacturing, deepening technology transfer capability, forming a new governance model, supporting regional connections, fostering collaboration across agencies and institutes, and expanding workforce education.

A Vision for the Manufacturing USA Program in 2030 and 2035		
Timeline for Implementation of Recommendations		
2026-2028	2030	2035
Rec. 2-1	Rec. 2-2	ALL RECOMMENDATIONS TO HAVE BEEN IMPLEMENTED
Rec. 2-3	Rec. 3-3	
Rec. 2-4	Rec. 4-2	

PREPUBLICATION COPY: Uncorrected Proofs

Rec. 2-5	Rec. 4-3	
Rec. 2-6	Rec. 4-4	
Rec. 3-1	Rec. 5-1	
Rec. 3-2	Rec. 6-1	
Rec. 3-4	Rec. 6-3	
Rec. 3-5	Rec. 6-6	
Rec. 3-6		
Rec. 4-1		
Rec. 4-5		
Rec. 4-6		
Rec. 4-7		
Rec. 6-2		
Rec. 6-4		
Rec. 6-5		

Chapter 1

Introduction

During the second half of the 20th century, the United States became the world technology leader. Science-based research and development (R&D) and mass production of goods led to unprecedented economic prosperity as well as national security during the Cold War.¹² In the decades following, the United States implemented a “linear pipeline” strategy in which the government generally funded earlier-stage research and left technology adoption and its production to industry. Today, the United States now faces a major strategic and economic competitor—China—that has adopted a different strategy built around world manufacturing dominance and has integrated its economic and national security strategies accordingly.

Manufacturing is central to the economic well-being of the United States. A National Academies’ evaluation found that value chains in the U.S. economy that rely on manufactured goods, as either a part of or as a necessary means (such as with software), for delivery of their major economic contribution, account for 25 percent of U.S. employment, more than 40 percent of U.S. gross domestic product, and almost 80 percent of U.S. R&D spending.¹³ The COVID-19 pandemic and the Russia-Ukraine War have underscored the deep problems of weak manufacturing supply chains and resiliency in U.S. manufacturing.

Despite manufacturing’s importance to the United States, it must be viewed as a system in decline. During the 2000–2010 period, approximately 66,000 factories were closed,¹⁴ manufacturing employment fell by nearly one-third, from 17.3 million to 11.5 million in direct employment; by 2025 it had only recovered to 12.7 million.¹⁵ The employment decline was due

¹² See, for example, S. Shivakumar and J. Heng, 2025, “The United States Cannot Win the Twenty-First Century Innovation Race with a Twentieth-Century Playbook,” CSIS, July 30, <https://www.csis.org/analysis/united-states-cannot-win-twenty-first-century-innovation-race-twentieth-century-playbook>.

¹³ National Academy of Engineering, 2015, *Making Value for America: Embracing the Future of Manufacturing Technology and Work*, Washington, DC: National Academies Press, p. 15, <https://nap.nationalacademies.org/read/19483/chapter/4#15>.

¹⁴ R.D. Atkinson, 2018, “Why Foreign Competition Not Productivity Is More to Blame for Job Losses in U.S. Manufacturing,” Information Technology and Innovation Foundation, February 26, <https://itif.org/publications/2018/02/26/why-foreign-competition-not-productivity-more-blame-job-losses-us>.

¹⁵ U.S. Bureau of Labor Statistics, “All Employees, Manufacturing, 1940–2025,” <https://fred.stlouisfed.org/series/MANEMP>.

predominantly to production competition with Asia, particularly with China. This shift has caused significant social disruption.¹⁶ Manufacturing was once a pathway to the middle class for those without college degrees, but that path has been significantly curtailed, producing a corresponding rise in economic inequality.¹⁷

China passed the United States as the world leader in manufacturing output in 2011, and its lead has been growing ever since. China currently has some 35 percent of gross world manufacturing production and the United States some 12 percent, \$297 billion in 2024, an over 60 percent rise since 2020.¹⁸ The nations have literally been trading places. The U.S. trade deficit in goods has been sharply rising and reached a record \$1.2 trillion in 2025 with its largest deficit with China (\$295 billion). That deficit was not simply in commodity goods; the United States ran a major deficit in advanced technology goods (e.g., aircraft, semiconductors, communications, robots).¹⁹

THE U.S. MANUFACTURING CHALLENGE

The last 15 years have witnessed the rise of the techno-economic state with competitor nations, principally in East Asia and led by China, practicing systematic industrial policy, linking the economic power of the state with industry to pursue integrated technological advances and production leadership for a host of critical technologies. The United States has also pursued industrial policy approaches through its Department of Defense policies in areas such as aerospace and computing, and in recent years the United States has embarked on a series of non-defense industrial strategies for electric vehicles, for development of Covid-19 vaccines through Operation Warp Speed, through the CHIPS Act (P.L. 117-167) for semiconductors, and in pursuit of rare earth and other minerals.

¹⁶ D.H. Autor, D. Dorn, and G.H. Hanson, 2016, “The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade,” NBER Working Paper 21906, January, National Bureau of Economic Research, <https://www.nber.org/papers/w21906>.

¹⁷ A. Sherman, D. Trisi, and J. Cureton, 2024, “A Guide to Statistics on Historical Trends in Income Inequality,” December 11, Center on Budget and Policy Priorities, Figure 1, <https://www.cbpp.org/research/poverty-and-inequality/a-guide-to-statistics-on-historical-trends-in-income-inequality>.

¹⁸ U.S. Census Bureau and U.S. Bureau of Economic Analysis, 2025, “U.S. International Trade in Goods and Services, June 5, 2025,” Exhibit 15, https://www.bea.gov/sites/default/files/2025-08/trad0625_0.pdf.

¹⁹ U.S. Census Bureau and U.S. Bureau of Economic Analysis, 2025, “U.S. International Trade in Goods and Services, June 5, 2025,” Exhibit 15, https://www.bea.gov/sites/default/files/2025-08/trad0625_0.pdf.

The United States led the production paradigm of mass production in the second half of the 19th and early 20th century. However, it missed the quality manufacturing paradigm led by Japan in the 1970s and 1980s. In recent years, it has fallen behind on the latest paradigm, which can be called advanced manufacturing,²⁰ built around new manufacturing technologies from robotics to digital production, biofabrication, additive manufacturing, and advanced materials. For example, although robotics can lead to major productivity gains, the United States is now rated 10th in the world in industrial robots per 10,000 manufacturing workers, just ahead of Slovenia, and far behind leaders such as Korea, China, and Germany.

The underlying U.S. manufacturing problems can be grouped into five broad areas: missing national manufacturing strategy, financing and cost burdens, limited manufacturing innovation, low productivity, and weak workforce education and development. Each of these is briefly discussed next.

Missing National Manufacturing Strategy

Nearly all of the leading competitor nations to the United States have detailed national manufacturing strategies that are aligned with their national economic strategies. These strategies integrate industry efforts with government support at critical gaps, including research, development, and implementation of new manufacturing technologies; financing the scale-up of these manufacturing technologies; regional adoption of these technologies; and workforce development to support them. The United States has various programs along some of these lines, including the Manufacturing USA Program. Overall, however, a coordinated strategy for alignment and adoption of advanced manufacturing across agencies and organizations that is integrated with industry is missing. Each year without such a strategy U.S. production leadership erodes.

²⁰ See, for example, D. Adler and W. Bonvillian, 2023, "America's Advanced Manufacturing Problem," *American Affairs Journal*, Fall, <https://americanaffairsjournal.org/2023/08/americas-advanced-manufacturing-problem-and-how-to-fix-it/> ; A. Kumar, 2025, "Why the US Needs Robots to Rebuild," CSIS, July 1. <https://www.csis.org/blogs/strategic-technologies-blog/why-united-states-needs-robots-rebuild>.

Financing and Cost Burdens

Financial Model of “Core Competency” and “Asset Light” Has Led to Manufacturing Disinvestment

While the United States has strong capital finance depth, the dominant U.S. financial model has favored firms that pursue “core competency” and “asset light” strategies, which focus on leveraging unique strengths (e.g., specialized production technologies, advanced R&D), and reducing ownership of capital assets such as factories and machinery. This model has led companies to divest manufacturing assets, through both outsourcing and offshoring. Although U.S. industrial firms were once vertically integrated, a dis-integrated approach has long been favored, leading to manufacturing disinvestment and extensive use of contract manufacturers located in the United States and increasingly abroad.

It is also difficult for manufacturing firms to get financing if they are or may be competing with lower-cost Chinese goods. In addition, venture capital (VC) financing, which has funded U.S. start-up and entrepreneurial firms, is overwhelmingly focused on software, biotechnology, and services. Capital needs and rates of return in “hard tech” areas with high-cost fixed assets such as manufacturing tend to be long term—10 or more years—which does not fit the VC timetable of high rates of return within 5 years. Manufacturing’s long development cycle, approach to risk, and its need for large-scale funding simply do not fit VC. This means that start-up firms that need to manufacture have trouble scaling up into production and are often driven to offshore production. In sum, traditional and venture financing models do not fit the capital needs for advanced manufacturing.

Gap in Governmental Financing of Manufacturing Scale-Up

China spends some \$500 billion annually in scale-up financing, and through various mechanisms about 4.6 percent of its gross domestic product (GDP).²¹ In contrast, the United States spends less than 1 percent of GDP, and little of that is specifically focused, unlike in

²¹ G. DiPippo, I. Mazzocco, S. Kennedy, and M. Goodman, 2022, “Red Ink: Estimating Chinese Industrial Policy Spending in Comparative Perspective,” CSIS, May 23, <https://www.csis.org/analysis/red-ink-estimating-chinese-industrial-policy-spending-comparative-perspective/>; C. Boullenois, A. Kratz and D.H. Rosen, 2025, Far From Normal, An Augmented Assessment of China’s State Support, Rhodium Group, March 17, <https://rhg.com/research/far-from-normal-an-augmented-assessment-of-chinas-state-support/>.

China, on manufacturing itself. In addition, China offers “guidance funds” that are private sector–led with government matching funding that provides equity investment, not just lending, in industrial firms producing critical technologies.²² These guidance funds are authorized for \$1.6 trillion and have invested some \$1 trillion. Recently, they have been extended to artificial intelligence (AI) areas. The United States has no governmental financing programs comparable to these funds.

Trade Policy Is Not Coordinated with Manufacturing and Innovation Policy

Tariffs can be an important tool for promoting domestic manufacturing, one that was applied extensively through the 19th and early 20th centuries to support nascent U.S. manufacturing industries. A massive new system of tariffs instituted in 2025 to restore U.S. manufacturing, however, has had a secondary consequence of imposing significant new costs on U.S. manufacturing firms, which have come to rely in significant part on foreign components, supplies, and resources. Uncertainty about tariff levels, which have been changing, has also limited industrial planning, leading to declines in hiring and capital investment at numerous firms. Although foreign direct investment in production by foreign firms in the United States has been growing, it has not offset the issues for U.S. manufacturers. Although a standard rule of tariff policies in East Asian nations has been not to tax components you need to manufacture priority technologies, U.S. tariff policy to date has not recognized this approach and has been imposing uniform national tariffs. Nor has the United States recognized, as East Asian tariff policies long have, the importance of longer-term certainty about tariff tax levels for industrial planning, which is inherently long term.

Key technology innovation policies have also been counteracted by tariff policies; for example, in quantum sensing and computing, U.S. firms must source key components from abroad with new taxes affecting supply chain access, security, and price competitiveness. In general, there has been a lack of strategy coordination between technology, innovation, and manufacturing policy and trade policy disrupting efforts toward re-industrialization.

²² D. Adler, 2019, “Financing Advanced Manufacturing; Why VCs Aren’t the Answer,” *American Affairs* 3(2): Summer, <https://americanaffairsjournal.org/2019/05/financing-advanced-manufacturing-why-vcs-arent-the-answer/>.

Regulatory Costs

Regulatory costs are difficult to estimate, with industry estimates consistently higher than periodic federal Office of Management and Budget estimates because of different methodologies used. However, a National Association of Manufacturers study²³ found these costs to be quite substantial for all manufacturing firms (\$29,100 per manufacturing worker) and higher (as much as \$50,100 per manufacturing worker) for smaller firms with fewer employees across whom to allocate compliance costs. According to the study, for all firms, economic regulations carry 36 percent of regulatory costs, while environmental regulations carry 59 percent and Occupational Safety and Health Administration regulations carry 3 percent.²⁴ Furthermore, because the time horizon for achieving a satisfactory return on capital has shortened, long regulatory and permitting cycles in the United States impose a growing disincentive to invest in new manufacturing capacity or to upgrade existing facilities. Of course, there are worker and other benefits offsetting the costs. Overall, however, regulatory costs, including the time-consuming and costly regulatory requirements to develop and equip new factory sites and improvements, remain a significant manufacturing entry and scale-up issue.

Limited Manufacturing R&D and Technology Development*Disconnect Between the U.S. Innovation System and Manufacturing*

With the offshoring of manufacturing, a deep divide has evolved between the U.S. innovation system and its manufacturing system. They are no longer well connected. For example, although the United States invented and led early technology advances for solar, lithium-ion batteries, electric vehicles, leading-edge semiconductors, and nuclear power, it now lags significantly behind foreign competitors in manufacturing these technologies. The United States continues to “innovate here” but increasingly the results are “produced there,” and since production is deeply tied to innovation, it increasingly risks the problem of “producing there and innovating there.” For example, in the global steel industry, which has undergone major consolidation, virtually all production innovations in the past half century, which have

²³ N.V. Crain and W.M. Crain, 2023, *The Cost of Federal Regulation to the U.S. Economy, Manufacturing and Small Business*, National Association of Manufacturers, <https://www.nam.org/wp-content/uploads/2023/10/Regulations-Exec-Summary.pdf>.

²⁴ This sentence was changed after release of the report to correct the percentages for accuracy.

transformed the sector, have come from foreign nations, not the United States. Overall, U.S. leadership in innovative technologies has been eroding at a significant pace. The United States is now engaged in a race to the next generation of technologies such as quantum and AI applications, and China's manufacturing lead, depth, and emphasis on applications may translate into leadership in those technologies as well. Furthermore, innovation leadership tends to create standard-setting leadership, which often translates into controlling the interfaces and commercial success of new technologies.

Government-Funding of Manufacturing R&D and Innovation Is Missing

Historically, the federal government has operated under the Vannevar Bush postwar “pipeline” model in which the government role was to fund basic research but not applied research. This pipeline model largely severed the R&D system at federal agencies from applied technology development and U.S. production needs. Therefore, U.S. R&D agencies have not had a significant applied R&D program for new manufacturing technologies. A notable exception has been the Department of Defense (DoD), which has long funded extensive applied R&D. However, its R&D spending typically supports new technologies for its platforms; it has generally not invested in overall manufacturing technologies or processes, leaving that task to industry.

DoD pursues critical technology advances if its defense mission requires, and manufacturing itself, meaning U.S. competitive applied R&D and technology development for broader industry production efficiency, has not been one. Aside from its R&D, DoD has another manufacturing investment tool, its procurement budget (including particular niche programs such as DoD ManTech, Industrial Base Analysis and Sustainment (IBAS) program, and the Defense Production Act Investments).²⁵ It uses procurement to secure production of products and technologies it requires, but technology development in overall industry-wide manufacturing advances have generally been left to industry. Once its platform programs and requirements are set, DoD focuses more on low-bid acquisition of specific products to meet shorter-term needs, preferring productization that is lower risk and rapid, not longer term. This in effect precludes its support for higher-risk and -reward advanced manufacturing processes and technologies. In the past, DoD was able to operate on the assumption that the United States was the dominant world

²⁵ This sentence was changed after release of the report to correct the name of the program.

manufacturing power, with more than adequate capacity to meet both current DoD requirements as well as to scale up to meet new ones. It can no longer make that assumption. It now faces major erosion in its industrial base which is affecting its ability to adopt new defense technologies, such as drones and AI. Despite this challenge, like the civilian R&D agencies, DoD's R&D and procurement organizations have yet to build significant applied research portfolios in manufacturing technologies.

Overall, government funding and support for R&D and innovation in manufacturing technologies have been missing. There is a federal R&D manufacturing innovation gap.

Industry Manufacturing R&D and Innovation Is Limited

The model of large corporate R&D labs tied to major manufacturers, which the United States led until the 1980s, has faded and not been replaced. The demise of Bell Labs starting in 1984 was symptomatic. Manufacturing firm labs that remain have increasingly shifted to work on shorter-term incremental advances with immediate payoffs, not longer-term innovative breakthroughs. In principle, firms would welcome the opportunity to pursue bold, long-term breakthroughs. In practice, however, accelerated return-on-capital demands, international competitive pressure, government incentives and regulatory challenges, and financial structures geared toward short-term performance constrain them to incrementalism, even when the strategic need for transformative innovation is clear. University labs could provide a partial substitute through collaborative R&D with industry, but university R&D is primarily focused on basic research because government funding has been largely for basic research. Less than 5 percent of Industry R&D goes to universities.

Although corporate R&D has been a significantly growing part of overall U.S. R&D, leading information technology, software, and pharmaceutical firms dominate this R&D, and dwarf, for example, research on machining or production processes. In general, manufacturing technologies and processes have not been a priority for corporate R&D, a problem exacerbated by the use of the federal R&D tax credit to incentivize industry research instead of going to industry R&D for manufacturing technologies and processes. The current R&D tax credit is inconsistent in its application to manufacturing, so companies cannot plan on its availability; the U.S. tax credit rates are not globally competitive (see Chapter 4); and the credit is not allowed for manufacturing process developments and innovations. These problems with the R&D tax

credit have created a further disincentive for companies in pursuing advanced manufacturing innovation.

Stagnating and Declining Manufacturing Productivity

Manufacturing advances through creating new production paradigms. These consist of new bundles of related technologies and process advances that drive significant productivity gains. In short, production innovation largely drives manufacturing productivity. The lack of investment to scale and implement new advanced manufacturing technologies is a primary cause of the declining and stagnating rate of U.S. manufacturing productivity for the past 15 years compared to increases for key competitor nations.

Small and Medium-Sized Manufacturers Have Failed to Adopt Advanced Manufacturing Technologies

The dominant cause of low U.S. manufacturing productivity numbers comes from the lack of adoption by small and medium-sized manufacturers (SMMs) with under 500 employees of advanced manufacturing technologies that could boost their productivity. These firms tend to be thinly capitalized; they face strong international competition in most sectors; they conduct little or no R&D, and they lack the resources and know-how to move on new manufacturing technology advances. Yet, close to half of U.S. manufacturing output is from SMMs. Small firms in general account for some 58 percent of U.S. employment and nearly 40 percent of value added, yet they are only 47 percent as productive as larger U.S. firms. SMMs share these problems. This gap between productivity levels of SMMs and larger firms creates a major drag on the overall efficiency, productivity, and economic impact of U.S. manufacturing.

Weak Workforce Education System

For advanced manufacturing technologies to be adopted, a workforce must be ready to implement them. Yet the United States does not have an effective workforce education system for its manufacturing technical workforce.²⁶ The list of problem points listed next is discussed in more detail in chapter 6 and only briefly summarized here. There has been a long history of both government and industry disinvestment in workforce education, and efforts by both have been

²⁶ W.B. Bonvillian and S. Sarma, *Workforce Education, A New Roadmap* (Cambridge, MA: MIT Press) 43-59.

misaligned and under-resourced²⁷ The Department of Education’s programs focus on college, not workforce training, and are disconnected from the U.S. Department of Labor programs. In turn, the Department of Labor programs are focused on the unemployed and underemployed with limited focus on upskilling incumbent workers or skills for advanced manufacturing. Although community colleges teach general manufacturing skills, they have only limited focus on advanced manufacturing education. This is in part because most SMMs are not ready to adopt advanced manufacturing technologies, so there is limited demand. These schools are also underfunded. Leadership at most colleges and universities, which could help in developing advanced manufacturing curricula via government policies and incentives, tends to hold the view that career technical education (CTE) is the job of high schools and community colleges - not theirs.

ORIGINS AND DEVELOPMENT OF MANUFACTURING INSTITUTES

In an effort to address U.S. manufacturing challenges, the 2012 Advanced Manufacturing Partnership report issued by a President-appointed committee of industry and university leaders recommended forming manufacturing institutes:

- as “long-term” collaboration mechanisms between industry, universities, and government (federal, state, and local)
- that would further advanced manufacturing technology R&D and implementation,
- including work with regional innovation systems, SMMs, and workforce education.²⁸

In turn, the Revitalize American Manufacturing and Innovation (RAMI) Act of 2014, directed at the Department of Commerce, authorized creation of a network of advanced manufacturing institutes that would serve eight purposes:

- “(A) improve the competitiveness of United States manufacturing and to increase production of goods manufactured predominately within the United States;

²⁷ H. Holzer, 2025, Workforce Development in the US: Recent Trends and Evidence, IZA Institute of Labor Economics, IZA DP No. 18061, August, <https://docs.iza.org/dp18061.pdf>

²⁸ Advanced Manufacturing Partnership, 2012, “Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing,” July 21–23, President’s Council of Advisors on Science and Technology, Executive Office of the President, https://www1.eere.energy.gov/manufacturing/pdfs/pcast_july2012.pdf.

A detailed discussion of the history of the Manufacturing USA program is in, W.B. Bonvillian and P.L. Singer, 2018, “Advanced Manufacturing – The New American Innovation Policy” (MIT Press). See also, D. Hart, S. Ezell and R. Atkinson, 2012, “Why America Needs a National Network for Manufacturing Innovation,” ITIF, December, <https://itif.org/publications/2012/12/11/why-america-needs-national-network-manufacturing-innovation/>.

- “(B) to stimulate United States leadership in advanced manufacturing research, innovation, and technology;
- “(C) to facilitate the transition of innovative technologies into scalable, cost-effective, and high-performing manufacturing capabilities;
- “(D) to facilitate access by manufacturing enterprises to capital-intensive infrastructure, including high-performing electronics and computing, and the supply chains that enable these technologies;
- “(E) to accelerate the development of an advanced manufacturing workforce;
- “(F) to facilitate peer exchange of and the documentation of best practices in addressing advanced manufacturing challenges;
- “(G) to leverage non-Federal sources of support to promote a stable and sustainable business model without the need for long-term Federal funding; and
- “(H) to create and preserve jobs.”^{29,30}

The RAMI Act reauthorization in 2019 expanded the scope of potential technology focus areas for institutes and set established required and permissible activities for institutes,³¹ The law also authorized the Secretaries of Commerce and Energy and other agency heads to extend the terms of the institutes through merit-based reviews based on a series of factors. DoD participation in Manufacturing USA was separately addressed through DoD Statute.³² Meanwhile, DoD had also instituted this practice of extending institute funding terms after a full evaluation. The act marked continued bipartisan support for the program.³³

²⁹ U.S. Congress, House, 2014, Revitalize American Manufacturing and Innovation Act of 2014 (“RAMI Act”), H.R. 2996, 113th Cong., 2nd Sess., <https://www.congress.gov/bill/113th-congress/house-bill/2996>.

³⁰ This sentence was changed after release of the report to accurately reflect the authorizing legislation.

³¹ PL 116-92. See, Congressional Research Service, 2021, “Manufacturing USA: Advanced Manufacturing Institutes and Network,” R46703, March 3, https://www.congress.gov/crs_external_products/R/PDF/R46703/R46703.3.pdf, report updated, September 2022, https://www.congress.gov/crs_external_products/R/PDF/R46703/R46703.7.pdf.

³² This sentence was changed after release of the report to clarify that DoD’s participation was addressed by a separate statute.

³³ For detailed reviews of the Manufacturing USA program see: Government Accountability Office, 2025, “Advanced Manufacturing: Aligning Strategies and Improving Agency Reviews Could Help Institutes Achieve National Goals (June 2025),” GAO-25-107369, and earlier GAO reports (December 2021, May 2019, April 2017), the periodic Manufacturing USA reports noted above, and National Academies reports, including :

NASEM, 2017, *Securing Advanced Manufacturing in the United States: The Role of Manufacturing USA: Proceedings of a Workshop*, Washington, DC: The National Academies Press;

The institutes were designed to help meet the U.S. manufacturing challenges identified in the first part of this chapter, including developing roadmaps and strategies for advanced manufacturing technologies, support for manufacturing innovation, and improved manufacturing workforce education. While they are not scale-up financing mechanisms, they can assist in the scale-up and transition of new manufacturing technologies. They were by no means the only effort needed to rebuild U.S. manufacturing capability but they were a significant new tool.

The first pilot institute, now known as America Makes (additive manufacturing) was established in 2012. The Manufacturing USA Program was established in statute in 2014 as the National Network for Manufacturing Innovation and was renamed in statute as Manufacturing USA in 2019. The institutes filled a critical and otherwise unfilled gap in U.S. manufacturing by bringing together the key actors that must be involved in adopting advanced manufacturing at scale—industry, universities, and government (including federal, state, and local governments). With the goal to increase U.S. manufacturing competitiveness and promote a robust and sustainable national manufacturing R&D infrastructure. By the mid-2020s, the network had grown to include 17 institutes (see Table 1-1).

TABLE 1-1 Current 17 Institutes in the Manufacturing USA Program.

Acronym	Name or Description; Sponsoring Agency
AFFOA	Advanced Functional Fabrics of America; <i>originally DoD</i> ³⁴
AIM Photonics	American Institute for Manufacturing Integrated Photonics; DoD
America Makes	The National Additive Manufacturing Innovation Institute; DoD
ARM Institute	Advanced Robotics for Manufacturing Institute; DoD

NASEM, 2019, *Strategic Long-Term Participation by DoD in Its Manufacturing USA Institutes*, Washington, DC: The National Academies Press;

NASEM, 2021, *DoD Engagement with Its Manufacturing Innovation Institutes: Phase 2 Study Interim Report*. Washington, DC: The National Academies Press; and

NASEM, 2021, *DoD Engagement with Its Manufacturing Innovation Institutes: Phase 2 Study Final Report*. Washington, DC: The National Academies Press.

³⁴ This sentence was changed after release of the report to clarify that DoD no longer sponsors AFFOA.

ARMI BioFabUSA	Advanced Regenerative Manufacturing Institute; DoD
BioMADE	<i>Originally stood for</i> Bioindustrial Manufacturing and Design Ecosystem; DoD
CESMII	Collaborative Ecosystems for Smart Manufacturing Innovation Institute; DOE
CyManII	Cybersecurity Manufacturing Innovation Institute; DOE
EPIXC	Electrified Processes for Industrial eXCeLLence; DOE
IACMI	Institute for Advanced Composites Manufacturing Innovation; DOE
LIFT	<i>Originally stood for</i> “Lightweight Innovations for Tomorrow,” but now just LIFT; DoD
MxD	<i>Originally</i> “Digital Manufacturing and Design Innovation Institute (DMDII) and now Manufacturing × Digital; DoD
NextFlex	Flexible Hybrid Electronics Manufacturing Institute; DoD
NIIMBL	National Institute for Innovation in Manufacturing Biopharmaceuticals; DOC
PowerAmerica	Next Generation Power Electronics Manufacturing Innovation Institute; DOE
RAPID	Rapid Advancement in Process Intensification Deployment Institute; DOE
REMADE	Materials Recycling and Manufacturing Supply Chain Optimization; DOE

The institutes, as their names suggest, support technology development in a range of technology sectors, from additive manufacturing to biomanufacturing, production cybersecurity, photonics, digital production, flexible electronics, and robotics. They were designed to be industry-led; although organized as non-profits, they generally reflect strong industry as well as university involvement. While the three mission agencies (Defense, Energy and Commerce Departments) have selected the technology focus areas of the institutes their missions support, these have generally reflected industry advanced manufacturing technology concerns. Alignment with agency missions has also helped lead to continued agency involvement with the institutes.

ASSESSMENT OF THE MANUFACTURING INSTITUTES

Under the RAMI Act, the National Institute of Standards and Technology (NIST) has undertaken a periodic strategic planning process in cooperation with the institutes and other involved agencies. The many accomplishments of the institutes (noted at various points in the next chapters) have been well summarized in the annual reports issued by the Advanced Manufacturing National Program Office at NIST.³⁵ Accomplishments include significant manufacturing technology advances, innovation in workforce education, and support of regional

³⁵ See, for example, Z. Brunner, 2024, *Manufacturing USA 2023 Annual Report*, National Institute of Standards and Technology, <https://doi.org/10.6028/NIST.AMS.600-14>.

development. The institutes all have large industry membership and have enabled significant industry involvement, through technology strategies and roadmapping, technology development projects, regional engagement efforts, and workforce education.

Progress of the Institute Model as Implemented

Given the limited scale of the resources provided, the institutes have been tackling a very important set of roles. These are summarized briefly in a few key categories:

- **Technology:** Using technology roadmaps, institutes have engaged their members to prioritize and pursue technology development as a core mission and have had success in implementing a number of new manufacturing advances, as set out in NIST’s annual reports.
- **Standards development:** Although institutes vary, many have succeeded in supporting critical standards development—either directly or in partnership with standards organizations—for their technology area.
- **Connecting smaller tech firms with larger potential customer firms:** Although institutes vary, many have succeeded in creating connections between smaller firms developing new technologies that are working in the institute’s technology areas and larger firms that are potential customers. This has benefited technology validation and adoption.
- **Commons for information sharing:** Institutes have attracted members interested in their particular technology areas and have provided a unique forum for sharing information on technology advances. Each institute has created its own commons capability where member firms can share technology understanding, can collaborate on development, and, in particular, where small innovator firms can connect with larger firms.
- **Workforce education:** Although resources are limited, a number of institutes have been successful in developing creative workforce programs and have developed a series of best practices in this area. There has also been networking across some institutes in implementing effective workforce programs.

Each institute has an expansive list of achievements in these and other areas, including accomplishments largely not being addressed by any other program.³⁶

Challenges in the Institute Model as Implemented

Despite success in some areas, the manufacturing institute model has also faced a series of challenges, including:

- **Limited interagency coordination exists.** Each of the three departments supporting the 17 Manufacturing USA institutes that have been formed (Commerce through NIST, DoD through Office of the Secretary of Defense Manufacturing Technology (DoD ManTech) Program, and Energy) has somewhat different policies and focus areas for their institutes based on departmental missions. However, the institutes face overlapping challenges and needs that require collaboration to meet national needs. While AMNPO provides high-level coordination, there is presently no interagency body that sets a detailed interagency strategy to guide institute program coordination and investment within a review of national manufacturing priorities.³⁷
- **Networking across institutes is limited.** Although manufacturing firms typically want integrated packages of technologies, the institutes have worked predominantly within their particular technology areas. Some institutes have collaborated with each other on workforce education and some on regional engagements. However, no mechanism or incentive exists for institutes to develop complementary packages of technologies together.
- **Institutes focus the bulk of their funding support on R&D and technology development.** Development projects are aimed at Technology Readiness Levels (TRLs) 4–7 and involve groups of collaborating firms as well as universities. Smaller, entrepreneurial firms working on developing a technology are also often involved. However, since SMMs—the “main street” manufacturing firms—tend to do little R&D, they are largely left out. Also, institutes do not reach TRL levels after TRL 7, which

³⁶ This sentence was changed after release of the report for clarity.

³⁷ This bullet was revised after release to clarify the role of the AMNPO.

creates a gap in technology implementation. This focus also tends to limit investment in workforce development.

- **Engagement with SMMs is limited.** SMMs that are developing new technologies are often involved in institutes. But what about SMMs that don't undertake R&D and constitute the great bulk of what could be called Main Street manufacturers? Institutes are membership organizations with members paying for participation at various levels. Hence, SMMs that are not particularly involved in an institute's manufacturing technology development are unlikely to join an institute. Since these SMMs are not members, institute outreach to SMMs is limited because it does not fit the current membership model. This is not the fault of the institutes, because they have not been given the scale of resources and organizational model to support this task of reaching the Main Street manufacturers at the scale needed. SMM's generally have the lowest productivity rates, lagging well behind larger firms in adopting new technologies, and this means that a key constituency that needs to adopt advanced manufacturing in the United States is generally not reached. The fact that the institutes are primarily technology focused and less regionally focused, as noted in chapter 5, also affects the level of SMM involvement.
- **Efforts by institutes in workforce education, with SMMs, and in regional manufacturing collaboration are allocated very limited resources.** These areas have been generally supported in various forms, but technology development has been the institutes' priority.

Limited Funding Has Affected the Institutes' Mission and Impact

Institutes have had limited overall funding which affects their missions. Institutes were initially funded with \$50 million to \$70 million for 5-year terms.³⁸ Since technology revolutions require larger resources, and longer time horizons, their ability to tackle their technology areas at scale was limited at the outset. The institutes faced the expectation that they would be

³⁸ E.G. Blevins, 2022, "Manufacturing USA: Advanced Manufacturing Institutes and Network," Congressional Research Service, Report R46703, <https://www.congress.gov/crs-product/R46703>, Oct. 3, , details in Table 1 the initial funding awards for each institute; and GAO, 2025, "Advanced Manufacturing" June 2025, GAO-25-107-369, <https://www.gao.gov/assets/gao-25-107369.pdf>, details in Table 1 and Figure 3 the total funding for FY2019-FY2023 received by DOW, DOC and DOE supported institutes.

independent and sustainable after their 5-year terms, which meant that they would have to be sustained mostly by larger firms that had the resources to do so. Most analysts viewed this approach as a fundamental design flaw since most large firms would not be willing to support the SMM outreach, regional engagements, and workforce programs that institutes were expected to carry out but would not directly benefit them.

In recognition of funding challenges, the agencies, starting with DoD, moved to extend the terms of their institutes based on a performance evaluation. Buttressed by the RAMI Act reauthorization in 2019, noted previously, DOC likewise implemented this approach. DOE, although delayed for various reasons, has also been moving in this direction. However, only DOC has extended its one institute (NIIMBL) that has come up for a term renewal at the same funding level that it initially received, whereas the other agencies have provided core funding in substantially lower amounts.³⁹ In turn, institutes have had to find other R&D funding projects, largely from their sponsoring agencies, for sustainment, which in turn runs the risk of diverting institutes away from core missions.

The resource problem for institutes deteriorated in 2025. The program overseeing the seven DOE institutes went through a major reorganization and was consolidated into a new organization. The federal funding share for these institutes has not been forthcoming, so they have faced major staffing cuts and program cuts and corresponding declines in membership support. These developments risk turning these institutes into empty shells. DoD's nine institutes are in a somewhat better situation but received 25 to 30 percent cuts in their federal share although they have been facing new program demands from the agency – they appear to be being asked to do more with less. At DOC, although the Manufacturing Extension Partnership program that reaches small manufacturers has faced elimination and reorganization, the agency Manufacturing USA program staff has not been cut. Both DOE and DoD institute programs are not sizable, so they are “below the account line,” which means they do not receive specific, separate appropriations and thereby not shielded by the Congressional Appropriations process. DOC's single institute has received sufficient funds to keep operating at last year's level, although its new institute for semiconductors and digital twin technologies was canceled.

³⁹ Two more DOC institutes were recently authorized, but one has since been canceled.

In summary, given the importance of their missions, institutes have been under-resourced through lack of a sustained federal support model.

STUDY STATEMENT OF TASK

The task of this committee, as set out in the statement of task (see Appendix A), is not to evaluate the decade of work under the current program but instead to develop a vision of where the program should move in the 2030–2035 time period. The report is therefore forward-looking, not a program assessment. It briefly highlights the current program including some of the challenges it faces, then moves to detail new features and efforts the program should undertake to help meet the deep manufacturing challenges the nation faces.

STUDY PROCESS AND DATA GATHERING

The committee's 13 members (see Appendix C) represented academia, industry, and other sectors and had expertise in areas relevant to the statement of task, including transitioning, financing, and commercially scaling advanced manufacturing technologies and products; workforce education policies; involvement in industries heavily reliant on advanced manufacturing R&D; and global competitive dynamics and best practices. Additionally, several members serve on boards of the institutes or are otherwise engaged in and highly knowledgeable of the Manufacturing USA institutes. The study was conducted over the course of approximately 9 months and consisted of a series of committee meetings and public information-gathering sessions. During this time, the committee held 30 public meetings, including several full-day or multiday workshops, roundtables, and a site visit (see Appendix B), speaking with nearly 100 experts across industry, academia, and government covering a wide range of topics to gather information that informed its findings and recommendations. Requested information was forthcoming when available from both government and experts. Focusing on the future vision of the Manufacturing USA Program emphasizing the impact of technology development, transition, scale-up, and workforce development efforts, the committee largely relied on and based its recommendations on these interviews as well as themes that emerged from input received from the institutes through a questionnaire and their own expertise.

STRUCTURE OF THE REPORT

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The report contains the committee’s findings, conclusions, and recommendations. New National Academies’ policy in effect as of the publishing of this report is that a finding, defined as a summary statement about the evidence presented in the report that is relevant to the statement of task and includes no judgment by the committee, is embedded with the supporting text within the report and has no deliberate callout, formatting, or style emphasis. There are many findings, therefore, embedded within report text. There are also two conclusions, one overarching conclusion, and 26 recommendations specifically called out. The report is divided into eight chapters. Chapter 1 provides background on longstanding and new challenges to U.S. advanced manufacturing and context for the report’s recommendations. Next, in Chapter 2 (addressing Tasks 6 and 7), the committee focuses on benchmarking of leading international advanced manufacturing programs early in the report because best practices from these analogous programs inform its analysis and recommendations regarding the main topics in the remaining chapters, including technology transfer (Chapter 3, addressing Task 1), interagency and cross-institute engagement (Chapter 4, addressing Task 2, the domestic program benchmarking of Task 6, as well as Tasks 8 and 9), regional economic development (Chapter 5, addressing Tasks 4 and 5a), and workforce education (Chapter 6, addressing Tasks 3 and 5b). The report concludes with A Vision for the Future Manufacturing USA Program in 2030 and 2035 (Chapter 7, addressing Tasks 10a–f) and a complete list of study recommendations (Chapter 8).

Chapter 2

International Program Comparison and Benchmarking

International manufacturing institutes serve as a global benchmark for the Manufacturing USA institutes. Foreign models informed the launch of the Manufacturing USA institutes which borrowed elements from Germany's well-known Fraunhofer manufacturing institutes when the U.S. program was being designed. China has since studied the Manufacturing USA institutes when designing its own system. The committee considered a number of the approaches of leading manufacturing nations to identify lessons for the ways Manufacturing USA institutes might evolve in the future.

The committee found that there are significant differences between leading-edge foreign models and the approach taken by Manufacturing USA. These distinctions include program offerings that are standard in foreign institutes but are not always standard in the United States, such as state-of-the-art facilities for scale-up and testing, sizeable engineering staffs with in-depth technical expertise, in-house business development functions, and technology development and implementation efforts for small and medium-sized manufacturers (SMMs).

However, perhaps the more significant difference of successful foreign models from Manufacturing USA is not in the details of institute design but in the broader context of these countries' emphasis on industrial strategy, with manufacturing as a national priority. Institutes play a key role toward achieving this national strategic goal and are integrated into the strategy. The financial system is aligned as well, with the government directing it to target manufacturing. These countries use patient-capital financing tools not available in the United States, which underlie these countries' industrial policy programs. They also fund their institute-like programs at much larger scale than the United States.

An overall finding is that other nations have long-term, permanent manufacturing institute programs that are not term limited. These nations recognize that the advanced manufacturing challenge is enduring and cannot be addressed as a short-term issue.

INTERNATIONAL MODELS

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The committee benchmarked seven successful government-affiliated international advanced manufacturing programs analogous to the goals of the Manufacturing USA Program, with a focus on topics most relevant to the study. Although the programs are comparable in their overall objectives, each has unique approaches and program offerings including industrial strategy, dedicated scale-up financing, infrastructure, staffing, and much more. The following capsule descriptions briefly summarize the programs, and additional sources are referenced offering a fuller description of each program including its history.

Belgium: Interuniversitair Micro-Electronica Centrum VZW

Interuniversitair Micro-Electronica Centrum VZW (IMEC) is a globally leading R&D center for microchip technology. Infrastructure is key to IMEC's strategy, including "cleanrooms" that can be used for development, prototyping, and manufacturing. The underlying intuition—and need—for IMEC is that the complexity and costs of microelectronics research are beyond the capabilities of any single company or university. IMEC's semiconductor fabrication plant can be used for any maturity level of production short of true commercialization. Many U.S. companies and key suppliers to the U.S. semiconductor industry use IMEC as a critical R&D manufacturing resource, as these capabilities are not available in the United States.

IMEC has a distinctive R&D partnership model, with corporate partners sending staffers to IMEC who join teams undertaking the research. The intellectual property (IP) of resulting research is co-owned with IMEC. Currently IMEC has a research staff of 6,000 of which 1,000 are in-resident researchers from corporations and 1,200 are doctoral students. Seventy percent of IMEC's funding comes from corporations and 30 percent from government. Even though IMEC could be financially self-sustaining, government funding is deemed necessary for longer-term (5- to 10-year) advancements rather than short-term industry needs, according to IMEC executives.⁴⁰

United Kingdom: High Value Manufacturing Catapult

The UK High Value Manufacturing (HVM) Catapult was designed to bridge the same gap seen in the United Kingdom as in the United States between early-stage publicly funded basic research and later commercialization. However, unlike the Manufacturing USA institutes, it has a large in-house engineering and scientific staff of more than 3,500 employees. The

⁴⁰ IMEC, n.d., "About IMEC," <https://www.imec-int.com/en/about-us>. Accessed January 15, 2026.

Catapults also house the UK equivalent of the National Institute of Standards and Technology's Hollings Manufacturing Extension Partnership (MEP) and have multiple formal programs for collaborating with academics including engineering doctoral students.

The Catapults, which are independent not-for-profit businesses, follow the Fraunhofer “thirds” funding model of one-third core funding from government, one-third from business contract R&D projects, and one-third from collaborative R&D projects from a range of sources including other funding agencies. The funding is based on a strategy and delivery plan, with Catapults reporting quarterly against their key performance indicators. The HVM Catapult's capabilities have attracted the interest of global manufacturers. For instance, Boeing is a co-founder of the University of Sheffield's Advanced Manufacturing Research Centre's (AMRC's), which is part of the HVM Catapult, and Airbus's “Wing of Tomorrow Program” is being developed in partnership with the Catapults.⁴¹

Germany: Fraunhofer

Germany's Fraunhofer-Gesellschaft, along with Taiwan's Industrial Technology Research Institute, is often seen as the world's leading applied research organization. Its 32,000 staff, consisting primarily of scientists and engineers, operate with an annual research budget of approximately 3.6 billion euros. Fraunhofer follows the “thirds” funding model with one-third of their budget coming from contract research from industry, one-third from the German federal and state governments, and one-third from other publicly available research funding.⁴²

Each Fraunhofer is typically paired with a university and is also tightly linked to industry. The university tie-in provides fluidity in research staff. Funding from industry for contract research helps maintain commercial relevance. There are around 75 Fraunhofers, meaning that there is one for almost every significant industrial sector, and there are further international institutes including Fraunhofer USA. SMMs are a focus area. Recent Fraunhofer initiatives include ATHENE, Europe's largest cybersecurity research center.

⁴¹ HVM Catapult, n.d., “About us,” <https://hvm.catapult.org.uk>.

⁴² Fraunhofer Annual Report 2024, <https://www.fraunhofer.de/en/media-center/publications/fraunhofer-annual-report/annual-report-2024.html>; and NASEM, 2013, *21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program*, Washington, DC: The National Academies Press, <https://doi.org/10.17226/9807>, Appendix A2, 224-284, <https://www.nationalacademies.org/read/18448/chapter/13>.

Fraunhofer and Germany's excellence in engineering has underpinned the success of Germany's economic model, but now this model faces severe geopolitical challenges. Germany was heavily reliant upon Russia for energy, which it has not been able to cheaply replace. It also offshored much of its car industry to China, chasing that market, but China is now an EV exporter to Germany. These grave challenges show that institutes need to be understood in a broader context including a country's geopolitical strategy.⁴³

Japan: METI

The Ministry of Economy, Trade and Industry's (METI's) mission is to develop Japan's economy and industry by promoting economic vitality in private companies and smoothly advancing external economic relationships, and to secure stable and efficient supply of energy and mineral resources.⁴⁴

METI oversees four national institutions—Advanced Industrial Science and Technology (AIST), New Energy and Industrial Technology Development (NEDO), Kosetsusi (Public Testing Laboratories), and SME Support Japan (SMRJ)—each with its unique strengths, working together to support companies at different stages. AIST conducts world-class research, NEDO provides funding with large-scale financial resources, Kosetsushi supports measurement, and SMRJ offers services specifically tailored to small and medium enterprises (SMEs). This comprehensive ecosystem of support has contributed to Japan's strong position in manufacturing.

Established in 1980, NEDO is Japan's largest public R&D management organization. NEDO has a massive fund focused on technology diffusion for semiconductors and AI, electric vehicles, and disruptive innovations. Grant amounts for semiconductors and AI tend to be particularly large. For example, their R&D Project of the Enhanced Infrastructures for Post-5G Information and Communication Systems has a budget of \$18B to develop advanced semiconductor manufacturing technologies. Grants support not only the development of equipment and facilities, but also human resource development for R&D, commercialization, and industrialization, as well as scale-up of SMEs.

⁴³ W. Münchau, 2024, *Kaput: The End of the German Miracle*, Swift Press, London.

⁴⁴ Ministry of Economy, Trade and Industry, n.d., "About METI," Republic of Japan, https://www.meti.go.jp/english/aboutmeti/data/meti_mission.html.

Kosetsushi is quite different from the other three. Like AIST and NEDO, it supports all 47 prefectures, but its main services are inspection and measurement, commissioned R&D, and technical consulting. Its governance is under local governments, not the national government, so the quality of support varies from region to region.

SMRJ is closer to NEDO, but its programs are dedicated to SMEs, offering grants and hands-on consulting to accelerate technology diffusion. Grants are offered for manufacturing development and improvement (maximum \$200,000), rapid sales growth (maximum \$3 million), new business/ market expansion (maximum \$600,000) and information technology implementation (\$30,000), as seen in Figure 2-1. In addition, it operates nine SME universities that are focused on business training for SME chief executive officers (CEOs) and chief operating officers (COOs) on how to operate their companies, not on technical training.

Capital investment and Market development			DX promotion
 Monodzukuri (manufacturing) grant	 Grant for accelerating SME growth	 New business expansion grant	 IT implementation grant
✓ Equipment and facility investment ✓ Product development ✓ Improvement of production processes	✓ Support for bold investments by SMEs striving to exceed \$68B in sales ✓ Equipment and facility investment	✓ Supporting expansion into new markets and high value-added businesses ✓ Equipment and facility investment	✓ IT software ✓ Computers ✓ Cloud service ✓ Cyber security
Maximum grant amount: \$200K Grant rate: 50% - 66%	Maximum grant amount: \$3M Grant rate: 50%	Maximum grant amount: \$600K Grant rate: 50%	Maximum grant amount: \$30K Grant rate: 50%-80%

FIGURE 2-1 Organization for Small and Medium Enterprises and Regional Innovation (SMRJ) policies for SME grants.

SOURCES: Yukihiro Sato, presentation to the committee, and Y. Sato and A. Goenka, 2023, “How Can SMEs Play a Greater Role in Tech Adoption?” Cambridge Industrial Innovation Policy Blog, <https://www.ciip.group.cam.ac.uk/reports-and-articles/how-can-smes-play-a-greater-role-in-tech-adoption>.

Singapore: A*STAR

Despite its limited land area, Singapore is the world's 5th largest global exporter of high-tech goods.⁴⁵ Manufacturing plays a substantial role in the economy, contributing nearly 20 percent to GDP and employing over 12 percent of the workforce.⁴⁶ Established industries include semiconductors, aerospace, specialty chemicals, complex equipment, and biomedical.

Singapore's innovation strategy in advanced manufacturing thrives on multinational engagement and collaboration and is overseen by Singapore's Research Innovation and Enterprise Council, chaired by Lee Hsien Loong, former Prime Minister of Singapore. Singapore's Ministry of Trade and Industry funds and aligns Singapore's national Agency for Science, Technology and Research (A*STAR), Singapore's Economic Development Board and Enterprise Singapore. A*STAR's mission is to make factories in Singapore more competitive. A*STAR focuses on research, industry development and commercialization, and talent development with more than 6,000 staff, more than 4,700 researchers, engineers, and technical support staff. It is multinational with 37 percent of its staff from more than 60 countries. A*STAR receives 40 percent of its funding from the Ministry of Trade for Core Research Projects and 60 percent from industry and competitive grants. A*STAR Initiatives include the Advanced Remanufacturing and Technology Centre (ARTC), a public-private collaborative platform where industry leaders, research institutes, and government agencies co-develop and test-bed advanced manufacturing solutions to achieve translational R&D (TRL 4–7) with industry.

ARTC follows a membership consortium model with over 95 industry members, ranging from global multinational corporations to SMEs to start-ups. Many U.S. companies are anchor members and have secured strategic agreements with ARTC.^{47,48} ARTC is staffed with 35

⁴⁵ World Bank, 2023, data bank, micro data catalog high-technology exports (current US\$), https://data.worldbank.org/indicator/TX.VAL.TECH.CD?most_recent_value_desc=true

⁴⁶ Singapore Economic Development Board, 2024, "How Singapore Can Partner Businesses in Their Advanced Manufacturing Journey in Asia," <https://www.edb.gov.sg/en/business-insights/insights/how-singapore-can-partner-businesses-in-their-advanced-manufacturing-journey-in-asia.html>.

⁴⁷ Halliburton, 2019, "Halliburton Becomes Anchor Member of Singapore's ARTC Tech-Sharing Platform," News Release, November 3, <https://www.worldoil.com/news/2019/11/4/halliburton-becomes-anchor-member-of-singapore-s-artc-tech-sharing-platform>.

⁴⁸ ARTC, 2019, "P&G Anchor Membership," June 20, Agency for Science, Technology and Research, <https://www.a-star.edu.sg/artc/news-events/news-events/2019/the-anchor-membership-upgrade-signing-ceremony-was-held-on-20th-june-2019.-the-upgrade-signifies-the-strong-commitment-from-p-g-to-work-with-artc>.

business development managers with the mission of building value chains of end users, technology providers, suppliers, and system integrators within and across sectors. Eighty percent of the business development account managers are focused full-time on Tier 1 (anchor) and Tier 2 members. The other 20 percent are focused on new business development. In addition, 45 project managers are employed to support funded programs and train professionals. Eighty-four percent of the projects are with SMEs and start-ups. Jointly funded initiatives such as A*STAR Gap are also available for TRLs 8–9.

Taiwan: Industrial Technology Research Institute

Industrial Technology Research Institute (ITRI) is the global pacesetter for applied technology research institutes. ITRI's original technology transfer semiconductor contract with RCA was the basis for Taiwan's semiconductor manufacturing industry. Taiwan Semiconductor Manufacturing Company itself was a spinoff from ITRI led by its then-President Morris Chang.

ITRI's six different research labs are tied to an industry sector. Their focus can dynamically change depending on the technology trends and the funding from the Ministry of Economic Affairs. It has pilot and shared facilities that are set up like a quasi-factory equivalent at each campus. ITRI has a staff of 6,569, of which 1,251 hold doctorates, and a structured and active alumni network. It also has branch locations in the United States, Japan, and Germany.

Patents, licensing, and venture capital (VC) follow-up funding for start-ups are three major metrics for success for ITRI, and each can drive further government funding for specific programs. It incubates approximately 200 start-ups and supports spinouts through its ecosystem as well as its own VC arm. ITRI provides technical consulting to SMMs, including helping them move into overseas markets. Additionally, ITRI helps and manages 80 percent of the start-up program funding for all of Taiwan. They estimated that more than 50 percent of start-ups receive some sort of Taiwan government program subsidy in early stage. Thus, ITRI is part of a continuous pipeline from working with the Taiwanese government to identify future target areas, early development work, and all the way through scale-up for production readiness.

Currently, AI is a major focus for ITRI. It has created an AI Application Strategy Office to promote the development of innovative AI technologies and applications. "ITRI College" provides learning services and plans to train 350,000 government officials over the next 4 years in AI-related education. Additionally, Taiwan is setting up 100 pilot lines for SMMs to learn

how AI can help them in manufacturing lines, with ITRI accountable for roughly 45 of these pilots.⁴⁹

China: Manufacturing Innovation Centers

China has established approximately 45 manufacturing institutes (MICs), each with investments 10–100 times larger than a typical Manufacturing USA institute. China’s MICs program was modeled after Manufacturing USA and other international manufacturing institutes. The financial models of MICs are for-profit in focus areas, with equity institute owners, including central government support.

According to a Center for Strategic and International Studies (CSIS) report on the Made in China 2025 document (both published in 2015), 10 key industrial sectors were prioritized for innovation.⁵⁰ It is noteworthy that “equipment” or “machinery” is mentioned in 7 of the 10 areas, reflecting China’s determination to fund capital-intensive industries. More telling is the goal of achieving 80 percent domestic production of key equipment by 2025, but only 50 percent of industrial software. The United States still leads significantly in software development, fueled by its software-focused VC system.

Each institute connects with and collocates alongside State Key Laboratories and other resources, forming manufacturing ecosystems for its target industries. Research staff at those State Key Laboratories have a long tenure. Those research staff have been heavily leveraged by MICs. China has been forming entire industrial cities, bringing in small and large manufacturers clustered around its manufacturing technology institutes.

All the MICs are administered by one central government agency, while provinces and local governments follow closely what the central government calls for. Therefore, collaboration among sister institutes is common.⁵¹

⁴⁹ Industrial Technology Research Institute, 2019, “About us,” <https://www.itri.org.tw/english/ListStyle.aspx?DisplayStyle=20&SiteID=1&MmmID=617731521661672477>.

⁵⁰ S. Kennedy, 2015, “Made in China 2025,” Critical Questions (blog), Center for Strategic and International Studies (CSIS), <https://www.csis.org/analysis/made-china-2025>.

⁵¹ M. Molnar, K. Rogers, F. Gayle, S. Ipri-Brown, M. Tran, J. Long, C. Ray, A. Shih, and D. Thomas, 2025, *China’s Manufacturing Innovation Centers: A Benchmarking Report for the Manufacturing USA Network*, NIST AMS 600-17, National Institute for Standards and Technology, <https://www.nist.gov/publications/chinas-manufacturing-innovation-centers-benchmarking-report-manufacturing-usa-network>.

TABLE 2-1 Comparison of Manufacturing Institute Program Offerings⁵²

Country	Belgium	China	Germany	Japan	Singapore	Taiwan	United Kingdom	USA
Institute program offerings	IMEC	MICs	Fraunhofer	METI	A*STAR	ITRI	Catapult	MFG USA
Standards Development								
Business Development								
SMM Service & Support								
In House Technical Staff								
In House Pilot Production Facilities								
Higher TRL Offerings								
Industrial Strategy								
Cross Disciplinary Strategies								
Role/Influence on Early TRL Funding								
Institute Financing for Entrepreneurs								
Dedicated Scale-Up Financing								
Rotating/Permeable Technical Staff								
Foundational Technologies								

NOTES: Green indicates presence the offering; Yellow indicates the presence of the offering at some of the program institutes. A*STAR = Agency for Science, Technology and Research; HVM = High Value Manufacturing; IMEC = Interuniversitair Micro-Electronica Centrum VZW; ITRI = Industrial Technology Research Institute; METI = Ministry of Economy, Trade and Industry; MICs = Manufacturing Innovation Centers; MUSA = Manufacturing USA; SMMs = small and medium-sized manufacturers; TRL = Technology Readiness Level.

SOURCE: Committee Generated

⁵² The table was updated after release of the report to clarify that some Manufacturing USA institutes have program offerings in Business Development and Higher TRL.

KEY THEMES, BEST PRACTICES, AND RECOMMENDATION SYNTHESIZED FROM INTERNATIONAL MODELS

Industrial Strategy

As noted in the introductory chapter, although the United States has different programs supporting advanced manufacturing, it lacks a true industrial strategy reaching across government and the private sector, which could coordinate growth and adoption of manufacturing technologies. This is an ongoing vulnerability of the U.S. manufacturing system. Table 2-1 shows a comparison of manufacturing institute program offerings in the seven countries the committee benchmarked the Manufacturing USA program.

A common belief among mainstream American economists is that manufacturing is a legacy sector destined to decline in importance in an advanced economy, with industrial policy only hastening its demise.⁵³ East Asian countries take a very different view. The committee found that most of the nations it studied have industrial strategies that integrate technology development, trade, the financial system, tax policies, and other policies to support advanced manufacturing. These nations view manufacturing as a strategic sector that is critical for growth and economic and national security. Industrial strategy guides and enables growth of the sector.

For instance, the “Singapore Manufacturing 2030 vision” is a strategic plan for Singapore manufacturing to grow its value added by 50 percent by 2030. A*STAR is supporting this plan in numerous ways such as building an AI Center of Excellence to help the manufacturing sector adopt AI. Outreach to SMMs is part of this effort.⁵⁴

Taiwan has a formal plan to further grow five key industries—semiconductors, artificial intelligence (AI), military, security and surveillance, and next-generation communications⁵⁵—as well as to upgrade its start-up ecosystem. ITRI has created a 2035 Technology Strategy & Roadmap.⁵⁶

⁵³ G. Becker, 1985, “The Best Industrial Policy Is None at All,” *Business Week*, August 26.

⁵⁴ International Trade Administration, 2022, “Singapore Advanced Manufacturing,” August 28, U.S. Department of Commerce, <https://www.trade.gov/market-intelligence/singapore-advanced-manufacturing>.

⁵⁵ National Development Council, 2024, “Five Trusted Industry Sectors,” Executive Yuan, Republic of China (Taiwan), <https://english.ey.gov.tw/News3/9E5540D592A5FECD/52616955-2e61-4a30-95b0-1fd59c010933>.

⁵⁶ Industrial Technology Research Institute, 2025, “ITRI 2035 Technology Strategy and Roadmap,” <https://itrisdgs.itri.org.tw/eng/datadetailTab2?SiteID=1&MmmID=1307114034215647471>.

In China, the government's approach is to identify critical gaps in technology—often orchestrated by national academy members—to lay out a 5-year roadmap with clear milestones and timelines, and to then invest accordingly. This process repeats every 5 years, with the plan published broadly to align investments at provincial and regional levels. The advantage of China's approach is concentrated investment that establishes critical infrastructure to resolve major bottlenecks, with little concern for immediate return on investment. Government officials are promoted based on achievements in advancing local GDP. This creates both the motivation to adopt global best practices and a risk-tolerant environment that fosters innovative and competitive financial and incentive systems to attract manufacturing and technology investment.

A successful industrial strategy requires much more than just a written policy document. It requires institutions capable of implementing this strategy, as well as accountability. It requires high-level political support, but also independence from short term political meddling.⁵⁷

In other countries, this support for industrial strategy and manufacturing institutes is found at the highest level of government. For example, the current chair of A*STAR is also the Permanent Secretary of National Research and Development and a Permanent Secretary in the Prime Minister's Office of Singapore.

⁵⁷ Cherif, R., F. Hasanov, and G. Xie. 2026. Institutions for Industrial Policy: The Foundation of Economic Development. IMF Working Paper WP/26/63. Washington, DC: International Monetary Fund, <https://www.imf.org/-/media/files/publications/wp/2026/english/wpica2026063-source-pdf.pdf>.

President Xi Jinping has called out industrialization as a key task for comprehensively promoting the building of China into a superpower. He has specifically commented on the importance of translational research institutes, stating, “many exemplary models have been formed that combine industry, universities, and research institutions, and it will be well worth summarizing them carefully.”⁵⁸ Box 2-1 emphasizes the importance of an industrial strategy, including financing solutions.

BOX 2-1

WITHOUT A WHOLE-OF-GOVERNMENT INDUSTRIAL STRATEGY, THE UNITED STATES WILL CONTINUE TO LAG BEHIND IN ADVANCED MANUFACTURING

POLICY OPTIONS

The following are key considerations for an industrial strategy and other strategies:

- **WHOLE-OF-GOVERNMENT EFFORT TO DEVELOP INDUSTRIAL STRATEGY:** In concert with the National Security Strategy, a whole-of-government effort is needed to develop a formal Industrial Strategy, integrating technology development, scale-up financing, standards leadership, trade, and workforce development into a coherent national framework.
- **PROPOSED FINANCING SOLUTIONS IN THE UNITED STATES: A Role for the Institutes**
Within the next 2 years, create new federal manufacturing and financing mechanisms that include
 - globally competitive R&D tax credit
 - patient-capital funds,
 - a sovereign wealth fund with a strategic focus on manufacturing,
 - intellectual property-backed lending programs, and
 - coordinated public-private guidance funds.

Formally integrate Manufacturing USA institutes as advisors to manufacturing financing bodies, providing technical due diligence, scale-up roadmaps, readiness assessments, and first-of-kind validation data that de-risk future investments.

⁵⁸ X. Jinping, 2020, “Certain Major Issues for Our National Medium- to Long-Term Economic and Social Development Strategy” [国家中长期经济社会发展战略若干重大问题], Qiushi (求是), November 1, English translation by Georgetown University Center for Security and Emerging Technology, https://cset.georgetown.edu/wp-content/uploads/t0235_Qiushi_Xi_economy_EN.pdf.

Although the United States does not publish an industrial strategy, it does publish a National Security Strategy that calls for outcomes that are difficult to achieve absent an accompanying industrial strategy. The 2025 U.S. National Security Strategy prioritized economic security, including re-industrialization and reviving the defense industrial base.⁵⁹ Here it focused on emerging and critical technologies, but it was vague about how this re-industrialization would be accomplished, mentioning tariffs and new technologies. An industrial strategy could make these plans for re-industrialization and technological revival more concrete. As the 2025 report noted, “A strategy is a concrete, realistic plan that explains the essential connection between ends and means.” But unfortunately, that is currently lacking in the United States when it comes to industrial policy.

If there is lingering doubt about the value of a plan to grow the 14 technology sectors deemed critical by the U.S. government, an industrial strategy report could explicitly say so, or alternatively it could force policymakers to think through the next steps of how to do this. The recent findings of the U.S.-China Economic and Security Review Commission evaluating the success of MIC2025 add a sense of urgency about the need for such a strategy. While the strategy was not successful in every sector, the Commission found, “Across ten key technologies in MIC2025, China has met or exceeded many of the very ambitious global market share, local sourcing, and technology development targets it set for itself in 2015.”⁶⁰

Recommendation 2-1: In concert with the National Security Strategy, the National Economic Council, the Office of Science and Technology Policy and the Department of Commerce, Department of Defense, Department of Energy, and any other agencies supporting advanced manufacturing should convene and within the next 2 years issue a formal U.S. Industrial Strategy, integrating technology development, scale-up financing, standards leadership, trade, and workforce development to align resources and maximize the national impact of federal manufacturing programs including Manufacturing USA institutes.

⁵⁹ D.J. Trump, 2025, “National Security Strategy of the United States of America,” November, <https://www.whitehouse.gov/wp-content/uploads/2025/12/2025-National-Security-Strategy.pdf>.

⁶⁰ U.S.-China Economic and Security Review Commission, 2025, *Made in China 2025: Evaluating China’s Performance*, November 14, <https://www.uscc.gov/research/made-china-2025-evaluating-chinas-performance>.

Financing for Manufacturing

Perhaps the most critical element of a successful industrial strategy is resources, meaning both money and people. Financing directed toward advanced manufacturing underpins the industrial strategies of East Asian countries. The United States, in contrast, lacks key financing tools that could support the scale-up of hardware industries and the flourishing of the manufacturing sector. As discussed in the first chapter, the U.S. financial model has led to manufacturing disinvestment. There are gaps in government financing programs for TRLs 6–9 and scale-up. Even when it comes to something as simple as the size of its R&D tax credit, the United States lags other manufacturing nations. A 2024 Information Technology and Innovation Foundation analysis found that the United States ranked 31st out of 32 countries (28 Organisation for Economic Co-operation and Development [OECD] nations and the 4 BRIC [Brazil, Russia, India, and China] economies) in their R&D tax credit support. America’s low R&D tax credit (20 % ‘regular tax credit’ with the effective credit percentage significantly lower) is hindering advanced manufacturing.⁶¹

Increasing the R&D tax credit could help incentivize the growth of domestic U.S. manufacturing.⁶²

Recommendation 2-2: By 2030, the United States Congress should take legislative action to define a globally competitive research and development tax credit for manufacturing processes and technologies and should actively explore expanding other tax reforms supporting manufacturing.

R&D tax credits on their own are unlikely to be sufficient to address scale-up, with many constraints to widespread production and commercialization which can’t be resolved with just one tax credit. Therefore, East Asian countries have pursued targeted tools for financing the scale

⁶¹ Congressional Research Service, 2026, *The Federal Research and Development (R&D) Tax Credit*, CRS Report R48848, <https://www.congress.gov/crs-product/R48848>.

⁶² T. Long, 2025, *The Case for Expanding Federal and State R&D Incentives*, November 17, Information Technology and Innovation Foundation, <https://itif.org/publications/2025/11/17/the-case-for-expanding-federal-and-state-rd-incentives>.

up of advanced manufacturing using multiple investment approaches often missing in the United States such as government-backed patient capital.⁶³

China, as discussed previously, financed MIC2025 through government guidance funds, which combine VC with private equity, and as their name implies, are guided by the government's strategy.⁶⁴ Governments back manufacturing through subsidies, which are widespread. These subsidies can be covert and take many forms including below-market equity infusions, below-market loans, grants, tax concessions, cheap energy inputs, and other types of support, which are hard to identify and quantify. The OECD noted that "Assessing the scope and scale of government subsidies is difficult. This is due to a persistent lack of reliable data comparable across countries ... and the unwillingness of some governments to comprehensively disclose their own measures and associated costs."⁶⁵ Nonetheless, the OECD has been able to measure subsidies at the firm level. Here, China stood out compared to OECD countries, with sizable subsidies for firms in heavy industry. These firms in turn often gained global market share.

A related analysis by the International Monetary Fund found that industrial policy support has been equivalent to a subsidy of up to 4.4 percent of GDP as of 2023. The largest instruments are cash subsidies (2.0 percent of GDP in 2023), followed by tax benefits (1.5 percent), land subsidies (0.5 percent), and subsidized credit (0.4 percent).⁶⁶ In contrast, industrial policy subsidies in other major manufacturing countries averaged only about 1.4 percent of GDP.

⁶³ Definitions of R&D or other types of expenditures eligible for tax relief differ across jurisdictions. However, production scale up, pilot production, and commercialization is typically excluded (unless technical uncertainty is present), according to the internationally recognized methodology for collecting and using R&D statistics, the OECD's Frascati Manual; https://www.oecd.org/en/publications/2015/10/frascati-manual-2015_g1g57dcb.html

⁶⁴ N. Luong, Z. Arnold, and B. Murphy, 2021, *Understanding Chinese Government Guidance Funds: An Analysis of Chinese-Language Sources*, Georgetown University Center for Security and Emerging Technology, <https://cset.georgetown.edu/publication/understanding-chinese-government-guidance-funds>.

⁶⁵ OECD, 2025, "How Governments Back the Largest Manufacturing Firms: Insights from the OECD MAGIC Database," OECD Trade Policy Paper No. 289, https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/02/how-governments-back-the-largest-manufacturing-firms_64f9eef0/d93ed7db-en.pdf.

⁶⁶ D. Garcia-Macia, S. Kothari, and Y. Tao, 2025, "Industrial Policy in China: Quantification and Impact on Misallocation," International Monetary Fund Working Paper No. 2025/155, <https://www.imf.org/en/publications/wp/issues/2025/08/07/industrial-policy-in-china-quantification-and-impact-on-misallocation-568888>; and C. Criscuolo, L. Díaz, L. Guillouet, G. Lalanne, C.-É. van de Put, C. Weder, and H.Z. Deutsch, 2023, "Quantifying Industrial Strategies Across Nine OECD Countries," Science, Technology and Industry Policy Paper No. 150, OECD, <https://doi.org/10.1787/5f2dcc8e-en>.

Additionally, foreign nations have created government-owned sovereign wealth equity funds which can serve as a financing mechanism for scale-up and advanced manufacturing. Examples of state funds include Singapore's Temasek and the Japan Investment Corporation. The mission of some is to maximize returns, but others have industrial policy goals including growing national champions. The European Commission, as part of its "Start up and Scale up strategy" has called for a new fund precisely targeting the scale-up needs of hardware companies, the "Scaleup Europe Fund."⁶⁷

IP-backed financing is another financing mechanism for scale-up. Here, in essence, firms with few fixed assets pledge their IP as collateral for a bank loan. China, Singapore, Japan, and EU governments are exploring IP-backed financing programs for SMMs. Singapore has already piloted an IP-backed financing program and has launched the Singapore IP Strategy 2030 "for Singapore to become a global hub for IP financing." The United States significantly lags in developing comparable policies for IP-backed financing for hardware scale-up.

The U.S. VC system, the envy of the world, is not designed to finance capital-intensive sectors with slower, lower returns, such as manufacturing; rather, it supports software and pharma, less so hardware technology. In terms of 2024, U.S. VC Deal Value (\$B) by Sector, 46 percent went to software, followed by 12 percent to pharma.

The objective of Chinese government guidance funds is very different from that of U.S. VC funds. The U.S.-China Economic and Security Review Commission concluded that "[Chinese government] guidance funds have a mandate to focus on strategic technologies rather than simply generating return. By contrast, funding patterns in Silicon Valley have trended toward favoring consumer-facing companies with less innovative technology but a shorter timeline to profitability."⁶⁸ Furthermore, the U.S. VC investments are increasingly concentrated in AI. Of U.S. VC dollars allocated in 2025, 41 percent were allocated to just 10 start-ups, 8 of which were AI companies.

⁶⁷ European Commission, 2025, "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: The EU Startup and Scaleup Strategy," https://research-and-innovation.ec.europa.eu/document/download/2f76a0df-b09b-47c2-949c-800c30e4c530_en?filename=ec_rtd_eu-startup-scaleup-strategy-communication.pdf.

⁶⁸ U.S.-China Economic and Security Review Commission, 2021, *2021 Annual Report to Congress*, <https://www.uscc.gov/annual-report/2021-annual-report-congress>.

Conclusion 2-1: Based on the evidence available through international benchmarking by the committee, Manufacturing USA—equivalent organizations with leading advanced manufacturing sectors only achieve large-scale technology adoption and national impact when embedded within national industrial strategies.

Conclusion 2-2: Based on the evidence available through international benchmarking by the committee, Manufacturing USA—equivalent organizations with leading advanced manufacturing sectors deploy strategic financing tools that support a thriving manufacturing sector.

Overarching Conclusion 2-1: Given that leading foreign competitors with Manufacturing USA—analogue programs have industrial strategies and strategic financing tools, the committee concludes that without a national industrial strategy and new scale up financing tools including subsidies, the United States will continue to lag behind in advanced manufacturing due to implementation of piecemeal efforts.

Proposed Financing Solutions in the United States: A Role for the Institutes

U.S. policymakers have at times recognized the financing challenges facing American manufacturing, but previous legislative attempts to address this market failure have themselves failed. However, it is conceivable that economic competition with China will drive policy change in the United States, including the creation of new financing instruments and institutions. Current possibilities include:

- A U.S. sovereign wealth fund (with a mission of funding domestic manufacturing);
- A more globally competitive Export-Import Bank of the United States (U.S. Exim);
- Legislative proposals to provide manufacturers with more access to capital, such as the Industrial Finance Corporation Act; and
- An expanded DoD Office of Strategic Capital or a similar function in a different agency which can scale investments in technologies critical to the industrial base, not just the defense industrial base. DOE still retains its

loan program through the Office of Energy Dominance Financing, previously known as the Loan Programs Office.

Overall current financing programs are spread across 10 agencies. In general, the U.S. government does not offer equity financing. Current lending programs are typically risk averse and are serving other missions. The United States needs new financing solutions for manufacturing, and it would be beneficial for the institutes to have a voice in the proposals under discussion. Manufacturing USA could play an advisory role in identifying technologies for further support as well as finding the right new investment tools. Institute members have untapped first-hand knowledge of what would be most effective nationally.

Recommendation 2-3: To address systemic capital gaps facing hardware-intensive technologies, the United States Congress, working with relevant agencies, should, within the next 2 years, authorize funding and set policy to create new federal manufacturing and financing mechanisms that include patient-capital funds, a sovereign wealth fund with a strategic focus on manufacturing, intellectual property-backed lending programs, coordinated public-private guidance funds and other mechanisms. Manufacturing USA institutes should be formally integrated as advisors to manufacturing financing bodies, providing technical due diligence, scale-up roadmaps, readiness assessments, and first-of-a-kind validation data that de-risk future investments and inform investment decisions.

This infrastructure directly amplifies the Chapter 3 call for deeper institute responsibility in technology transfer and maturation, pilot-scale readiness, and TRL or Manufacturing Readiness Level (MRL) progression and quantification.

Manufacturing USA could also play a greater role in derisking new technology investments to enable higher rates of market adoption and commercial success. Derisking an investment in a technology can mean proving that a technology is scalable and can reach mass production; it is not just cost sharing or a financial guarantee. The institutes have the capability of road-mapping a technology from proof of concept all the way through TRLs 7–9. If you can show that a technology can successfully get through testing, demonstration, and pilot production,

you have gone a long way to derisking the actual investment for VC. The Manufacturing USA institutes with their unique capabilities can help rapidly figure out which technologies can and cannot successfully overcome bottlenecks to scaling, information of great importance to investors.

The institute directors and the Advanced Manufacturing National Program Office (AMNPO) could articulate and frame these capabilities to U.S. policymakers on an annual basis. As a first step, it is important that they consider and reposition the institutes as a vehicle for risk management in addition to their other offerings. It is critical that agencies such as DoD, which invest in new technologies and fund institutes, be made aware of the institutes' untapped capabilities to reduce financial risk. In this way, the institutes can accelerate the adoption of new technologies in the United States and advise on the optimal financing solutions needed to support manufacturing. AMNPO could lead these efforts.

Foundational technologies

Foundational technologies—broadly defined as technologies used for inputs in advanced technologies—are a focus point of institutes in competitor nations but not typically of Manufacturing USA. For instance, the National Institute of Standards and Technology's study of China's institutes found that as part of its industrial policy review process, China establishes a new institute where it sees a technology gap, including dependency on foreign sources:

Given that a bottleneck for China has been its dependency on foreign sources for core components, many topic areas have been designated to address this vulnerability, particularly in the foundational fields of new materials, semiconductors, and key components for advanced machinery and machine tools, in addition to maintaining their competitive edge in core and future technologies such as batteries, artificial intelligence, and next-generation information technology.⁶⁹

In contrast, the United States risks losing its lead, or even capabilities, in many foundational technologies (see Figure 2-3) as it has de-industrialized. In remarks to the committee, David Furrer of Pratt and Whitney, observed that the United States needs to

⁶⁹ M. Molnar, K. Rogers, F. Gayle, S. Ipri-Brown, M. Tran, J. Long, C. Ray, A. Shih, and D. Thomas, 2025, *China's Manufacturing Innovation Centers: A Benchmarking Report for the Manufacturing USA Network*, NIST AMS 600-17, National Institute for Standards and Technology, <https://www.nist.gov/publications/chinas-manufacturing-innovation-centers-benchmarking-report-manufacturing-usa-network>.

modernize foundation technologies such as “casting, forgings, and additive fabrications such as welding.”⁷⁰ Furthermore, in an August 2025 press release, the Advanced Robotics for Manufacturing Institute said

Cast and forged components lie at the heart of critical commercial and defense systems, providing a vital contribution to warfighter readiness for the United States. However, these industries are plagued by significant issues, including personnel safety concerns, material availability, and cost, further exacerbated by the legacy platforms, whose designs and processes were largely conceived, defined, and stored on paper. The challenges for the United States to produce low-volume, high-mix cast and forged components pose a critical and enduring issue.⁷¹

Additionally, the Institute for Advanced Composites Manufacturing Innovation states that

Workforce shortages in the U.S. casting and forging (C&F) industry, the downstream fabricator and OEM [original equipment manufacturer] supply chain installing castings and forgings, and the associated government workforce pose a significant risk for the U.S. defense industrial base. Department of Defense (DoD) assets and warfighter support systems depend on U.S. manufacturing capacity, which relies on adequate domestic and allied workforce and materials production. Between now and 2028, the defense industrial base will need at least 122,000 additional shipbuilders, engineers, and other critical DoD support roles. Failure to meet the demand for metallurgical engineers and related trade professionals in the base metals industry creates a critical vulnerability in U.S. national defense.⁷²

Foundational technologies have not traditionally been a strategic focus area for most Manufacturing USA institutes.^{73, 74} The institutes were established to pursue advanced technologies, to leapfrog competitors. But given U.S. vulnerabilities in foundational technologies used as inputs for advanced technologies, broadening the Manufacturing USA strategic focus to include these technologies is critical. The idea is not to drop advanced technologies but to apply these efforts to foundational technologies as well.

⁷⁰ David Whitney, presentation to the committee, August 13, 2025.

⁷¹ ARM Institute, 2025, “ARM Institute Funds New Robotic and Inspection Projects for Casting & Forging,” press release, August 28, <https://arminstitute.org/news/casting-forging-2025-projects>.

⁷² METAL (Metallurgical Engineering Trades Apprenticeship & Learning), 2024, “Transforming U.S. Metal Manufacturing Workforce in the Castings and Forging Industry,” METAL News (blog), August 5, IACMI, <https://www.metalforamerica.org/transforming-u-s-metal-manufacturing-workforce-in-the-castings-and-forging-industry>.

⁷³ LIFT is a clear exception.

⁷⁴ M.C. Demirel and D. Adler, 2024, Threading the innovation chain: Scaling and manufacturing deep tech in the United States, *American Affairs* 8(4): 58–79, <https://americanaffairsjournal.org/2024/11/threading-the-innovation-chain-scaling-and-manufacturing-deep-tech-in-the-united-states/>

Recommendation 2-4: Manufacturing USA sponsoring agencies should immediately conduct a coordinated assessment to identify foundational manufacturing technologies in which U.S. capabilities have eroded or are in danger of erosion relative to those of international peers. Within 2 years, agencies should either (a) add foundational technology workstreams to existing institutes or (b) stand up new institutes where critical gaps exist.

The Committee has observed that though some of the institutes have put resources into foundational technologies, the point of the coordinated assessment is to create a complete list, to identify agency priorities and potential solutions and determine future investment requirements.

These foundational capabilities reinforce the advanced technology transfer and scale-up issues presented in Chapter 3.

One outcome of this exercise is that existing institutes may need to make improvements in foundational technologies as part of their agenda. Certain foundational technologies might be used as inputs across institutes, meaning that there is room for collaboration across Manufacturing USA and avoidance of duplication by the institutes.

As part of this exercise, the sponsoring agencies may find that entirely new institutes will be required to address U.S. deficiencies in foundational technologies.

U.S. manufacturing success requires both advanced and foundational technologies. The United States needs to be proficient in both. Foundational technologies mark a strategic shift for most Manufacturing USA institutes, but also an opportunity for Manufacturing USA and DoD, DOE, and DOC to engage in how to broaden their technology focus.

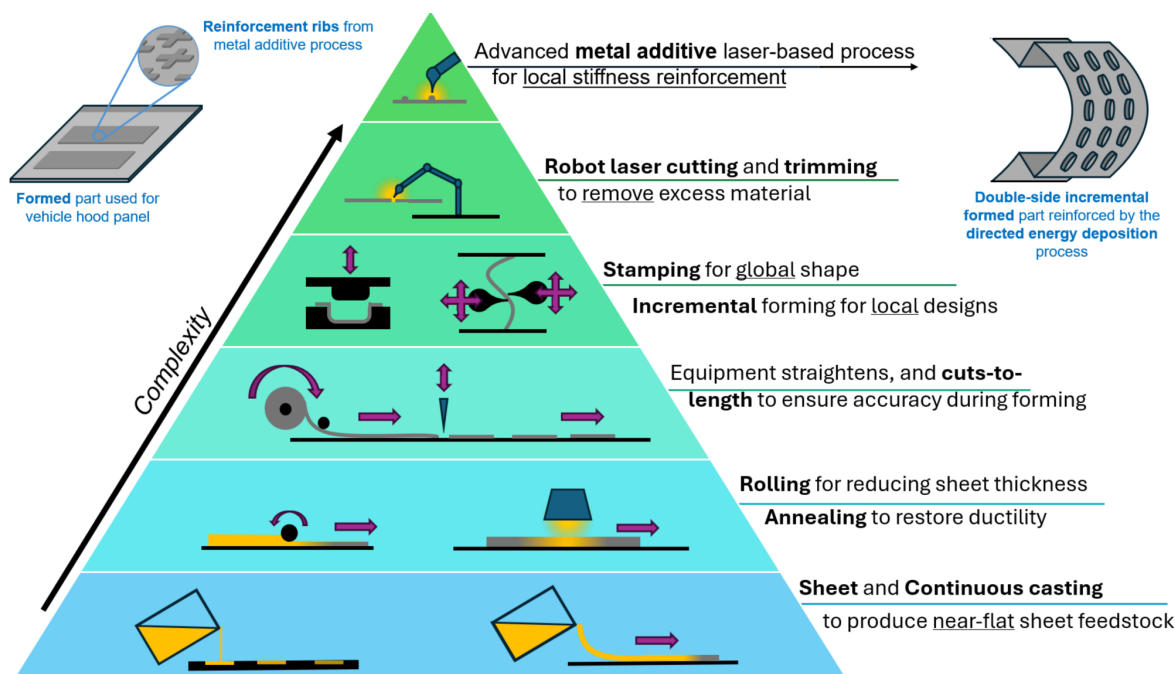


FIGURE 2-3 Pyramid describing foundational technologies and their importance to advanced manufactured products.

DESIGN, STAFFING, AND OPERATION OF THE INSTITUTES

Business Development

Business development is just as important for a technology's flourishing and success as technology development. The premise that institutes are going to solve the innovation "valley of death" purely from a technology program is a fallacy. Entrepreneurs also need to understand market needs and trends, including around product design and competitors' offerings.

Successful international models have dedicated business development programs for entrepreneurs to help their companies grow. The offerings include market assessment and advice, IP strategies, active alumni support, and in some cases, financing. For example:

- When ITRI becomes involved with a start-up, the project is assessed by a committee of venture capitalists from Taiwan and Silicon Valley, as well as entrepreneurs outside of ITRI who have relevant start-up experience and interest in the area.

- ITRI has a center that engages with different industries and companies to understand their needs, with the information linked back to ITRI labs.
- ITRI has a structured alumni network. When people who have worked with ITRI retire, they can join the alumni network to provide mentorship for start-ups. ITRI has a pool of 24,000 alumni experts.
- ITRI has a 100 percent owned subsidiary VC arm, Industrial Technology Investment Corporation. It was formed roughly 40 years ago.
- A*STAR in Singapore has an “Innovation & Enterprise (I&E) Group” which “helps companies turn research into business results.”⁷⁵
- Japan, as noted previously, has created 9 SME universities that are focused on training SME CEOs and COOs on how to operate their companies. This goes well beyond just tech transfer issues.
- Fraunhofer has two dedicated programs to support business development. AHEAD is Fraunhofer’s “deep tech accelerator,” identifying industry partners and assessing if there is an actual market need for a technology. Fraunhofer Venture includes access to internal and external funding and support leading to spin-offs.

A critical offering missing from the Manufacturing USA system is an in-house business development function. This is not just technology transfer at a higher TRL but around technology development from lower TRLs throughout the valley of death. The business case for a technology is often missing from these technical discussions.

Business development requires national-level, cross-institute solutions because it involves the broader scale-up challenge facing U.S. technologies, as well as the specific challenges facing specific entrepreneurs. Therefore, it requires new program elements for Manufacturing USA to support entrepreneurs, such as the possibility of a CEO university. But it also includes advising on new public policies supporting scale-up of technologies in the United States, such as new financing tools.

⁷⁵ Singapore Agency for Science, Technology and Research (A*STAR), n.d., “Innovation & Enterprise (I&E),” <https://www.a-star.edu.sg/enterprise>

Business development can be tightly linked to regional development, both as a source of demand for new technologies and a source of supply for a skilled workforce. This finding is further addressed and incorporated into Recommendation 5-1 in Chapter 5.

SMMs: Closing the Productivity Gap

The productivity gap between global frontier firms (top 5 percent) and non-frontier firms continues to increase across 21 developed countries.⁷⁶ Laggard firms (bottom 40% of productivity distribution) despite being in general younger and smaller than productive firms “converge at a slower rate in digital and skills intensive industries” according to the OECD.

In the United States, SMMs lag in adopting advanced manufacturing technologies, and are often not even digitalized. For example, McKinsey Global Institute found that “micro, small, and medium-sized enterprises (MSMEs) in the U.S. are only half as productive as large companies, a stark contrast to the 60% productivity ratio seen in other advanced economies.”⁷⁷

Addressing this gap has been seen as more of a MEP issue, rather than an issue for the institutes, but in fact, it is a national issue. Other countries have implemented massive, targeted programs to improve SMM capabilities and technology diffusion. These include tech advisory services and sometimes subsidies for tech implementation. The scale and resources devoted to these efforts are unmatched by the United States. These programs hold lessons for how the United States can improve the performance of SMMs.

For instance, in Japan, SMRJ offers both consultative services and subsidies with an annual budget of GBP 1.6 billion (2023 totals) to improve productivity and facilitate technology diffusion: a manufacturing subsidy, a business sustainability subsidy, IT implementation subsidy, and business succession subsidy.

⁷⁶ F. Calvino and C. Criscuolo, 2022, “Gone Digital: Technology Diffusion in the Digital Era,” Brookings Institution (blog), January 20, <https://www.brookings.edu/articles/gone-digital-technology-diffusion-in-the-digital-era>.

⁷⁷ K. Ellingrud, 2024, “Time to think big to close America’s small business productivity gap,” McKinsey, originally published in Forbes, December 19, <https://www.mckinsey.com/mgi/media-center/time-to-think-big-to-close-americas-small-business-productivity-gap>; P.M. Swamidass, 2003, Modeling the Adoption Rates of Manufacturing Technology Innovations by Small US Manufacturers: A Longitudinal Investigation. *Research Policy* 32(3): 351–66. [https://doi.org/10.1016/S0048-7333\(02\)00019-7](https://doi.org/10.1016/S0048-7333(02)00019-7); S. Berger and B. Armstrong, 2022, The Puzzle of the Missing Robots, *MIT Case Studies in Social and Ethical Responsibilities of Computing*, Winter (January). <https://doi.org/10.21428/2c646de5.9461c9fb>.

In Germany, where SMMs form the backbone of the industrial economy, they have been a focus of the Fraunhofer program. Starting in 1976, Fraunhofer created a government-financed program dedicated to contract research for SMMs. Even today, Germany's SMMs are not always digitized, and here, Fraunhofer offers digital transformation programs, with a program representative suggesting what is the most suitable technology, the cost, and the benefits

In the United Kingdom, MEP-like programs are housed inside the HVM Catapult. The HVM Catapult provides workforce training as well as helping SMMs to access new markets or connect with the right partners.

A*STAR has a technology adoption program targeted to SMMs, which identifies and then translates technologies of use to them. In another program, research scientists and engineers are seconded to the SMEs to facilitate their in-house R&D technology upgrading to further enhance their business competitiveness. See Figure 2-4 for comparisons.

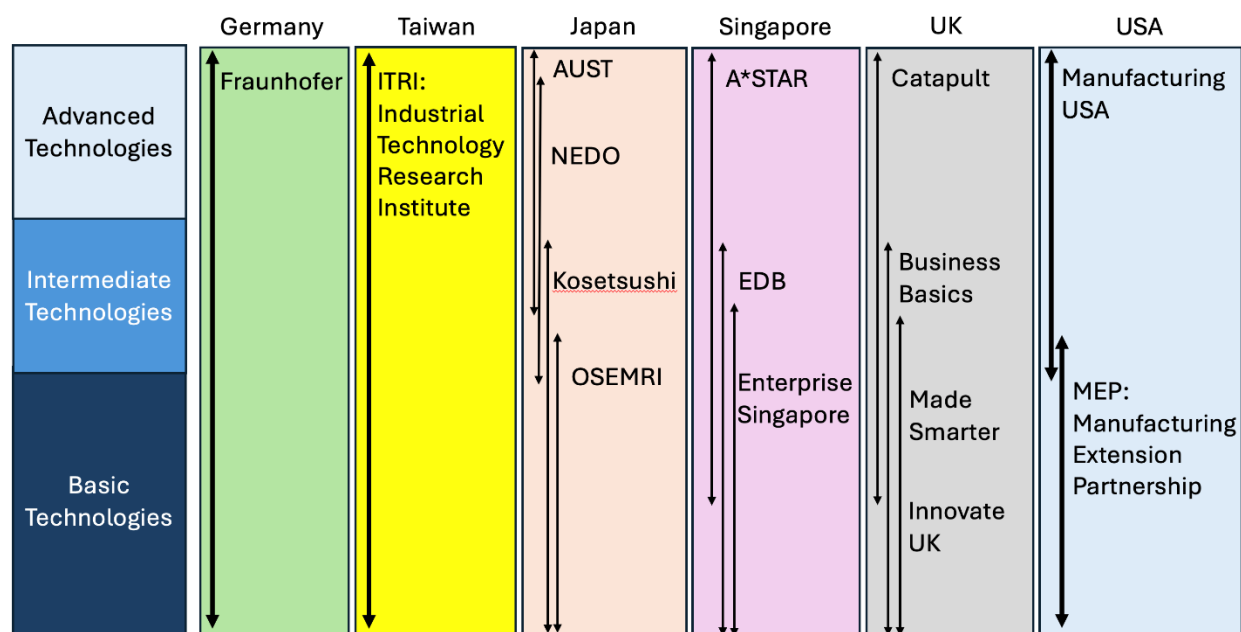


FIGURE 2-4 Comparison of institutions for technology diffusion.

AI implementation for SMMs is increasingly a key part of these international SMM technology transfer offerings. This is quite distinct from AI model competition, the focus of much of the discussion in the United States.

Countries have established dedicated AI implementation programs for manufacturing. Fraunhofer has developed an AI-based system for automation that it offers to SMMs. ITRI, as noted previously, has created an AI Application Strategy office, and Taiwan is setting up pilot production lines for SMMs so they can learn about how AI can be deployed in manufacturing.

In-House Prototyping and Pilot Production Capabilities

A recurring feature of successful international manufacturing institutes surveyed by the committee was the capability for in-house prototyping and pilot production, as found at IMEC, the HVM Catapult, A*STAR, ITRI, and elsewhere. The underlying rationale for these shared physical facilities is that they are necessary to achieve economic competitiveness and help foster eventual commercial production of new technologies.

The European Commission views these scale-up production capabilities as a strategic asset for European competitiveness. It uses the broader terminology of “technological infrastructure” to describe these pilot production facilities which it defines as:

Facilities, equipment, capabilities and support services required to develop, test and upscale technology to advance from validation in a laboratory up to higher Technology Readiness Levels prior to competitive market entry. They can have public, semi-public or private status. Their users are mainly industrial players, including SMEs, which seek support to develop and integrate innovative technologies towards commercialization of new products, processes and services, whilst ensuring feasibility and regulatory compliance.⁷⁸

In the United States, technological infrastructures can be housed at universities, original equipment manufacturers (OEMs), in addition to institutes. Others been created regionally outside of the Manufacturing USA system through the Economic Development Administration or state grants.

University production facilities tend to be early stage in orientation with limited capacity and not suitable for higher MRL or TRL testing. OEMs are unlikely to offer access to SMMs or other potential competitors.

As the committee heard from one SMM founder, the absence of pilot productions facilities for his technology (spinning) at the institutes caused him to leave the United States and shift scale-up production to Germany.

⁷⁸ European Commission: Directorate-General for Research and Innovation, 2019, *Technology infrastructures – Commission staff working document*, Publications Office, <https://data.europa.eu/doi/10.2777/83750>.

Hence, there are good reasons to provide these pilot production facilities at an institute. In the case of Manufacturing USA, NextFlex offers them, but they are not widespread across the institutes. Creating these facilities at institutes could offer scale and higher TRL levels not found at a university. They could also provide access for SMMs not found with an OEM. Furthermore, the cost of these facilities can be too burdensome for even an OEM to undertake in-house. The rationale for IMEC is that the cost of a fab was too expensive for any single company and so a shared production facility was required.

Technological infrastructure is indeed expensive, requiring substantial capital investments and ongoing operational expenditures. The EU commission noted that “funding is a key challenge.” It therefore is developing a strategic roadmap of how to prioritize investments in these facilities which it noted are essential to supporting SMMs and start-ups. Part of this exercise is building the business case for these facilities, identifying both user demand and the potential funding mix that could make them financially sustainable.

The cost of adding production capability depends on the technology. Therefore, institutes interested in expanding in this direction could set up a working group to identify the cost and other challenges, but also the benefits, particularly to the region or state as well as the business case for facility. The European Union has already undertaken a similar planning exercise that is worth examining as a model.

These production capabilities could go beyond the TRL level found at universities. Flexibility, controllability, reconfigurability, standard interface in terms of hardware and software could all be considered in planning. Adding these new piloting capabilities to an institute could have a snowballing effect on regional economic development. Ideally, the state or region, in addition to the federal government, could provide funding. This finding is expanded into Recommendation 3-3 in Chapter 3.

In-House Research Staff

Applied research conducted by an in-house engineering and scientific staff is a core offering of international institutes. IMEC has approximately 6,000 in-house researchers. HMMV Catapult has in-house scientific and engineering staff of 3,500 employees. A Fraunhofer board member told the committee that “applied research is the foundation of our organization.”

U.S.-based OEMs often turn to foreign institutes for these applied research capabilities. Their reasons are multifold including access to scaling capabilities not available in the United States, access to expertise and talent, access to foreign markets and customers, and access to international funding, all of which are indicative of the strengths of these institutions, particularly given that many of these companies have large research staffs of their own. The impact to SMMs would be that much greater given their lack of research staff.

An executive from Boeing, Philip Freeman, told the committee that the company uses manufacturing institutes outside the United States for their dedicated research staffs and laboratory facilities. For instance, Boeing executes projects through AMRC in Sheffield, part of the HMV Catapult. Freeman told the committee why:

You have the opportunity to develop research knowledge that spans several corporations. Boeing may have an interest in machining operations. GE may have an adjacent interest. AMRC staffers that end up working on those projects gain an appreciation for the needs across multiple industries and can stitch that knowledge together into directed research projects that can have a broader scope than individual company-led projects. Universities have a high turnover of graduate students. One of the advantages of AMRC is their employees are going to be there for 10 years and are able to carry that knowledge from project to project and grow that capability as opposed to someone who is pursuing their doctorate.

University research labs, which are common in the United States, are not an equivalent to a staffed industry research consortium. They typically do not work on the same technological issues, and researchers do not bring the same industry knowledge and experience.

Rotating Research Staff

As a subset of their research staff, some international institutes have formal programs to rotate through doctoral-level or postdoctoral engineering staff as researchers. For instance, IMEC has 1,200 doctoral students or postdocs, working on long-term topics related to the manufacturing activities at IMEC but not directly for any company. At the Catapults, government funding supports collaboration with various academic doctorate programs.

This staff turnover is a purposeful strategic activity. It benefits students, industry, the manufacturing institutes, as well as the nation and its industrial base. The students typically move into the manufacturing industry and SMEs. The churn, rather than a loss of talent, for institutes is a way to grow a specialized workforce and increase the capacity of the nation to absorb or pioneer new manufacturing technologies.

In the United States, by way of contrast, there is a bifurcation between university education and applied manufacturing research, with a few exceptions such as the handful of engineering policy centers or introductory manufacturing survey courses taught as part of mechanical engineering.⁷⁹

For Manufacturing USA institutes to offer in-house research capabilities would require significant additional resources, and so government funding is required.

An in-house research staff and a stronger research base could open additional potential funding streams for institutes. It would allow the institutes to tackle more ambitious technological challenges and to capture funding for joint or umbrella research projects that would otherwise be inaccessible to them. To facilitate collaborations with academic and national labs, and to prevent duplicate research, the research area and scope of in-house research (and the staff level) would need to be carefully designed to leverage the existing regional resources. Joint paid appointments between Manufacturing USA institutes and other entities are highly encouraged.

Higher TRL and MRL Offerings

One outcome of institutes having in-house production facilities as well as scientific staff would be the ability to offer higher TRL and MRL than are currently the case. Foreign institutes quite often target higher TRLs that may include TRL 7, and even TRL 8. Typically, to do this, well-equipped and well-staffed facilities are needed. Some of the equipment and staffing may come from the industry partners. This higher TRL offering is one reason OEMs turn to these institutes.

But a key beneficiary of Manufacturing USA institutes being able to offer higher TRLs would be SMMs, particularly if they do not have the proficiency or resources to develop technologies to the highest TRL approaching commercialization. However, for institutes to be able to offer higher TRL and MRL levels would take resources. It would also require other changes: Under RAMI, DOC institutes cannot offer this without a statutory change.

COMBINING TECHNOLOGIES: CROSS-DISCIPLINARY STRATEGIES

⁷⁹ NASEM, 2023, *Infusing Advanced Manufacturing into Undergraduate Engineering Education*, Washington, DC: The National Academies Press, <https://doi.org/10.17226/2593>.

International models have pursued a cross-disciplinary strategy, incorporating and fostering advanced technologies used horizontally as inputs across institutes. The goal is not merely for an institute to be able to provide more than one technology as demanded by users but also to combine them in innovative ways.

For instance, Taiwan ITRI'S 2035 Technology Strategy and Roadmap is focused on a cross-disciplinary strategy incorporating advanced technology to “foster breakthroughs in applications. Dedicated to driving industry growth, ITRI continues to explore innovative combinations. ITRI has also launched a cross-disciplinary strategy office to facilitate collaborations.

Combining technologies is a core part of China's Innovation Development Strategy, where AI, 5G, and robotics are being used to try to improve productivity across economic sectors. In the United States, the committee heard from Michael Cook from Rockwell Automation who expressed the desirability of increased collaboration among the institutes around “horizontal technologies” such as AI or cybersecurity.

This finding is further addressed and incorporated into recommendations in Chapter 4, including Recommendation 4-3, which highlights the potential role of MEP in coordinating integrated technology packages.

Standards

Standards enable new technology acceptance, deployment, and commercialization, and help grow market size. The establishment of technological standards as the result of a project can be a metric of the project's success. It can also aid technology transition because the results can be communicated through the standard. A collaborative environment to identify needed standards and to generate content and support for a given standard naturally aligns with the institute's capabilities. One area of success for many of the institutes has been activities leading to standards.

There are important global strategic considerations in setting the standard for a technology. A recent World Bank study found that China “has emerged as an increasingly

prominent player in international standard setting, with its influence growing rapidly.”⁸⁰ China’s approach to setting standards involves multiple stakeholders: the government, universities, industry, and research institutes, supported by preferential policies.

This focus by China on leading and driving standards has been highlighted by others, including the difference in approach where the U.S. model is private-sector led, while China’s strategy is government led which aligns with their industrial policies.⁸¹ The NIST benchmarking study found that the Chinese MICs differ from Manufacturing USA in that one of their tasks is to “strengthen the guiding and guaranteeing of standards.”

Additionally, in China and other countries, predominantly in Asia, but sometimes seen in the UK, the government will fund individuals to formalize the standard with a Standards Development Organization (SDO) such as the International Electrotechnical Commission (IEC) or the International Organization for Standardization.

Partly in response to this situation, NIST funded a new Standardization Center of Excellence in the area of critical and emerging technologies,⁸² which aligns with the U.S. government’s National Standards Strategy for Critical and Emerging Technology and its Implementation Roadmap.

However, it is unknown if the new Center of Excellence strategy will include leveraging the institutes, who are already naturally focused on standards in their topic area.

Recommendation 2-5: The setting of standards is increasingly a geopolitical consideration; hence, within 2 years, Manufacturing USA institutes and the Advanced Manufacturing National Program Office should highlight the standards roadmaps that different institutes are generating, encourage the new National Institute of Standards and Technology–funded Standardization Center of Excellence to leverage these roadmaps, and obtain funding for actual standards writing as part of the institutes’ projects.

⁸⁰ J. Gong and V. Zhang, 2025, “China’s Evolution in International Standardization: From Follower to Global Leader,” World Bank Working Paper, <https://thedocs.worldbank.org/en/doc/a588e8a85c44aca841687aff78d25a54-0050062025/original/John-Jiong-Standardization-in-China.pdf>

⁸¹ A. Agarwal, 2025, “The Silent Struggle: How Technical Standards Shape Global Tech Power,” Special Competitive Studies Project newsletter, <https://scsp222.substack.com/p/the-silent-struggle-how-technical>.

⁸² See www.ascet.com.

A more proactive and nationally aligned approach to standards will accelerate technology adoption, improve interoperability, and enhance U.S. competitiveness in global markets.

This recommendation supports Chapter 3’s emphasis on definitional clarity, interoperability, and ecosystems required for late-stage technology transfer.

INTERNATIONAL COLLABORATION OPPORTUNITIES

Foreign institutes have a presence in the United States and are working with U.S. companies and universities. For instance, IMEC has offices in the United States and works with U.S. companies and universities, and Fraunhofer USA conducts “applied research and development for customers in industry and for state and federal government.”⁸³ Collaboration between Manufacturing USA institutes and international institutes, however, has not been part of the U.S. initiatives.

There are other international candidates for collaboration opportunities. ITRI is one example. It has a track record of working with international institutes to conduct joint R&D research. Here ITRI’s capabilities in 6G development have been an area of focus for collaborative work. ITRI has worked with Catapults in the United Kingdom, Fraunhofer in Germany, and the U.S. national laboratories.

Recommendation 2-6: With on-going sponsoring agency review and approval, starting in 2026, Manufacturing USA institutes should pursue structured collaborations with leading international manufacturing institutes in areas where complementary strengths exist. These partnerships should focus on shared research, pilot-scale demonstration, standards development, and knowledge exchange that advances domestic technology transfer and scale-up.

Agency oversight is deemed necessary to ensure that such collaborations support U.S. strategic interests while strengthening the nation’s competitive position in advanced manufacturing. Collaborations with countries of concern as identified by Congress or the Federal government should be excluded.

⁸³ Fraunhofer USA, <https://www.fraunhofer.org/en/startpage/profile.html>.

Chapter 3

Technology Transfer and Scale-Up

Technology transfer and scale-up are central to the mission of the Manufacturing USA institutes and to the nation’s capacity to transform innovation into economic growth, industrial competitiveness, and national security. Established to bridge the innovation “valley of death” (nominally, the transition from TRL 4 to 7) between research and production, the institutes enable the movement of new technologies, materials, and processes from the laboratory into domestic manufacturing. Earlier National Academies discussions of the Manufacturing USA program similarly emphasized the importance of manufacturing innovation institutes as mechanisms for connecting research, development, and industrial production capabilities within the U.S. innovation system.⁸⁴ Through collaborative partnerships, shared facilities, and coordinated road-mapping, the institutes reduce risk, validate manufacturability, and accelerate technology adoption across industries of every scale.

A defining strength of the Manufacturing USA institutes is their convening power, their ability to unite industry, academia, and government around shared manufacturing challenges that no single organization can singularly address. Acting as neutral platforms, the institutes align diverse interests, resources, and expertise to create communities of practice that would not otherwise exist. This convening role is the foundation of every institute’s impact: it enables stakeholders to identify common priorities, establish standards, and collectively address barriers to technology transition and scale-up. Many institutes employ a tri-leadership model, pairing senior representatives from industry, academia, and government to ensure that technical decisions, workforce needs, and policy considerations are jointly addressed.

Through this convening process, some institutes develop and continuously refine technology roadmaps that are living documents that capture critical gaps, specify target readiness levels, and define milestones for investment and implementation. These roadmaps help align research and development efforts with workforce, supply chain, and market needs. Road-mapping sessions bring together participants across the supply chain to agree on success metrics,

⁸⁴ NASEM, 2017, *Securing Advanced Manufacturing in the United States: The Role of Manufacturing USA: Proceedings of a Workshop*, Washington, DC: National Academies Press, <https://doi.org/10.17226/24875>.

resource contributions, and expected economic outcomes. When used effectively, these efforts translate collaboration into measurable action, providing a structured pathway from early innovation to large-scale industrial deployment.

These dynamics lay the groundwork for the expanded institute role envisioned in Chapter 7, in which technology transfer, scale-up capacity, and advisory services become central pillars of a more ambitious national manufacturing strategy. Strengthening technology transfer begins with a clear understanding of what the term means within the Manufacturing USA context and how the institutes operationalize it through shared definitions, coordinated road-mapping, and convening diverse partners around common goals. Furthermore, lessons from international manufacturing systems summarized in Chapter 2 underscore that institute convening power is most effective when embedded within a coherent national industrial strategy; this context highlights the importance of strengthening U.S. coordination mechanisms as the foundation for technology transfer.

DEFINITIONS AND CONCEPTS OF TECHNOLOGY TRANSFER

Technology transfer encompasses the movement of knowledge, innovations, and manufacturing capabilities from one organization to another to achieve practical use and economic benefits. Within the Manufacturing USA network, it refers specifically to the effective transition of institute-developed technologies and know-how into commercial, public, or defense applications through collaboration among industry, academia, and government partners. The definition of technology transfer is critical to the development, adaptation, and adoption of each institute's technology transfer roadmap, which identifies current capability gaps, defines readiness milestones, and guides collaborative projects that accelerate industrial adoption.

Understanding how institutes define and operationalize technology transfer is essential to ensuring alignment, accountability, and measurable progress. Institutes that define technology transfer narrowly as a hand-off of intellectual property may overlook the broader processes of validation, demonstration, and adoption that are central to their mission. Conversely, broad definitions that lack metrics can obscure accountability and reduce comparability across institutes. Because institutes operate across diverse technological domains, they employ several readiness-level frameworks to measure progress toward application. The committee uses the term XRL as a generalized shorthand—where “X” represents the most relevant readiness

construct for a given context (e.g., TRL, MRL, ARL—Technology Readiness Level, Manufacturing Readiness Level, or Adoption Readiness Level, respectively). This generalized framework emphasizes that technology transfer depends not only on technical progress but also on production capability, market readiness, and user adoption. Understanding how these levels align, and where they differ, allows institutes to communicate progress more clearly, identify gaps, and tailor project milestones to their specific missions.⁸⁵

As Chapter 6 emphasizes, workforce readiness is a determining factor in adoption readiness; therefore, it is essential that XRL assessments be constructed to incorporate skills, training, and credentialing requirements that directly affect technology deployment. Technology transfer encompasses a broad range of activities, and its meaning and measures of success vary widely across institutes, sponsoring agencies, and member organizations. Each institute defines technology transfer differently according to its technology domain, end-use markets, and operational norms. This variability makes it difficult to develop and apply a consistent technology transfer roadmap that can be regularly reviewed, compared, and updated to assess progress in enhancing U.S. industrial competitiveness and economic growth across institutes.

It is critical that roadmaps include pathways leading to implementation and large-scale adoption, particularly by small and medium-sized manufacturers (SMMs), and specify milestones, resource needs, and partners required to transition technologies from demonstration to production. Review and regular updating of these roadmaps is important to ensure alignment with institute missions and to track progress in advancing U.S. manufacturing competitiveness and economic growth. Box 3-1 describes how technology road-mapping can be a core tool for institutes. As detailed in Chapter 2, leading international institutes employ unified, system-wide

⁸⁵ Technology Readiness Levels (TRLs), established by NASA, assess the maturity of technologies from basic research (TRL 1) to operational deployment (TRL 9) (C.G. Manning, 2023, “Technology Readiness Levels,” NASA, <https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/>). Manufacturing Readiness Levels (MRLs), introduced by the Department of Defense, complement TRLs by evaluating manufacturability and production readiness (U.S. Government Accountability Office, 2010, *Best Practices: DOD Can Achieve Better Outcomes by Standardizing the Way Manufacturing Risks are Managed* (GAO-10-439). Adoption Readiness Levels (ARLs), developed by the Department of Energy, focus on the likelihood that a technology will be successfully adopted, incorporating market and organizational factors beyond technical maturity (U.S. Department of Energy, 2024, “Adoption Readiness Levels,” <https://www.energy.gov/arl/adoption-readiness-levels>). The term “XRL” is used throughout this report as a generalized construct encompassing TRL, MRL, and ARL, depending on the technology domain. It reflects the committee’s view that successful technology transfer depends on aligned progress across technical, manufacturing, and adoption-readiness dimensions.

definitions of technology transfer to ensure comparability and accountability, reinforcing the need for common U.S. frameworks across the Manufacturing USA network.

Recommendation 3-1: Within a year, each Manufacturing USA institute should define “technology transfer” in its roadmap with measurable milestones. These should be updated annually and where possible aligned with existing Manufacturing USA performance metrics and reporting frameworks used by the Advanced Manufacturing National Program Office and sponsoring agencies.

BOX 3-1

Technology Road-Mapping as a Core Institute Tool

Technology road-mapping is a cornerstone of institute strategy and a primary mechanism for aligning stakeholders around shared objectives. Effective roadmaps identify critical technical gaps, define readiness milestones, and link research activities with workforce, supply chain, and market needs. Institutes demonstrating best practice engage stakeholders through structured workshops and tri-leadership teams of industry, academia, and government. These teams agree on priority challenges, required investments, and expected impacts. For example, NextFlex convenes flexible-electronics partners annually to update its roadmap and set milestones for manufacturing readiness, while BioMADE integrates a design–build–test–learn framework to advance biomanufacturing processes. A well-constructed roadmap functions as both a planning and an accountability tool—translating a shared vision into measurable steps that strengthen U.S. manufacturing competitiveness.

INDUSTRY AND OTHER STAKEHOLDER NEEDS

The diversity of stakeholders within the Manufacturing USA ecosystem defines both the opportunity and the complexity of technology transfer. Each participant engages with the institutes for different reasons, and the flow of technology among these actors is multidirectional, moving into, through, and out of the institutes depending on partner needs and the maturity of the technology. Understanding these relationships is essential to designing mechanisms that move technologies from concept to deployment while ensuring tangible industrial and societal benefits.

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As emphasized in Chapter 2, other nations' institutes structure stakeholder engagement through permanent, well-resourced organizations that integrate industry, small and medium enterprises (SMEs), and government; the fragmented U.S. approach to institute engagement reflects this contrast and reinforces the need for stronger, more consistent mechanisms for participation. As is highlighted in Chapter 1, the limited ability of SMMs and entrepreneurial firms to adopt advanced technologies remains a core barrier to national productivity growth. This chapter's framework for technology transfer directly addresses that adoption bottleneck.

Large multinational corporations (LMCs) use the institutes primarily to validate and de-risk technologies that can later be absorbed into their production systems. These companies often continue internal development once feasibility has been demonstrated, making some results less visible to the wider community. One result of this approach for LMCs is that they tend to transition technologies to their internal R&D at a lower XRL.⁸⁶ Another common mode of technology transition occurs when the LMC plays the role of technology integrator. In such instances, new technologies are directly transferred into the company's product line, which leads to rapid technology transfer and dissemination into the marketplace.⁸⁷

SMMs generally lack the in-house R&D capacity, capital investment, or specialized staff required to evaluate and implement advanced manufacturing technologies. Similar challenges facing smaller manufacturers in adopting advanced technologies have been documented in previous National Academies analyses of technology diffusion and manufacturing extension programs.⁸⁸ Institutes therefore provide shared access to facilities, demonstrations, and training that lower both technical and financial barriers, enabling these firms to modernize operations and remain globally competitive. Engagement of SMMs through institutes also supports regional economic development by retaining manufacturing activity and jobs within local supply chains. In general, technology is transferred to SMMs from the institutes. Chapter 2 notes that high-performing foreign institutes couple technology development with intensive business-development support and SMM outreach; this international experience highlights the importance

⁸⁶ From discussions on May 13, 2025, during open session.

⁸⁷ From discussions on July 18, 2025, during open session.

⁸⁸ NASEM, 2013, *21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program*, Washington, DC: National Academies Press, <https://doi.org/10.17226/18448>.

of ensuring that stakeholder needs, in particular those of SMMs, are fully reflected in institute technology transfer pathways.

Entrepreneurial start-ups and small technology developers depend on the institutes for both technical validation and exposure to potential partners, customers, and investors. Institute membership often provides credibility and visibility that facilitate follow-on financing and partnerships. Assistance in intellectual-property management, standards participation, and pilot-scale testing helps these companies bridge the gap between prototype and production. In general, new technologies are transferred from entrepreneurial start-ups through the institutes to disseminate these new technologies.

National laboratories and universities view the institutes as essential conduits for translating discoveries from research into manufacturable processes. Collaborative projects and shared testbeds enable these institutions to validate technologies under realistic production conditions while simultaneously training students and researchers in advanced manufacturing practices.

Federal agencies engage with the institutes to meet strategic objectives in defense readiness, energy security, and economic competitiveness. Agency partnerships ensure that institute outputs align with national priorities, strengthen critical supply chains, and provide measurable returns on federal investments.

State and regional economic development agencies benefit from access to advanced technology assets, support for workforce development, and de-risking technology adoption by local firms to achieve state and regional manufacturing and economic competitiveness.

Because the needs of these groups differ, maintaining flexible technology transfer mechanisms and adaptive governance structures in the Manufacturing USA network is essential. Balancing collaboration with large firms while ensuring broad participation by smaller manufacturers and emerging innovators and regional developers is fundamental to achieving sustainable national benefit and global manufacturing leadership. For scale-up and deployment-focused activities, co-investment requirements could be project based and structured to reflect where value accrues. Industry and government end users are the primary beneficiaries of successful scale-up and hence financial mechanisms which are attractive to those end users are important. Universities play a critical role in technical execution and workforce development, but financial cost-sharing requirements should not inadvertently discourage participation in projects

whose benefits accrue primarily outside academia. Similarly, SMMs are critical parties to which technology needs to be transferred, and cost-sharing requirements may be detrimental to successful technology transfer, especially to those SMMs that are highly budget constrained.

Technology Maturation

Technology maturation takes different forms across the Manufacturing USA network, reflecting the breadth of technology domains, industrial sectors, and stakeholder needs. It bridges the gap between early-stage discovery and industrial application by transforming promising research results into manufacturable, scalable, and cost-effective solutions. National Academy of Engineering analyses have likewise emphasized that sustaining U.S. technological leadership requires the ability to translate research advances into domestic manufacturing capabilities and production systems.⁸⁹ Building on the broad needs of their stakeholders, institutes undertake pre-competitive projects that validate performance, refine manufacturing processes, and establish confidence in new materials, tools, and systems. These efforts reduce technical and financial risk, accelerating the transition of innovation from laboratory proof of concept to production environments.

Technology maturation typically involves three interdependent activities:

- Technical validation—testing and verification of materials, processes, and systems under realistic operating conditions.
- Pilot-scale demonstration—replicating production steps at partial scale to evaluate manufacturability, cost, and quality.
- Business-case development—assessing supply chain readiness, regulatory compliance, and economic viability to support industrial investment.

The institutes illustrate a variety of approaches to technology maturation. To demonstrate these approaches, several institutes are discussed in the ensuing text.

⁸⁹ NASEM. 2015. *Making Value for America: Embracing the Future of Manufacturing, Technology, and Work*. Washington, DC: National Academies Press. <https://doi.org/10.17226/19483>.

Advancing Materials and Manufacturing Processes

LIFT, advances new materials and forming technologies from laboratory-scale prototypes to full production readiness. Its high-bay pilot facility in Detroit enables members to evaluate alloy performance, forming behavior, and process repeatability using industrial-grade equipment. By providing access to shared data and facilities, *LIFT* reduces risk for manufacturers exploring the substitution of lightweight alloys in vehicles, aircraft, and defense systems.

America Makes, the additive-manufacturing institute, focuses on validating additive processes and materials for demanding applications such as aerospace and energy. Collaborative projects among its members have demonstrated new powder-bed fusion techniques, qualified materials and geometries for flight hardware, and established shared data standards for part certification. Through these efforts, *America Makes* has helped move additive-manufacturing technologies from TRL 4–5 to TRL 7–8, shortening the qualification cycle and expanding industrial confidence in additive production.

BioMADE, the biomanufacturing institute, accelerates the scale-up of bioindustrial processes that convert renewable feedstocks into materials, chemicals, and other products. The institute helps its members mature bioprocessing technologies from laboratory-scale proof of concept to pilot-scale demonstration using standardized “design–build–test–learn” cycles. *BioMADE*’s projects include validating new fermentation and purification methods and developing open-access standards for bioprocess readiness. These efforts shorten the time to scale and train a workforce skilled in bioindustrial production, enabling broader adoption of sustainable manufacturing technologies across multiple sectors.

As these examples demonstrate, advances in materials, process innovation, and biomanufacturing often lay the technical foundation upon which automation and digital systems can later be deployed. The progression from validation to pilot-scale demonstration mirrors the capabilities embedded in international models discussed in Chapter 2, where in-house scientific staff and dedicated pilot facilities allow technologies to advance at higher TRLs before technology transition to industrial partners. Furthermore, as stated in Chapter 6, effective scale-up must also incorporate workforce upskilling requirements, since a technology can mature technically yet still fail in implementation if firms lack personnel prepared to operate, maintain, or integrate it.

Automation and Human–Technology Integration

The *Advanced Robotics for Manufacturing Institute* (ARM Institute) accelerates the maturation of robotics and automation technologies that enhance efficiency and safety in manufacturing environments. Its projects validate collaborative robots (“cobots”), autonomous systems, and human–machine interfaces under real production conditions. By combining technology development with training and credentialing programs, ARM Institute ensures that automation advances are accompanied by a skilled workforce capable of deploying and maintaining these systems on the factory floor.

These advances in robotics and workforce integration complement the growing emphasis on smart, connected manufacturing systems that rely on digital infrastructure and secure data environments.

Digital and Cyber-Physical Manufacturing Systems

The *Collaborative Ecosystems for Smart Manufacturing Innovation Institute* (CESMII) advances digital manufacturing and energy-efficient production technologies that integrate sensors, controls, and data analytics to improve factory performance. Through its network of regional innovation centers, CESMII supports projects that mature smart manufacturing solutions, validate open-data architectures, and develop interoperable systems that link equipment across production environments. These initiatives reduce energy consumption, improve productivity, and make digital transformation accessible to firms of all sizes.

The *Cybersecurity Manufacturing Innovation Institute* (CyManII) advances secure digital-manufacturing systems from research concepts into operational practice. CyManII partners with manufacturers to develop and test cybersecurity architectures that protect digital-production networks and industrial-control systems. Its work includes creating reference frameworks, verifying interoperability among vendors, and training manufacturing personnel to manage cyber risks. These initiatives provide the foundation for broad adoption of secure, connected-manufacturing technologies essential to smart-factory operations and national security.

Together, these examples demonstrate how technology maturation across the institutes spans materials, biological, automation, and digital domains, and how shared access to facilities, data, and expertise helps industry partners validate technologies efficiently and confidently.

Institutes face uncertainty about how far to advance technologies before transition to external partners. Differences in missions and stakeholder expectations lead to inconsistent decisions on when to hand off technologies for commercialization. Establishing ambitious targets for transitioning technologies beyond demonstration into scaled industrial adoption targeting TRL 7–9 is a critical benefit of roadmaps. It is critical that institutes be evaluated on their ability to advance technologies to implementation in production environments and to demonstrate measurable adoption across their sectors. It is important that the institutes document successful transition to higher XRLs for all projects.

Recommendation 3-2: Within a year, each Manufacturing USA institute should specify and clearly and consistently document its initial and target readiness levels (Technology Readiness Level [TRL], Manufacturing Readiness Level, or Adoption Readiness Level, generally expressed as, XRL) and demonstrate and document transitions to TRLs 7–9 using consistent reporting metrics coordinated through the Advanced Manufacturing National Program Office. These should be updated annually.

Pilot and Scale-Up Facilities

Building on the technologies matured through the efforts described in the previous section, pilot and scale-up facilities serve as the critical bridge between laboratory validation and industrial implementation. These facilities provide production-relevant environments where members can test, refine, and validate technologies before committing to full-scale investment. Early evaluation of manufacturability, quality, and cost reduces risk, accelerates learning, and increases the likelihood of successful commercialization. As discussed in Chapter 2, international institutes maintain substantial in-house engineering and scientific teams to support continuous technology transition, underscoring the importance of comparable staffing models across the Manufacturing USA network.

Facilities may be operated directly by an institute or through partnerships with universities, national laboratories, or industry collaborators. Some are physical pilot plants or high-bay laboratories equipped with production-scale systems, while others take the form of digital testbeds that simulate manufacturing environments for data analysis, process control, and

workforce training. These physical and virtual facilities together create a distributed ecosystem for technology demonstration and scale-up. This dual technical-and-workforce function reflects the integrated education role described in Chapter 6, in which hands-on learning environments are essential to enabling adoption of advanced manufacturing technologies, particularly among SMMs.

Several institutes demonstrate how these facilities function in practice:

- LIFT operates a high-bay pilot plant in Detroit that allows industry and academic members to scale new metal-forming and -joining technologies using industrial-grade machinery.
- NextFlex, the flexible hybrid electronics institute, operates a Technology Hub in San Jose, California, that serves as a pilot-scale fabrication and prototyping facility for flexible hybrid electronic (FHE) devices. The hub integrates design, printing, assembly, and encapsulation capabilities, allowing members to validate processes, materials, and equipment for manufacturing lightweight, conformable electronics. The facility also provides workforce development programs where engineers and technicians receive hands-on training with FHE manufacturing tools. By bridging research and production, NextFlex's Technology Hub accelerates commercialization and strengthens domestic supply chains for emerging electronics technologies (see Box 3-2).

BOX 3-2

NextFlex's Best Practice for Small and Medium Enterprise Engagement

NextFlex, the flexible-hybrid electronics institute, exemplifies how proactive community engagement can accelerate technology transfer to small and medium enterprises (SMEs). Through its member councils, industry working groups, and open project call process, NextFlex aligns academic innovation with SME manufacturing capabilities. Participating SMEs gain access to shared prototyping facilities, join demonstration projects, and receive technical guidance on scaling new processes. The institute's collaborative governance and transparent intellectual-property framework lower barriers for SMEs to participate in research and

commercialization, offering a proven model for broadening industrial adoption across the Manufacturing USA network.

- MxD maintains a “future factory floor” where companies can test digital-manufacturing solutions and cybersecurity architectures before deploying them in their own operations.
- BioMADE is planning to support pilot-scale biomanufacturing through collaborations with university and industry partners to demonstrate fermentation and purification processes for bio-based products.
- CESMII provides both virtual and physical smart manufacturing test-beds that allow companies to integrate sensors, controls, and analytics into existing production systems.

The success of pilot and scale-up facilities depends not only on the availability of infrastructure but also on the presence of skilled staff and sustainable funding for operations and equipment. Engineers, technicians, and process specialists ensure that facilities function safely and efficiently, while also helping project teams adapt laboratory innovations to industrial equipment and practices. Trainers and instructional personnel support hands-on workforce development for institute members and regional partners, while project managers coordinate multiple users, maintain safety and intellectual-property compliance, and optimize scheduling. Sustaining these facilities over time requires funding for equipment maintenance, renewal, and periodic upgrades to keep pace with evolving technologies. Institutes also need personnel skilled in cost recovery, membership management, and facility planning to ensure that pilot environments remain technically relevant, accessible, and financially viable. Without dedicated staff and continued investment in maintenance and modernization, pilot facilities cannot fulfill their role as the final proving ground for emerging manufacturing technologies and are subject to obsolescence.

Shared access to these facilities is particularly valuable for small and medium-sized manufacturers (SMMs), which often lack capital investment, equipment, or technical staff to evaluate new technologies independently. Institutes help lower these barriers by providing

affordable access, technical assistance, and workforce training that enable SMMs to experiment safely with advanced processes. This role is amplified by the regional dynamics described in Chapter 5, where institutes' ability to anchor shared facilities within local ecosystems is foundational to scaling innovative technologies into commercial production. Furthermore, Chapter 2 highlights that leading international institutes routinely offer such production-relevant facilities—including cleanrooms, demonstration factories, and configurable pilot lines—underscoring a capability gap in the current U.S. institute network that must be addressed to accelerate scale-up. Engagement through pilot and scale-up facilities also creates regional hubs of innovation, linking industry, academia, and government to strengthen supply chains and expand local economies.

Pilot and scale-up facilities are essential for validating and demonstrating manufacturing readiness, yet they are unevenly distributed across technology domains and regions. Many institutes face challenges in maintaining and upgrading equipment, funding skilled technical staff, and ensuring that these facilities remain accessible to SMMs. Without sustained investment in staffing and modernization, pilot facilities risk obsolescence and diminished value to the manufacturing ecosystem. Institutes could leverage existing shared facilities and establish new ones where critical gaps exist, using government and partner funding to support both facility creation and long-term sustainability. Pilot and scale-up sites could include provisions for equipment maintenance, renewal, and modernization, and could be staffed by personnel with the technical and management expertise needed to support multiple users safely and efficiently. These facilities must be affordable and readily accessible to SMMs for learning, demonstration, and training in advanced manufacturing technologies. A coordinated national network of such facilities, supported by skilled staff, sustainable funding models, and a clear commitment to long-term investment, will help de-risk technology adoption and accelerate industrial implementation.

Recommendation 3-3: Manufacturing USA institutes, in conjunction with sponsoring-agency support, should begin immediate planning and initial implementation of pilot-scale and scale-up facilities, with defined milestones and early operational capability established by 2030 and full-scale operations, broadly accessible to small and medium-sized manufacturers, achieved by 2035.

Implementation will require sustained federal funding and coordinated co-

investment from industry and regional partners. Manufacturing USA institutes and such facilities should be supported through long-term, renewable federal sponsorship that reflects their role as enduring national manufacturing infrastructure rather than short-term projects, with periodic performance-based review rather than assumptions of self-sufficiency within a single award cycle.

The effectiveness of these facilities ultimately depends on the people who operate them, engineers, project managers, and trainers, whose expertise forms the foundation of every institute's technology transfer capability. The next section explores how institutes organize and staff these technology transfer functions to ensure long-term impact.

Technology Transfer Teams and Staffing Models

Building on the infrastructure and technical expertise provided by pilot and scale-up facilities, effective technology transfer depends on the human capacity and organizational structures that guide innovations from demonstration to adoption. Institutes require teams with technical, business, and program-management skills to coordinate projects, engage partners, and manage the complex process of moving technologies into industrial use. National Academies studies of Manufacturing USA institutes have similarly emphasized that sustained institutional expertise and staffing are essential for supporting technology maturation and successful transition from research environments into industrial production systems.⁹⁰ These technology transfer teams serve as the bridge between laboratory success and manufacturing deployment, ensuring that innovations are ready for production and that adopters are equipped to implement them successfully.

A technology transfer team typically performs several core functions: assessing technology and factory readiness; coordinating among research, engineering, and operations; supporting intellectual-property and licensing processes; and providing training to end users. These teams often include institute staff, partner engineers, business-development specialists, and representatives from regional ecosystems such as Manufacturing Extension Partnership (MEP) centers, state economic development agencies, and community and technical colleges.

⁹⁰ NASEM, 2021, *DoD Engagement with Its Manufacturing Innovation Institutes: Phase 2 Study Final Report*, Washington, DC: National Academies Press, <https://doi.org/10.17226/26329>.

International models illustrate how formalized transfer teams contribute to sustained innovation. Germany's Fraunhofer Institutes and Taiwan's Industrial Technology Research Institute (ITRI) embed cross-functional teams directly within projects, ensuring continuity from research through commercialization. These organizations demonstrate the importance of maintaining teams with both technical depth and strong industry experience to navigate the handoff between R&D and production efficiently and consistently.

Within the Manufacturing USA network, staffing structures and levels of in-house expertise vary depending on each institute's mission, maturity, and technology domain. Five archetypes illustrate common models observed across the institutes:

- Proposal Development or Program Management Office—functions primarily as a convener and project coordinator, managing funding and stakeholder engagement without maintaining in-house facilities.
- Training Center or Services—focuses on knowledge transfer, workforce development, and dissemination of best practices.
- Testing Center or Services—provides laboratory-scale or certification-testing capabilities for members to validate technology performance.
- Process Development Center—offers engineering, modeling, and process-optimization expertise to mature technologies and improve manufacturability.
- Pilot or Scale-Up Facility—combines technical staff, equipment, and production environments for high-TRL demonstration and validation.

Institutes that maintain experienced, cross-functional teams tend to achieve faster and more reliable technology transitions. Skilled staff can identify manufacturability challenges early, anticipate barriers to adoption, and ensure that project outcomes align with industry needs. As noted in Chapter 2, foreign institutes maintain sizable in-house research and business-development staffs that provide continuity and technical depth; establishing comparable staffing models is essential if Manufacturing USA institutes are to achieve similar scale-up impact. Retaining this expertise requires stable funding and long-term staffing strategies, as turnover and reliance on short-term project funding can erode institutional knowledge.

Many institutes lack dedicated expert staff for technology transfer and commercialization, limiting their ability to support adoption at scale. Inadequate funding for long-term staffing and professional development can reduce the consistency and quality of technology transfer outcomes. Concerning teams for technology transfer, institutes could identify or establish dedicated technology transfer teams with sufficient technical, business, and program-management expertise to guide projects through adoption and implementation. Funding could include support for recruiting, training, and retaining expert staff capable of bridging technical, economic, and operational aspects of technology transfer. These teams could be available to support SMMs and entrepreneurial firms. Institutes could also develop long-term staffing strategies to ensure that institutional knowledge and expertise are sustained as technologies, members, and priorities evolve. Some of these staffing functions could be provided or coordinated through centrally located personnel within the Advanced Manufacturing National Program Office (AMNPO) or through other federal agencies working in partnership with AMNPO, to ensure that smaller institutes and those with limited resources can access specialized expertise and best practices.

Recommendation 3-4: Within 2 years, Manufacturing USA institutes and the Advanced Manufacturing National Program Office should establish dedicated, well-staffed technology transfer teams and long-term staffing plans, leveraging existing federal technology transfer expertise and programs where appropriate.

As discussed further in Chapter 4, cross-institute collaboration and interagency alignment will be essential to ensure that these teams can draw on shared expertise and avoid duplicated efforts across the network.

Convening Partners and Building Communities

A defining strength of the Manufacturing USA institutes is their role as neutral conveners that bring together industry, academia, and government to address complex manufacturing challenges that no single organization can singularly address. Through this convening function, the institutes create communities of practice that foster collaboration, trust, and shared purpose—conditions essential for effective technology transfer.

Institutes convene members and partners through technical councils, road-mapping workshops, annual meetings, and thematic working groups. These activities enable stakeholders to align with research priorities, coordinate investments, and accelerate the transition of innovations to industrial application. This coordinating function is particularly important given Chapter 2's finding that competitor nations anchor their manufacturing institutes within overarching industrial strategies, supported by strong central bodies that align technology, finance, and workforce systems. The convening role also supports workforce and standards development, ensuring that new technologies are accompanied by trained personnel, common terminology, and interoperable practices.

NextFlex, for example, has built a national community for flexible hybrid electronics that integrates small and medium-sized enterprises, universities, and defense partners through coordinated projects and shared facilities. The ARM Institute and MxD use similar models, organizing networks of manufacturers, solution providers, and educators to test and deploy automation, digital manufacturing, and cybersecurity solutions across sectors.

Although the institutes have established many successful partnerships, stakeholders, particularly SMMs, have noted that ease of engagement remains a barrier to broader participation. For some companies, it can be difficult to determine which institute aligns with their needs, how to join, or what return on investment to expect. Smaller firms often lack experience collaborating with academic or consortium-based organizations and may require guidance to navigate membership processes or project opportunities. This difficulty in SMM engagement reflects challenges identified in Chapter 2, where international programs such as SME Support Japan and ITRI in Taiwan employ structured outreach and advisory services that systematically integrate SMMs into their technology-diffusion pipelines. Simplifying engagement, clarifying value propositions, and developing common terminology across institutes could significantly expand industry participation and accelerate technology adoption. Institutes that make engagement intuitive and transparent strengthen their communities and increase the overall impact of the Manufacturing USA network.

Convening also extends beyond member engagement to include coordination across the broader innovation ecosystem. Institutes act as connection points among regional and national manufacturing programs, including MEP centers, workforce boards, and industry and professional associations. This networked approach ensures that lessons learned in one region or

sector can be shared widely and adapted to local needs, thereby amplifying the collective impact of public and private investment in manufacturing innovation. Chapter 4 expands on this point by demonstrating that fragmented engagement across agencies and institutes limits the scalability of technology transfer, reinforcing the need for coordinated, cross-institute mechanisms to support implementation and adoption.

Institutes that actively convene partners and foster accessible, transparent engagement are more effective in accelerating technology transfer and broadening participation across the U.S. manufacturing ecosystem. However, inconsistent engagement models and unclear membership processes can limit the ability of smaller firms and new entrants to benefit fully from institute resources and collaborations. Concerning building community, institutes could strengthen their convening capacity by simplifying engagement processes, standardizing communication of membership benefits, and aligning outreach across the network. Institutes could collaborate with AMNPO and other federal and regional partners such as MEP centers and economic-development agencies to improve accessibility for SMMs and entrepreneurial companies, and to share successful engagement practices across institutes. Enhanced coordination and transparency will ensure that all stakeholders can participate fully in the Manufacturing USA ecosystem and contribute to national manufacturing competitiveness. Institutes, working with AMNPO and regional partners, could simplify engagement processes and standardize outreach practices, as stated in Recommendation 4-6.

Effective convening and engagement also depend on clear measures of success. Establishing consistent metrics to evaluate collaboration, technology transfer outcomes, and community impact is therefore essential.

MEASURING SUCCESS: METRICS AND EVALUATION

Determining metrics for technology transfer is essential to evaluate institute effectiveness and ensure accountability. Metrics must balance near-term, leading indicators—such as the number of pilot projects launched, companies engaged, or technologies advancing through readiness levels—with long-term, lagging indicators, such as technology commercialization, job creation, export growth, and productivity gains. Leading indicators provide early signals of progress and help guide management decisions, while lagging indicators measure realized

outcomes and long-term impact. A comprehensive evaluation framework could incorporate both to capture the full innovation life cycle—from discovery to sustained market adoption.

Many institutes currently rely on limited measures such as publications or patents, which fail to capture the broader impact of technology diffusion. Quantitative metrics could therefore be supplemented with qualitative assessments, including stakeholder satisfaction, cross-institute collaboration, and regional economic benefits.

To develop a more comprehensive and consistent approach, metrics could encompass four interrelated categories:

- Technology metrics, such as advancement of technologies through specific readiness levels (TRLs, MRLs, ARLs, or XRLs), validation studies completed, standards developed, or intellectual property licenses executed.
- Economic metrics, including private investment leveraged, new product introductions, time-to-commercialization, and contributions to regional or national supply chain resilience.
- Workforce metrics, measuring the number of individuals trained, credentialed, or placed in advanced-manufacturing roles, as well as diversity and inclusion indicators.
- Ecosystem and collaboration metrics, such as the number and type of partnerships formed, engagement of SMMs, and evidence of technology diffusion beyond direct institute members.

Developing consistent, network-wide metrics is particularly important to benchmark performance and justify public investment. Earlier National Academies analyses examining Department of Defense engagement with manufacturing innovation institutes have also emphasized the importance of clear evaluation frameworks and consistent performance metrics for assessing institute performance and technology transition outcomes.⁹¹ The Government

⁹¹ NASEM, 2021, *DoD Engagement with Its Manufacturing Innovation Institutes: Phase 2 Study Interim Report*, Washington, DC: National Academies Press, <https://doi.org/10.17226/26149>.

Accountability Office^{92, 93} (GAO 2019, 2021) and previous National Academies' studies have emphasized the need for such standardization, but progress has been slow due to confidentiality constraints, data-collection challenges, and sectoral differences.

Improving network-wide data sharing will be essential to overcome these barriers. Institutes currently collect data independently, using varying definitions and formats, which limit comparability and the ability to aggregate results at the national level. A common digital platform or secure data-exchange framework, coordinated by AMNPO in collaboration with sponsoring agencies, will enable consistent reporting, protect sensitive information, and facilitate real-time analysis of progress across the network. Enhanced data interoperability would also allow lessons learned in one institute to inform others, accelerating learning and reducing duplication of effort.

Institutes and sponsoring agencies also face the challenge of aligning what they measure with what truly matters. While technology transfer outcomes—such as licenses executed, products commercialized, or workforce trained—are relatively straightforward to count, the deeper effects on competitiveness, resilience, and innovation culture are harder to quantify. The need for consistent, outcome-oriented metrics also reflects the international comparison in Chapter 2, where long-term, permanent institute programs employ standardized key performance indicators that reinforce accountability and enable sustained national manufacturing strategies. Balancing output metrics (activities and immediate results) with outcome-oriented indicators (enduring economic and societal impact) will be essential to capture the full value of Manufacturing USA investments.

The absence of clearly articulated standardized, outcome-oriented metrics across institutes impedes the ability to evaluate the effectiveness of technology transfer and to demonstrate the full return on public investment. Without comparable data and a common data-sharing framework, institutes and agencies face challenges in benchmarking performance, identifying leading indicators of success, and communicating impact to policymakers and the public. AMNPO, in collaboration with sponsoring agencies and other supporting organizations,

⁹² GAO, 2019, *Space Command and Control: Comprehensive Planning and Oversight Could Help DOD Acquire Critical Capabilities and Address Challenges*, GAO-20-146, <https://www.gao.gov/products/gao-20-146>

⁹³ GAO, 2018, *National Institute of Standards and Technology: Additional Review and Coordination Could Help Meet Measurement Service Needs and Strengthen Standards Activities*, GAO-18-445, <https://www.gao.gov/products/gao-18-445>.

could develop and coordinate a standardized framework of technology transfer metrics applicable across the Manufacturing USA network. These metrics could capture both quantitative outputs (e.g., technologies advanced, patents, licenses, adoption rates) and qualitative outcomes (e.g., partnerships formed, workforce impact, regional economic growth). The framework could include clear definitions, guidance on data-collection methods, mechanisms for benchmarking performance, and procedures for secure, network-wide data sharing. It could also balance leading and lagging indicators to measure both early progress and long-term impact. AMNPO could facilitate regular review and updating of the metrics framework to ensure continued relevance and alignment with evolving national manufacturing priorities.

Recommendation 3-5: Within 2 years, the Advanced Manufacturing National Program Office, with sponsoring agencies, should implement a standardized network-wide technology transfer metrics framework. If necessary, Congress should consider clarifying statutory reporting authorities to enable consistent performance metrics across all Manufacturing USA institutes.

ROLES FOR THE ADVANCED MANUFACTURING NATIONAL PROGRAM OFFICE

AMNPO plays a central role in coordinating, aligning, and amplifying the work of the Manufacturing USA institutes. As technology transfer mechanisms mature across the network, AMNPO's leadership and coordination are critical for ensuring that lessons learned, best practices, and performance data are shared efficiently and systematically. A strong, visible AMNPO presence also helps connect the institutes' collective efforts to broader national goals for innovation, workforce development, and industrial competitiveness.

Building on the findings of this chapter, AMNPO's leadership responsibilities encompass four interrelated functions:

1. **Establishing frameworks and common definitions.** AMNPO could provide clear, network-wide guidance on key concepts—such as technology transfer, scale-up, readiness levels, and commercialization—to promote a shared understanding across institutes and sponsoring agencies. Common definitions will

reduce duplication, improve communication with policymakers and stakeholders, and ensure that performance assessments are comparable and transparent. Chapter 2 shows that coordinated national governance structures are central to international institute success, highlighting the strategic importance of AMNPO in providing cross-institute alignment and integrating technology transfer functions within a broader industrial strategy.

2. **Coordinating shared resources and best practices.** AMNPO could serve as a central hub for identifying, collecting, and disseminating effective models for technology transfer. This includes establishing a Technology Transfer Best Practices Office, modeled after the existing Education and Workforce Development best practices framework. The office would gather and distribute proven approaches to project management, industry engagement, intellectual-property management, and technology demonstration. As noted in Chapter 2, international benchmarks illustrate that systematic sharing of best practices, including pilot facilities, staffing models, and business-development processes, substantially increases network impact and reduces duplication. AMNPO could also facilitate peer-learning workshops, maintain a repository of case studies, and promote collaboration among institutes facing similar technical or organizational challenges. The effectiveness of pilot and scale-up facilities depends critically on the ability to recruit and retain highly skilled technical and operational staff. Short-term funding horizons create disincentives for experienced personnel to join or remain at institutes, particularly when hiring occurs several years into a fixed-term award. For pilot-scale operations that require continuity, institutional knowledge, and operational reliability, long-term staffing models supported by stable federal funding are essential. As stated in Chapter 2, entities such as the Interuniversitair Micro-Electronica Centrum VZW have demonstrated the benefits of such longer-term commitments.
3. **Facilitating access to federal expertise and partner programs.** AMNPO could coordinate with other federal agencies such as the Department of Energy (DOE), Department of Defense (DoD), National Institute of Standards and Technology/Department of Commerce (NIST/DOC), and National Science

Foundation (NSF) to streamline institute access to technical expertise, funding opportunities, and standards-development resources. Where appropriate, AMNPO can also help broker partnerships with programs **within** NSF (e.g., I-Corps, I/UCRC, ERC) for commercialization training or NIST’s MEP centers for regional technology deployment. These collaborations can accelerate technology maturation and diffusion across sectors.

4. Developing and maintaining network-wide data and metrics systems.

Consistent with the recommendations of the prior section (“Measuring Success: Metrics and Evaluation”), AMNPO could lead the creation and ongoing refinement of a standardized metrics framework and secure data-sharing infrastructure for the Manufacturing USA network. This system could enable institutes to collect and report comparable information on technology transfer outcomes, including both leading and lagging indicators, while safeguarding proprietary or confidential data. The ability to benchmark performance across institutes will strengthen accountability and help demonstrate the return on public investment in advanced manufacturing.

Beyond these functional responsibilities, AMNPO also has an opportunity to champion long-term capacity building across the network. By promoting consistent definitions, data systems, and collaborative mechanisms, AMNPO can help sustain institutional knowledge even as individual institutes evolve. This continuity is critical to ensuring that the Manufacturing USA network remains adaptable, resilient, and aligned with national manufacturing priorities.

Although AMNPO has made significant progress in coordinating the Manufacturing USA network, opportunities remain to expand its leadership role in aligning institute practices, facilitating data sharing, and disseminating best practices. The absence of a formalized structure for coordinating technology transfer efforts limits the potential for collective impact across the network. These coordination responsibilities are closely tied to Chapter 5’s discussion of regional innovation ecosystems, as AMNPO’s national frameworks must enable institutes to translate technology transfer strategies into regionally grounded implementation models. Concerning technology transfer best practices, AMNPO, in collaboration with sponsoring agencies and institute leadership, could establish a formal mechanism such as a Technology

Transfer Best Practices Office to coordinate, document, and disseminate effective models for technology transfer and scale-up. This office could collect and share lessons learned, promote the use of standardized definitions and metrics, and facilitate access to federal and private-sector expertise. AMNPO could also continue to strengthen cross-agency collaboration with DOE, DoD, NIST/DOC, NSF, and other partners to ensure that institutes benefit from the full range of federal resources available to support technology maturation, transfer, and commercialization.

Recommendation 3-6: Within a year, the Advanced Manufacturing National Program Office should establish a Technology Transfer Best Practices Office and formal cross-agency coordination mechanisms, building on lessons identified in previous National Academies and GAO studies of Manufacturing USA institutes.

The committee's review of technology transfer and scale-up within the Manufacturing USA network underscores that effective coordination among institutes, agencies, and partners is essential for sustained national impact. AMNPO in conjunction with the proposed interagency directorate, as discussed in Chapter 4, provides the foundation for this coordination, but the continued success of the network depends on its ability to connect institutes not only through shared data and best practices but also through collaborative projects and cross-institute partnerships. Chapter 4 examines how networking across institutes and related programs can amplify these efforts, strengthen innovation ecosystems, and extend the reach of advanced manufacturing capabilities nationwide.

Chapter 4

Cross-Institute and Cross-Agency Networking

The wide-ranging technical waterfront covered by the current Manufacturing USA institutes offers a number of opportunities for enhanced interagency engagement and institute networking to spur innovation. Although the committee found examples of interagency engagement with institutes and cross-institute networking, greater innovation and impact of technical solutions are important as engagement and networking are expanded.

INTERAGENCY ENGAGEMENT

Manufacturing strategy at the national level has been previously set by the National Science and Technology Council (NSTC) under the auspices of the Office of Science and Technology Policy in the Executive Office of the President.⁹⁴ Recent examples of this strategy have set high-level goals and objectives for agencies to work toward achieving, but do not generally direct funding for specific technologies or the means by which technologies are to be developed. For example, the most recent strategy does not address the role of the Manufacturing USA network in support of the strategy. Instead, individual agencies determine which technologies will best support their own missions within the strategy and how to go about development. In general, NSTC processes do not support detailed program coordination between agencies to develop an overall national strategy for the development, manufacture, and deployment of specific technologies. More robust national-level planning with detailed agency coordination on technology development would serve the nation better by concentrating resources and ensuring that all required stakeholders understand their role in meeting strategy goals.

The institutes have generally been conceptualized, budgeted, competed, and managed by individual federal agencies. The agencies define the technical focus areas for institutes that will meet the needs of their specific missions. In this manner, the institutes are well aligned with the

⁹⁴ National Science and Technology Council, 2022, *National Strategy for Advanced Manufacturing*, <https://bidenwhitehouse.archives.gov/wp-content/uploads/2022/10/National-Strategy-for-Advanced-Manufacturing-10072022.pdf>.

needs of the sponsoring agency, and there is excellent incentive for the sponsoring agency to set requirements, connect with applications, and facilitate technology transition. Industry, academia, and non-profits have responded to agency requirements by proposing institute approaches and membership that meet their constituent's needs. As noted in Chapter 2, the committee did not encounter international models where government did not set strategic direction for funding priorities. The committee concludes that an agency-centric funding model provides the best set of incentives for success in meeting mission priorities while incorporating industry interests, guidance, and solutions. However, interagency collaboration is currently difficult because formal policies, processes, and incentives for interagency collaboration that could provide synergistic benefits with broader, national impact are not built into the Manufacturing USA network.

In this agency-centric funding model, institutes were generally well-funded through their first agreement period, as the scope of an institute was originally envisioned. Institutes undergo periodic review for effectiveness and relevancy by the sponsoring agency. If an institute is continued upon successful review, consistent with an intent to promote institute self-sufficiency, funding is in nearly all cases reduced to a much smaller amount that can cover basic operating expenses as well as some technical projects. The institutes therefore must seek other funding streams to sustain themselves. These streams are typically awarded through single projects that have a specific agency application target. These projects may be awarded by another agency within the sponsoring department other than the original supporting agency. Although these projects no doubt have good payoff for the funding agency, they tend to drive the institutes' efforts to nearer-term, more-focused applications.

The Manufacturing USA Strategic Plan published in December 2025 notes that in FY2023, "State, industry, and noncore federal funds contributed about \$380 million to these activities, representing a 2.4:1 investment match to the core federal funds."⁹⁵ Therefore, the Federal investment was approximately \$158 million. Further, the Manufacturing USA 2023 Annual Report states that in 2022, "the institutes attracted \$307 million from state, federal, and private funds in addition to \$109 million in base federal funding. This 2.8 to 1 investment match exceeds the program design of a 1-to-1 match, demonstrating how federal investment effectively

⁹⁵ Manufacturing USA Program Strategic Plan, 2025, Advanced Manufacturing National Program Office, National Institute of Standards and Technology, Department of Commerce, <https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.600-18.pdf>

catalyzes investment in industrial innovation.”⁹⁶ It is a tribute to the effectiveness of the program that the investment match exceeds the program design match. However, \$100-\$160 million spending annually between three agencies’ discretionary funds for the Manufacturing USA program is significantly lower than the \$1 billion-plus budgets for analogous programs of several international counterparts.

Conclusion 4-1: Based on the available evidence, the lack of dedicated, long-term institute funding runs the risk of reducing an institute’s ability to have broader industrial impact in addressing pervasive and/or higher-payoff technologies.

The committee found that the most widely cited example of interagency engagement by both agencies and institute directors was in the area of education and workforce development, as discussed in more detail in Chapter 6. Workforce education has broad interest across the agencies, is a core mission of the institutes, is noncompetitive (i.e., limited intellectual property [IP] barriers), and the approaches developed can be more easily transitioned across technologies. Importantly, workforce education is a unique focus area in that agencies such as the Department of Defense (DoD) have allocated separate funding specifically for education projects. The spread of NextFlex’s FlexFactor® program, for example, is a success story that was dependent on highly effective interagency collaboration and cross-institute networking.^{97,98}

However, examples of interagency engagement on technology were sparse. Agencies and institute directors noted several barriers during the committee’s May 20, 2025, Manufacturing USA Interagency Engagement and Cross-Network Collaboration Workshop and in responses to the committee’s Institute Director Questionnaire:

- Diverse mission focuses of the sponsoring agencies can lead to divergent technical priorities.

⁹⁶ Manufacturing USA Program Strategic Plan, 2023, Advanced Manufacturing National Program Office, National Institute of Standards and Technology, Department of Commerce, <https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.600-14.pdf>

⁹⁷ Building Manufacturing Workforce Programs that Can Have a National Impact, Manufacturing USA, <https://www.manufacturingusa.com/studies/building-manufacturing-workforce-programs-can-have-national-impact>

⁹⁸ This reference was added after release of the report to provide additional information on the program.

- Inconsistent agreement terms and conditions, IP agreements, infrastructure, and funding mechanisms in different institutes impede seamless collaboration.
- Funding and/or personnel are insufficient for collaborative projects.
- Opportunity for technical overlap is limited.
- Levels of maturity of the institutes and of the maturity of the technologies they are pursuing differ.

During the interagency workshop, the committee identified a best practice within DoD that better positions institutes to operate across a broad range of stakeholders by tailoring agreement terms and conditions prior to solicitation. DoD initiated a process that identified the range of potential stakeholders (e.g., industry, agencies, transition partners, and nonprofits) likely to be engaged in a particular technology during solicitation development. Stakeholders provided input on the anticipated range of applications, funding sources, and technology transition paths, for example. This information allowed the DoD program manager to work with an agreements officer to tailor the terms and conditions to provide maximum flexibility in accommodating potentially unique stakeholder characteristics and requirements prior to release of the solicitation. This tailored approach led to proposals that minimized some of the administrative friction cited previously by agencies and institute directors.

Translating technology advances for implementation at small and medium-sized manufacturers (SMMs) is a high priority for the institutes but is fraught with difficulties, perhaps chief among them being bandwidth of the institutes themselves to reach a large number of manufacturers. In this regard, the Advanced Robotics for Manufacturing Institute's (ARM Institute) collaboration with the National Institute of Standards and Technology's (NIST's) Hollings Manufacturing Extension Partnership (MEP) program and Pennsylvania State University's Digital Foundry at New Kensington, Pennsylvania, stands out as an example of a best practice.⁹⁹ Several MEPs across the nation are ARM Institute members, including Catalyst Connection (Pennsylvania), TechSolve (Ohio), MassMEP (Massachusetts), MANTEC (Pennsylvania), FuzeHub (New York), and others. This type of approach leverages the resources available to support a notionally regional center to extend its reach nationally.

⁹⁹ Institute Director Questionnaire Responses; Digital Foundry at New Kensington, <https://digitalfoundrynk.com>, accessed August 15; committee meeting with Sherri McCleary, Digital Foundry of New Kensington, August 12, 2025.

BOX 4-1**Digital Foundry Model—Supporting Technology Transfer for Small and Medium-Sized Manufacturers**

Pennsylvania State University's Digital Foundry at New Kensington, working in partnership with the ARM Institute, the Collaborative Ecosystems for Smart Manufacturing Innovation Institute (CESMII), and regional Manufacturing Extension Partnership (MEP) centers, demonstrates how shared facilities can accelerate technology adoption by small and medium-sized manufacturers (SMMs). The foundry provides digital and physical test-beds where manufacturers can explore robotics, automation, and smart manufacturing solutions without large capital outlays. It pairs these demonstrations with workforce-training programs and technical-advisory services that help firms integrate new systems into existing operations. The foundry provides: (1) technical assistance for start-ups and existing manufacturers, (2) access to advanced technologies and engineering and business-development expertise, and (3) strategic planning to accelerate innovation and growth. By combining technology transfer, workforce development, and community engagement under one roof, the Digital Foundry offers a replicable model for de-risking technology adoption, strengthening local supply chains, and driving regional economic growth.

The ARM Institute is collocated and collaborates closely with Catalyst Connection, the MEP supporting southwestern Pennsylvania. The ARM Institute has held several interactive workshops in partnership with Catalyst Connection for SMMs, aiming to provide two of these workshops each year. Past workshop topics have included robotics for sanding and finishing, robotic welding, and robotics for visual inspection. These workshops convene expert speakers for presentations centered on the workshop topic, an exhibit hall of robotics suppliers, and robotics demonstrations. Each workshop has convened around 80 attendees. The ARM Institute and Catalyst Connection now host these as hybrid events, furthering the reach and impact of this series.

The committee found that while individual projects do provide tangible advances in manufacturing technology, the results are typically targeted to a very specific product application

that can limit transferability of the technology more broadly.¹⁰⁰ On the other hand, internationally sponsored manufacturing institutes are able to address larger, more ambitious projects that can have broader and deeper impact. For example, as discussed in Chapter 2, these can be in the range of \$30 million and bring multiple institutes, industry, and academic partners together to solve a large technical challenge facing manufacturers.

COLLABORATION WITH FEDERAL LABORATORIES

Federal laboratories provide a rich resource for collaborative efforts with the institutes but are presently underutilized for a variety of reasons. Their deep technical expertise, access to world-class facilities, and long-term R&D can provide critical support to institute projects.

Note that there are several key differences between DoD, Department of Commerce (DOC), and Department of Energy (DOE) laboratories in their ability to easily engage with the institutes. In general, DoD and DOC laboratories, which are government owned and operated, do not have a mandate for full cost recovery from collaborative efforts with the institutes; DOE's national laboratories do, as a requirement of their contracts with DOE. Thus, DoD and DOC laboratories may be able to provide any required in-kind cost sharing more readily. Additionally, each DOE's national laboratory has contractual terms and conditions under which they operate that can create administrative friction when interfacing with the terms and conditions imposed by collaborative efforts with the institutes. While DoD and DOC laboratories must comply with federal and agency laws and regulations, there are no additional contractual terms and conditions that could create barriers to collaboration.

Some national laboratory leaders cited their contract's management and operating terms and conditions with DOE as being, at times, inconsistent with membership and intellectual property agreements with institutes, making collaboration with the institutes difficult or even intractable.¹⁰¹ Idaho National Laboratory (INL) has worked with DOE to modify the terms and conditions for its management and operations contract to facilitate collaboration with the institutes. The committee views this proactive approach to modifying contractual arrangements to facilitate collaboration a best practice.

¹⁰⁰ Committee meeting with Dr. Philip Freeman, Senior Technical Fellow, Boeing Research and Technology, July 1, 2025; Institute Director Questionnaire Responses.

¹⁰¹ Interagency Workshop.

Several leaders from National Laboratories noted that the cost-sharing requirement for the institutes makes it difficult for them to participate in collaborative projects, making their capabilities inaccessible. For example, the National Laboratory of the Rockies (NLR) and INL maintain unique test-bed laboratories, called ARIES (Advanced Research for Integrated Energy Systems) and Integrated Energy Systems, respectively, that are able to test megawatt-class, integrated electrical power and heat systems. The Electrified Processes for Industrial eXcellence (EPIXC) institute is developing suites of technologies for manufacturing plants that could be effectively demonstrated with integrated testing in these facilities, but the cost of using the facilities is prohibitive as neither the institute nor the laboratory is able to cover these costs. The committee took note of a couple of best practices that address this challenge. In the first, the Collaborative Ecosystems for Smart Manufacturing Innovation Institute (CESMII) worked with DOE to provide funds directed to the national laboratories for the purpose of collaboration on CESMII projects. In another best practice, NLR is able to leverage funding provided by the state of Colorado to collaborate with institute projects.¹⁰² Several of the Federal and National Laboratory participants in the interagency workshop noted that they are not able to meet, or justify, the cost-sharing match requirement for education and workforce development projects and suggested that these types of projects could be exempt from requiring cost sharing.

CROSS-INSTITUTE NETWORKING

Although there may not be, nor should there be, universal opportunities for collaboration between all institutes, it was evident that collaboration between institutes is not commonplace. The committee concludes that increasing the level of collaboration on joint projects would achieve the maximum impact on U.S. manufacturing by offering more integrated solutions, particularly to SMMs. A good example of a cross-institute collaboration (cited in a response to the committee's institute director questionnaire) is on a project called BIO INSPECT (BIOlogical, Integrated, Novel, Silicon Photonics for Efficient Characterization and Testing), where AIM Photonics is working with BioFabUSA to automate processes that turn human stem cells into pancreatic islets that can be used to treat diabetes. In this project, AIM Photonics uses its expertise in optoelectronics to apply photonic integrated circuits-based sensors to in-process

¹⁰² Ibid.

monitoring, while BioFabUSA employs its competency in biofabrication for cell production. The major benefit will be to make the islet production a more predictable and better-controlled process. Agencies and institute directors alike cited technology roadmap and standards development as high-impact outputs of the Manufacturing USA network. The committee noted a best practice in the co-development by Manufacturing x Digital (MxD) and America Makes of a joint technology roadmap for additive manufacturing that includes a secure data framework and use of artificial intelligence and machine learning in the qualification of additively manufactured parts. It took the competencies engaged in both institutes to generate integrated roadmaps.

Both agency representatives and institute directors cited the same barriers listed previously for interagency engagement as barriers to cross-institute collaboration: differing mission focuses, administrative barriers, insufficient funding and/or staff, limited technical overlap, and differing maturity levels of the institutes. Some agency and institute representatives indicated that, because of limited funding and adjacency of technologies for some institutes, there could be a sense of competition between institutes. This sense of competition was most notable among those institutes that were concentrated on digitally native technologies. Furthermore, the committee did not find evidence of substantial incentives for institutes to collaborate and only observed limited encouragement for collaboration across agencies.

The MEP Enterprise Information System (MEIS) is used by the MEP National Network to track and report on the performance of its centers and the services they provide to U.S. manufacturers. MEIS enables the collection, tracking, and reporting of data related to MEP center activities, including services delivered, clients served, center staff, expenses, revenues, and more.¹⁰³ It also facilitates the reporting of client impact data, such as new and retained sales, jobs, and cost savings. It is a relational database that links company profiles to discrete activities, allowing for detailed tracking and analysis. It also includes features for updating staff, locations, contacts, and roles, as well as for managing survey results and validating outlier data, and can interface with other systems including Customer Relationship Management systems such as

¹⁰³ National Institute of Standards and Technology, 2016, *Reporting Guidelines: Center Operations, Job Accelerator, Make It in America, M-TAC, and B2B Network*, January 1, Department of Commerce, https://www.nist.gov/system/files/documents/2018/08/24/nist_mep_6.4_car_reporting-guidelines-080117.pdf; National Institute of Standards and Technology, 2019, *Privacy Impact Assessment for the 480-01 MEP Enterprise Information System (MEIS)*, Department of Commerce, https://www.commerce.gov/sites/default/files/opog/NIST_480-01_PIA_SAOP_Approved_FY21.pdf.

SalesForce. For the Manufacturing USA network, a system similar to MEIS could help to support data-driven decision making, program evaluation, impact, and accountability, as well as help support collaboration across institutes.

Dealing with Ineffective Interagency Strategic Planning and Coordination

There is currently no formal process for agency decision authorities to participate in interagency budget planning, coordination, and alignment for the purpose of meeting national manufacturing strategic priorities. A newly established Interagency Council could develop this process for the Manufacturing USA network. This body could consist of the Associate Director for Innovation and Industry Services (NIST), the Assistant Secretary of Energy (Critical Minerals and Energy Innovation), and the Director, Technology Innovation for the Industrial Base (DoD). Such a body would develop and, on an ongoing basis, update and implement a strategy that would (1) align national priorities in manufacturing with manufacturing institute programs and investments across the agencies, as consistent with the recommendations in this report; (2) identify critical technology areas where agency funding is required to meet industry needs; and (3) coordinate agency investments to maximize cross-agency and cross-institute technology efforts leveraging the institutes' reach and resources. The Advanced Manufacturing National Program Office (AMNPO) would support this body in analysis, coordination, execution, and strategy development.

The key to successful interagency engagement is maintaining positive relationships among all the institutes and taking an entrepreneurial approach to building these relationships that will enable a seamless transfer of assistance to industry, a strong ethic of shared benefit and being able to strive for aggregate reach for achieving a higher level of mission at a cost saving to taxpayers. The Interagency Council would be able to measure success as purposeful collaboration of complementary technologies which would allow their members to get a full range of support to grow multiple aspects of their R&D needs and gain the ability to increase effectiveness nationally.

Recommendation 4-1: Within the next 2 years, Manufacturing USA institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense)

should create an Interagency Council as a formal, overarching directive body to set an integrated strategy for the Manufacturing USA institutes.¹⁰⁴

Dealing with Differences Within and Across Agencies

Differences between the terms and conditions of various agency agreements, institute intellectual property agreements (consistent with industry-sector practices), challenges with exchanging funds between agencies, and differences in data-sharing policies create barriers to both interagency engagement as well as inter-institute networking.

Recommendation 4-2: The Advanced Manufacturing National Program Office, working with the Interagency Council and sponsoring agencies, should establish harmonized procurement, funds-transfer, intellectual-property, and data-management policies that enable seamless collaboration across agencies and institutes. This effort should be undertaken in consultation with the United States Manufacturing Innovation Council, as appropriate, and aim for harmonized policies and processes by 2030.

Dealing with Competing Institute and Agency Missions

As each institute is sponsored by a single federal agency, which provides the majority of the institute's federal funding, agencies place first priority on their mission areas when funding and setting technical priorities for the institutes they sponsor. This model generally works well by driving institute connection with specific agency needs and technology transition to stakeholders. However, it can also create either real or perceived barriers to interagency collaboration and cross-institute networking with little incentive to overcome barriers. Additionally, limits to federal funding and adjacency of some technology areas covered by the institutes can create a real or perceived competitive environment within the Manufacturing USA network. The lack of cross-institute collaboration to develop integrated packages of advanced manufacturing technologies limits the ability of institutes to provide meaningful support to

¹⁰⁴ This sentence was changed after release of the report to clarify that the recommendation applies to all institute sponsoring agencies.

SMMs, a core Manufacturing USA constituency that has been slow in adopting advanced manufacturing.

Recommendation 4-3: By 2030, Congress should appropriate funding on par with comparable international programs to the Manufacturing USA institutes to create an interagency initiative that would competitively award dedicated funds to incentivize cross-institute collaboration by addressing grand challenges in manufacturing. A project source selection team should comprise representatives from the Manufacturing institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense) to ensure broad applicability across mission spaces and alignment with national manufacturing priorities.^{105, 106}

An initiative specifically focused on interagency and inter-institute collaboration would better promote innovation at the cross section of technologies. Additional funding beyond current levels would be needed to enable a focus on integration of technologies across institutes that would provide broad and impactful capabilities and make them more accessible to SMMs. The network could consider using MEPs as a source of requirements and coordinate this development with MEP to better ensure access by SMMs to these packages. This could enhance institute effectiveness, sustainability, and impact by providing additional stakeholders and resources to the network. The Digital Foundries model in southwestern Pennsylvania also provides an approach for dissemination of these integrated packages to SMMs that institutes could move to adopt.

Recommendation 4-4: The Advanced Manufacturing National Program Office should work with the Manufacturing Extension Partnership (MEP) program to create a process by 2030 that ensures that these integrated packages of advanced manufacturing technologies developed by institutes are disseminated to MEPs nationwide for implementation by small and medium-sized manufacturers.

¹⁰⁵ This recommendation was changed after release of the report to clarify that the recommendation applies to all institute sponsoring agencies.

¹⁰⁶ This recommendation was changed after release of the report to clarify the budgetary reference.

Digitally Native Manufacturing Technologies

There are tremendous technological needs, integration points, and standards that are pervasive across digitally native manufacturing technologies. To address these, an integrated strategy is needed across the Manufacturing USA network to chart a path forward. Such a focus would help clarify roles and responsibilities across the digitally-focused institutes, whose technologies are also largely horizontal, (i.e. ARM Institute, CESMII, CyManII, and MxD), to promote multi-disciplinary innovation across the Manufacturing USA network, broaden considerations of cybersecurity across all the institutes, and address data management policies and standards across the network and industry. When considering cross-institute collaboration, it is recommended that institutes focused on horizontal technologies (e.g., crosscutting) take the leading role.

Recommendation 4-5: Within the next 2 years, the Advanced Manufacturing National Program Office, in coordination with the Interagency Council, should lead an interagency effort to develop a robust strategy specifically focused on digital manufacturing across the Manufacturing USA network.

Reaching Small Manufacturers

Institutes are hampered in reaching a greater number of SMMs, given limitations in the number of technical personnel and funding resources available within the institutes. Leveraging federal programs, such as the Manufacturing Extension Partnership program, and state programs has proven to be effective in expanding institute impact.

Recommendation 4-6: Within the next 2 years, the Advanced Manufacturing National Program Office, in coordination with the Interagency Council, should create a multiprong strategy that enhances use of the Manufacturing USA network's capabilities across federal and state government agencies and small and medium-sized manufacturers (SMMs), including coordination with the Manufacturing Extension Partnership (MEP) network, and provides resources as to how agencies and SMMs can work with institutes to enhance interagency engagement.

The strategy could include collaboration with MEP to develop and provide organic resources to make SMMs more aware of the Manufacturing USA network institutes and how best to work with them. In turn, AMNPO and other sponsoring agencies for institutes could develop at institutes a better understanding of needs for SMMs in their industrial sector. Development of internal technical expertise to offer an organic technical capability to assist SMMs could be encouraged within the institutes to aid technology translation to SMMs. At the same time, institutes could simplify their engagement processes and standardize outreach practices to ensure clear, consistent, and easily navigable entry points for stakeholders.

Collaboration Between Institutes and National Laboratories

Collaboration between the institutes and DOE's national laboratory system can be challenging due to the laboratories' requirement for cost reimbursement and lack of dedicated project funding available to the national laboratories to work with the institutes. Some institutes have successfully worked with DOE-allocated funding specifically to be used for collaboration with the laboratories. Established DOE programs, such as its High-Performance Computing for Advanced Manufacturing, provide competition-based resources that could provide a model to enhance collaboration between its laboratories and the institutes. Additionally, the terms and conditions in national laboratory management and operations contracts can present barriers to collaboration, given incompatible institute project agreement terms and conditions.

Recommendation 4-7: Within the next 2 years, the Department of Energy (DOE) should work with national laboratories to explore modifying management and operations contractual agreements to be compatible with institute agreement terms and conditions. Additionally, DOE should make funding available to national laboratories for the specific purpose of collaborating with institutes on DOE priority projects.

Chapter 5

Regional Economic Development

In the 21st century, global technology competition—characterized by multiple centers of research and development around the world, the deep integration of advanced manufacturing and research, and the rapid rise of China as a technology competitor and a strategic rival—has proven that U.S. technology leadership in and of itself is not sufficient. Sustaining global technological leadership and the benefit it brings requires a robust domestic supporting ecosystem that sustains this leadership as well as the manufacturing scale-up environment that takes advantage of this leadership to bolster the nation’s economic growth and national security objectives.

In this context, the Manufacturing USA institutes could serve a critical national mission. It is important that they provide a robust shared space for industry and academia to work together to conduct applied research, develop new technologies, products, and manufacturing processes, and establish programs to build the skilled technical workforce—all with the goal of driving innovations from early-stage research to scalable domestic production at a globally competitive pace.

Although technology-based competition is global, ecosystems supporting manufacturing in the United States are inherently regional, and thus it is critical that new manufacturing technologies be introduced and experimented with regionally and then move toward national adoption at larger scale. So, for institutes to introduce their advanced manufacturing technologies, it is critical that they have regional implementation links.

Although the institutes can play a significant role in connecting stakeholders across a region into a viable network or ecosystem for production and innovation, and although there are important examples of how institutes across the Manufacturing USA network do address aspects of this role, they currently lack the scale and long-term viability to fully address this complex assignment.

To better understand this local dimension, the committee engaged with numerous regional stakeholders. Most notably, during the committee’s roundtable at the ARM Institute, committee members met with regional leaders from southwest Pennsylvania to discuss assets and capabilities as pertains to the region’s : science and engineering enterprise; skilled

workforce; and facilities and equipment; capital investment; supply chains; entrepreneurship; and scale-up challenge; and regional networks and institutions; local impact; and federal/state/local partnership programs. The committee also held a virtual roundtable with NextFlex leadership and stakeholders to discuss key drivers, partnerships, and metrics for regional networks and institutions; hubs, particularly, the impact and role of science and engineering enterprise; skilled workforce; facilities and equipment.

THE LOCAL CONNECTION

The institutes' role as ecosystem connector is necessarily regional in focus for three reasons.

Assets are local: Technology development and production scale-up take place in the context of local geographic distributions of capital equipment, infrastructure, know-how, workforce skills, and cooperative arrangements. A given region will have, given its own history, a mix of resources and organizations, including start-ups, manufacturing firms, government agencies, labs, universities, and technical colleges as well as banks, philanthropies, and other providers of financial capital. Also, often in the mix are workforce investment boards, economic development agencies, and community colleges, which can be some of the institutes' most important non-federal partners. Each institute—working alongside regional development agencies—has an important role in taking stock of available regional assets and contributing to the establishment of additional capabilities, the repurposing of others, and developing new proficiencies where there are gaps. Indeed, the institutes' generative role of building the ecosystem is significant. Often, institutes must actively create assets because many regions served by Manufacturing USA institutes do not have a pre-existing, well-distributed stock of capital equipment, workforce skills, and cooperative arrangements. The institute is often the catalyst that causes these assets to materialize in a region, particularly in regions that have experienced industrial decline.

Connecting assets requires local cooperative networks: Connecting this stock of local but often disconnected assets into a productive network requires cooperation across a variety of organizations that often have differing missions and operating cultures. Cooperation can stall when there is missing information or when incentives are misaligned. The Manufacturing USA institutes have a role in recognizing the challenges that these various actors have in working with each other and in helping to design locally focused rules that build trust and cooperation. For

example, one set of rules may pertain to the shared use of technical facilities where participants need to figure out who contributes what to maintain the facility and who owns the resulting intellectual property and know-how. The committee acknowledges there can be tension between locally tailored rules and the federal oversight framework, including Part 200 of the Code of Federal Regulations prescribing instructions for federal cooperative agreement structures such as specific terms around cost share, intellectual property (IP), and deliverables. Some institutes themselves face the same cooperation challenges they are asked to solve. The federal terms they operate under do not always align neatly with the needs of regional partners—particularly SMMs which can face particular barriers to participation in these cooperative networks because they may lack the administrative capacity to navigate federal compliance requirements.

Local stakeholder buy-in is needed to sustain the effort: Regional innovation ecosystems are cooperative networks of regional assets and capabilities that also effectively draw in national resources. Effective innovation ecosystems yield local economic benefits in terms of employment and economic growth. By connecting the local community to the opportunities inherent in a region's growing industry, each manufacturing institute has a role in helping to drive this regional dynamic. Institute efforts that contribute to workforce development, for example, not only invest in their own needs but also support the emergence of new industries, while also creating a constituency to encourage public and private contributions to maintain the work of the institute. Rooting the institute in the region, in this way, helps sustain the institute over the long run. In turn, the long-term viability and scale of the institute are needed to develop the technology and to create local economic and employment benefits.

In reality of course, the institutes operate within a set of constraints and the operational realities—particularly around federal compliance constraints, SMM accessibility, and the sustainability transition. These are structural challenges inherent in the Manufacturing USA model. While benefits of regional engagement is very important, it does not compensate for the conditions under which these benefits may break down, such as if an institute's technology focus does not align with the region's dominant industries or when the regional labor market cannot supply the workforce the institute needs.

KEY CHALLENGES

The committee's long-term vision is for the Manufacturing USA institutes to serve as reliable and sustainable institutional anchors enhancing regional capabilities to innovate and scale up a variety of technologies that advance regional economic development and employment. In turn, the network of these locally focused efforts collectively contributes to the nation's competitiveness and national security objectives.

Success depends on sustained efforts over the long term and at sufficient scale. In this regard, the institutes' role in regional economic development and technology leadership currently faces several major hurdles.

Narrow focus on technical missions: Although distributed across U.S. regions, the Manufacturing USA institutes do not always take full advantage of this network structure to lead and drive regional growth. Most institutes, in part because of limited resources and the national orientation of the agencies that support them, remain focused on their technical missions in accelerating technological development and coordinating pre-competitive research. In many cases, institutes by definition often have a narrow focus by design. Sponsoring agencies define technology focus areas that serve their mission needs, and cooperative agreements bind institutes to those focus areas. Institutes that have successfully broadened their regional engagement have typically done so by interpreting their technology charter creatively to be congruent with existing technology mission, not around it.

Missing strategic perspective: Moreover, and as a result, many institutes lack the strategic perspective and associated dedicated expertise to build regional ecosystems as a means of accelerating economic development and engaging a stakeholder base positioned to rapidly commercialize their advanced technologies.

Fragmented and subcritical funding structures: The current financing structure for the institutes—which provide small amounts of support over short timelines—does not allow the institutes to build the scale and capacity to grow regional roots needed to address global competitive challenges. The tension between time-limited federal funding and the long-time horizons required for regional ecosystem development pose a significant sustainability challenge. Arguably, the transition from federal to non-federal funding is the single most significant challenge facing the institute network as also addressed in chapters 3 and 4. Existing sources of funding are often highly fragmented across federal and state agencies. Furthermore, bureaucratic

constraints make coordination across federal programs needed to achieve a sufficient scale of effort difficult (see Chapter 4). Support from philanthropic foundations is valuable when available but is often idiosyncratic and, at best, forms a patchwork solution. In practice, an institute pursuing a regional workforce initiative may need to braid funding from (for example) its cooperative agreement, a state workforce board, a Department of Labor grant, and an EDA investment—each with different reporting requirements, cost-share rules, and performance metrics. The administrative burden of managing these overlapping compliance frameworks is substantial and falls disproportionately on smaller institutes with fewer administrative staff.

INSTITUTES AS ECOSYSTEM INTEGRATORS

The Manufacturing USA institutes are designed to connect a broad range of stakeholders, including member companies, universities, community colleges, state and federal agencies, and research entities. They can provide shared infrastructure, facilitate public–private partnerships, and focus on region-specific needs to accelerate innovation, integrate supply chains, and revitalize communities, ultimately strengthening the entire U.S. industrial base. This outreach takes place in a variety of contexts.

Partnering with Universities

Manufacturing USA institutes engage universities through collaborative applied research, shared workforce development programs such as internships and apprenticeships, and the creation of integrated technology and innovation ecosystems. For example,¹⁰⁷

- The Cybersecurity Manufacturing Innovation Institute (CyManII) is led by the University of Texas San Antonio and has named The University of Texas System, Clemson University, University of Pittsburgh, University of California, Irvine, Indiana University, and Purdue University as managing members.
- The Advanced Robotics for Manufacturing Institute (ARM Institute) includes, for example, the University of Maryland as one of its more than 400 partners.

¹⁰⁷ This list was changed after the release of the report to correct the leadership and management of these institutes, the engagement of the universities, and the role of ARM institute as an independent non-profit.

- North Carolina State University is a long-time partner of Manufacturing USA institutes, including being the lead organization for PowerAmerica.

These partnerships are a win-win for both the institutes and universities. The institutes can help bridge the gap between academic research and market applications, while universities can gain access to state-of-the-art equipment and resources offered by the institutes.

Providing Small Firms Access to Advanced Facilities

Some institutes offer access to pilot-scale manufacturing facilities and cutting-edge equipment that many smaller companies would not be able to afford on their own. For example,

- MxD, in Chicago, Illinois, offers a 22,000-square-foot “future factory” floor where manufacturers can experiment with new technologies.
- LIFT operates a 100,000-square-foot high-bay facility in Detroit, Michigan.
- CESMII offers a nationwide network of Smart Manufacturing Innovation Centers (SMICs). Through the CESMII Smart Manufacturing Interoperability Platform, members can use shared software and digital tools for data modeling, analytics, and other applications to increase efficiency and productivity.

Connecting Small and Large Companies¹⁰⁸

A number of institutes facilitate collaboration by bringing together their large members and smaller technology providers. For example, ARM Institute connected ARIS—a robotics start-up that developed an intuitive, augmented-reality user interface for programming robotic 3D scanning—with a large automotive manufacturer for a human–robot collaboration project.

Partnering with Philanthropic Organizations

Philanthropies can align with Manufacturing USA institutes to address shared priorities, including those focused on workforce development and support for veterans.

¹⁰⁸ An example was deleted after release of the report to remove an incorrect partnership example.

- A prime example is the Caterpillar Foundation’s grant, which supports the Heroes MAKE America initiative, a program that provides training and credentialing to help transitioning service members, veterans, and military spouses find careers in modern manufacturing.
- The ARM Institute has acted as a fiscal sponsor for a grant from the Richard King Mellon Foundation to the Keystone Space Collaborative, a Pittsburgh-based space industry organization. This grant supports the development of the next generation of space industry businesses and talent in the region. By working with philanthropies, the ARM Institute diversifies its funding sources beyond its primary support from the Department of Defense (DoD) and member organizations.

Engaging State and Local Governments

While the level and scope of engagement vary across the states, several institutes work with state and local governments to establish programs and initiatives that directly benefit their communities.¹⁰⁹ States often provide financial investment and other resources to match federal and private investments in the institutes. This co-investment model creates a strong incentive for other partners to join and contribute as well. State and local governments can also contribute to the institutes’ public–private partnership models by investing in shared facilities and equipment, which in turn create shared resources and expertise that boost local and regional economic development. Finally, states and local governments often collaborate with institutes on programs such as apprenticeships, internships, and mid-career training to build the advanced manufacturing workforce needed to support technological innovation and economic growth in their region.

Drawing in Private Investments

While the institutes themselves are not venture capital firms and do not directly invest in companies or provide venture funding, they can “convene the right people” in their industry clusters, helping to facilitate introductions and build networks that lead to investment

¹⁰⁹ Manufacturing USA, n.d., “How to Engage with Manufacturing USA Institutes,” <https://www.manufacturingusa.com/pages/how-engage-manufacturing-usa-institutes>

opportunities. They can also help to explain or demystify the technology, thereby lowering perceptions of risk and encouraging new investments.

Institutes often bring together a wide range of partners, including industry, academia, and government agencies. This networking helps forge relationships between manufacturers (including small and medium-sized businesses) and financial partners, which can lead to new funding opportunities. The NextFlex institute, for example, has worked with local city planners to attract capital and talent to San Jose. Similarly, America Makes has worked with local municipal planners to attract capital and talent to northeastern Ohio.

The institutes also collaborate with banks and financial institutions indirectly through their industry members and by fostering a favorable ecosystem for innovation and investment. Although financial firms are not typically core members of a manufacturing ecosystem, the institutes' activities—such as de-risking new technologies and convening industry stakeholders—reduce barriers that help manufacturers secure financing for development and expansion.

BUILDING THE REGION'S ADVANCED MANUFACTURING SKILLED WORKFORCE

As described in Chapter 6, many institutes work with local partners to offer educational and skill development programs, helping to meet the current and emerging needs of the workforce in high-demand manufacturing fields. These institutes partner with universities, community colleges, and local schools to develop the manufacturing workforce pipeline. For example, the ARM Institute has developed an accreditation program to highlight quality training programs and a website to connect students to these opportunities.

In many cases, institutes offer a variety of training initiatives, including internships, entry-level programs, and training for current employees to upskill them for advanced manufacturing technologies. For instance, ARM Institute and CESMII, through the Digital Foundry in New Kensington, Pennsylvania, offer training to workers at small and medium-sized manufacturers from engineering to the shop floor.

Institutes such as the BioFabUSA project in Manchester, New Hampshire, connect local, underserved residents with job training programs that broaden the skills pool for bioindustrial manufacturing.

Furthermore, some institutes partner with nonprofits and other community organizations to address nonacademic barriers to workforce participation, such as lack of childcare or transportation. The University of Texas at El Paso (UTEP) works with a local economic development agency and CESMII to train area residents in smart manufacturing for local companies. The program specifically aligns the skills of an underserved, local population with the needs of nearby technologically advanced factories.

Key Challenges

Even though there are many such best practices initiated by the institutes to be found, successful institute initiatives and partnerships with local efforts to build skilled workforces face a major challenge in scaling these efforts for reasons that rest within a region's prevailing institutions and structures.

Missing incentives: Building the high skill and skilled technical workforce necessary to support the scale-up of an emerging technology presents the proverbial chicken-and-egg problem—missing incentives for students and workers to invest in the skills needed for an industry that does not yet exist, but without which the industry cannot come to be. There is often a mismatch between the need for workforce skills and the institutional capacity and flexibility to provide this training.

Limited local funding: In some regions, there may be insufficient funding or resources at the local level to support the creation of updated training programs that keep pace with evolving technologies and the specialized skill requirements for new technical roles.

Complex processes: Local community colleges and educational institutions often face long and complex bureaucratic processes to update their course offerings. This makes it difficult to quickly adapt curricula to reflect new technologies and industry best practices, leading to a skills lag.

Misaligned incentives and regulations: Out-of-date regulations and misaligned incentives often hinder direct collaboration between local businesses and educational institutions. This limits the flow of information about industry needs and creates missed opportunities for practical guidance for students.

Aligning these incentives is a complex task, and while the institutes are well positioned to provide leadership in this effort, they lack at present the budgetary and political muscle power to

redirect priorities. Chapter 6 discusses more about framing workforce activities as a partnership function rather than a standalone institute activity to overcome funding constraints.

CONNECTING TO STATE AND OTHER FEDERAL RESOURCES

As currently structured, the Manufacturing USA institutes receive initial “start-up funding” from DoD, the Department of Energy (DOE), and the Department of Commerce (DOC) through cooperative agreements. These federal funds are expected to be matched by substantial nonfederal contributions from industry, academia, and state governments. This funding model is supposed to ensure that federal investment stimulates innovation while being augmented by significant local private and state resources. Moreover, as noted previously, the current approach expects that federal funding will decrease over time as the institutes become self-sufficient.

Addressing State and Local Priorities

State support for the Manufacturing USA institutes—which is expected to complement the federal start-up contribution—varies significantly. This source of funding depends on several factors, including the state's economic priorities, the technological focus of a specific institute, and the availability of supplementary funding programs.

The focus of a state's support for an institute can also vary, often concentrating on specific tasks within the broader set of its missions. For example, the State of Pennsylvania's support to the Pittsburgh-based ARM Institute focuses narrowly on education and job training activities through its Manufacturing PA Innovation Program and Manufacturing Fellows Initiative.

The Manufacturing USA institutes also collaborate with local governments by including them as partners in their public–private partnerships, establishing regional workforce development programs and training networks, investing in local economic ecosystems, and creating new manufacturing hubs to attract businesses and provide access to shared prototyping and manufacturing facilities.

Institutes vary in their ability to address this diversity of state and local priorities. This results in varying levels of financial and resource investment for institutes located across the United States. It also means that each institute has to coordinate and balance funding from its home state with other sources to balance its budgetary portfolio.

Coordinating with Additional Federal Programs

The institutes also leverage support from other federal initiatives that complement their work to advance manufacturing.

The Manufacturing Extension Partnership (MEP): MEP, administered by the National Institute of Standards and Technology, and the Manufacturing USA institutes are natural complements (see Chapter 4). The latter focuses on groundbreaking research and development for new technologies, while the MEP National Network, with its local centers, focuses on bringing these emerging technologies and existing best practices to small and medium-sized manufacturers to help them implement innovations, improve operations, and develop a skilled workforce. Both programs also collaborate to address workforce needs by identifying skills gaps and providing training opportunities. The MEP network helps local manufacturers implement the new technologies by training their existing workforce and developing new talent.

The Tech Hubs Program: Established by the CHIPS and Science Act, the program of the DOC Economic Development Administration allows states and regional consortia to receive federal funding to build innovation ecosystems, which can include Manufacturing USA institutes as key partners. The Advanced Regenerative Manufacturing Institute (ARMI), for instance, was able to secure additional grant money for its regional technology hub through the Tech Hubs program.

The State Manufacturing Leadership Program: This DOE program helps states fund initiatives that assist small- and medium-size manufacturers (SMMs) in adopting smart manufacturing technologies. Funded by the Infrastructure Investment and Jobs Act (P.L. 117-58), this program involves states such as California, Ohio, and Pennsylvania.

Taken together, the regional integration mission of the Manufacturing USA institutes is a complex one requiring simultaneous outreach across these many actors each of whom has differing policy objectives, operating procedures, and budgetary cycles. As a result, these available resources are rarely aligned, making it difficult for institutes to readily create cohesive regional networks that effectively link stakeholders involved in research, workforce development, and production capabilities across different businesses and locations. While this

ecosystem building role may be essential to their success, institutes are often constrained, lacking the resources, expertise, and strategic outlook to carry out this essential task.

The distribution of assets, people, and cooperative networks supporting manufacturing are highly local in nature. Although regionally located, however, these capabilities are not necessarily aligned with each other. Building cooperative ecosystems requires strong alignment across these many actors.

The Manufacturing USA institutes are a platform to build innovation ecosystems by bringing together industry, academia, and government to develop and scale new manufacturing technologies. The institutes act as a neutral ground to *convene diverse stakeholders* where corporations, SMMs, start-ups, universities, and government agencies can collaborate on shared challenges. This cooperation leverages existing resources and expertise to drive innovation. By providing shared access to world-class facilities and expertise, the institutes help companies—especially start-ups and SMMs—to *de-risk technology development* and bridge the “innovation valley of death.” This lowers the cost and risk of developing, prototyping, and scaling new technologies for domestic production. Each institute has a distinct technological focus, allowing it to act as a hub for its local and regional economies and *drive regional economic development*.

Mapping and coordinating existing public and private resources—often a patchwork of disparate elements—is a significant challenge. Although existing local ecosystems are home to varied combinations of public and private assets, these often are not connected and are in various states of maturity to support manufacturing missions, especially for emerging technologies. The institutes face a daunting task in connecting a variety of public and private actors into a network that supports the scale-up of research and development into a growing industry.

Institutes often lack the expertise and resources to carry out their mission to grow manufacturing ecosystems. Building cooperative networks, aligning incentives, and connecting resources and stakeholders is challenging work. As documented in Chapter 2, other leading industrial nations have dedicated and well-resourced programs to grow supportive ecosystems to advance their technological strengths. The Manufacturing USA institutes have a critical mandate in this regard but face significant constraints in terms of dedicated expertise and budgetary resources.

Recommendation 5-1: By 2030, Congress should provide sustained dedicated funding above current appropriations to establish business development offices at each Manufacturing USA institute to support commercialization, scale-up, and regional ecosystem integration for entrepreneurs and small and medium-sized manufacturers, working in coordination with regional economic development organizations and federal manufacturing programs.

In some cases, formalizing these existing relationships, rather than building entirely new offices from scratch, may be a more practical and cost-effective path. Additionally, business development offices should incorporate lessons learned from university business development offices which are engaged in regional development, such as the Digital Foundry. As with workforce development, AMNPO could also consider adding a 1–2-person coordination cell at the national level to support these efforts and to share best practices. These offices would deliver coordinated business development services for entrepreneurs and SMMs, accelerating domestic adoption and promoting production of institute-developed technologies. Together, these functions will strengthen regional manufacturing ecosystems and accelerate domestic adoption and production of institute-developed technologies.

Responsibilities for this office would include identifying business growth opportunities and investment partners, engaging with state and regional economic development officers, and supporting new business development and entrepreneurship. This office would also be instrumental in attracting regional and national investments to facilitate rapid scaling and dissemination of institute intellectual know-how, capabilities, and services and ensuring that business development expertise is in place to execute these tasks.

A regional economic development office aligned with each manufacturing institute could advance the mission of the institute in ecosystem building by crafting partnerships and other mechanisms to institutionalize cooperation across local networks. It could also empower SMM business growth, including business and technology assessments, supporting demonstration scaling, and providing upskilling and reskilling education and training to enable the business needs of their SME network.

Chapter 6

Workforce Education and Development

It has long been understood that without a trained and skilled workforce fluent in advanced manufacturing, those technologies simply cannot be adopted.

The American manufacturing workforce was cut by about one-third in the decade of the 2000s, and, as noted in Chapter 1, employment in the sector remains far below the year 2000 level.¹¹⁰ At the same time, manufacturing wages were stagnating. Manufacturing production workers have long held a wage premium over other workers, but that wage premium has declined significantly since 2003.¹¹¹ These declines have led the public to conclude that manufacturing was not a secure base for career employment, discouraging entry into manufacturing work. This has contributed to an aging manufacturing workforce; estimates are that there is an estimated current shortfall in manufacturing employment of some 500,000, with a need for close to 2 million workers by 2033.¹¹² Sixty percent of manufacturers in a late 2024 survey expressed talent acquisition and retention as their top challenge.¹¹³ These concerns about manufacturing careers and the potential manufacturing workforce shortages emphasize the need for new workforce education strategies where Manufacturing USA institutes could play an important role.

Improved workforce education is vital to advanced manufacturing because it can enable a pipeline of workers with the skills to operate, maintain and innovate with complex emerging manufacturing technologies in such areas as robotics, data analysis, digital production, and new materials. The great majority of manufacturing firm leaders believe that smart factory solutions

¹¹⁰ Federal Reserve Economic Data (FRED), All Employees Manufacturing, 1940–2024 (table), <https://fred.stlouisfed.org/graph/?g=1TLxD>.

¹¹¹ J. Elvery and J. Dunn, 2021, “Manufacturing Wage Premiums Have Diverged Between Production and Non-Production Workers,” in Federal Reserve Bank of Cleveland, Regional Policy Report, November 8, <https://www.clevelandfed.org/publications/regional-policy-report/2021/rpr-20211109-manufacturing-wage-premiums-have-diverged-between-production-and-nonproduction-workers>.

¹¹² J. Coykendall, V. Reyes, K. Hardin, and J. Morehouse, 2024, *Taking Charge: Manufacturers Support Growth with Active Workforce Strategies*, April, 5, Figure 2, Deloitte and the Manufacturing Institute, https://themanufacturinginstitute.org/wp-content/uploads/2024/04/Digital_Skills_Report_April_2024.pdf.

¹¹³ National Academy of Manufacturing, 2024, 2024 Fourth Quarter Manufacturers’ Outlook Survey, <https://nam.org/2024-fourth-quarter-manufacturers-outlook-survey>.

will be key to their future competitiveness.¹¹⁴ and offers an opportunity to restore productivity growth and corresponding competitiveness innovation to U.S. production. The traditional means to grow productivity adopted by the U.S. manufacturing industry is through investment in and implementation of new capital plants and equipment. However, the other way to raise productivity is through investment in workforce. Unless the United States invests in both, it is not likely to get the productivity offered by either. In other words, the potential gains of new advanced manufacturing technology and processes will not be realized without significant workforce capability improvements to implement those technologies and processes.

WORKFORCE EDUCATION CHALLENGE IN THE UNITED STATES

Despite the importance of workforce education for the implementation of advanced manufacturing, the U.S. workforce education system as a whole, particularly the technical workforce, is not well positioned to respond.

There is a history of deep, underlying problems in U.S. workforce education. For the technical manufacturing workforce, there is a major “work-learn” barrier because schools and jobs are disconnected, community colleges lack resources, most vocational education ended in the 1970s and 1980s, apprenticeships are largely missing, labor markets lack an efficient information system, the Departments of Labor and Education lack programs to upskill incumbent workers, there is only a limited curriculum in advanced manufacturing skills, small manufacturers in particular lack the skilled talent for advanced manufacturing, online workforce education is limited, and technical manufacturing workers lack solid career paths that would encourage entry. For engineering professionals in manufacturing, the United States has long separated engineers doing design from factory floors, there is limited manufacturing content in engineering curricula, and there is limited online professional-level courseware in advanced manufacturing.¹¹⁵ There are, then, major challenges in advanced manufacturing workforce

¹¹⁴ T. Gaus and M. Schlotterbeck, 2025, “2025 Smart Manufacturing and Operations Survey: Navigating challenges to implementation,” Deloitte, May 1, <https://www.deloitte.com/us/en/insights/industry/manufacturing-industrial-products/2025-smart-manufacturing-survey.html>.

¹¹⁵ For a program aimed at manufacturing engineering education, see 10 U.S.C. 2196, <https://uscode.house.gov/view.xhtml?req=granuleid:USC-2000-title10-section2196&num=0&edition=2000>. See also, National Academies, National Materials and Manufacturing Board, “Infusing Advanced Manufacturing into Undergraduate Engineering Education, 2023, <https://www.nationalacademies.org/read/26773/chapter/1>.

education at both technical and professional levels, although the primary focus of this chapter and most institutes is on the technical workforce where the problems are greater.

Workforce Education as a Core But Underfunded Manufacturing Institute Mission

The importance of addressing workforce education has long been understood as a manufacturing challenge. Workforce education was one of the four priorities from the outset of Manufacturing USA (along with creating new production technologies, serving as proving grounds for such technologies, and supporting deployment of these technologies).¹¹⁶ It was recommended as a core policy in the 2012 and 2014 reports to the President made by the Advanced Manufacturing Partnership, an industry–university–labor commission that recommended the advanced manufacturing institute program to the President.¹¹⁷ Workforce was one of the four core priorities in the Revitalize American Manufacturing and Innovation Act, which authorized the Manufacturing USA program.¹¹⁸ And it has been emphasized repeatedly as a core goal in Manufacturing USA Strategic Plans, including the 2024 plan.¹¹⁹ Workforce education, therefore, has long been recognized as a critical element in the Manufacturing USA institute program. Given the nature of the manufacturing workforce challenges listed previously, there is a need for transformational workforce programs to implement advanced manufacturing. Although a core manufacturing institute mission, workforce education programs at institutes have suffered from limited resources.

Typically, Manufacturing USA institutes, which are trying to mount quality programs in high-cost areas such as advanced technology development or providing technology demonstration facilities, will be able to muster only a few million dollars (often ≤ 5 percent of annual institute budgets) for their annual workforce education efforts. This inevitably has led to

¹¹⁶ M. Molnar, S. Linder, and M. Shuart, 2016, “Building a New Partnership—the National Network for Manufacturing Innovation,” presentation to the National Council for Advanced Manufacturing, April 29.

¹¹⁷ Advanced Manufacturing Partnership, 2012, *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing*, July 21–23, President’s Council of Advisors on Science and Technology, Executive Office of the President, pp. x–xi, 28–36, https://www1.eere.energy.gov/manufacturing/pdfs/pcast_july2012.pdf; Advanced Manufacturing Partnership 2.0 Steering Committee, 2014, *Report to the President on Accelerating US Advanced Manufacturing*, October, pp. 30–32, https://www.manufacturingusa.com/sites/manufacturingusa.com/files/amp20_report_final.pdf.

¹¹⁸ U.S. Congress, House, 2014, Revitalize American Manufacturing and Innovation (RAMI) Act of 2014, H.R. 2996, 113th Cong., 2nd Sess., <https://www.congress.gov/bill/113th-congress/house-bill/2996>.

¹¹⁹ National Institute of Standards and Technology, 2024, *Strategic Plan for the Manufacturing USA Institutes*, August, AMS 600-15, Department of Commerce, <https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.600-15.pdf>.

small numbers of relatively modest education programs at institutes. Institutes will often concentrate their limited funding on two or three particular programs, but because of insufficient funding, they cannot mount comprehensive programs addressing the range of workforce issues.

The resource issues are further exacerbated by the funding situation that most institutes have now faced after the end of their initial 5-year terms. Institutes have been funded with federal cost sharing that ranges between \$50 million and \$70 million for their initial 5-year terms. While the initial approach for institutes was to assume that they could be self-sustaining after 5 years, that approach broke down because their only likely source of continuing nonfederal support would be large firms. However, those firms had limited ability to fund institute programs that did not directly benefit them, for example, workforce education outside their firms. After detailed program evaluations, two of the federal agencies sponsoring institutes (Department of Commerce [DOC] and Department of Defense [DoD]) elected to renew the terms of their institutes, although DoD has provided much lower core funding for its institutes for their second terms. DOE has only recently developed a renewal process for some institutes, also with limited funding, and now faces major funding reductions. This limited funding after initial terms has further curtailed institute workforce education support. Member firms are less willing to share workforce development costs unless they directly benefit—a flaw in the funding model that can only be corrected by sustaining the federal program share. While project cost-sharing by industry can work on technology development, it is much less workable for workforce projects because of this employer issue. While workforce education funding during an institute's first 5 years rarely exceeded 5 percent of its total funding, funding pressure after terms were renewed was even tighter. This pressures workforce education directors at institutes to spend their time chasing grants as opposed to implementing programs, a further problem. Workforce outcomes are also inherently longer-term and harder to quantify than technology development deliverables. This means that when competing priorities create pressure on an institute's overall budget, workforce development resources are structurally vulnerable. Workforce development is therefore a required institute function where every institute faces the same resource constraint, regardless of technology focus, sponsoring agency, or technology maturity stage.

Gradual Adoption of Shared Programs Across Institutes

There are growing efforts at institutes, however, to offset limited resources through cross-institute collaborations. Some have developed a model where one institute pioneers a program and funds its initial build-out, and then other institutes pick it up without having to fund its initial development and can increase its impact. For example, some institutes share a program to develop interest among high school-level students in advanced manufacturing. Another example is efforts to develop a common portal for sharing online programs in manufacturing skills. Although this shared program approach is not yet systematic, it has promise.

In addition, there are periodic meetings hosted by NIST's Advanced Manufacturing National Program Office (AMNPO) for institute workforce education leads to sharing best practices and project ideas, which is helping to foster a community of thinking on workforce issues. AMNPO has also begun cross-institute collaborations on an overall advanced manufacturing credentialing system and on methods to better track outcomes from institute workforce programs.

Integration with regional educational institutions, including community colleges and state workforce programs, offers another opportunity to share limited resources. In addition, some institutes have been able to obtain workforce funding from other education programs at their sponsoring agencies. This has particularly been the case for DoD-sponsored institutes.

Overall, program sharing across institutes and regionally offers opportunities for offsetting limited resources.

BEST PRACTICES IN WORKFORCE EDUCATION ADOPTED AT MANUFACTURING INSTITUTES

Despite the resource challenges they face, and the deep problems in U.S. workforce education discussed previously, Manufacturing USA institutes have developed a range of approaches. Many aim to fill gaps in a manufacturing context in the overall workforce education system. Preferably, each institute could offer a mix of programs across a broad framework of workforce needs. That framework would include efforts in the following categories:

- a. Develop advanced manufacturing curricula,
- b. Develop online education,
- c. Create advanced manufacturing credentials,

- d. Support workforce education delivery,
- e. Collaborate across institutes, and
- f. Broaden the manufacturing talent base

However, as noted previously, workforce education has not been resourced to allow each institutes to tackle more than a few workforce projects. Nonetheless, a number of best practices have been developed that create potential models for more broad-based approaches.¹²⁰ Several individual programs are having impacts, including through collaborations with other institutes. Some of the best practices within this framework are summarized next.

Develop Advanced Manufacturing Curricula

The best-practice programs in this category attempt to counter a number of the underlying structural problems in the overall U.S. workforce education system identified in the previous section, particularly the limited curricula available for advanced manufacturing skills, but also the limited programs available for incumbent workers, and the limited vocational education still available.

Create Educational Curricula: Manufacturing USA institutes are well-positioned to address a significant gap in manufacturing workforce education by developing curricula tailored to the new advanced manufacturing technologies they support. By leveraging the competencies and skill roadmaps (noted next) that they identify within their industries, these institutes can collaborate with industry experts and educational institutions to create training materials and courses that align with current needs and insights. For example, LIFT with Manufacturing x Digital (MxD) and America Makes have undertaken curricula development.

Develop Knowledge, Skills, and Abilities and Competencies: To create educational curricula and related materials, Manufacturing USA institutes must define a comprehensive set of knowledge, skills, and abilities (a process known as “KSA”)—clear descriptions of what is required to build an advanced manufacturing technology skill set. Additionally, they need to

¹²⁰ This section is drawn from W.B. Bonvillian, 2022, *The Playbook, for Workforce Education at Manufacturing Innovation Institutes*, DoD ManTech, January 10.

establish the corresponding competencies, which are the specific skills an individual must possess to perform a job effectively. Projects at LIFT's Ignite, BioFab, and the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL), for example, have undertaken this.

Form Skill Roadmaps: To support and implement educational programs in their respective technology fields, Manufacturing USA institutes must create data-driven skill roadmaps that align with regional and national skill demands. It is important that these institutes ensure that their technology and workforce roadmaps are synchronized, so the development of workforce skills keeps pace with technological advancements. The American Institute for Manufacturing Integrated Photonics (AIM Photonics) and MxD are examples of institutes that have developed skill roadmaps. Overall, in developing curricula, it is important that these efforts have major input from industry which should be involved in active advisory groups helping to guide content.

Develop Online Education

The best-practice programs in this category take on issues noted in the second part of this chapter, particularly the need for more online education for advanced manufacturing, given the need to scale up these offerings. Because of online education's wide availability and the ability to use it at the individual's pace, it also helps counter the lack of programs for incumbent workers as well as the limited course material available in advanced manufacturing.

Use Online Venue as a Tool to Scale Workforce Education: The technologies supported by Manufacturing USA institutes are emerging and rapidly expanding, but the existing workforce education system has been slow to scale up to meet this need. Educational institutions together with manufacturers can leverage online education to reach and train larger numbers of potential workers. Although manufacturing education must be for a significant part hands-on to convey particular skills, online elements can complement and reinforce this content. And with new computer simulations and augmented reality (AR) and/or virtual reality (VR) tools, more of

the hands-on content can move online over time.¹²¹ As part of their educational initiatives, manufacturing innovation institutes can develop online learning materials that are both scalable and can be tailored to specific audiences. For example, AIM Photonics has online courses in photonics design at the professional level, ARM Institute has a searchable roboticscareers.org site with some links to numerous robotic online training materials, and America Makes has developed additive manufacturing courses available through ToolingU-SME.

Create Advanced Manufacturing Credentials

Programs in this area directly address the workforce education problem, identified in the Workforce Education Challenge in the United States section of this chapter, of the broken information system that disrupts labor market efficiency including in manufacturing. They also help make up for the limited availability of vocational education.

Support Credentialing: The United States lacks an effective workforce information system, weakening the overall labor market. Employers often do not have reliable information on the skills that candidates possess, workers are unsure of which skills they need to develop, and educational institutions lack clear direction on what to teach. Industry-recognized credentials can help address this disconnect by offering proof of qualifications for employers, giving workers transferable skills, and guiding educators on relevant curriculum content. Technology companies such as Microsoft and Cisco successfully developed credentialing systems for their information technology platforms, which played a key role in their widespread adoption. Manufacturing USA institutes can take a similar path by assessing existing industry-recognized credentials in their fields and collaborating with industry and education partners to address any gaps or develop new ones. Where solid, industry-recognized credentials exist, institutes can work with them. For example, ARM Institute certifies or endorses education institutions for robotics programs, and American Makes supports credentials in additive manufacturing.

¹²¹ See, for example, A.M. Al-Ansi, M. Jaboob, A. Garad, and A. Al-Ansi, 2023, Analyzing Augmented Reality (AR) and Virtual Reality (VR) Recent Development in Education. *Social Sciences & Humanities Open* 8(1): 100532. <https://doi.org/10.1016/j.ssaho.2023.100532>.

Support Workforce Education Delivery

Programs in this category reach a series of workforce education problems noted in the Workforce Education Challenge in the United States section of this chapter. These include limited vocational education, limited programs for incumbent workers, limited curricula and programs in advanced manufacturing, the need for an improved career pathway in manufacturing, and the need for groups of companies rather than single firms to collaborate in offering workforce solutions. The apprenticeship and internship programs specifically noted in the next discussion help tackle this missing link in the gap between education and workforce as the specific need for apprenticeships efforts. Programs include:

Support Regional Collaborations for Implementation: Partnerships with state and local governments, regional industries, Manufacturing Extension Partnerships, and educational institutions will be essential for expanding the reach of institute workforce development programs. Taking a regional approach helps ensure that these efforts align with local needs and priorities, while successful regional pilots can serve as models for national implementation. In engaging firms, it is generally more productive to engage with groups of firms, which tends to be a more enduring and resilient approach than with single firms. Examples include ARM Institute, NextFlex, America Makes, and NIIMBL, which runs a major annual conference with industry including projects on workforce education.

Support Apprenticeships and Internships: In today's economy, the transition from education to employment is often difficult and uneven, causing many students to miss out on fulfilling career opportunities. To bridge this work–learn gap, there is an increasing need for internships and apprenticeships, as discussed further in Recommendation 6-5. Manufacturing innovation institutes can play a vital role in initiating and supporting these programs, while also ensuring that their advanced technologies are integrated into the experience. Numerous institutes have internships and apprenticeships, including BioFab and the Apprenticeship Carolina program.

Use Demonstration Labs for Education: Developing a skilled workforce in advanced manufacturing still depends heavily on hands-on learning. As part of their regional initiatives, many Manufacturing USA institutes have created labs equipped with cutting-edge technologies and process expertise. These labs can function both as practical workforce training centers as well as hubs for technology demonstration and prototyping to support local industry. Examples

include programs at LIFT and AIM Photonics. Hands-on facilities with the advanced equipment for topics being taught can provide significant support for workforce efforts.

Train the Trainers: Instructors at community colleges, high schools, and within industry will need to gain proficiency in emerging manufacturing technologies in order to teach these topics. Manufacturing USA institutes can play a key role by providing “train-the-trainer” programs in their manufacturing technologies. Online education could be an effective method for delivering this training at scale. America Makes provides an example of this. Train the trainers programs are a key attribute of solid programs.

Create “Technologists” from Skilled Technicians: Technical career paths in manufacturing tend to be stove-piped and limited. As noted in the first part of this chapter, technicians tend to be trained in a particular skill—welding or computer numerical control (CNC) machining, for example—and spend their careers in these categories. They are trained for their machines and stay there—there is no career advancement path. Yet advanced manufacturing calls for individual machines to be incorporated much more into a system, taking advantage of digital production technologies, data analytics, and potentially artificial intelligence (AI) to drive new efficiencies and productivity. However, the job of operating this system has not yet really been created. A new category some call the “technologist” is needed, training talented technicians from the shop floor in these new systems skills including advanced manufacturing skills. This in turn could lead to a new, more solid career path in manufacturing with continuing opportunities for advancement. Importantly, the task of manufacturing workforce education programs is not only to reach new entrant workers but to significantly upskill the existing workforce to work with the new manufacturing technologies. The technologist approach is an important potential mechanism to reach this critical group of workers. Although no Manufacturing USA institutes as yet have developed programs to do this, a technologist curriculum has been created and a pilot project with DoD funding is being run to test it, which could be adopted by institutes.¹²² The program includes development of key competencies supported by defined coursework and hands-on experiences (apprenticeships, internships).

¹²² J. Liu and W.B. Bonvillian, 2024, “The Technologist,” *Issues in Science and Technology*, Winter, <https://issues.org/technologist-advanced-manufacturing-workforce-liu-bonvillian>.

Educate Entrepreneurs: The United States has traditionally depended on start-ups to drive technological innovation, but the number of new manufacturing start-ups has dropped significantly. Entrepreneur education programs can play a role in fostering start-ups within an institute's technology area—especially when those technologies are some distance from broad adoption in workplaces. Institutes can support this effort by tapping into existing entrepreneurship programs or by creating new ones tailored to their focus areas: Advanced Functional Fabrics of America (AFFOA) provides an example of this kind of program.

Collaborate Across Institutes

Programs developed in this area help offset the resource problems that institute workforce programs face, as identified early in this chapter, as well as multiplying the effects that institutes can have on advanced manufacturing workforce needs.

Share Workforce Education Programs Across Institutes: Given the limited resources available to Manufacturing USA institutes for workforce education, institutes can expand their reach by sharing workforce initiatives across institutes. An institute can develop a workforce program, build and test it, and other institutes can ally or replicate it without the initial development costs. NextFlex and LIFT provide examples of these practices. As noted previously, NIST's program office is also leading a consortia of institutes in developing programs to be shared by all institutes around workforce credentialing and metrics for tracking student performance.

Broaden the Manufacturing Talent Base

The first part of this chapter noted the issues in attracting talent to the manufacturing workforce, and programs in this category try to help address this. They also try to address problems of the work–learn barrier, limited vocational education, and problems with the labor market information system. Particularly important is not only new entrant workers but also reaching incumbent workers with advanced manufacturing skills so they can support the introduction of new manufacturing technologies.

Build Awareness of Advanced Manufacturing: In the 2000s, American manufacturing lost 5.8 million jobs—a blow to the middle class that also shaped public perception. As a result, many students and, importantly, their parents began to view manufacturing as an unpromising career path. Today, however, with a rapidly aging workforce, some 2 million manufacturing jobs are projected to become available in the next decade. To meet this demand, Manufacturing USA institutes must help attract new talent equipped with advanced skills. As part of their skill demand analysis and road-mapping efforts, it is critical that they evaluate both current and future workforce needs and develop targeted strategies to raise awareness about opportunities in advanced manufacturing, at both the high school and college undergraduate levels. NextFlex has built a program at the high school level, supported by additional institutes that now operate in a number of states; NIIMBL’s BioLogic introductory program for biomanufacturing works at the high school and college levels.

Reach Additional Workers and Communities: With an aging workforce and rising number of retirements, job openings in manufacturing are expected to increase significantly. Current estimates noted previously suggest a shortage of 500,000 workers, which could grow to 2 million by 2033. To address this gap, manufacturers must broaden their outreach to untapped talent pools and underserved communities. Collaborating with industry partners, community colleges, and high school programs will be essential to expanding and strengthening the manufacturing workforce. LIFT’s Ignite program and NextFlex provide examples of outreach activities that are an important part of workforce development initiatives.

Reach Separating Service Members and Veterans: Manufacturers are facing a shortage of skilled workers, and Manufacturing USA institutes have a valuable opportunity to help close this gap by training veterans and transitioning service members into advanced manufacturing. Many of these individuals already possess strong technical skills from their military experience, making them well-suited for careers in the sector. DoD-sponsored institutes, with their ties to the military and expertise in relevant manufacturing technologies, are well-positioned to engage this talent pool. Scalable solutions—such as online training programs—can help extend the reach of these efforts. LIFT’s Operation Next first developed this approach.

Engage with Defense Depots, Arsenal, and Shipyards: DoD employs more than 80,000 civilian personnel across its major depots, arsenals, and shipyards to maintain and service aircraft, combat vehicles, ships, and other critical equipment. These depots compete with the

private sector for highly skilled workers, even as retirements among their workforce continue to rise and more employees become eligible to retire. Partnering with these depots and facilities presents an opportunity to secure additional funding for workforce program development and to train military-employed personnel in advanced manufacturing technologies. For example, ARM Institute works in this area.

To summarize this section, despite resource constraints, a significant number of institutes have worked in recent years to develop successful workforce programs for advanced manufacturing that help fill gaps in the workforce system. The best practices launched by individual institutes enumerated previously create a potential model for a more broad-based effort by institutes. This could aim at implementing program elements across the framework identified previously: developing advanced manufacturing curricula, developing online education, creating advanced manufacturing credentials, supporting workforce education delivery, collaborating across institutes, and broadening the manufacturing talent base.

FINDINGS AND RECOMMENDATIONS

Adopt Best Practices Using a New Competitive Funding Mechanism

After a decade of program development, many institutes have developed successful programs that deserve emulation across other institutes. These include programs to

- develop advanced manufacturing curricula (including developing knowledge–skills–awareness sets and competencies and skill road-mapping),
- develop online education,
- create advanced manufacturing credentials,
- support workforce education delivery (including supporting regional collaborations and internships and apprenticeships; using demonstration labs; creating technologists from technicians, and educating entrepreneurs),
- collaborate across institutes, and
- broaden the manufacturing talent base (including broadening manufacturing awareness, reaching additional workers and communities, upskilling incumbent workers, reaching veterans and separating service members, and engaging with depots, arsenals, and shipyards).

Replicating best practices from other institutes can avoid initial program development costs and help institutes adopt the broader range of programs that they need to address additional aspects of workforce education needs beyond the programs they currently offer. A new funding mechanism to help scale up these options could accelerate their implementation. For example, during the COVID-19 pandemic, NIST obtained a block of funding, and institutes competed for it to implement relevant programs; such a mechanism could be applied to this effort. But institutes need to move from providing one to three workforce education programs to a much more comprehensive offering.

There is a second and related issue that needs addressing as part of this effort: regional collaborations. U.S. manufacturing is inherently local and regional; different manufacturing sectors have built strengths in different regions, and workforce education programs need to be geared to these different regional strengths and needs. Manufacturing USA institutes themselves have combined goals: developing new manufacturing technologies and processes to be available nationally and implementing them regionally. Since a skilled workforce is a prerequisite for adoption of advanced manufacturing, collaborations on workforce education, including with regional manufacturing firms, community colleges, secondary schools, area universities, and state and local governments, are needed. Workforce education program delivery is inherently a regional activity, to be developed, tested, and implemented in manufacturing regions. These issues are discussed further in Chapter 5, including the need for an economic assessment process involving regional workforce cooperation that can bring productivity advances. Concerning collaborations with industry, these have been more resilient and productive over time when conducted with groups of employers as opposed to single employers who are more prone to economic shifts than employer groups. There is a need to expand the availability of successful workforce education delivery programs to function across institutes to increase the scale and impact of institute programs.

One noteworthy example is provided by the PRIME (Partnership Response In Manufacturing Education) program of SME (formerly the Society of Manufacturing Engineers) which has reached some 12,000 students in 118 schools in 25 states. It is a high school-level program that also works with community colleges, universities, and manufacturing firms in providing a 4-year curriculum for high schools in key manufacturing areas. It provides wrap-around services for these programs, including training for teachers who can obtain certifications

in manufacturing processes, extracurricular activities and summer camps in manufacturing for participating students, skills certifications, and student scholarships for further education in manufacturing at community colleges and universities. It is designed as a sustainable program and SME offers ongoing support and equipment to enable schools to adopt and continue it. There is a significant opportunity for Manufacturing USA institutes to engage in these regional education programs, providing expertise and content in advanced manufacturing technologies.

Education is not the only issue: attracting and retaining manufacturing talent is a major challenge for the United States, and this must be implemented in regions. Some institutes are already working on this issue, as noted in Chapter 3. Institutes can play a major role in attracting and retaining talent through building awareness of career and technical education programs that incorporate advanced manufacturing elements. Overall, improving talent entry is a key front-end element in moving to a workforce skilled in advanced manufacturing.

Skilled talent is a particular problem for small and medium-sized manufacturers (SMMs) considering adopting advanced manufacturing, raising a third issue that needs addressing. As discussed earlier in the report, SMMs tend to have the lowest manufacturing productivity rates compared to larger firms and face great difficulty in adopting advanced manufacturing technologies. Institutes need to adopt technology transfer programs that focus on reaching these smaller “Main Street” firms in addition to their long-standing technology development focus. The Digital Foundry advisory programs in Pennsylvania, with whom ARM Institute and the Collaborative Ecosystems for Smart Manufacturing Innovation Institute (CESMI) work, provides, as noted in Chapter 3, a model for this kind of outreach to small and medium enterprises for educating and helping small firms implement advanced manufacturing.¹²³ However, the new technologies will not be adopted unless the workforces in these firms are ready for them. Digital Foundry therefore has workforce education programs for SMMs that always accompany its technology transfer programs. Small firms must have upskilling programs for their incumbent workers in order to adopt new manufacturing technologies and processes. As institutes implement the broadened workforce offerings, an effort to reach SMMs with workforce education advisory, support, and training programs is needed.

¹²³ Digital Foundry, New Kensington, Pennsylvania, <https://digitalfoundrynk.com>; committee meeting with Sherri McCleary, Digital Foundry, New Kensington, Pennsylvania, August 12, 2025.

Recommendation 6-1: By 2030, Manufacturing USA institutes should adopt a broad range of programs to address workforce education needs in advanced manufacturing, based on best-practice programs developed by various institutes, including to develop advanced manufacturing curricula, develop online education, create advanced manufacturing credentials, support workforce education delivery, collaborate across institutes, and broaden the manufacturing talent base. These broadened programs should be executed in collaboration with regional stakeholders, such as area companies and education institutions, and should include efforts to reach small manufacturers with workforce education advisory services and training programs.

In undertaking this, institutes could consider programs specifically identified in Chapter 6 (see Best Practices in Workforce Education Adopted at Manufacturing Institutes). Instead of offering one to three specific programs, institutes could move by 2030 to offer larger groups of programs addressing the topics listed previously. This could include, for example, apprenticeships, technologist education, engaging veterans, and curriculum or online development.

Program expansion will require additional resources, and the following policy options for a funding mechanism could be considered. NIST and other sponsoring agencies could provide additional funding where groups of Manufacturing USA institutes can apply and compete to implement best-practice programs across institutes. Sponsoring agencies could prioritize those best practices with the potential to scale up and be replicated by other institutes and include regional workforce education implementation. Sponsoring agencies could collaborate with institutes in developing and implementing an overall roadmap for this broad-based workforce education program that could be available across the institutes. Within 5 years, implementation of these broadened offerings could be well underway with completion within 10 years.

Concerning the second aspect of this recommendation, sponsoring agencies and Manufacturing USA institutes could examine best practices currently in place at institutes and other entities for delivering and implementing regional workforce education programs in advanced manufacturing and support their implementation across institutes. Partnerships of existing regional programs with community colleges, manufacturers (both small and large), and state and local governments or development of new efforts is important.

One best-practice approach that institutes could consider is the SME PRIME program. This is a 4-year high school education program with nationwide adoption. Institutes could develop collaborations and contribute advanced manufacturing content and supplemental programs. To bolster their regional commitments, institutes could also consider collaboratively aligning their institute workforce outreach efforts to focus on regional needs. It is important that they maintain sector-relevant outreach and engagement programs, including with industry, as well as partnerships with regional and national education and workforce organizations. Train-the-trainer efforts are also important throughout.

Concerning the third aspect of this recommendation, institutes could develop workforce education programs to accompany advisory, support, and training services to small “Main Street” manufacturing firms in their regions to enable them to adopt advanced manufacturing technologies. It is also important that manufacturing firms be deeply involved in the curriculum development efforts to reflect practical needs.

This joint technical advisory services and workforce education effort can be based on the Digital Foundries model noted in Chapter 4.

Unified Curriculum, Outcomes Measurement, and a Common Industry-Recognized Credentialing System

Manufacturing USA institutes generally develop curricula in their particular technology areas. However, manufacturers, particularly SMMs, need curricula that cut across specific technologies and provide more generalized advanced manufacturing courses. There are private-sector education providers offering courses on aspects of advanced manufacturing. However, community colleges have been slower to adopt advanced manufacturing curricula because there must be sufficient demand from students in the area first. Institutes have identified this as a common issue, understanding that much of advanced manufacturing education content is common across institute technologies, hence they have been discussing a common NIST-led effort to address this. A core advanced manufacturing curriculum that could be shared across institutes, where particular institutes might add specialized areas, would be a major service to all institute workforce programs. This would help spur workforce education in advanced manufacturing in general. Its ability to scale and reach larger numbers of learners and be

implemented by education institutions and firms would be enhanced if the curriculum could be turned into online course offerings.

In addition, education institutions in general have had great difficulty in tracking students and developing data on the outcomes of the programs they offer. Nonetheless, Manufacturing USA institutes could undertake a major effort to track participants in their workforce education programs and develop outcomes data, which in turn can be used to foster program improvements and reforms. A set of common metrics is needed in undertaking these evaluations. No single institute could undertake such an effort, but a common effort across institutes could place this difficult task within range. Once developed, it would need to be systematically applied and updated as necessary.

Concerning industry-recognized credentials, although some institutes work in technology areas where there are already industry-recognized certifications, most of the advanced manufacturing technology areas are too new for this to have developed. A number of institutes have made progress working with their industry members to develop skill certification and credentialing systems for their particular technology areas acceptable to and potentially recognizable across industry. NIST has undertaken a project with the institutes to develop a common credentialing system across the Manufacturing USA institutes representing a range of advanced manufacturing skills. Workforce education programs at institutes need to move the curricula they develop into industry-recognized credentials for their programs to be effective and to scale. In advanced manufacturing technology areas where credentials are already in place, these could be linked to and incorporated in an overall, cross-institute credentialing system.

In addition to new advanced manufacturing credentials, particularly where acceptable credentials already exist in a technology area, institutes could certify education programs at particular institutions as meeting advanced manufacturing education requirements and standards (following the ARM Institute Endorsement approach).

Recommendation 6-2: Within approximately 2 years, agencies sponsoring the Manufacturing USA institutes working with the Advanced Manufacturing National Program Office should develop a unified advanced manufacturing curriculum available online that combines and unifies curricula and materials developed by institutes along with successful education and workforce development programs. Supporting this, they should develop an outcomes measurement and a credentialing

system coordinated with industry and aligned with Manufacturing USA workforce metrics and programs.

This common curriculum could be a core element, and institutes could develop content spokes in their particular technology areas to supplement it. A common core—with foundational manufacturing concepts, safety, quality, digital literacy—could be developed initially. Then technology-specific modules requiring a more a focused development cycle with deeper industry engagement could be led by particular institutes. Elements of this curriculum which could be drawn upon have already been developed in programs such as the technologist program noted previously.¹²⁴ This curriculum could be available across institutes for implementation with regional education and industry partners, and broadly available to other institutions interested in implementing it. The curriculum could also be developed as an online offering available across institutes (see Recommendation 6-6). This could be a continuing process with ongoing updates as needed. Industry should play a key advisory role in developing this curriculum, and it should be coordinated with potential delivery partners that could implement it. Such a curriculum could be completed and scaled across the institutes within approximately 2 years. Along with this curriculum development, institutes could jointly develop with support from NIST and sponsoring agencies, a common, shared outcomes measurement and tracking system on educational and career outcomes for those who have completed workforce education programs at the institutes. This would include a corresponding common system across institutes for measuring program outcomes. This information could be regularly updated and applied to make program improvements. This could be accomplished in a 2-year time period.

Consistent with a program already initiated by NIST and the institutes, the Manufacturing USA institutes could also network to develop a common credentialing system for advanced manufacturing skills in cooperation with industry. Working with industry groups and their members, this institute credentialing effort could be translated into industry-recognized credentials across advanced manufacturing skills. In addition, institutes, working collaboratively, could play a role in certifying advanced manufacturing programs at educational institutions as

¹²⁴ See materials on the Technologist Advanced Manufacturing Program (TechAMP), <https://leapgroup.mit.edu/techamp/>.

meeting advanced manufacturing requirements and standards. This could be accomplished within a 5-year timeline.

Manufacturing USA's AMNPO, working with the institutes, could establish a clear definition of a career path for the manufacturing workforce that they are developing. This would include developing and refining a curriculum using a layered, competency-based framework.⁷¹ Working with industry, and educational organizations, AMNPO could define the lower layers of the framework that contain foundational skills, so that these are common to all institutes. The upper-layer definition would be assisted by industry and education constituencies at institutes. The development of the competencies would be supported by defined “knowledge–skills–abilities” components, by coursework, and by hands-on experiences (through apprenticeships and internships). Such a curriculum could be made available to potential constituencies through a centralized entity (see proposal for a Manufacturing Academy, Recommendation 6-6). This approach eliminates the need for each institute to separately create the common competencies. As institutes develop their workforce development plans, they could use the common competency in the proposed Manufacturing Academy. Going hand in hand with this would be standardized competency-based assessment criteria. Train-the-trainer curricula and related programs could also be part of this effort.

Advanced Manufacturing Technologist Programs

Manufacturing technicians tend to be trained in a particular skill—welding or CNC machining, for example—and spend their careers in these categories tied to their machine set. While higher skill levels in these fields yield higher benefits, there is no real step-by-step career path for these manufacturing workers. However, advanced manufacturing calls for their individual production machines to be incorporated much more into a system, using a host of new technologies around digital production, data analytics, and potentially AI, to drive new productivity. This would allow the factory floor to function as much more of a system. Yet the job of running and operating this system has not yet really been created. A new category, known as the advanced manufacturing “technologist,” is required to train talented technicians in these new systems skills, including specific advanced manufacturing skills. A pilot project with DoD Industrial Base and Sustainment funding has developed a specific advanced manufacturing technologist curriculum which is now being tested in community colleges. While there have

been other training programs labeled technologist or engineering technologist training, this recommendation is specifically referring to the definition and curriculum previously mentioned, meaning filling the gap between engineers and technicians and oriented toward the new skill sets required for integrating advanced manufacturing systems into the production process.

An additional challenge with defining this “technologist” pathway is in differentiating these new technologists from graduates of engineering technology programs. There might be some confusion for employers in understanding which candidates’ skills meet their needs. Many SMMs will hire graduates of engineering technology programs and recognize them as engineers, while large companies will not. Large companies will differentiate graduates of engineering versus engineering technology programs. A further differentiation is now required for this new technologist program for advanced manufacturing. Establishing clear standards for the technologist program, following the suggested definition, as well as appropriate marketing, could help manufacturers to understand the differences. “Train the trainer” programs for both existing and new teachers will be important. Approaches for educating and qualifying teachers and instructors were adopted in the SME PRIME program noted previously in this chapter, and it serves as a potential model. ASM International’s Materials Camp®-Teachers, also provides a possible model for educating middle and secondary school teachers in the elements of a technologist program.¹²⁵ In addition, curriculum standards and marketing efforts will be needed in making this program scale. In sum, if the United States is to lead in advanced manufacturing, it likely will need the advanced manufacturing skill sets—in effect, a new career path in manufacturing for upgrading technicians—embodied in the technologist curriculum and program.

Recommendation 6-3: By 2030, Manufacturing USA institutes should implement new technologist curricula, such as the Department of Defense’s Industrial Base and Sustainment funded pilot projects. They should work toward implementing it in cooperation with regional partners in industry and community colleges and, if

¹²⁵ ASM Materials Education Foundation, n.d., “Materials Camp®-Teachers, Program Overview, <https://www.asmfoundation.org/teachers/materials-camps/year-one>.

deemed appropriate, incorporate it into the recommended Manufacturing Academy.¹²⁶

Likewise, institutionalizing a train-the-trainers program to accompany implementation of this technologist pathway can help in attracting and retaining the qualified teachers that the program will require. The proposed Manufacturing Academy standards could house the train-the-trainer materials. It appears to be a quite constructive approach for upskilling incumbent workers in advanced manufacturing skills.

The program could also be adapted to other education settings. Concerning the future manufacturing workforce, Manufacturing USA could leverage this concept of advanced manufacturing technologist to help attract people into the profession. Developing this as an industry standard and marketing it as a career pathway with its multiple possibilities for growth would provide considerable appeal to potential students. Institutes could assist with developing a program to educate middle and secondary school teachers on manufacturing and how to incorporate these emerging technologist concepts into their own curricula. It could also be readily adapted for CTE programs at community colleges and technical schools. A standardized curriculum on manufacturing basics could be taught by master teachers to groups of middle and secondary school teachers, presenting technologist careers and opportunities, and how to incorporate this material into their curricula. The technologist curriculum itself, including institute inputs, could be incorporated into the Manufacturing Academy effort in Recommendation 6-6, as well as adapted by collaborative institute-community college-manufacturer efforts, as recommended.

Catalyze Cross-Agency Partnerships

Advanced manufacturing is a relatively new and evolving field. Manufacturing USA institutes and their sponsoring agencies through their workforce education programs are helping fill a gap in the workforce education system largely not met by existing programs at agencies working in this area, including the Departments of Labor and Education. These agencies generally lack programs in advanced manufacturing education and to upskill incumbent manufacturing workers. Nonetheless, there are programs at those agencies that can help boost

¹²⁶ This recommendation was changed after release of the report to accurately reflect how programs are implemented.

and scale institute efforts. In addition, efforts at institutes in developing curricula and other programs in manufacturing can complement efforts sponsored by those agencies. For example, the Labor Department's Workforce Innovation and Opportunity Act (WIOA) system has established relationships with employers, training providers, and community organizations in every region where institutes operate. Yet the institute network and the WIOA system have historically operated in parallel with limited coordination. Collaboration could be an untapped opportunity for institutes.

In addition, the National Science Foundation's Advanced Technological Education (ATE) program already works to enable community colleges to develop advanced manufacturing curricula in various fields and has worked to coordinate with manufacturing institute efforts. In turn, workforce education work at Manufacturing USA institutes could contribute programs at these agencies. An overall effort to better coordinate workforce education across these agencies and to create complementary workforce education projects and programs with Manufacturing USA institutes is lacking. Such programs and potential funding could enhance institute efforts and provide better advanced manufacturing workforce outcomes.

Recommendation 6-4: The White House Office of Science and Technology Policy and the Domestic Policy Council should convene a cross-agency workforce education project and implement within the next 2 years a strategy to coordinate efforts across agencies to enhance Manufacturing USA institute and other agency manufacturing education programs. This would include relevant programs at the Manufacturing USA institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense), as well as at the Departments of Labor and Education, and the National Science Foundation's Advanced Technological Education Program.¹²⁷

A common strategy across these organizations for manufacturing workforce education by 2027 is clearly needed. If additional legislation or appropriations are needed to ensure deeper coordination at the program level, such a recommendation could be made and changes sought by the White House agencies and executive branch departments. This may prove necessary since

¹²⁷ This sentence was changed after release of the report to clarify that the recommendation applies to all institute sponsoring agencies.

dedicated funding for such cross-agency efforts may be needed to prompt the agencies to collaborate.

Embrace Apprenticeship Programs

The United States has long suffered from a gap between work and learning—there is generally no clear path between school and work that helps lead students into productive careers. Apprenticeship programs in Europe, including in Germany, Austria, and Switzerland, as well as in other countries, combine work and learning as part of the secondary school experience, which leads directly to solid employment opportunities. While apprenticeships have long been prevalent in the construction trades, they are missing in most other fields in the United States, including for manufacturing. They typically involve combined education and paid on-the-job training programs, and offer a certification that can directly lead to employment. There is a significant movement in American community colleges to help groups of employers in their regions by administering these programs and combining work at those firms with skills courses at the community college.

Apprenticeship programs can act as a mechanism to attract and retain manufacturing talent and offer a high return on investment for students, industry, and society. They allow students to earn while they learn, receive career mentorship, and inevitably earn credentials. Approximately 93 percent of employees who finished a registered apprenticeship obtained employment.¹²⁸ Employers benefit from apprenticeships because they reduce labor and recruitment costs while increasing retention rates, productivity, and safety. In addition to students and employers, apprenticeships benefit society by supporting economic mobility and providing financial savings to federal and state governments. The average starting salary for workers who complete an apprenticeship is \$77,000 annually.

Apprenticeships are much more extensive than short-term internships. Most Manufacturing USA institutes offer various internship programs, which can be quite valuable in offering work exposure; however, some institutes have also supported more in-depth manufacturing apprenticeship programs, including in their specialty areas. To tackle the fundamental work–learn divide in U.S. education, many consider apprenticeships a key answer.

¹²⁸ ApprenticeshipUSA, 2022, “Factsheet,” U.S. Department of Labor, https://www.apprenticeship.gov/sites/default/files/dol_apprenticeshipusa_v13_web-ready.pdf.

Manufacturing USA institutes, which can bring together groups of regional employers with community colleges, are well positioned to help enable manufacturing apprenticeships, also providing curricula and support certifications in advanced manufacturing skills.

Recommendation 6-5: Given the need for apprenticeships in manufacturing, and especially to enable the scale-up of advanced manufacturing, within the next 2 years, Manufacturing USA institutes should become active promoters and enablers of manufacturing apprenticeships as part of their regional engagements.

Institutes and their sponsoring agencies could work with apprenticeship intermediaries including with the Department of Labor’s Office of Apprenticeship and its ApprenticeshipUSA program, with regional community colleges supporting apprenticeships, and with Tooling U-SME pre-apprenticeship and apprenticeship support education programs. Institutes, for example, could help convene company and community college collaborators in their regions, contribute curricula and assist in train the trainer programs for advanced manufacturing technologies, and encourage member companies to participate in apprenticeship collaborations.

Online Advanced Manufacturing USA Academy

The current workforce education system is limited in the numbers it can reach and, as noted previously, it has been slow to adopt education for incumbent workers or for advanced manufacturing technologies and processes. Online education offers a significant opportunity for scaling workforce education efforts in advanced manufacturing. While blended learning approaches that incorporate hands-on instruction with online content are necessary and important, moving some education content online, including with simulations and VR and/or AR materials, offers a major opportunity to help scale up workforce education in manufacturing. It cannot replace hands-on education but can supplement it. Online can assist, for example, with foundational knowledge, theory, safety, quality concepts, and digital manufacturing skills—areas where online delivery is genuinely effective. Such online material can be adopted by community colleges and company training programs. DoD ManTech and several institutes have already experimented with this academy concept.

Available online material could be utilized along with material developed by institutes. Currently, a number of Manufacturing USA institutes have a shared learning portal for posting online course material that they have developed. In addition, MxD has developed an online portal for its own materials as well as from numerous other sources, as has ARM Institute, which has some 17,000 links to robotics training materials that are searchable by learners (roboticscareers.org). These, too, could be linked to and incorporated into a Manufacturing Academy portal. This capability could be significantly expanded and incorporate the overall advanced manufacturing education program recommended in the section on best practices. Material developed for the technologist program noted in Recommendation 6-3 could also be included. Since blended learning is needed in manufacturing, the site could also include curricula that could be adopted by community colleges and company training programs that incorporate online materials. The site could use “Manufacturing USA” branding for improving recognition of advanced manufacturing skills and competencies.

In addition, SME (formerly the Society of Manufacturing Engineers) offers online education programs through its Tooling U, which are supplemented by in-person programs. These provide extensive manufacturing curricula in a wide range of manufacturing skills.¹²⁹ Several institutes already collaborate with SME and Tooling U, but given a larger online education focus by institutes, there is an opportunity for an Advanced Manufacturing Academy to link closely through sharing, disseminating, and producing advanced manufacturing content with and through Tooling U.

In addition, such an Academy could push technology reforms that can enhance the education experience. Application of new education technologies is important for scaling advanced manufacturing workforce education. Online education has reached significant scale through massive open online courses and is now being supplemented with online gaming, technology simulations, and modeling. In addition, extended reality (XR) technology, which is a combination of VR, AR, and mixed reality, can potentially create immersive interactive educational experiences, allowing new kinds of content engagement that may offer deeper

¹²⁹ Tooling U-SME, <https://learn.toolingu.com>; committee meeting with Chap Schron, vice president, Tooling U-SME, August 12, 2025.

understanding and better knowledge retention.¹³⁰ Course materials combining these technologies with online content could be available on a 3 to 5-year time horizon. On a 10-year horizon, further integration with AI tutoring could offer virtual training environments. Advanced manufacturing workforce education is critical enough to society that it should take advantage of these developing technology opportunities. These reforms could be spurred by Manufacturing USA institutes, working through the proposed Academy, with collaborations between universities, community colleges, and industry, but will require resources to develop them.

Recommendation 6-6: A collaboration across Manufacturing USA institutes enabled by the proposed Interagency Council and the National Institute of Standards and Technology’s Advanced Manufacturing National Program Office should build out a robust online Manufacturing Academy portal of advanced manufacturing online courses and programs. By 2030, the online portal should include simulations, virtual reality, and augmented reality material developed by Manufacturing USA institutes. The online portal should include materials and links from other verified sources, as well as new material.

The online Manufacturing Academy could include “train-the-trainer” programs. Consistent with Recommendation 6-2, an institute collaboration could develop online course materials in advanced manufacturing technologies that cross over institute topic areas for a full advanced manufacturing education course menu that could be offered through this Academy. NIST and sponsoring agencies could provide resources for the development of this Advanced Manufacturing Academy, potentially with groups of institutes competing (see discussion of Recommendation 6-1). The Academy and the institutes could also consider collaboration with the Tooling U-SME online education program, given an enlarged online education focus by institutes. There is a potential opportunity for an Academy to share, disseminate, and produce advanced manufacturing content with Tooling U, ensuring larger scale distribution and reach.

¹³⁰ See, for example, A. Jiyani, 2024, “Revolutionizing Education: How Extended Reality Is Shaping the Future of Learning,” *eLearning Industry*, June 6, <https://elearningindustry.com/revolutionizing-education-how-extended-reality-is-shaping-the-future-of-learning>; M. Georgieva, J. Nelson, R. LaFosse, and D. Contis, 2024, “XR in Higher Education: Adoption, Considerations and Recommendations,” *Educause Review*, January 10, <https://er.educause.edu/articles/2024/1/xr-in-higher-education-adoption-considerations-and-recommendations>.

Institutes working through the Advanced Manufacturing Academy could spur adoption of new education technologies to better enable introduction of advanced manufacturing technologies. These technologies include online content, online gaming, technology simulations and modeling, and XR, which could be made available by 2030 and integrated with AI tutoring, which could be made available within 10 years. Courses and materials applying these technologies could be offered through the online Academy. NIST and the other sponsoring agencies could support collaborations across institutes (potentially through competitions between groups of institutes (see discussion in Recommendation 6-1) to bring these evolving technologies into their workforce education programs.

Chapter 7

Vision for the Future

A NEW INSTITUTE VISION

The intent of this chapter is to synthesize the committee’s analysis and findings and recommendations described in the earlier chapters of the report into a comprehensive vision for the future of the Manufacturing USA program. The vision for the program is completely covered in the recommendations described in chapters 2, 3, 4, 5, and 6 and listed in total in Chapter 8. The Manufacturing USA institutes have established important manufacturing technology development programs, supported significant advanced technology research and development (R&D), embarked on innovative workforce education efforts, and most importantly, supported the growth of nascent manufacturing sectors. They are now a proven model that needs expanding, providing a strong foundation to build the public–private partnerships that U.S. manufacturing requires. No other policy mechanism connects the key actors needed for advanced manufacturing technologic progress: industry small and large, engineering and science expertise, and links to state and local government economic development. But the institute program has been under-resourced, limiting its potential for driving the scale and pace of systematic change needed for U.S. manufacturing to reassume a leadership role. The committee finds that the current federal sponsorship model for Manufacturing USA institutes, particularly its reliance on 5-year award cycles and uniform cost-sharing expectations, does not meet the requirements for manufacturing scale-up, pilot-scale infrastructure, coalition-based technology development, and workforce development.

This reality presents an opportunity to reimagine the program so it can provide additional impact. The U.S. manufacturing challenge is now huge; the committee emphatically feels that now is the time for Manufacturing USA to “Go Big.”

Forming a New Governance Model: Nearly all leading competitor nations have advanced manufacturing strategies. Although the United States has in recent years moved manufacturing near the top of its policy agenda, it has no overall **manufacturing industrial strategy**. It needs one. In support of that effort, Manufacturing USA needs an overarching strategy for its Manufacturing USA institutes. Institutes all have industry-informed technology roadmaps, but an

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overall strategy on top of these is now needed. Institutes cannot remain stove-piped; they need to be integrated into a more collaborative model, as discussed next. **A new Interagency Council shared between the agencies** supporting the institutes is now needed to undertake this strategy and develop the institute collaboration, complementing the executive direction that the Advanced Manufacturing National Program Office (AMNPO) can provide. AMNPO can operationalize the interagency strategy and support corresponding coordination across the institutes. AMNPO's current collaborative efforts with the institutes on workforce education illustrates how this can work. A critical element to the continued and expanded success of the Manufacturing USA institutes is a shift from treating them as time-limited experiments to managing them as long-term national manufacturing assets. This includes aligning funding duration, staffing expectations, and co-investment models with the realities of manufacturing scale-up. Periodic review, adaptation, and where appropriate, repurposing or sunseting of facilities should remain integral to governance, but within a framework that assumes robustness and resilience rather than rapid self-sufficiency. Additionally, cost-sharing requirements do not always reflect who benefits from scale-up activities. For deployment-oriented projects, industry and government end users capture the primary value, suggesting the need for greater emphasis on industry-led co-investment and reduced reliance on university financial matching. Membership and cost-sharing structures should be reviewed to ensure that total participation costs do not unintentionally suppress industry engagement while preserving institutes' operational flexibility.

Reaching Small Manufacturers with New Technologies and Processes: Small and medium-sized manufacturers (SMMs) make up nearly half of U.S. manufacturing output. A core mission of the Manufacturing USA institutes is getting the United States to advanced manufacturing because U.S. manufacturing productivity has been stagnating for 15 years. The worst productivity problems are in SMMs that lack the know-how and access to technology to implement it. Institutes have lacked the resources for significant outreach to the SMM “Main Street” manufacturing firms. Institutes need to provide **technology adoption and business development advisory services for SMMs**, working with them to identify productivity and efficiency savings from the advanced manufacturing technologies that best fit their processes. These are advisory roles that manufacturing institute programs in other nations often play. Institutes can do this by working with the Manufacturing Extension Partnership (MEP), which has the outreach connections with SMMs across the country. SMMs are not in a position to adopt

stand-alone technologies; they want the robotics integrated with a digital production system and other new technologies and processes. So, institutes need to be networked so they can create **integrated packages of their advanced technologies** ready for firms to adopt.

Supporting Entrepreneurship in Manufacturing: New ideas become innovations in the U.S. system typically because new and small companies nurture them and bring them into implementation. This entry is vital for transforming manufacturing. But venture capital (VC), the means that the United States developed to support entrepreneurship, is overwhelmingly focused on software and services, and simply does not fund hardtech (i.e., combination of hardware and software) areas where goods need to be manufactured. Hardtech development does not match the VC timetable, risk, and cost framework. Yet, there is much innovation in hardtech in both technologies and processes, but hardtech manufacturing firms do not have the resources to scale them. Entrepreneurial firms require technological know-how, technology, and equipment. Institutes can provide this to move them into the risk range so that financing can come into reach. This includes offering **business development services to advise innovating firms** on technology value, production, potential financing, and possible customers. **Facilities where new technologies** can get thorough testing, demonstration, and pilot production can also be important institute assets. International manufacturing institutes, trying to emulate an American entrepreneurship model applied to hardtech, often have strong programs in this area and provide a benchmark for what is possible.

Deepening Technology Transfer Capability: Institutes were designed to undertake late-stage technology development, in Technology Readiness Levels (TRLs) 4 through 7. But introducing innovation into the U.S. system requires a more in-depth program reach. Institutes need to continue late-stage technology development but go further into technology demonstration and pilot production testing. This means reaching TRLs 4–9, effectively crossing over the so-called valley of death for technology development and deployment resulting in successful commercialization. To achieve this, including the outreach to Main Street SMMs and entrepreneurial firms discussed previously, means having much stronger **in-house technical expertise and staff**. It also means having the advanced equipment for **pilot production facilities**. Pilot facilities, workforce-intensive operations, and multistakeholder coalitions require longer time horizons to reach technical maturity and economic impact. Short-term funding cycles

create barriers to recruiting and retaining skilled personnel, discourage ambitious infrastructure investments, and complicate sustained regional engagement. Work on innovation in **foundational manufacturing technologies** is also required. If manufacturing is viewed as a pyramid, the tip is advanced manufacturing technologies, but the base on which they must operate makes up the rest of the pyramid—fields such as casting, welding, machining, molding and lithography. Innovation needs to enter these foundational technologies as well, integrating advanced manufacturing capabilities throughout. A foundational technology focus may be needed within many institutes. Deepening the technology transfer reach of institutes also means they will need to connect their technology roadmaps with R&D agencies, universities and national labs who are undertaking research at TRLs 1–3. This will require outreach efforts with these agencies to ensure this linkage. A number of international institutes illustrate this broader reach from research through product applications. Also required will be **technology transfer advisory and business development teams** to work with companies on implementing new technologies emerging from the institutes, as noted previously.

Fostering Collaboration Across Agencies and Institutes: Manufacturing USA institutes were organized to foster particular advanced manufacturing technologies, from robotics to 3D printing to advanced composites. Yet their technologies need to be presented in integrated packages if they are to be readily adopted by industry, as noted previously. And institute strengths can complement each other. A new level of both **cross-agency and cross-institute collaboration** is now needed. This will require cross-agency leadership, hence the new Interagency Council suggested previously, supported by the AMNPO. A new common fund for groups of institutes to compete for in implementing new programs can support this collaboration and networking. This new mechanism, in turn, can promote cross-institute efforts to develop **integrated technology packages**. For example, there are five institutes working in the digital technology space; technology development coordination among them could enhance efforts at each. Coordination with the **MEP** program is also needed to ensure that manufacturing technologies get into the hands of SMMs, including the integrated technology packages noted previously.

Supporting Regional Connections: A new level of regional engagement is also needed. All manufacturing is local—it happens not nationally but in areas and regions. Manufacturing USA institutes, to make an impact, must be **engaged in the regional manufacturing economies** in which they operate, in addition to fostering manufacturing technologies at the national level. For regional ecosystem engagement, institutes need to have substantial, sustained, and dedicated resources focused on ecosystem integration, business development, technology transfer and scale-up. To further this, Manufacturing USA institutes should have an **office for regional economic development** accountable for establishing and executing the institute’s regional economic development strategy. These offices should identify business growth opportunities and investment partners, engage with state and regional economic development officers, support new business development and entrepreneurship, attracting regional as well as national investments to facilitate rapid scaling and dissemination of institute technologies. Regional engagement by institutes is also important for empowering SMMs for growth, as discussed previously.

Expanding Workforce Education: Advanced manufacturing will not happen unless there is a workforce ready to implement it. Recognizing this, workforce education has been a manufacturing institute priority, although hindered by limited resources. Institutes have developed a series of innovative workforce programs in advanced manufacturing curricula, online education, skill credentialing, education delivery, and broadening the manufacturing talent base, but each institute has only been able to adopt one or two such programs. Instead, **multiple best-practice workforce programs developed at institutes need to be adopted at each institute** to increase their impact. Institutes have recently initiated a **common advanced manufacturing workforce education curriculum** which all can share and apply. In addition, this needs to include common outcomes measurement and an industry-recognized credentialing system. It could also build in the new **“technologist”** curriculum to create a new manufacturing career path between engineers and technicians trained in adopting advanced manufacturing for the factory floor. As noted previously, an advisory services program to bring advanced manufacturing to SMMs is needed; a **workforce upskilling program for these SMMs** must accompany this effort. **Apprenticeship programs** offer a much stronger entry pathway for manufacturing careers; institutes should collaborate with companies and community colleges on these programs, ensuring that advanced manufacturing is part of the training. In addition, institutes should develop **an online Advanced Manufacturing Academy** for workforce

education. It would include online courses and programs, including simulations and virtual reality (VR) and/or augmented reality (AR) material, developed by Manufacturing USA institutes and their partners, as well as links from other verified sources, so it could become a true Manufacturing Academy with in-depth offerings widely available to community colleges, industry, technical high schools, and workers seeking to upskill.

These recommendations would create significant new thrusts in the Manufacturing USA program. They amount to a new and bigger vision for the program. U.S. manufacturing challenges are long term and structural. This means scrapping the notion that institutes will be self-sustaining in the short term and substituting the idea that they should be around for the long term, requiring ongoing federal investments for continuing 5-year terms at least equal to the level of their initial terms. Their programs need to be comparable in scope to those offered by their international institute competitors, as discussed in Chapter 2. The nation will need new structures for implementing advanced manufacturing, including a financing mechanism for scale-up and an overall manufacturing strategy, and expanded institutes need to be one of them.

These are highlights but, with the detailed recommendations in the report's chapters, they represent a potentially transformative model for the Manufacturing USA institutes, if they are provided with the additional resources required. U.S. manufacturing is at a crossroads and is being systematically outcompeted. Unless the United States introduces advanced manufacturing technologies and processes at scale, the nation will lack the productivity edge to compete. Upgrading the Manufacturing USA institutes is a critical means to meet that goal.

THE WORK AHEAD

Much work must be done on each of the areas discussed in the first section—from advising SMMs, to expanding technology transfer, to developing an overall strategy, to reaching entrepreneurial firms, to networking technologies across institutes, to workforce education—to obtain maximum benefit from the institute model. There are clear advantages of focus and concentration to institutes specializing in specific manufacturing technologies, but, in particular, there remains a need for further coordination across institutes and the agencies that support them, as well for a manufacturing strategy behind this. A new governance model will be essential in implementing these proposals, creating a role for a new Interagency Council shared across the

agencies supporting institutes, and supplementing the AMNPO which can take on the needed operational and executive function.

Chapter 8

Study Recommendations

The following is a list of all study recommendations found in chapters 2 through 6.

Recommendation 2-1: In concert with the National Security Strategy, the National Economic Council, the Office of Science and Technology Policy, the Department of Commerce, Department of Defense, Department of Energy, and any other agencies supporting advanced manufacturing should convene and within the next 2 years issue a formal U.S. Industrial Strategy, integrating technology development, scale-up financing, standards leadership, trade, and workforce development to align resources and maximize the national impact of federal manufacturing programs, including Manufacturing USA institutes.

Recommendation 2-2: By 2030, the United States Congress should take legislative action to define a globally competitive research and development tax credit for manufacturing processes and technologies and should actively explore expanding other tax reforms supporting manufacturing.

Recommendation 2-3: To address systemic capital gaps facing hardware-intensive technologies, the United States Congress, working with relevant agencies, should, within the next 2 years, authorize funding and set policy to create new federal manufacturing and financing mechanisms that include patient-capital funds, a sovereign wealth fund with a strategic focus on manufacturing, intellectual property-backed lending programs, coordinated public-private guidance funds and other mechanisms. Manufacturing USA institutes should be formally integrated as advisors to manufacturing financing bodies, providing technical due diligence, scale-up roadmaps, readiness assessments, and first-of-a-kind validation data that de-risk future investments and inform investment decisions.

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Recommendation 2-4: Manufacturing USA sponsoring agencies should immediately conduct a coordinated assessment to identify foundational manufacturing technologies in which U.S. capabilities have eroded or are in danger of erosion relative to those of international peers. Within 2 years, agencies should either (a) add foundational technology workstreams to existing institutes or (b) stand up new institutes where critical gaps exist.

Recommendation 2-5: The setting of standards is increasingly a geopolitical consideration; hence, within 2 years, Manufacturing USA institutes and the Advanced Manufacturing National Program Office should highlight the standards roadmaps that different institutes are generating, encourage the new National Institute of Standards and Technology–funded Standardization Center of Excellence to leverage these roadmaps, and obtain funding for actual standards writing as part of the institutes’ projects.

Recommendation 2-6: With on-going sponsoring agency review and approval, starting in 2026, Manufacturing USA institutes should pursue structured collaborations with leading international manufacturing institutes in areas where complementary strengths exist. These partnerships should focus on shared research, pilot-scale demonstration, standards development, and knowledge exchange that advances domestic technology transfer and scale-up.

Recommendation 3-1: Within a year, each institute should define “technology transfer” in its roadmap with measurable milestones. These should be updated annually and where possible aligned with existing Manufacturing USA performance metrics and reporting frameworks used by the Advanced Manufacturing National Program Office and sponsoring agencies.

Recommendation 3-2: Within a year, each Manufacturing USA institute should specify and clearly and consistently document its initial and target readiness levels (Technology Readiness Level [TRL], Manufacturing Readiness Level, or Adoption Readiness Level, generally expressed as, XRL) and demonstrate and document transitions to TRLs 7–9 using consistent reporting metrics coordinated through the Advanced Manufacturing National Program Office. These should be updated annually.

Recommendation 3-3: Manufacturing USA institutes, in conjunction with sponsoring-agency support, should begin immediate planning and initial implementation of pilot-scale and scale-up facilities, with defined milestones and early operational capability established by 2030 and full-scale operations, broadly accessible to small and medium-sized manufacturers, achieved by 2035. Implementation will require sustained federal funding and coordinated co-investment from industry and regional partners. Manufacturing USA institutes and such facilities should be supported through long-term, renewable federal sponsorship that reflects their role as enduring national manufacturing infrastructure rather than short-term projects, with periodic performance-based review rather than assumptions of self-sufficiency within a single award cycle.

Recommendation 3-4: Within 2 years, Manufacturing USA institutes and the Advanced Manufacturing National Program Office should establish dedicated, well-staffed technology transfer teams and long-term staffing plans, leveraging existing federal technology transfer expertise and programs where appropriate.

Recommendation 3-5: Within 2 years, the Advanced Manufacturing National Program Office, with sponsoring agencies, should implement a standardized network-wide technology transfer metrics framework. If necessary, Congress should consider clarifying statutory reporting authorities to enable consistent performance metrics across all Manufacturing USA institutes.

Recommendation 3-6: Within a year, the Advanced Manufacturing National Program Office should establish a Technology Transfer Best Practices Office and formal cross-agency coordination mechanisms, building on lessons identified in previous National Academies and GAO studies of Manufacturing USA institutes.

Recommendation 4-1: Within the next 2 years, Manufacturing USA institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense) should create an

Interagency Council as a formal, overarching directive body to set an integrated strategy for the Manufacturing USA institutes.

Recommendation 4-2: The Advanced Manufacturing National Program Office, working with the Interagency Council and sponsoring agencies, should establish harmonized procurement, funds-transfer, intellectual-property, and data-management policies that enable seamless collaboration across agencies and Manufacturing USA institutes. This effort should be undertaken in consultation with the United States Manufacturing Innovation Council, as appropriate, and aim for harmonized policies and processes by 2030.

Recommendation 4-3: By 2030, Congress should appropriate funding on par with comparable international programs to the Manufacturing USA institutes to create an interagency initiative that would competitively award dedicated funds to incentivize cross-institute collaboration by addressing grand challenges in manufacturing. A project source selection team should comprise representatives from the Manufacturing USA institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense) to ensure broad applicability across mission spaces and alignment with national manufacturing priorities.

Recommendation 4-4: The Advanced Manufacturing National Program Office should work with the Manufacturing Extension Partnership (MEP) program to create a process by 2030 that ensures that these integrated packages of advanced manufacturing technologies developed by institutes are disseminated to MEPs nationwide for implementation by small and medium-sized manufacturers.

Recommendation 4-5: Within the next 2 years, the Advanced Manufacturing National Program Office, in coordination with the Interagency Council, should lead an interagency effort to develop a robust strategy specifically focused on digital manufacturing across the Manufacturing USA network.

Recommendation 4-6: Within the next 2 years, the Advanced Manufacturing National Program Office, in coordination with the Interagency Council, should create a multiprong strategy that enhances use of the Manufacturing USA network’s capabilities across federal and state government agencies and small and medium-sized manufacturers (SMMs), including coordination with the Manufacturing Extension Partnership (MEP) network, and provides resources as to how agencies and SMMs can work with Manufacturing USA institutes to enhance interagency engagement.

Recommendation 4-7: Within the next 2 years, the Department of Energy (DOE) should work with national laboratories to explore modifying management and operations contractual agreements to be compatible with Manufacturing USA institute agreement terms and conditions. Additionally, DOE should make funding available to national laboratories for the specific purpose of collaborating with institutes on DOE priority projects.

Recommendation 5-1: By 2030, Congress should provide sustained dedicated funding above current appropriations to establish business development offices at each Manufacturing USA institute to support commercialization, scale-up, and regional ecosystem integration for entrepreneurs and small and medium-sized manufacturers, working in coordination with regional economic development organizations and federal manufacturing programs.

Recommendation 6-1: By 2030, Manufacturing USA institutes should adopt a broad range of programs to address workforce education needs in advanced manufacturing, based on best-practice programs developed by various institutes, including to develop advanced manufacturing curricula, develop online education, create advanced manufacturing credentials, support workforce education delivery, collaborate across institutes, and broaden the manufacturing talent base. These broadened programs should be executed in collaboration with regional stakeholders, such as area companies and education

institutions, and should include efforts to reach small manufacturers with workforce education advisory services and training programs.

Recommendation 6-2: Within approximately 2 years, agencies sponsoring the Manufacturing USA institutes working with the Advanced Manufacturing National Program Office should develop a unified advanced manufacturing curriculum available online that combines and unifies curricula and materials developed by institutes along with successful education and workforce development programs. Supporting this, they should develop an outcomes measurement and a credentialing system coordinated with industry and aligned with Manufacturing USA workforce metrics and programs.

Recommendation 6-3: By 2030, Manufacturing USA institutes should implement new technologist curricula, such as the Department of Defense’s Industrial Base and Sustainment funded pilot projects. They should work toward implementing it in cooperation with regional partners in industry and community colleges and, if deemed appropriate, incorporate it into the recommended Manufacturing Academy.

Recommendation 6-4: The White House Office of Science and Technology Policy and the Domestic Policy Council should convene a cross-agency workforce education project and implement within the next 2 years a strategy to coordinate efforts across agencies to enhance Manufacturing USA institute and other agency manufacturing education programs. This would include relevant programs at the Manufacturing USA institute-sponsoring agencies (currently Departments of Commerce, Energy, and Defense), as well as at the Departments of Labor and Education and the National Science Foundation’s Advanced Technological Education Program.

Recommendation 6-5: Given the need for apprenticeships in manufacturing, and especially to enable the scale-up of advanced manufacturing, within the next 2 years, Manufacturing USA institutes should become active promoters and enablers of manufacturing apprenticeships as part of their regional engagements.

Recommendation 6-6: A collaboration across Manufacturing USA institutes enabled by the proposed Interagency Council and the National Institute of Standards and Technology’s Advanced Manufacturing National Program Office should build out a robust online Manufacturing Academy portal of advanced manufacturing online courses and programs. By 2030, the online portal should include simulations, virtual reality, and augmented reality material, developed by Manufacturing USA institutes. The online portal should include materials and links from other verified sources, as well as new material.

Appendix A

Statement of Task

The National Academies of Sciences, Engineering, and Medicine will convene an ad hoc committee of experts to envision the Manufacturing USA Program in 2030 and 2035, emphasizing the impact of technology development, transition, and scale-up and workforce development efforts. In doing so, this study shall examine:

- 1. Technology transfer. Evaluate the mechanisms by which the institutes promote technology transition and scale-up of new manufacturing technologies and processes to drive adoption by domestic industries. Survey best practices at specific Manufacturing USA institutes and the contributions of the individual successes at those institutes to the effectiveness of the Manufacturing USA network as a whole in encouraging industrial adoption of institute-developed technologies. Identify gaps and opportunities where the Advanced Manufacturing National Program Office (AMNPO) can encourage, augment, and expand technology transfer and scale-up approaches more systematically. Include in this analysis the appropriate role of contract research, drawing on the analysis of similar R&D-focused advanced manufacturing programs described next. Note that this work is also called out in Division B of the CHIPS and Science Act.
- 2. Institute capabilities. Evaluate the effectiveness of Manufacturing USA institutes in establishing, maintaining, and engaging membership to include stakeholders who are critical missing stakeholders for advancing targeted technologies and sectors, as well as the technical relevance and impact of activities and investments within the institutes. Analyze the approaches taken by the institutes, including best practices at individual institutes and the extent to which these practices have been adopted by other institutes, to assess the characteristics and benefits of different approaches. Recommend network-wide enhancement priority areas.
- 3. Workforce. Incorporating existing resources and analysis conducted by recent Office of Advanced Manufacturing contracting initiatives, identify best practices for Education and Workforce Development (EWD) and examine the extent to which these practices have been

adopted across the network of institutes, and by other educational institutions and industries, along with any barriers that limit adoption. Identify areas for improvement and ways AMNPO, the sponsoring agencies, and the institutes can maximize institute successes or leverage opportunities for greater network-wide benefit.

- 4. Regional manufacturing ecosystems and domestic advanced manufacturing growth. Examine the extent to which the Manufacturing USA institutes engage in regional economic development and support domestic advanced manufacturing growth. Identify any foundational barriers, untapped resources, or missing stakeholders, and recommend ways for institutes and federal agency sponsors to address these findings.

- 5. Division B-CHIPS and Science Act. Develop recommendations for implementing the requirements of Division B of the CHIPS and Science Act

- a. Promote domestic production of institute-developed technologies.

- b. Evaluate current institute workforce development efforts in industry credentialing and recommend the best ways to implement the relevant Division B provision.

- 6. International and domestic program comparison and benchmarking. Identify analogous international and domestic government programs that may be used as comparative case studies for Manufacturing USA. Recommend where the most successful program elements or practices from these international and domestic R&D-focused advanced manufacturing programs with similar missions can be incorporated into the design of the institutes and network. Identify necessary scaling based on U.S. investments in the institutes and in institute growth with respect to these comparisons.

- 7. International collaboration opportunities. Leveraging work from the international comparison above, recommend where collaboration with international programs could be beneficial in advancing the Manufacturing USA program's domestic purposes.

- 8. Institute network. Recommend mechanisms to support cross-institute and cross-agency efforts to develop new technologies, including research and development for such technologies,

and support workforce development for advanced manufacturing. Recommend a framework for interagency collaborations, including mechanisms such as the transfer of funds between agencies, the ability of agencies to communicate with all institutes, and parameters for such interactions. Identify best practices for collaboration across institutes, along with recommendation for a platform for sharing best practices among institutes on an on-going basis.

•9. Federal sponsorship. Review whether the original institute funding model, as described in the design document and implemented in the initial institutes established after 2014, is still optimal for meeting the program's goals. Recommend if any changes should be made in the size, structure, duration for federal sponsorship of institutes, and co-investment requirements. Recommend how to determine appropriate funding levels for an institute renewed for follow-on federal sponsorship.

- 10. Provide recommendations on the above-listed categories and the following topics:
- a. Identify the principles and mechanisms that should inform sponsoring agencies' decisions about increasing, maintaining, decreasing, or ceasing support for sponsored institutes, including appropriate funding levels, and how institute performance and program goals inform those decisions. Also recommend how institutes no longer receiving federal base funds might be designated and appropriately participate within the Manufacturing USA network.
 - b. Evaluate the rationality of funding levels with respect to expected technological scope and impact for the network of institutes relative to the program's statutory purposes and strategic goals when compared with programs with similar missions established by international competitor nations.
 - c. Identify what changes and resources would be needed to accomplish each study recommendation, including identifying any statutory impediments.
 - d. Recommend approaches that could accelerate the impact of technology transition and scale up efforts of the institutes.
 - e. Identify enhancements to AMNPO network operations and activities in support of the Manufacturing USA Network. Recommend methods by which AMNPO can improve the effectiveness of Manufacturing USA. Recommend how the value proposition of the AMNPO can be clearly communicated to the institutes and agency partners and articulated to all

stakeholders.

f. Recommend actions that strengthen the impact of cross-network collaboration and assess whether access to collaborative funding increases the return on investment for the U.S.

Government, with benefits to both organizations participating in institute activities and to the public. Identify actions that the AMNPO and the sponsoring agencies can take to enhance connections between the Manufacturing USA institutes and other Federal programs.

The above listed bullets will be addressed with varying degrees of coverage in the final study.

While this could evolve based on ongoing findings, data, and evidence available within the time frame of the study, this coverage could range from light (potentially bullets 5 and 7), moderate (potentially bullets 1, 3, 4, 6, and 8), and in-depth (potentially bullets 2, 9, and 10).

Appendix B

Public Meeting Agendas

JANUARY 8, 2025

- 11:00–1:00 Mr. Mike Molnar, Director, Advanced Manufacturing National Program Office, and Director, National Institute of Standards and Technology (NIST) Office of Advanced Manufacturing
- Dr. Kelley Rogers, Deputy Director, NIST Office of Advanced Manufacturing
- Dr. Robert Rudnitsky, Division Chief for Strategy and Planning, NIST Office of Advanced Manufacturing

JANUARY 28, 2025

- 12:00–1:00 Dr. Phillip Singerman, Senior Advisor, Center for Strategic and International Studies, and former Associate Director for Innovation and Industry Services, NIST

FEBRUARY 10 AND 11, 2025

Hybrid Meeting

The Keck Center, 500 Fifth Street, NW

Washington, DC 20001

February 10

OPEN SESSION - Critical Needs of the Manufacturing USA Institutes Today and in 2030 and 2035; Roles of the Department of Energy and Department of Defense Manufacturing USA institutes

- 10:30–11:30 Dr. Diana Bauer, Deputy Director, Department of Energy Advanced Materials and Manufacturing Technologies Office

- 11:30–12:30 Dr. Stephen Recchia, Program Manager, Department of Defense Manufacturing Innovation Institutes, DoD Manufacturing Technology Program

February 11, 2025

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OPEN SESSION - Critical Needs of the Manufacturing USA Institutes Today and in 2030 and 2035; U.S. Manufacturing Innovation Council

- 10:30–12:00 Dr. Kelvin H. Lee, Chair, U.S. Manufacturing Innovation Council (USMIC), and Director, National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL)
- Dr. Douglas Friedman, Vice Chair, USMIC, and Chief Executive Officer, BioMADE
- Dr. Ignasi Palou-Rivera, President, USMIC, and Executive Director and Chief Technology Officer, Rapid Advancement in Process Intensification Deployment Institute
- Mr. Nigel Francis, Treasurer, USMIC, and Chief Executive Officer and Executive Director and Officer, LIFT
- Mr. Ira Moskowitz, Secretary, USMIC, and Chief Executive Officer, ARM Institute

FEBRUARY 18, 2025

- 12:00–1:00 Robert Atkinson, President, Information Technology and Innovation Foundation (ITIF)

MARCH 4, 2025

- 12:00–1:00 Dr. Brad Conrad, Education and Workforce Development Manager, NIST Office of Advanced Manufacturing
- Mr. Michael Britt-Crane, Education and Workforce Strategist, NIST Office of Advanced Manufacturing

MARCH 11, 2025

- 12:00–1:00 Dr. Lonnie Love, Fellow, Sandia National Laboratories
- Dr. William H. Peter, Advanced Manufacturing Program Director, Oak Ridge National Laboratory

MARCH 18, 2025

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- 12:00–1:00 Dr. Charlene Stokes, Program Manager, Manufacturing Education and Workforce Development, Manufacturing Technology Program Office, DoD
Nebiat Solomon, Workforce Development in the Advanced Materials and Manufacturing Technologies Office (AMMTO), Department of Energy

APRIL 1, 2025

- 12:00–1:00 Mr. Stephen Luckowski, Director of the Technology Transfer, Transition, and Commercial Partnerships (T3CP) Office, DoD Manufacturing Technology (DoD ManTech) Program

APRIL 8, 2025**Manufacturing USA Education and Workforce Development Workshop**

- 11:00–11:05 Welcome
- 11:05–12:05 Federal Workforce Education
Brad Conrad, Education and Workforce Development Manager, NIST
Charlene Stokes, Program Manager, Education and Workforce Development, DoD Manufacturing Technology Program
- 12:05–1:15 Institute Workforce Leads
Suzy Teele, Chief Strategy Officer, ARM Institute
Ed Herderick, Director of Education and Workforce Development, America Makes
Christy Johnson, Director of Education and Workforce Development, ARMI | BioFabUSA
Bob Geer, Vice President for Education and Workforce Development, AIM Photonics
- 1:15–1:30 Break
- 1:30–2:40 Institute Workforce Leads
Rebecca Lewis, Director of Workforce Development, NextFlex
John Balchunas, Workforce Director, NIIMBL
Lizabeth Stuck, Vice President, Government Affairs and MxD Learn, MxD

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2:40–2:55	Break
2:55–4:00	Outside Commentators Corey Adams, Education Program Manager, Universal Robots Paul Perkins, President and Co-founder, Amatrol, Inc. Courtney Taylor, Executive Director, AccelerateMS John D. Williams, Technical Fellow, Boeing Research and Technology
4:00	Adjourn

MAY 6, 2025

12:30–1:30	Mr. Jeffrey W. Frankston, Acting Deputy Secretary of Defense Industrial Base Resilience
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MAY 13, 2025

Manufacturing USA Technology Transfer Workshop

9:30–9:35	Welcome
9:35–10:30	Current Technology Transfer Processes at the Manufacturing USA Institutes— Federal Perspectives: Dr. Kelley Rogers, Deputy Director, Office of Advanced Manufacturing, NIST, Department of Commerce Mr. Keith DeVries, Director, Office of the Secretary, DoD Defense Manufacturing Technology Program Dr. Kate Peretti, Program Manager, Advanced Materials and Manufacturing Technologies Office, Department of Energy
10:30–11:30	Technology Transfer Best Practices at the Manufacturing USA Institutes Dr. Gabriela F. Ciocarlie, Acting Chief Technology Officer, Cybersecurity Manufacturing Innovation Institute (CyManII) Dr. Melanie Tomczak, Chief Technology Officer and Head of Programs, BioMADE Dr. Scott Miller, Director of Technology, NextFlex
11:30–11:40	Break
11:40–12:45	Innovation to Scale-up

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	Mr. Dean Kamen, Executive Director and Chair of the Board, BioFabUSA
	Dr. Jennifer MacDonald, Chief Operating Officer, ARMI
	Mr. Peter Russo, Strategic Innovation Partner, New Approach Development, LLC
	Ms. Ellen Ellsworth, Director of Growth and Innovative Services, MassMEP
12:45–1:15	Break
1:15–2:00	Technology Transfer Approaches at International Programs
	Dr. Guendalina Anzolin, Research Associate, Center for Science, Technology and Innovation Policy, Institute for Manufacturing, University of Cambridge
	Dr. Constantin Häfner, Executive Vice President for Research and Transfer, Fraunhofer-Gesellschaft
	Dr. Barry Kennedy, Chief Executive Officer, Irish Manufacturing Research
2:00–3:00	Non-technical Considerations
	Dr. Kelvin Lee, Director, NIIMBL
	Dr. Chuck Brandt, Chief Technology Officer, ARM Institute
	Dr. James F. Davis, University of California, Los Angeles, Vice Provost Emeritus; Program Oversight and Principal Investigator, Collaborative Ecosystems for Smart Manufacturing Innovation Institute (CESMII)
3:00–3:10	Break
3:10–4:15	Sharing Intellectual Property/Proprietary Information/Licensing
	Mr. Billy Bardin, Global Climate Transition Director, Dow
	Lisa Strama, Chief Executive Officer, National Center for Manufacturing Sciences
4:15	Adjourn

MAY 20, 2025

Manufacturing USA Interagency Engagement and Cross-Network Collaboration Workshop

10:00–10:05	Introduction
10:05–10:45	Strengthening Federal Laboratory Engagement with the Manufacturing USA Program

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Mr. Paul Zielinski, Executive Director, Federal Laboratory Consortium for Technology Transfer

10:45–11:45 Strengthening Department of Defense Laboratory Engagement with the Manufacturing USA Program

Dr. Jonathan Miller, Technical Director, Manufacturing, Industrial Technology and Energy Division, USAF Air Force Research Laboratory Manufacturing and Industrial Technologies Division

Dr. Jennifer Wolk, Division Director, Advanced Naval Materials and Systems, Sea Warfare and Weapons Department, Office of Naval Research

Dr. Adam Rawlett, Senior Research Scientist (ST) Material Science, U.S. Army Research Laboratory

11:45–11:50 Break

11:50–12:45 Strengthening NIST and DOE Laboratory Engagement with the Manufacturing USA Program

Dr. Robert W. Ivester, Senior Advisor on Advanced Manufacturing, NIST, Department of Commerce

Dr. Peter F. Green, Deputy Laboratory Director, Science and Technology, Chief Research Officer, National Renewable Energy Laboratory

Dr. Carol Burns, Deputy Director of Research and Chief Research Officer, Lawrence Berkeley National Laboratory, Department of Energy

12:45–1:15 Break

1:15–2:15 Facilitating Interagency Engagement by Mitigating Administrative Barriers

Dr. Greg Hudas, Director, Sustainment Technologies Office, OUSD(R&E)/Technology Innovation Industrial Base, DoD

Dr. Wayne Austad, Chief Technology Officer, National & Homeland Security at Idaho National Laboratory; Chief R&D Officer, CyManII

Dr. Kathryn Peretti, Program Manager, Advanced Materials and Manufacturing Technologies Office, Department of Energy

2:15–3:00 Models for Federal Coordination and Strategy Development

Dr. Jyoti K. Malhotra, Division Chief for National Programs, Hollings Manufacturing Extension Partnership, NIST, Department of Commerce

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- 3:00–4:00 Enhancing Strategic Engagement with Federal Agencies
 Dr. Kelley Rogers, Deputy Director, NIST Office of Advanced Manufacturing,
 Department of Commerce
 Mr. Keith DeVries, Director, Office of the Secretary of Defense Manufacturing
 Technology Program, DoD
 Dr. Christopher Saldaña, Director, Advanced Materials and Manufacturing
 Technologies Office, Department of Energy
- 4:00 Adjourn

MAY 27, 2025

- 12:00–1:00 Dr. Todd Younkin, Executive Director, SMART USA and President and Chief
 Executive Officer, Semiconductor Research Corporation

JUNE 17, 2025

- 12:00–1:00 Hilary Benedict, Acting Director, Science, Technology, Assessment, and
 Analytics, U.S. Government Accountability Office (GAO)
 Christopher Murphy, Assistant Director, GAO
 Jeff Rueckhaus, Senior Analyst, GAO

JULY 1, 2025

- 12:00–1:00 Dr. Philip Freeman, Senior Technical Fellow, Boeing Research and Technology

JULY 8, 2025

- 12:00–12:05 Introduction
- 12:05–1:30 Dr. Eoin O’Sullivan, Babbage Fellow of Technology and Innovation Policy and
 Director of the Center for Science, Technology, and Innovation Policy, Institute
 for Manufacturing, University of Cambridge
 Mr. Abishek Ramesh, Technology Strategy Manager, High Value Manufacturing
 Catapult
- 1:30–2:15 Dr. Melik Demirel, Huck Endowed Chair Professor of Biomimetic Materials,
 Pennsylvania State University

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- 2:15–3:45 Dr. Patrick Bressler, Director, International Cooperation, Emerging Technologies, and Innovation, Fraunhofer Microelectronics Group
Dr. Peter Gumbsch, Director, Fraunhofer Institute for Mechanics of Materials

JULY 15, 2025

- 12:00–1:00 Michael Cook, Director, Industry-Academia Enablement, Global Portfolio Engineering, Rockwell Automation

JULY 18, 2025

- 2:00–3:30 Mike Molnar, Director, Advanced Manufacturing National Program Office, and Director, NIST Office of Advanced Manufacturing

JULY 22, 2025

Manufacturing USA Regional Manufacturing Ecosystems Roundtable—ARM Institute
Mill 19 A
4501 Lytle Street, Suite 200
Pittsburgh, PA 15207

- 8:30–9:00 Tour of ARM Institute Facilities
9–9:15 Welcome and Objectives
9:15–9:30 Introduction by All Participants
9:30–10:15 Discussion Topic 1—Science and Engineering Enterprise; Skilled Workforce; Facilities and Equipment
10:15–11:00 Discussion Topic 2—Capital Investment; Supply Chains; Entrepreneurship; Scale-Up Challenge
11:00–11:15 Break
11:15–12:15 Discussion Topic 3—Regional Networks and Institutions; Local Impact; Federal/State/Local Partnership Programs
12:15–1:00 Key Takeaways and Recommendations, Roundtable Adjourns at 1 p.m.
1–1:30 Lunch
1:30–3pm Ad Hoc Discussion with Participants

JULY 24, 2025

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12:00–1:00 Dr. Lode Lauwers, Senior Vice President, Business Development and Strategy,
Interuniversitair Micro-Electronica Centrum VZW

JULY 30, 2025

Manufacturing USA Regional Manufacturing Ecosystems Roundtable II, Focus Institute:
NextFlex

12:00–12:15 Welcome and Objectives; Introduction by All Participants
12:15–1:00 Discussion Topic 1—Regional Networks and Institutions: Key Drivers,
Partnerships, and Metrics
1:00–1:45 Discussion Topic 2—Hubs: Science and Engineering Enterprise; Skilled
Workforce; Facilities and Equipment
1:45–2:00 Break
2:00–2:45 Discussion Topic 3—Scale-Up Challenges and Opportunities; Supply Chains;
Entrepreneurship; Capital Investment
2:45–3:00 Key Learnings and Recommendations
3:00 Roundtable Adjourns

JULY 31, 2025

12:00–1:00 Rob Luce, Vice President, SME Education Foundation
Adrienne Cloud, Chief Executive Officer, SMARTech Construction

AUGUST 8, 2025

1:00–2:00 Mark Peevy, Chief of Staff, Technical College System of Georgia

AUGUST 12, 2025

9:00–10:00 Sherri McCleary, Executive Director, Digital Foundry at New Kensington
10:00–11:00 Chad Schron, Vice President, Tooling U–SME

AUGUST 13, 2025

10:00–11:00 David Furrer, Principal Technical Fellow and Discipline Lead—Materials and
Processes Engineering, Pratt & Whitney

AUGUST 14, 2025

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- 3:00–4:00 David McFeeters-Krone, Partnership Expert, Intellectual Assets
4:00–5:00 Mike Gilroy, Senior Workforce Fellow, Center for Regional Economic Competitiveness

AUGUST 19, 2025

- 12:00–1:00 Dr. Huijuan Dai, Next Generation Materials and Processes Program Manager, Advanced Materials and Manufacturing Technologies Office, Department of Energy

AUGUST 20, 2025

- 8:30–10:00 Stephen Su, Senior Vice President, IITRI
Dr. BoGaun Chen, Director, ITRI North America Office and Director, Operations & Innovation Community, ITRI International Inc.
10:00–11:00 Yukihiro Sato, Deputy Director, Ministers Secretariat, Minister of Economy, Trade, and Industry (METI), Government of Japan

AUGUST 21, 2025

- 8:00–9:00 Dr. David Low, Executive Director, Singapore Institute of Manufacturing Technology (SIMTech), and Chief Executive Officer, Advanced Remanufacturing Technology Center (ARTC), Agency for Science, Technology, and Research (A*STAR)

OCTOBER 1, 2025

- 10:00–11:00 Dr. Celest Carter, former Director, Advanced Technological Education Program, National Science Foundation
11:00–12:00 Dr. Kelvin Lee, Director, NIIMBL, and Chair, USMIC
Mr. Franz Wuerfmannsdobler, Executive Director, USMIC

Appendix C

Committee Member Biographical Information

THERESA KOTANCHEK (NAE) (*Chair*) is the chief executive officer of Evolved Analytics LLC, an augmented intelligence and predictive analytics software and solutions provider. Prior to assuming her current role, Kotancheck spent 23 years in executive and leadership positions at the Dow Chemical Company, including vice president for Sustainable Technologies, Innovation Sourcing, and Information Research. She is a member of the National Academy of Engineering and currently chairs the National Academies of Science, Engineering, and Medicine’s National Materials and Manufacturing Board, as well as serving on numerous external boards, including the National Science Foundation’s Engineering Research Center for Cell Manufacturing Technologies. Kotancheck holds a PhD in materials science, an MS in ceramic science, and a BS in ceramic science and engineering from The Pennsylvania State University.

WILLIAM B. BONVILLIAN (*Vice Chair*) is a lecturer at the Massachusetts Institute of Technology (MIT), a senior advisor to the MIT Initiative for New Manufacturing, and teaches courses on innovation systems and science and technology policy. Previously, he was the director of MIT’s Washington Office; served as an advisor to MIT’s major cross-campus policy initiative, “Production on the Innovation Economy,” on advanced manufacturing; and was an MIT representative to the President’s industry–university Advanced Manufacturing Partnership, which formed U.S. manufacturing policies in the 2011–2016 period, including the development of the Advanced Manufacturing Institute program. Prior to MIT, he worked for more than 15 years on science and innovation issues as a senior advisor in the U.S. Senate and earlier was a Deputy Assistant U.S. Secretary of Transportation. He has authored a number of books and articles on these topics, including on manufacturing, *Advanced Manufacturing—The New American Innovation Policies* with Peter L. Singer (MIT Press 2018), *Workforce Education: A New Roadmap with Sanjay Sarma* (MIT Press 2021), *Pioneering Progress—American Science Technology and Innovation Policy* (MIT Press 2024), “Could an ARPA Help Resurrect US Manufacturing in Issues in Science and Technology” (2025), “The Technologist—A New Occupational Category Can Both Create Opportunities for Workers and Position the US to Lead in Advanced Manufacturing” in *Issues in Science and Technology* (2024), and “America’s

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Advanced Manufacturing Problem—and How to Fix It” with David Adler in *American Affairs* (2023), and other publications. He served on the National Academies of Sciences, Engineering, and Medicine’s National Board on Materials and Manufacturing and has participated on nine other National Academies’ committees and boards. In recent years, he chaired the Standing Committee on Science and Engineering Public Policy at the American Association for the Advancement of Science (AAAS), served on the board of the Information Technology and Innovation Foundation, and is a member of the Babbage Forum at Cambridge University’s Institute for Manufacturing and of the Polaris Council of advisors to the Government Accountability Office’s science and technology group. He was named an AAAS Fellow in 2011 and awarded IEEE’s public service award in 2007. He has degrees from Columbia, Yale, and Columbia Law.

DAVID ADLER is a contributing editor at *American Affairs* magazine and a senior advisor at XA Investments LLC (XAI). He is interested in finding ways to strengthen American manufacturing. For *American Affairs* he has written extensively about the scale-up challenges facing domestic production. His articles include “Inside Operation Warp Speed: A New Model for Industrial Policy.” XAI is a Chicago-based investment manager that provides investors with access to illiquid alternative investments. As a senior advisor, Adler focuses on the “illiquidity premium,” a topic he has written about and researched for the CFA Institute Research Foundation. Adler has an MA and a BA in economics from Columbia University and spent a post-graduate year studying economics at New College, Oxford, on a scholarship from the Columbia University Department of Economics. He is the co-editor of the anthology *The Productivity Puzzle: Restoring Economic Dynamism* (CFA Institute Research Foundation 2019) and the author of the monograph *Financial Frictions* (CFA Institute Research Foundation 2015). He is the author of the behavioral economics book *Snap Judgment* (Financial Times Press 2009) and was a producer of the related PBS/NOVA documentary, “Mind Over Money.” Additionally, he has written a series of articles about economic security for *Foreign Policy* magazine, comparing the approaches taken by the United States, the European Union, and Japan. He has organized conferences related to productivity as well as economic security.

FELICIA BENTON-JOHNSON is the vice president for Diversity and Inclusive Excellence at Clemson University. In her current role, she acts as the senior advisor on inclusive excellence to Clemson's president and serves on the president's executive leadership team. She develops and implements strategic initiatives to advance inclusive excellence across the Clemson community. Benton-Johnson has been a co-principal investigator (co-PI) or PI on several research projects, securing more than \$10 million in funding from the National Science Foundation, corporations, and foundations for initiatives that broaden participation in science, technology, engineering, and mathematics fields. Benton-Johnson has served on regional and national boards and committees including the National GEM Consortium Executive Board of Directors, the 50K Coalition Community Linkages Committee, and the National Association of Multicultural Engineering Program Advocates. Currently, she is a member of the National Academies of Sciences, Engineering, and Medicine's National Materials and Manufacturing Board. Prior to joining Clemson University, Benton-Johnson spent more than 19 years at the Georgia Institute of Technology where she served as the assistant dean and founding director of the Center for Engineering Education and Diversity. While at Georgia Tech, she and her team created a portfolio of successful programs related to attracting, empowering, and retaining diverse students, faculty, and staff in STEM fields. Benton-Johnson received her BS in biology and MED in curriculum and instruction from Tennessee State University in 1993 and 1996, respectfully. She received her EdD in educational leadership with an emphasis on diversity and inclusion from the University of Sarasota, Florida, in 2005.

STEPHANIE WATTS BUTLER is the president of WattsButler LLC, an innovation services company focused on the semiconductor and nanotechnology industries. Previously, she was a technology innovation architect with Texas Instruments. Butler's expertise is in silicon and wide bandgap manufacturing, technology, and integrated circuit product development from research and development (R&D) through production. While at Texas Instruments, her inclusive approach to innovation creation led to 17 U.S. patents. Butler has extensive experience in leadership roles in private-public partnerships, as well as joint development programs. She has chaired or co-chaired consortia technical advisory boards at SEMATECH, Semiconductor Research Corporation, IMEC, and PowerAmerica; served on university department advisory boards at The University of Texas at Austin; and founded and led JEDEC and International Electrotechnical

Commission working groups. She was responsible for the largest university research portfolio within product divisions. She has led several joint development projects with equipment and material suppliers and other semiconductor companies. She is a fellow of the AVS and a senior member of IEEE, the American Institute of Chemical Engineers, and the Society of Women Engineers (SWE). SWE recognized Butler in 2016 with their highest award, the Achievement Award for Outstanding Technical Contributions, and *Business Insider* named Butler to their 2017 most powerful female engineers list. Butler received her bachelor's degree from Oklahoma State University and her MS/PhD from The University of Texas at Austin.

JIAN CAO (NAE) is currently the Cardiss Collins Professor and director of the Northwestern Initiative for Manufacturing Science and Innovation at Northwestern University. She also serves as an associate vice president for research, overseeing university research institutes and centers and the office for research development. Cao specializes in innovative manufacturing processes and systems, particularly in the areas of deformation-based processes and laser additive manufacturing processes. Her research has integrated analytical and numerical simulation methods, control and sensors, design methodologies, and machine learning to advance manufacturing processes and systems. Cao is an elected member of the National Academy of Engineering and the American Academy of Arts and Sciences. She is a fellow of the American Association for the Advancement of Science, the American Society of Mechanical Engineers, the International Academy for Production Engineering, and SME. Cao was the editor-in-chief of the *Journal of Materials Processing Technology*. Cao received her PhD in mechanical engineering from the Massachusetts Institute of Technology. She currently serves as a member of the National Academies of Sciences, Engineering, and Medicine's National Materials and Manufacturing Board and Defense Materials, Manufacturing, and Its Infrastructure Standing Committee, the Board of Directors of SME, and the Board of mHUB—an accelerator for hardtech innovation and manufacturing in Chicago. Cao led a Far-Term Technology Forecast Study on Additive Manufacturing, sponsored by the Army Research lab, and was a member of the National Academies' consensus study *Option of a National Plan for Smart Manufacturing* from 2022 to 2023, and a member of the planning committee for the National Academies' Convergent Manufacturing Platform—A Future of Additive, Subtractive, and Transformative Manufacturing: A Workshop from 2021 to 2022.

DIANNE CHONG (NAE) was the vice president in the Boeing Company's Engineering, Operations & Technology organization where she led materials and manufacturing research and development and production program integration. Chong was elected to the National Academy of Engineering (NAE) and the Washington State Academy of Science in 2017. She serves on the NAE Council and co-chairs EngineerGirl. She is a member of the Governing Board of the National Research Council and a member of the National Academies of Sciences, Engineering, and Medicine's Division of Behavioral and Social Sciences and Education. She serves on the National Science Foundation's Directorate for Engineering Advisory Committee. Chong is the past president of ABET (formerly the Accreditation Board for Engineering and Technology, Inc.) and serves on its Inclusion, Diversity, and Equity Advisory Council. Chong is the past president and a fellow of the SME (formerly the Society of Manufacturing Engineers). She is a fellow of ASM International (formerly the American Society for Metals) and in 2007–2008 was elected its first female president. She received an award for alumna achievement from the University of Illinois in 2019 and has received numerous technical and diversity awards. She was inducted into the first class of the Women in Manufacturing Hall of Fame. Chong received bachelor's degrees in biology and psychology and master's degrees in physiology and metallurgical engineering. Chong received her doctorate in metallurgical engineering from the University of Illinois. She has an Executive Master of Manufacturing Management degree from Washington University and a green belt in Six Sigma. Chong is a member of The Minerals, Metals & Materials Society, American Institute of Aeronautics and Astronautics, ASM International, Society of Women Engineers, Beta Gamma Sigma, and Tau Beta Pi.

STEPHEN R. FORREST (NAS/NAE) is the Peter A. Franken Distinguished University Professor and the Paul G. Goebel Professor of Electrical Engineering, Physics, and Materials Science and Engineering at the University of Michigan. He received a BA in physics in 1972 from the University of California (USC) and an MSc and a PhD in physics in 1974 and 1979, respectively, from the University of Michigan. In 1985, Forrest joined the Electrical Engineering and Materials Science Departments at USC. In 1992, Forrest became the James S. McDonnell Distinguished University Professor of Electrical Engineering at Princeton University where he

chaired the department from 1997 to 2001. In 2006, he rejoined the University of Michigan as the vice president for research where he served until 2014. He is a fellow of the American Physical Society, IEEE, and the Optical Society of America and a member of the National Academy of Engineering, the National Academy of Sciences, the American Academy of Arts and Sciences, and the National Academy of Inventors. He is the co-founder or founding participant of Sensors Unlimited, Epitaxx, Inc., NanoFlex Power Corp., Universal Display Corp., Heat2Power, and Apogee Photonics, Inc., and has served on the board of directors and the Growth Technology Advisory Board of Applied Materials. He is the past chair of the board of the University Musical Society, from 2009 to 2012 was the chair of the board of Ann Arbor SPARK, and serves on the board of governors of the Technion–Israel Institute of Technology, where he holds an honorary doctorate.

THOMAS R. KURFESS (NAE) is the chief manufacturing officer of the Georgia Institute of Technology and the executive director of the Georgia Tech Manufacturing Institute. At Georgia Tech, he is the HUSCO/Ramirez Distinguished Chair in Fluid Power and Motion Control and Regents' Professor of Mechanical Engineering. He also serves as the chief technology officer at the National Center for Manufacturing Sciences. During 2019–2021 he was on leave serving as the chief manufacturing officer at Oak Ridge National Laboratory (ORNL), where he was responsible for strategic planning for ORNL in advanced manufacturing. He was also the founding director for the Manufacturing Science Division at ORNL. During 2012–2013 he served as the assistant director for Advanced Manufacturing at the Office of Science and Technology Policy in the Executive Office of the President of the United States of America, where he was responsible for coordinating federal advanced manufacturing R&D. He served as the president of the American Society of Mechanical Engineers (ASME) in 2023–2024 and was the president of the Society of Manufacturing Engineers in 2018. His research focuses on the design and development of advanced manufacturing systems targeting secure digital manufacturing, additive and subtractive processes, and large-scale production enterprises. He is an elected member of the National Academy of Engineering and is a fellow of ASME, the American Association for the Advancement of Science, and SME (formerly the Society of Manufacturing Engineers). He received his SB, SM, and PhD in mechanical engineering from the Massachusetts Institute of Technology (MIT) in 1986, 1987, and 1989, respectively. He also

received an SM from MIT in electrical engineering and computer science in 1988. Kurfess serves on the Executive Council for Manufacturing x Digital (MxD), on the board of directors for the parent company of America Makes, Manufacturing Technology Deployment Group, Inc., and serves as the chief manufacturing and energy officer of the Cybersecurity Manufacturing Innovation Institute.

SUJAI SHIVAKUMAR directs Renewing American Innovation at the Center for Strategic and International Studies, where he also serves as a senior fellow. Shivakumar brings more than two decades of experience in policy studies related to U.S. competitiveness and innovation. Previously, he directed the Innovation Policy Forum at the National Academies of Sciences, Engineering, and Medicine and led major studies of U.S. policies supporting advanced manufacturing, small business growth, workforce development, and entrepreneurship. He was also a lead contributor to a seminal National Academies' study of strategies adopted by U.S. states and regions to foster entrepreneurship, drive technology transfer, and encourage regional high-technology ecosystems. He also helped prepare National Academy of Public Administration studies on laboratory technology transfer and the management of space situational awareness. Reflecting his expertise in innovation policy, Shivakumar has testified before the Senate Committee on Commerce, Science, and Transportation and has been quoted in leading publications such as the *Financial Times* and *The Wall Street Journal*. His academic background includes a doctorate in economics from George Mason University and service as an Earhart Foundation scholar at the Ostrom Workshop at Indiana University Bloomington, where he authored *The Constitution of Development* (Palgrave Macmillan 2005) and co-authored with Nobel Laureate Elinor Ostrom *The Samaritan's Dilemma: The Political Economy of Development Aid* (Oxford University Press 2005). During his tenure at the National Academies, he contributed to more than 50 assessments of U.S. and foreign innovation programs.

CRISTINA URDANETA THOMAS (NAE) recently retired from 3M where she managed Global and Corporate Knowledge Discovery and Analytics, Electronic Lab Environments/LIMS, Global Technical Learning Academy, and R&D Data & Information Transformation. Thomas has more than 34 years of technical and leadership experience in R&D within the oil, chemical, and materials industries. Her expertise spans high-performance computing, modeling and

simulation, polymer science and engineering, technology and product development, strategy, and organizational leadership. She has researched, designed, and commercialized products, processes, systems, and solutions for MARAVEN (Venezuelan Oil Company), IBM, and 3M. She is a co-inventor of more than 28 patents. Her accolades include the 2023 American Chemical Society (ACS) Stanley C. Israel Regional Award for advancing diversity in chemical sciences, the 2019 American Institute of Chemical Engineers (AIChE) Leadership Award for pioneering computational-materials modeling, and the 2019 AIChE Management Division Award for leadership in chemical engineering. She is an ACS fellow, an ACS Polymer Science, Materials, and Engineering (PMSE) fellow, an AIChE fellow, and a member of the 2024 National Academy of Engineering class. She serves on the boards of Cristo Rey Jesuit Twin Cities High School, Computer Aids for Chemical Engineering Corporation, and Project Scientist. She is also involved with Achievement Rewards for College Scientists, AIChE, ACS PMSE Division, Advanced Energy Technology External Council at Argonne National Laboratory, and she serves on the Advanced Scientific Computing Advisory Committee for the Department of Energy Office of Science. She holds undergraduate degrees in chemistry (Universidad del Zulia) and mathematics (Universidad Nacional Abierta) in Venezuela and a PhD in chemical engineering from the University of Massachusetts Amherst.

CARROLL THOMAS is the former National Institute of Standards and Technology acting associate director for Innovation and Industry Services, director of the Hollings Manufacturing Extension Partnership (MEP), and most recently senior advisor for MEP. Thomas has held senior leadership positions in government, including as the associate administrator for the national Small Business Development Center program at the Small Business Administration. She has served in senior leadership positions in industry and was once a small business owner. Thomas currently serves on the boards of the Information Technology Innovation Foundation; SMART USA Institute (chair); Manufacturing x Digital; Federal Laboratory Consortium; and the Department of State Federal Credit Union. Thomas is a recognized catalyst for groundbreaking collaborations and partnerships across federal and state governments, with universities and community colleges, as well as with foreign governments such as Sweden, Mexico, and Colombia. She has brokered partnerships with U.S. Original Equipment Manufacturers and their supply chains, helping organizations to consider their local ecosystem as it relates to their

national presence. She has a BS from Drexel University in design and an MBA from Johns Hopkins University in international business.

CHARLES H. WARD is currently a senior technical fellow at ARCTOS Technology Solutions. Prior to this position, Ward's career spanned several research and development positions in materials, manufacturing, and propulsion systems as an active-duty officer and civilian with the U.S. Air Force. His last position was chief of the Manufacturing and Industrial Technologies Division of the Air Force Research Laboratory. In this position he led the Air Force's research investment in manufacturing technology and the Department of Defense's execution of the Defense Production Act Title III program. Ward is presently the editor-in-chief of the peer-reviewed journal *Integrating Materials and Manufacturing Innovation*. He is a fellow of ASM International and received the Distinguished Lectureship in Materials and Society Award from ASM International and The Minerals, Metals and Materials Society and the Hollomon Award for Materials and Society from Acta Materialia. Ward received his BS in metallurgical engineering and materials science and his MS and PhD in materials science and engineering from Carnegie Mellon University. He previously served on the National Academies of Sciences, Engineering, and Medicine's committee to identify opportunities for developing new advanced technologies for gas turbines in 2019. While chief of the Manufacturing and Industrial Technologies Division, he oversaw the management of America Makes, Advanced Robotics Manufacturing Institute, and NextFlex manufacturing institutes.

Appendix D

Disclosure of Unavoidable Conflicts of Interest

The conflict-of-interest policy of the National Academies of Sciences, Engineering, and Medicine (<http://www.nationalacademies.org/coi>) prohibits the appointment of an individual to a committee authoring a Consensus Study Report if the individual has a conflict of interest that is relevant to the task to be performed. An exception to this prohibition is permitted if the National Academies determine that the conflict is unavoidable and the conflict is publicly disclosed. A determination of a conflict of interest for an individual is not an assessment of that individual's actual behavior or character or ability to act objectively despite the conflicting interest.

Carroll Thomas has a conflict in relation to her service on the Committee on a Vision for the Manufacturing USA Program for 2030 and 2035 because of her position as chair on the board of the SMART USA Institute and membership on the board of Manufacturing x Digital (MxD), a Manufacturing USA institute. The National Academies have concluded that for the committee to accomplish the tasks for which it was established, its membership must include at least one member with current experience working directly with the Manufacturing USA institutes in establishing, maintaining, and engaging membership of stakeholders in targeted technologies and sectors across the innovation ecosystem. Likewise, as described in her biographical summary, as chair of the SMART USA Institute board, a member of MxD board, and as prior director of the Hollings Manufacturing Extension Partnership (MEP) at the National Institute of Standards and Technology (NIST), Thomas has helped facilitate collaborations and partnerships across federal and state governments, academic institutions, industry, and foreign governments. Her expertise and experience leading a national network of manufacturing experts focused on global competition, particularly regarding small and medium-sized manufacturing and supply chain management, and contributions to U.S. manufacturing strategic policy and investment on a national level address several critical areas in the statement of task. The National Academies have determined that the experience and expertise of Thomas are needed for the committee to accomplish the task for which it has been established. The National Academies could not find another available individual with the equivalent experience and expertise who did not have a conflict of interest. Therefore, the National Academies have concluded that the

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conflict is unavoidable. The National Academies believe that Thomas can serve effectively as a member of the committee, and the committee can produce an objective report, considering the composition of the committee, the work to be performed, and the procedures to be followed in completing the study.

Thomas R. Kurfess has a conflict in relation to his service on the Committee on a Vision for the Manufacturing USA Program in 2030 and 2035 because he serves on the board of directors of the Manufacturing Technology Deployment Group, Inc., the parent company of America Makes; serves on the Executive Council of Manufacturing x Digital (MxD), and serves as the chief manufacturing and energy officer of the Cybersecurity Manufacturing Innovation Institute. The National Academies have concluded that for the committee to accomplish the tasks for which it was established, its membership must include at least one member with current experience working directly with one or more of the Manufacturing USA institutes to help inform recommendations for mechanisms for cross-institute and cross-agency efforts to develop new technologies, review funding models, and survey best practices at specific Manufacturing USA institutes. As described in his biographical summary, Kurfess in his senior roles at several Manufacturing USA Institutes and his prior positions as chief manufacturing officer at Oak Ridge National Laboratory and former assistant director for Advanced Manufacturing at the Office of Science and Technology Policy, has extensive expertise and experience in strategic planning for advanced manufacturing, coordinating federal advanced manufacturing R&D, and carrying out research focusing on large-scale production enterprises at Georgia Tech, which addresses several critical areas in the statement of task. The National Academies have determined that the experience and expertise of Kurfess are needed for the committee to accomplish the task for which it has been established. The National Academies could not find another available individual with equivalent experience and expertise who did not have a conflict of interest. Therefore, the National Academies have concluded that the conflict is unavoidable. The National Academies believe that Kurfess can serve effectively as a member of the committee, and the committee can produce an objective report, considering the composition of the committee, the work to be performed, and the procedures to be followed in completing the study.

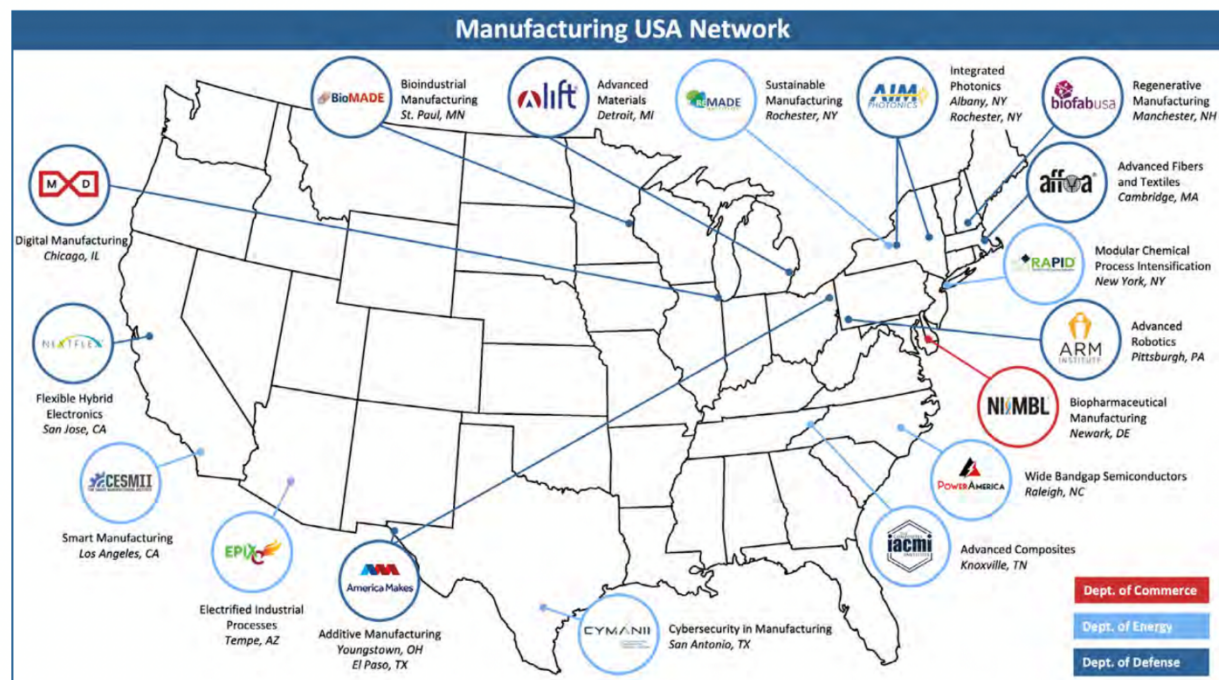
Appendix E

Manufacturing USA Program-Specific Information

TABLE E-1 Current 17 Institutes

Acronym	Name / <i>Description</i>
AFFOA	Advanced Functional Fabrics of America
AIM Photonics	American Institute for Manufacturing Integrated Photonics
America Makes	The National Additive Manufacturing Innovation Institute
ARM Institute	Advanced Robotics for Manufacturing Institute
ARMI BioFabUSA	Advanced Regenerative Manufacturing Institute
BioMADE	<i>Originally stood for</i> Bioindustrial Manufacturing and Design Ecosystem
CESMII	Collaborative Ecosystems for Smart Manufacturing Innovation Institute
CyManII	Cybersecurity Manufacturing Innovation Institute
EPIXC	Electrified Processes for Industrial eXcellence
IACMI	Institute for Advanced Composites Manufacturing Innovation
LIFT	<i>Originally stood for</i> “Lightweight Innovations for Tomorrow,” <i>now just</i> LIFT
MxD	<i>Originally</i> “Digital Manufacturing and Design Innovation Institute (DMDII) and now Manufacturing × Digital; DoD
NextFlex	Flexible Hybrid Electronics Manufacturing Institute.
NIIMBL	National Institute for Innovation in Manufacturing Biopharmaceuticals
PowerAmerica	<i>The Next Generation Power Electronics Manufacturing Innovation Institute</i>
RAPID	Rapid Advancement in Process Intensification Deployment Institute
REMADE	Materials Recycling and Manufacturing Supply Chain Optimization

NOTE: For the location of the institutes, see Figure E-1.



*Manufacturing USA Network at time of publication, March 2026. Credit: NIST

FIGURE E-1 U.S. map showing the location of each institute in the Manufacturing USA Network.

SOURCE: National Institute of Standards and Technology. *Manufacturing USA Annual Report 2025*. NIST AMS 600-19. National Institute of Standards and Technology, 2026.

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