Restoring U.S. Leadership in Manufacturing

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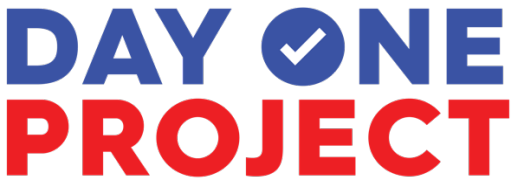

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Summary

Manufacturing is a critical sector for American economic well-being. The value chains in the American economy that rely on manufactured goods account for 25% of employment, over 40% of gross domestic product (GDP), and almost 80% of research and development (R&D) spending in the United States.[1] Yet U.S. leadership in manufacturing is eroding. U.S. manufacturing employment plummeted by one-third—and 60,000 U.S. factories were closed—between 2000 and 2010. Only some 18% of the production jobs lost in the United States during the Great Recession were recovered in the following decade. Production output only recently returned to its pre-Great Recession levels. This "hollowing out" of U.S. manufacturing has been largely driven by international competition, particularly from China. China passed the United States in 2011 as the largest global manufacturing power in both output and value added.

Declining U.S. manufacturing has sharply curtailed a key path to the middle class for those with high-school educations or less, thereby exacerbating income inequality nationwide. We as a country are increasingly leaving a large part of our working class behind an ever-advancing, upper-middle class. The problems plaguing the domestic manufacturing sector are multifold: American manufacturing productivity is historically low; diminished financial support for manufacturing is hurting small and mid-sized firms; these firms lack access to R&D; startups have scale-up problems; manufacturing is poorly supported by our workforce-education system; and we have disconnected our innovation systems from our production systems.

The United States can address many of these problems through concerted efforts in advanced manufacturing. Advanced manufacturing means introducing new production technologies and processes to significantly lower production costs and raise efficiency, positioning the United States to better compete internationally. Advanced manufacturing also requires that we reconnect innovation with production. A milestone in advanced manufacturing came in 2012, when the federal government established the first of an eventual 14 Advanced Manufacturing Institutes. Each institute in this network is organized around developing new advanced technologies, from 3D printing to digital production to biofabrication. Each also represents a collaboration among industry, government, and academic institutions. Today, three federal agencies invest a total of approximately $330 million per year in the institutes—an amount matched by industry and states.

[1] National Academy of Engineering, *Making Value in America, Embracing the Future of Manufacturing, Technology and Work* (Wash., DC: National Academies Press 2015), 14,15, https://www.nap.edu/catalog/19483/making-value-for-america-embracing-the-future-of-manufacturing-technology.

The manufacturing institutes have proven successful to date.[2] But they alone cannot reboot American manufacturing. Key U.S. trading partners and competitors spend far more on maintaining their manufacturing base and investing in advanced manufacturing compared to their GDP than the United States does.[3] To restore U.S. leadership in manufacturing and rebuild manufacturing as a route to quality jobs for Americans, the federal government must double down on advanced manufacturing nationwide. Specifically, the federal government should:

- Develop a strategic plan for positioning the United States as world leader in advanced manufacturing.
- Grow the number of manufacturing institutes to at least 25 and significantly raise institute funding.
- Work through the institutes to create a new workforce education system designed to prepare workers for jobs in advanced manufacturing.
- Better connect the institutes to the strengths of the federal research system.
- Develop an ongoing assessment of advanced production capabilities emerging in other nations.

More detail on these and related recommendations is provided below.

1. Challenge

1.1 Obstacles facing U.S. manufacturing

The United States faces multiple obstacles related to manufacturing, including:

- **Low manufacturing productivity.** U.S. manufacturing productivity increased by an average of 2% per year from 1992–2004 but declined by an average of 0.3% per year from 2004–2016.[4] At no time in the past eight years has domestic manufacturing productivity grown by 1% or more.[5] Low productivity signals a problem with the innovation system underlying the domestic manufacturing sector.
- **A thinned-out manufacturing ecosystem.** Investment in capital plants, equipment, and information technology is at historically low levels. The U.S. financial sector has pressured firms to lower financial risk by going "asset light"—*i.e.*, cutting back

[2] Advanced Manufacturing Office, *Manufacturing USA 2018 Annual Report*, National Institute for Standards and Technology (NIST), U.S. Department of Commerce, 600-5 (2019).

[3] National Materials and Manufacturing Board, *Strategic Long Term Participation by DOD in its Manufacturing USA Institutes*, Division on Engineering and Physical Sciences, National Academies of Sciences, Engineering, and Medicine (2019), 43. This paper is drawn from contributions by the author to this report as well as his book and prior articles.

[4] Bureau of Labor Statistics, "Multifactor productivity slowdown in U.S. manufacturing", U.S. Department of Labor, July 2018, https://www.bls.gov/opub/mlr/2018/article/multifactor-productivity-slowdown-in-us-manufacturing.htm.

[5] Bureau of Labor Statistics, "Productivity and Costs: Third Quarter 2019, Revised", USDL 19-2143, December 10, 2019, https://www.bls.gov/news.release/pdf/prod2.pdf. *See also*, Susan N. Houseman, *Understanding the decline of US manufacturing employment*, W.E. Upjohn Institute for Employment Research, 18-287 (June 2018).

on the scope of their production activities and connections to suppliers. Offshoring resulted, and the shared links between firms in areas like training and best production practices—the "manufacturing commons"—thinned out. This was particularly problematic for small and mid-sized manufacturers who relied on the commons.[6]

- **Limited capacity to conduct and scale innovation.** Small and mid-sized manufacturers tend to be risk averse and thinly capitalized. As such, these firms have limited capacity to conduct in-house R&D and innovation activities despite the importance of these activities to output competition.[7] Larger firms have greater capacity for innovation. But as large U.S. firms have become increasingly globalized, their innovation capacity has been affected. Moreover, the entrepreneurial, venture-backed startups that have traditionally injected innovation into the U.S. economy, driven by their venture-capital backers, have focused overwhelmingly on software, services, and biotechnology.[8] "Hardtech" firms that plan to manufacture received only 5% of U.S. venture-capital investments in 2015.[9] Limited capacity to conduct and scale manufacturing innovation in the United States significantly affects the viability of the U.S. manufacturing sector.
- **Poor support from the workforce-education system.** A highly skilled workforce is essential to enabling the United States to rapidly introduce new technologies from the R&D system into the manufacturing sector.[10] Yet the United States has reduced spending on workforce training, including in manufacturing. On the corporate side, workers who reported they received employer-provided training declined from close to 20% to approximately 11% between 1996 and 2008.[11] The U.S. government also significantly underinvests in workforce-training programs. Today, the U.S. government dedicates just 0.1% of GDP to active labor-market programs—less than half of what it did 30 years ago (as a share of GDP). [12] By comparison, other Organization for Economic Development (OECD) governments dedicate an average of 0.6% of GDP to such programs. The U.S. labor market also

[6] Suzanne Berger with the MIT Task Force on Production and Innovation, *Making in America*, Cambridge, MA: MIT Press (2013): 20.
[7] Thomas C. Mahoney and Susan Helper and Thomas Mahoney, *Ensuring American Manufacturing Leadership Through Next Generation Supply Chains*, Mforesight, MF-TR-2017-0201 (June 2017).
[8] William B. Bonvillian and Peter L. Singer, *Advanced Manufacturing: The New American Innovation Policies*, Cambridge, MA: MIT Press (2018): 185–215. *See also*, William Lazonick, *Sustainable Prosperity in the New Economy?: Business Organization and High-Tech Employment in the United States*, Kalamazoo, MI: W.E. Upjohn Institute for Employment Research (2009).
[9] Bonvillian and Singer, *Advanced Manufacturing*: 193–194.
[10] Berger, *Making in America*; Susan Helper and Raphael Martins, "The High Road in Manufacturing", in Paul Osterman, ed., *Creating Good Jobs: An Industry-Based Strategy*, Cambridge, MA: MIT Press (2019).
[11] Council of Economic Advisors, *2015 Economic Report of the President, Achievements and Challenges in the U.S. Labor Market*, c.3, 2015, 146-147.
[12] Sanjay E. Sarma and William B. Bonvillian, "The Quest for Quality Jobs", *Issues in Science and Technology* 35, no. 1 (Fall 2018).

lacks a sound information system to help employers and employees learn about and navigate training programs that do exist.[13]

- **Delinked innovation and production.** There is a tendency to think of innovation exclusively as part of R&D, not manufacturing. Yet production is a key stage in the innovation pipeline. Production, especially initial production of a new technology, requires creative engineering and iteration with researchers. When we as a nation invest in basic R&D but fail to invest in innovative manufacturing technologies and processes, we create a situation in which we are strong on technology ideas but lack the capacity to move these ideas from prototype to production. Delinked innovation and production has emerged as a real problem in the United States. The American economy is increasingly based on a philosophy of "innovate here, produce there [*i.e.*, overseas]".[14] This way of thinking is inherently flawed. Because innovation and production are so closely linked, outsourcing production equates to outsourcing innovation. Outsourcing innovation, in turn, makes it easier for international competitors to capitalize on American ingenuity and erode American economic strength.

From 2000–2010, U.S. manufacturing employment fell precipitously from about 17 million to under 12 million. While employment declined in all manufacturing sectors, those most prone to globalization (such as textiles and furniture) were especially badly affected. This is largely attributable to China's competitive entry into manufacturing, which experts estimate caused the loss of 2.4 million U.S. manufacturing jobs.[15]

The U.S. manufacturing decline has adversely affected economic well-being in numerous historically industrialized regions—especially for the men without college degrees who have long led U.S. manufacturing employment. Full-year employment of men with a high-school diploma but without a college degree dropped from 76% in 1990 to 68% in 2013. The share of these men who did not work at all rose from 11% to 18%.[16] While real wages have recently grown for men and women with college degrees, they have fallen for men without college degrees. These trends have affected the working class overall and are particularly worrying for the socioeconomic mobility of minority populations in the United States. African Americans and Hispanics have long comprised a significant portion of the manufacturing workforce, and manufacturing jobs have long been a critical

[13] Sanjay E. Sarma and William B. Bonvillian, Fixing an Imperfect Labor Market Information System, *Issues in Science and Technology* 35, no. 1 (Fall 2018).
[14] Bonvillian and Singer, *Advanced Manufacturing*: 57–58.
[15] David Autor, David Dorn, and Gordon Hanson, *The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade*, National Bureau of Economic Research, NBER Working Paper No. 21906 (January 2016).
[16] Melissa S. Kearney, Brad Hershbein, and Elisa Jacome, "Profiles of Change: Employment, Earnings and Occupations from 1990-2013", The Hamilton Project (April 2015).

route for minority communities to enter the middle class. With manufacturing's decline, this avenue upward has significantly narrowed.

2. Opportunity

Although our nation is lagging behind countries such as Germany, Japan, Korea, Taiwan, and China when it comes to manufacturing innovation, the United States is a world leader on R&D innovation. There is a valuable opportunity to leverage domestic capabilities in R&D innovation to bolster domestic capabilities in manufacturing. A variety of cutting-edge technologies—including new sensor and control systems, big data and analytics, robotics, artificial intelligence (AI), complex simulation and modeling, advanced materials and composites, biofabrication, mass customization (the ability to produce small customized lots at mass-production costs through 3D printing and computerized controls), nanofabrication, and photonics[17]—have potential applications in manufacturing. Using such technologies to create new advanced-manufacturing paradigms could transform manufacturing efficiency, productivity, and returns on investment (ROIs) in the United States.

A national advanced manufacturing initiative in the United States would yield multiple benefits. Investment in advanced manufacturing could restore U.S. manufacturing leadership and therefore help employment; in addition, certain advanced-manufacturing technologies (*e.g.*, 3D printing) have the potential to re-localize supply chains and thereby generate additional jobs. Pursuing innovative manufacturing methods could improve production cost efficiency, thereby enabling the United States to compete successfully with nations where labor costs are lower. Production innovation will also generate better products and create new product markets. Finally, robust domestic manufacturing capabilities are essential to national security.

2.1 The emerging effort: Advanced Manufacturing Institutes

The federally funded Advanced Manufacturing Institutes (the "institutes") have begun to close the gap between R&D innovation and production innovation in the United States. Established based on recommendations from the industry- and university-led Advanced Manufacturing Partnership (AMP)[18,19] in 2012, the 14 institutes are designed to create new production paradigms in different production areas,[20] shared across the supply

[17] The discussion below draws on William B. Bonvillian and Peter L. Singer, "What Economists Don't Know About Manufacturing", *The American Interest* 13, no. 5 (May/June 2018): 17–23.
[18] President's Council of Advisors on Science and Technology (PCAST), *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing*, Executive Office of the President (July 2012).
[19] PCAST, *Report to the President on Accelerating U.S. Advanced Manufacturing*, Executive Office of the President (October 2014).
[20] Formation of a 15th institute focusing on cybersecurity in manufacturing was announced by the Department of Energy in March 2019. *See* U.S. Department of Energy, "DOE Announces $70 Million for Cybersecurity Institute for Energy Efficient

chains of large and small firms and across industry sectors. In late 2018, Congress proposed establishing a 15th institute to focus on cybersecurity in manufacturing. The institutes are partially funded by federal agencies: eight are funded by the Department of Defense (DOD), five (and soon six) by the Department of Energy (DOE), and one by the Department of Commerce (DOC). Total federal funding for the institutes is approximately $330 million per year. Each federal dollar is typically matched by about two dollars from industry and state governments.

Why institutes? One key reason is that the great majority of the U.S. manufacturing sector firms are small and mid-sized, producing nearly half of U.S. output,[21] that—as noted above—typically don't perform in-house R&D and have difficulty accessing the production innovation they need to compete. Challenges facing small and mid-size manufacturing firms became even greater when U.S. manufacturing output declined and factories closed in the 2000s. Moreover, even larger firms with R&D capabilities need to collaborate to share the major risks and costs of transitioning to new production paradigms. The institutes address these challenges and needs by acting as test beds—that is, by providing a range of industries and firms with opportunities to collaborate on, test, and prove prototypes for advanced production technologies and processes. The institutes also help fill manufacturing talent gaps, training technical workers to use advanced technologies and to develop processes and routines for introducing advanced technologies into established production systems.

In short, the manufacturing institutes help fill gaps in the U.S. manufacturing innovation system by:

- Connecting small and large firms in collaborative innovation to restore the thinned-out manufacturing ecosystem.
- Relinking innovation and production through collaborations between firms and universities.
- Pursuing innovations that improve manufacturing efficiency and productivity.
- Providing shared facilities to support scale-up of promising technologies.
- Training a skilled workforce to use advanced manufacturing technologies.

Manufacturing", March 26, 2019, https://www.energy.gov/articles/doe-announces-70-million-cybersecurity-institute-energy-efficient-manufacturing.

[21] Small Business Administration, *Frequently Asked Questions About Small Business, Small Businesses Comprise What Share of the U.S. Economy*, 2012, https://www.sba.gov/sites/default/files/FAQ_Sept_2012.pdf.

Although technology development is a long-term project, the institutes have already delivered some notable results. Institute-supported achievements to date include:[22]

- The first foundry for tissue engineering.
- Standards to guide implementation of 3D-printing technology.
- Optimized sensor networks for smart manufacturing.
- Advanced fibers that contain individually controllable electronic devices.
- A virtual software tool that replicates supplier tools in order to verify that production can meet highly precise standards.
- A suite of online courses to educate technicians and engineers in integrated photonics production.

These successes notwithstanding, the institutes alone cannot solve the systemic problems plaguing manufacturing in the United States. The federal government should dramatically scale up and expand the role of the institutes to usher in a new era of advanced manufacturing nationwide.

3. Proposed action

The institutes' collaborative, cost-shared, public/private model is well designed to engage all critical stakeholders—industry, universities, community colleges, state governments, and federal agencies. But in the $20 trillion U.S. economy, spending just $330 million annually to support the institutes (even if those funds are matched by industry and state governments) won't make a large impact. A concerted national effort is needed to position the United States as a global leader in advanced manufacturing and truly realize the transformative economic and social benefits that advanced manufacturing can deliver. This section recommends ten actions that the federal government can take to achieve these goals.

3.1 Develop a strategic plan for positioning the United States as a world leader in advanced manufacturing

It's hard to lead without a plan. This is particularly true in a complex technology area like advanced manufacturing. Individual institutes are developing institute-specific roadmaps tailored to their respective technology areas of focus. The federal government should build on these efforts by developing a national strategic plan for advanced manufacturing that cuts across all sectors—as proposed in the AMP's 2014 Report on

[22] Advanced Manufacturing Office, *Manufacturing USA 2018 Annual Report.*

Accelerating U.S. Advanced Manufacturing.[23] The AMP specifically recommended that such a plan be built on four pillars:

(1) Industry/market pull.
(2) Cross-cutting impact across multiple industry sectors.
(3) Importance to national security and competitiveness.
(4) Leverage current U.S. strengths/competencies.

Although initial work to develop a national manufacturing strategic plan was undertaken in 2016,[24] the product was limited and not a true roadmap. Four years later, the need for a plan—one that addresses advanced manufacturing overall—remains.

Action steps

The next administration should, through the President's Council of Advisors for Science and Technology (PCAST), name an expert committee comprised of industry, university and government leaders to develop a public/private national advanced manufacturing strategic plan. Staffing and support for the planning effort should come from Manufacturing USA (the network organization for the institutes) and the three federal agencies that fund the institutes (DOD, DOE, and DOC). The plan should:

- Specify the coordination functions of the institutes and the Manufacturing USA network.
- Specify funding levels needed to carry out key advanced-manufacturing efforts and address recommendations listed below.
- Outline recommended policies to support overall manufacturing-technology development, expand advanced workforce education, and secure a sound manufacturing economic climate.
- Provide specific implementation steps for the President and Congress.

The expert committee should also establish a mechanism and timeline for periodic updating of the plan.

3.2 Grow the number of institutes to at least 25 and significantly raise institute funding

The institutes are delivering successes, but there are not enough of them. Germany, for example, has over 60 Fraunhofer Institutes doing comparable work. Numerous important advanced-manufacturing areas that require further development are not covered by the

[23] PCAST, *Report to the President on Accelerating U.S. Advanced Manufacturing*: 20–21. Eight of the recommendations listed below are drawn from proposed studies the author worked on in National Materials and Manufacturing Board, *Strategic Long Term Participation by DOD in its Manufacturing USA Institutes*.

[24] Advanced Manufacturing National Program Office, *National Network for Manufacturing Innovation and Strategic Plan*, National Science and Technology Council, Executive Office of the President (February 2016). This study was conducted in response to the bipartisan Revitalize American Manufacturing and Innovation Act of 2014 (RAMI Act), 15 U.S.C. § 278s.

existing institutes. Gaps in the current institute network include nanofabrication,[25] next-generation electronics (building on DARPA's Electronics Resurgence Initiative),[26] AI and machine learning,[27] and visualization and the digital thread, including new tools for digital design.[28] In addition, the federal investment per institute needs to grow, from the $50–70 million per institute over five years currently available to a total level that starts to resemble what our international competitors are investing. The new national strategic plan for advanced manufacturing (described above) could guide funding requests.

Action steps

The next administration should seek funding for additional institutes, with a goal of increasing the total number nationwide to at least 25 in the next several years. The next administration should also ask other federal agencies with significant research budgets and mission stakes in the industrial economy—such as the National Aeronautics and Space Administration (NASA), the U.S. Department of Agriculture (USDA), and the Department of Health and Human Services (HHS)—to consider sponsoring institutes. Finally, the next administration should seek to significantly increase the level of federal matched funds dedicated to the institutes. Funding levels should be determined by a combination of institute performance, national-strategy recommendations, the particulars of proposed projects.

3.3 Instead of term-limiting institutes, establish a formal process for determining whether or not an institute's term should be extended

The institutes were initially established with five-year fixed terms. But the job of the institutes is not done—addressing the deep structural issues in U.S. manufacturing innovation will require sustained effort over decades. Congress has recently recognized that the institutes should not face fixed terms.[29] But this does not mean that all institute terms should be automatically renewed. The federal government should extend those that are working well, end those that aren't, and require improvements in others.[30] Like any experiment, the institutes will engender successes and failures. The institute network needs a governance process that recognizes that.

[25] *See generally*, National Nanotechnology Initiative, https://www.nano.gov.
[26] Defense Advanced Research Projects Agency, "DARPA Electronics Resurgence Initiative", U.S. Department of Defense, December 19, 2019, https://www.darpa.mil/work-with-us/electronics-resurgence-initiative.
[27] *See*, for instance, Accenture, *Rethink, Reinvent, Realize. How to successfully scale digital innovation to drive growth* (2019).
[28] *See* proposal in, PCAST, *Report to the President on Accelerating Advanced Manufacturing*: 22–25.
[29] S.1947, Global Leadership in Advanced Manufacturing Act of 2019, 116th Congress, 1st Session (passed Congress as part of S.1790, The National Defense Authorization Act for FY2020).
[30] National Materials and Manufacturing Board, *Strategic Long Term Participation by DOD in its Manufacturing USA Institutes.*

The three federal agencies that currently fund and oversee the institutes—DOD, DOE and DOC—should develop performance metrics aligned with the strategic goals of the institutes. Funding agencies should consider implementing a formal evaluation process that each institute must go through when it approaches the end of its term and applies for term renewal. This process could consider elements such as an institute's progress on its technology-development roadmaps, the impact of its current and planned technology development, the reach of its workforce-education efforts, involvement of small and mid-sized firms, and continued support from and cost-sharing by industry and states. The evaluation process and evaluation criteria must be carefully developed such that evaluations can be conducted by an impartial, third-party expert review team. The evaluation process must also be transparent, so that institutes and their industry and university participants can fully understand how they will be evaluated ahead of time and align their work with evaluation metrics. Finally, the evaluation process must be as consistent as possible across the entire institute network.

For those institutes that have not yet reached the end of their initial five-year terms, the evaluation could be completed early in year five. For those institutes that have already reached the end of their terms and obtained interim extensions of federal support, the evaluation could be completed toward the end of interim extensions. If the evaluation concludes that an institute is making adequate progress, the evaluation team could recommend to its funding agency that it be renewed for an additional five-year term. If progress is inadequate, the institute could be terminated or recommended for renewal contingent on specific improvements. In cases where an inadequate institute has responsibility for an essential technology area, the evaluation team could also recommend re-competing the technology area seeking different leadership and organizational changes. All evaluations—even those for institutes deemed to be making adequate progress—could provide recommendations for improvements.

Action steps

Federal agencies supporting the institute network should promptly assemble a team comprised of agency representatives as well as outside experts to develop an overall framework and criteria for the evaluation process. The framework and criteria should be as uniform as possible across institutes, while making allowances for key differences. As individual institutes reach the ends of their terms (or interim extensions), expert teams should be assembled by the supporting federal agencies to undertake institute evaluations.

3.4 Work through the institutes to create a new education system designed to prepare workers for jobs in advanced manufacturing

The institutes' focus on technology development necessitates a parallel focus on workforce education. Engineers and technicians need adequate workforce education in order to be able to learn, adopt, and implement advanced-manufacturing technologies. In other words, unless engineers and technicians at companies of all sizes are familiar with and equipped to handle new technologies, it will be impossible for innovations coming out of the institutes to be adopted at the scale and in the timeframes needed. Workforce readiness will determine the scale and pace of new technology adoption.

Unfortunately, American workforce-education systems are largely broken. Causes include:

- Disinvestment in workforce education by both government and employers in recent decades.
- Federal training programs that have limited focus on higher technical skills and incumbent workers.
- Federal education programs that have large gaps in filling workforce needs and are not linked or complementary to other federal programs.
- A vocational education system in secondary schools that has largely been dismantled.
- Underfunded community colleges that lack the resources to provide advanced training in emerging fields.
- Colleges and universities that could help develop higher-end, new technology skills, are disconnected from workforce education and other participants in workforce-education systems (particularly community colleges).
- A general disconnect between the still-separate worlds of work and learning, as well as scarce support of lifelong learning.
- The limited scale of those creative, advanced technical education programs that do exist.
- A broken labor-market information system that doesn't effectively serve workers, employers, or educators.

Complicating efforts to establish new and improved workforce-education systems is the fact that existing systems depend heavily on actors in complex, established "legacy" sectors that are hard to change. At the federal level, only a modest NSF program in Advanced Technological Education (ATE), through community colleges, provides education and training in advanced manufacturing. Neither the Department of Labor (DOL) nor the Department of Education (E) has a program dedicated to education or training in advanced manufacturing. The institutes, through their unique blend of

academic, public, and private-sector participation, are well positioned to help spur change and build a skilled advanced-manufacturing workforce in the United States. The institutes also have the deep technical expertise needed to effectively guide the content and structure of new workforce-education modules.

Because companies pursuing advanced manufacturing are likely to implement technologies developed by more than one institute, workforce education is a critical space for cross-institute interaction and cooperation. It may be appropriate for an individual institute to develop specialized courses tailored to that institute's focus area, but institutes could collaborate in preparing courses on the basics of advanced manufacturing skills. institutes could also work together in developing online education modules (including modules that incorporate new virtual- and augmented-reality tools and computer-gaming approaches) that demonstrate how different technologies can complement each other. Finally, institutes could work together to standardize delivery platforms, leading to a common online course system accessible by members of all institutes.

Action steps

Manufacturing USA should launch a coordinated effort to identify best practices in workforce education at the institutes and elsewhere, including for online education. Manufacturing USA should also work through the institutes in developing an education "commons" of shared advanced-manufacturing courses, modules, and materials. Manufacturing USA, relevant federal agencies (including NSF ATE, ED, and DOL), and the institutes themselves should ensure that current and future workforce-education efforts are coordinated. The institutes—perhaps in partnership with existing manufacturing skills standards groups such as the Manufacturing Skill Standards Council (MSSC)—will likely also need to establish standards for certifications in their advanced manufacturing fields, so that certifications can be earned at one place and recognized at another. Expert teams will need to be assembled to develop these training resources and standards, as well as to evaluate their effectiveness. Because workforce education tends to suffer from the "tragedy of the commons" (many want but few want to pay for it), the federal government should support federal funding for all of the above efforts and should ensure that relevant participating agencies include these efforts in their budget requests.

3.5 Better connect the institutes to the strengths of the federal research system

Because the institutes work almost exclusively on applied and later-stage research, they rely on "feeder systems" of early-stage research. When the institutes aren't connected closely enough to early-stage research systems—when they have limited knowledge of

what research is being carried out and limited capacity to inform the research agenda—they risk "stranded technology" problems. In other words, they will be limited in their ability to capitalize on new results and/or to keep developing concepts in progress. The federal government should strive to better link the federal basic-research system (including DOD's 6.1–6.3-level research,[31] NSF's engineering and related research, and DOE research at ARPA-E, OS, and EERE) to the institutes and their technology focus areas.

Action steps

The federal government should work through OSTP, with its agency-convening authority, to encourage Manufacturing USA and federal entities responsible for basic research to jointly institute planning and roadmapping processes to support the institutes' technology focus areas. Such an effort will assist agencies in developing and highlighting research activities that complement the institutes' technology-development activities, and vice versa.

3.6 Use the institutes to strengthen industry supply chains by bringing all supply-chain participants into demonstration facilities

Most of the institutes have established "hands on" and virtual demonstration and design facilities accessible to small and mid-sized firms participating in the institutes. These facilities are important because smaller firms are very unlikely to adopt new production technologies unless firms can see how those technologies would work within production lines, train employees in using new technologies, and estimate the potential efficiency gains new technologies could yield for them.

But many advanced-manufacturing technologies—such as digital-production technologies—cannot be implemented unless adopted by *all* participants in a given supply chain. The institutes need to bring in participants of industrial supply chains other than individual firms in order to disseminate advanced-manufacturing technologies most successfully.

Action steps

The institutes should be instructed to develop programs whereby larger manufacturers can bring in other participants in their supply chains as new technologies become ready for adoption. Manufacturing USA should support supply-chain-level demonstration and testing using institute demonstration facilities. NIST's Manufacturing Extension

[31] The RAND Corporation, *"Appendix B: Government-Wide and DOD Definitions of R&D", Discovery and Innovation: Federal Research and Development Activities in the Fifty States, District of Columbia, and Puerto Rico* (2000).

Partnership (MEP) programs should be asked to assist in these efforts. In general, the federal government should support expanded collaboration and system-wide thinking at the implementation stage of advanced-manufacturing technologies.

3.7 Link new technologies emerging from the institutes to acquisition by the Department of Defense

DOD didn't select the technology focus areas for its institutes by accident. The agency supports these particular technologies because it needs them. A growing problem for DOD is that results from its R&D system end up being produced abroad. The DOD-funded institutes are intended to provide DOD with game-changing new advanced-manufacturing technologies that can be readily incorporated into DOD's production systems. In other words, the institutes are critical for ensuring that DOD possesses the domestic capacity to produce new innovations at scale. Technologies produced by non-DOD-funded institutes are often relevant to DOD as well. For one example, the power electronics coming out of one DOE-funded institute will yield not only improved energy efficiency but improved electronics and power systems in general, which is important to DOD as well. Another DOE-funded institute is developing advanced composites that could dramatically improve DOD operating platforms.

Unlike other agencies, DOD has a major acquisition system connected to its R&D system—it can research, develop, *and* build new technologies. Most private-sector manufacturing firms tend to be risk- and cost-averse and are hence often reluctant to lead on production in new areas. DOD can fill this gap by using its acquisition system to support testing, design prototyping, and initial procurement for new technologies coming out of the institutes. This would benefit the nation by jump-starting deployment of emerging innovations, and would benefit DOD by providing the agency with early access to technologies not yet available on the private market.[32]

Action steps

The next administration should direct DOD to (1) review its relevant demonstration, testing, and acquisition processes, (2) identify options for the agency to leverage these processes to procure emerging technologies it needs from the institutes, and (3) identify changes to existing regulations and systems that would help link DOD acquisition with institute innovation.[33] The administration should then take prompt action to implement recommendations arising from the review.

[32] A National Academies study has made recommendations along these lines. National Materials and Manufacturing Board, *Strategic Long Term Participation by DOD in its Manufacturing USA Institutes.*

[33] For example, DOD may be able to reinstitute a form of its industrial/modernization incentive program or apply its Defense Production Act Title III authorities.

3.8 Expand the current role of Manufacturing USA

As noted in Section 3.4, because companies will want to adopt a series of new technologies, collaboration across the institutes will likely be essential to improving workforce education. Cross-institute collaboration will also help private-sector participants build "factories of the future" that integrate multiple advanced-manufacturing technologies. The role of Manufacturing USA needs to be expanded to support collaboration in these areas as well as areas such as cost sharing, dissemination of institute best practices in intellectual property (IP), membership organization, involvement of small and mid-sized firms, and joint access to facilities and equipment.

Action steps

The current institutes and their supporting agencies have worked to create Manufacturing USA as a network. The federal government should expand the role of Manufacturing USA to help the institutes, participating companies, and the workforce as a whole confront the challenges of implementing advanced manufacturing. Broadly speaking, these challenges can be divided into three categories: (1) workforce education, (2) integrating multiple advanced-manufacturing technologies, and (3) resource sharing. With additional funding and executive support, Manufacturing USA will be ideally placed to help address all three.

3.9 Develop clear guidelines for international participation in the institutes

A basic goal of the institutes and Manufacturing USA program is to strengthen the *American* ecosystem for manufacturing innovation. Currently, different institutes have different practices regarding participation of international companies, including for international firms with significant production employment and facilities in the United States. There is a need to catalogue existing practices and develop clear guidelines regarding international participation in the institutes.

Action steps

The federal government should direct Manufacturing USA, with input from relevant federal agencies, to develop a set of best practices regarding international participation in the institutes. An important goal of this exercise is ensuring that international participation does not prevent U.S.-based production of new technologies from establishing a strong foothold, but also to take advantage of know-how from international firms with a solid U.S. base. The best practices should take into consideration factors that affect the validity and value of international participation, including: that technologies at different stages of implementation may require broader consortia, ability and willingness of a particular international company to contribute to

U.S. production efforts and scale-up in U.S. markets, and the presence of a particular company in the United States and in U.S. supply chains.

3.10 Develop an ongoing assessment of advanced production capabilities emerging in other nations

DOD sponsors more than half of the current institutes. The agency initially became committed to the institute model because it needed to assure its future defense industrial base in an era of strong international technology development. Achieving this goal requires assessment of manufacturing advances and developments in other nations, relative to progress in the United States. DOD already conducts a periodic evaluation to understand "where its parts come from" and ensure a reliable domestic source of critical defense components. But assessing the provenance of finished parts is arguably less important than assessing the production capabilities of different nations. After all, if an evaluation shows a dominance of foreign parts then it may already be too late—foreign end-market dominance is a strong indication that underlying production capabilities have already been eroded domestically.

Action steps

The federal government should direct DOD (working with DOC and DOE, which also have relevant technical capabilities) to conduct an ongoing assessment of the progress of other leading nations in advanced manufacturing. The assessment should examine the strategic goals, internal organization, and funding levels of international advanced-manufacturing initiatives. Such an assessment should emphasize aspects of advanced manufacturing where the U.S. industrial base—and therefore DOD—has a significant stake in future technology, such as advanced materials, composites, photonics, functional fibers, power electronics, biofabrication, and a suite of digital tools that are finding applications in manufacturing (*e.g.*, AI, machine learning, the "Internet of Things", robotics, simulations and modeling, data analytics, and quantum computing). Such an assessment would help DOD understand the status of critical elements of its industrial base and would inform the focus areas and technology-development agendas of the various institutes. The assessment would also benefit the United States as a whole by guiding overall national manufacturing strategy and ensuring that the institutes are used in ways that maximize global competitiveness of the United States in manufacturing.

4. Implementation

The public understands the need to bolster the U.S. manufacturing sector. The 2016 election results in key Midwestern industrial states demonstrate that support for manufacturing has become a political imperative for both parties. Many aspects of the

recommendations detailed above could be implemented quickly by Presidential directives and would not require legislation. Increasing funding for the institutes and advanced manufacturing generally is, of course, the exception. But Congressional approval for increased advanced manufacturing funding seems likely. Despite the sharp political divides of the past decade, Congress overwhelmingly passed bipartisan legislation in 2014 authorizing the institutes and amended that legislation in 2019—a strong political signal of political support around this issue. Congress has also been solidly willing to back advanced manufacturing in appropriations bills each year. A bipartisan Congressional manufacturing caucus, and deep understanding by a number of key Congressional figures of issues related to advanced manufacturing, provide a solid foundation of expected legislative-branch support for executive-branch actions to further advanced manufacturing.

5. Conclusion

Production plays a disproportionate role in U.S. economic wellbeing. As international competitors move rapidly on advanced manufacturing while U.S. manufacturing capabilities stagnate or decline, the U.S. economy is increasingly vulnerable. The public-private model established by Manufacturing USA and the institutes around advanced manufacturing is a promising model for helping reverse these trends and restoring U.S. leadership in manufacturing. But the institutes as they now stand simply do not have the capacity to affect the U.S. manufacturing sector at the scale needed. The ten recommendations detailed in this paper provide the federal government with a roadmap for launching a concerted nationwide effort to strengthen advanced manufacturing in the United States—an effort that builds on the successes of the institutes and significantly expands institute capabilities, roles, and impacts. Briefly summarized, the recommendations are:

(1) Develop a strategic plan for positioning the United States as a world leader in advanced manufacturing.
(2) Grow the number of institutes to at least 25 and significantly raise institute funding.
(3) Instead of term-limiting institutes, establish a formal process for determining whether or not an institute's term should be extended.
(4) Work through the institutes to create a new education system designed to prepare workers for jobs in advanced manufacturing.
(5) Better connect the institutes to the strengths of the federal research system.
(6) Use the institutes to strengthen industry supply chains by bringing all supply-chain participants into demonstration facilities.
(7) Link new technologies emerging from the institutes to acquisition by the Department of Defense.

(8) Expand the current role of Manufacturing USA.
(9) Develop clear guidelines for international participation in the institutes.
(10) Develop an ongoing assessment of advanced production capabilities emerging in other nations.

Douglas Brinkley's book *American Moonshot*[34] tells how President Kennedy in 1961 was able to mobilize the American public around a new space mission. The mission was rationalized in part on Cold War competition but also on the dramatic mission-related technology advances—from communication satellites to STEM education to computing—that President Kennedy argued would (and did) boost the economy. The direct tie between advanced manufacturing and the future of the American economy is, frankly, far more visible to the public than the space race. Strong Presidential leadership could unify public support around a shared goal of manufacturing leadership and building quality jobs in a period of political fracture. There is a dramatic competitive aspect: China has already passed the United States on manufacturing output while we as a nation play catch-up, and China's increased economic power and corresponding U.S. decline has important implications for the future of democracy and world leadership. Furthering advanced manufacturing in the United States also involves rethinking and rebuilding our workforce-education systems, another potentially highly popular imperative. And finally, advanced manufacturing includes not only government, but industry, universities, foundations, community colleges, and nonprofits as well. In short, advanced manufacturing can unite nearly all American institutions—and nearly all Americans.

[34] Douglas Brinkley, *American Moonshot, John F. Kennedy and the Great Space Race*, New York: Harper Collins (2019).

About the author

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The Day One Project is dedicated to democratizing the policymaking process by working with new and expert voices across the science and technology community, helping to develop actionable policies that can improve the lives of all Americans, and readying them for Day One of a future presidential term. For more about the Day One Project, visit dayoneproject.org.