Strategy for American Leadership in Advanced Manufacturing

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
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Goal 1: Develop and Transition New Manufacturing Technologies

Worldwide competition in manufacturing has been dominated in recent decades by the maturation, commoditization, and widespread application of computation in production equipment and logistics, effectively leveling the global technological playing field and putting a premium on low wages and incremental technical improvements. Pervasive networking and recent advances in machine learning, biotechnology, and materials science are creating new opportunities for global competition in manufacturing based on scientific and technological innovation. Although global competitors are well organized, as evidenced by the European Union's *Industrie 4.0 Programme* and China's *Made in China 2025 Program*, the United States still leads the world in scientific and technological innovation. America must protect and leverage this strength to rapidly and efficiently develop and transition new manufacturing technologies into practice within our domestic industrial base and international allies.

A recent study reports that addressing scientific and technical challenges in advanced manufacturing can conservatively save U.S. manufacturers over $100 billion annually while further enhancing the economic value to the private sector of federally performed R&D.[1] Although Federal investments in advanced manufacturing-related research, development, and deployment are typically focused on mission-specific goals, portfolio-based strategies coordinated across agencies would more effectively develop and transition new manufacturing technologies.

Public-private partnerships that bring together diverse stakeholders with overlapping interests and capabilities to advance targeted technology sectors and establish the United States as a leader in those sectors are key to developing and transitioning new manufacturing technologies. Large-scale consortia with shared resources, such as physical infrastructure and colocation of tools, technology, and embedded expertise, can expand regional innovation ecosystems and drive economic growth both within and across regions.

The following strategic objectives for the next four years have been identified under Goal 1:

- Capture the future of intelligent manufacturing systems;
- Develop world-leading materials and processing technologies;
- Assure access to medical products through domestic manufacturing;
- Maintain leadership in electronics design and fabrication; and
- Strengthen opportunities for food and agricultural manufacturing.

For each **objective**, a set of **technical priorities** is identified, with each priority including *specific actions and/or outcomes* to be accomplished over the next four years.

Capture the Future of Intelligent Manufacturing Systems

Digital design and manufacturing seamlessly distributes the information needed to transform designs and raw materials into products, resulting in a highly connected industrial enterprise that can span multiple companies within a supply chain. Smart manufacturing enables the execution of that transformation by sensing and correcting anomalies to ensure product uniformity, quality, and traceability. These advances depend on the innovation of a robust industrial internet of things (IIoT), machine learning algorithms that can be applied across a broad range of manufacturing processes, and machine tools and controllers that can plug-and-play in an integrated, information-centric system.

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1 *https://nvlpubs.nist.gov/nistpubs/eab/NIST.EAB.1.pdf*

Taking the lead in digital design and manufacturing also requires the United States to expand ongoing efforts to represent, structure, communicate, store, standardize, and secure product, process, and logistical information in a digital manufacturing environment.

The technical priorities for this objective are smart and digital manufacturing; advanced industrial robotics; infrastructure for artificial intelligence; and cybersecurity in manufacturing.

Smart and Digital Manufacturing. Technology-based productivity improvements have consistently driven job growth. The emergence of widespread, high-speed information and communications technologies provides the opportunity to capture tremendous new productivity gains, but only if information technology can be properly integrated and leveraged with operational technology (OT). Two distinct but interrelated areas within this emerging field are smart manufacturing[2] and digital manufacturing[3].

The ultimate promise of smart and digital manufacturing is seamless integration from design to part production, producing guaranteed good parts. Current smart manufacturing implementations lack 100 percent dependability, with fixes for execution failures representing most of the engineering cost in both production and customizing smart manufacturing methods to specific processes. Improvements will enable the highly integrated design and manufacturing of complex products in reduced time and at lower cost, while accelerating the pace at which new products can be brought to market.

The following specific actions are planned for the next four years (as noted above, this format will be used throughout this document):

Facilitate a digital transformation in the manufacturing sector by enabling the application of big data analytics and advanced sensing and control technologies to a host of manufacturing activities. Prioritize support for real-time modeling and simulation of production machines, processes, and systems to predict and improve product performance and reliability; mine historical design, production, and performance data to reveal the implicit product and process know-how of the expert designers who created them. Develop the standards that will enable seamless integration between smart manufacturing components and platforms.

Advanced Industrial Robotics. Collaborative smart robots enable human-robot teamwork, thereby decreasing mental and physical stress on workers, reducing manufacturing costs, increasing quality, and providing quick response to changing customer demands. Advanced robotic systems can perform multiple tasks, thus reducing capital investment and increasing manufacturing agility by eliminating the need for several special-purpose tools. Robot-based production systems can also enable efficient batch-of-one production (also known as mass customization).

Improved robotics technology benefits manufacturing by lowering technical, operational, and economic barriers to the wider adoption of the robots that will, in turn, drive further growth in the U.S. manufacturing sector. Key industrial sectors that will benefit from the next generation of robotics include aerospace, automotive, electronics, biotechnology, and textiles. Robotics technology areas ripe with opportunities for advancement include human-robot interaction, adaption, learning, manipulation, autonomy, mobility, agility, dexterity, and perception. Some industrial robots in use today move without awareness of their environments, making their vicinities hazardous to humans and precluding their use as assistants to human workers, or cobots[4]. In addition, because human co- workers are inherently unpredictable, new breakthroughs in artificial intelligence are needed to allow robots to anticipate human actions and thereby improve occupational safety.

Promote development of new technologies and standards that enable wider adoption of robotics in advanced manufacturing environments and promote safe and efficient human-robot interactions.

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2 *Smart manufacturing generally refers to the integration of sensors, controls, and software platforms to optimize performance at the unit, plant, and supply chain levels.*

3 *Digital manufacturing involves the use of an integrated, computer-based system incorporating simulation, three-dimensional visualization, analytics, and collaboration tools to create product and manufacturing process definitions simultaneously.*

4 *A cobot is a collaborative robot intended to physically interact with humans in a shared workspace, distinct from robots designed to operate autonomously or with limited guidance.*

Infrastructure for Artificial Intelligence. The convergence of cloud computing, data analytics, and computational modeling with artificial intelligence (AI) will be a key enabler of IIoT, allowing individual manufacturers to extract pinpoint guidance from the collective experience of every manufacturer. Machine learning may provide future manufacturing systems with the benefit of all of the historical knowledge gained from production experiences from similar systems in the country. The machine learning methods used to mine this vast store of manufacturing experience need massive datasets. They also become more powerful as more data becomes available, making data curation and access critical enablers of machine learning and AI applications. However, companies will contribute their manufacturing data only if proprietary data can be identified and kept secure.

Develop new standards for artificial intelligence and identify best practices to provide consistent availability, accessibility, and utility of manufacturing data within and across industries, while maintaining data security and respecting intellectual property rights. Prioritize R&D to develop new approaches to data access, confidentiality, encryption, and risk assessment for U.S. manufacturers.

Cybersecurity in Manufacturing. As the implementation of intelligent manufacturing grows, the U.S. manufacturing sector becomes increasingly vulnerable to malicious actors and data piracy. The manufacturing sector represents a particularly inviting target for both state- and competitor-sponsored spying. Not only can data be stolen, but it can be changed and manipulated to cause production of defective products, which can cause system disruption and failure. Strengthening cybersecurity is a national priority[5].

Traditional cybersecurity solutions and efforts are centered on protecting information technology (IT)- based systems, with such actions as better authentication, updated security patches, and risk management for cloud computing. Cybersecurity in manufacturing organizations is complicated by the need to clearly understand the differences in vulnerabilities between both IT and OT systems. Manufacturing systems and their integrated control systems are OT systems that have a direct effect on the physical world and often cannot be updated on demand, so typically cannot be protected by simply adopting newer IT methods.

New research efforts are needed to develop and/or update standards and guidelines[6] for implementing emerging technologies for cybersecurity in manufacturing systems, including AI for threat detection and handling, blockchain for security of sensitive manufacturing information, and security of IIoT devices when deployed in smart manufacturing systems. Recently developed quantum devices have shown the potential to easily infiltrate conventional safeguards. Therefore, new approaches to cyber security in the traditional and quantum domains are needed.

Develop standards, tools, and testbeds, and disseminate guidelines for implementing cybersecurity in smart manufacturing systems. Focus efforts on moving American manufacturers towards better cybersecurity.

Develop World-Leading Materials and Processing Technologies

Advanced materials are essential for the development of new products and for economic and national security, with applications across multiple industrial sectors including defense, energy, transportation, aerospace, and healthcare. Unfortunately, it can take 20 or more years to move from materials discovery to the market. Because material properties drive performance, the definition of advanced materials depends on the intended application for the materials. For example, advanced materials may include extreme-temperature composites used in hypersonics, energetic materials, high-strength lightweight metal alloys, synthetic biologic materials, anti-corrosion membranes for advanced filtration systems, ultra-high temperature structures for more efficient turbines in power generation, and many others. Advanced processes for shaping and enhancing the performance of these materials can increase the cost-effectiveness and competitiveness of entire sectors by replacing prevailing methods with faster, more efficient, precise, and robust technologies. Advanced processing techniques under development or on the horizon that offer potential breakthroughs include chemical and thermal process intensification, advanced remanufacturing and recycling technologies, and atomically precise manufacturing.

The technical priorities for this objective are high-performance materials; additive manufacturing; and critical materials.

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5 *https://www.whitehouse.gov/presidential-actions/presidential-executive-order-strengthening-cybersecurity- federal-networks-critical-infrastructure/*

6 *https://www.nist.gov/cyberframework*

High-Performance Materials. The discovery and development of lightweight and modern metals, composites, and other classes of advanced materials have the potential for significant performance enhancements in defense, energy, transportation, and other sectors. There are unrealized opportunities for sharing expertise across sectors. Many American high technology companies use expensive materials and processing methods to keep their products on the forefront of performance, while others are proven leaders in high-volume, low-cost production, with deep experience in reducing production costs. Transfer of expertise between high-tech and high-volume non-competitors can reduce the cost of high-performance products and increase the performance of low-cost products, providing significant benefits across all sectors.

Powerful new methods for predicting material behavior using high-performance computing will facilitate this knowledge transfer. Emphasis is needed on transitioning to practice advanced computational methods, such as those being pioneered in the Materials Genome Initiative[7]. Those methods compute the likely properties of advanced materials systems in processing and in service, thereby minimizing costly and time-consuming experimentation currently needed to design new materials.

Promote a materials genome and systems-level computational approach to material design, optimization, and implementation to significantly reduce design time and cost in identifying, developing, qualifying, and scaling production of high-performance materials.

Additive Manufacturing. Additive manufacturing (AM)—the ability to directly create structures using three-dimensional (3D) printing and related techniques—is now beginning to realize its revolutionary potential to impact the commercial and defense manufacturing sectors, in terms of both cost per part and system performance. For example, AM of monolithic, high-performance metal parts can provide huge weight savings and performance gains for the aerospace sector. Similarly, printing of biological cells promises to produce future human tissues and organs. However, producing reliable and safe parts may require the accurate and reproducible printing of millions of particles of metal powder or living cells, and this precision is not yet easily achieved.

The adoption of AM into manufacturing sectors depends on the ability to dependably set processing parameters that result in reliable and repeatable production across different machines and across different sites, requiring machine/process standardization and reliable constituent material quality. AM creates a new design paradigm, as parts can be made without the constraints of traditional machining, casting, or forging processes. Designers must learn how to incorporate AM technology in their future systems to remain competitive. As the production capacity of AM expands, new standardization efforts, supported by fundamental research, are needed to ensure the repeatability and reliability of production parts.

Continue advancements in process control and process monitoring to secure AM technologies as viable production alternatives. Develop new methods to measure and quantify the interactions between material and processing technology to better understand the material-process-structure relationship. Establish new standards to support the representation, presentation, and evaluation of AM data to ensure part quality and reproducibility. Expand research efforts to establish best practices for applying computational technologies to AM, including simulation and machine learning.

Critical Materials. Critical materials, including critical minerals, are key building blocks subject to supply risk in a number of advanced technologies that underpin America's energy production, defense technologies, manufactured products, and the overall economy. Such materials often have unique and exceptional properties that are difficult to replicate using alternative material systems. However, lack of a robust and resilient domestic production industry has created distinct supply chain vulnerabilities[8].

To help ensure a more robust supply of critical minerals, President Trump issued Executive Order 13817, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*[9]. In response, Federal agencies developed a list of 35 minerals that are critical to the United States and for which the supply chain is vulnerable to disruption[10]. The assessment indicated that production of many critical minerals is concentrated in just a few foreign countries, creating a risk of price spikes and supply disruptions that threaten our economy and national security. R&D is needed on the cost-effective processing and separation of critical materials, including critical minerals, that are very similar chemically but have dramatically different properties and

7 *https://www.mgi.gov/*
8 *https://defense.gov/StrengtheningDefenseIndustrialBase*
9 *https://www.whitehouse.gov/presidential-actions/presidential-executive-order-federal-strategy-ensure- secure-reliable-supplies-critical-minerals/*
10 *https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018*

therefore can be used in different applications. In parallel, materials research is required to find new ways to more efficiently use these materials in existing and future applications, reduce materials loss during manufacturing of down-stream components, and recycle and recover these materials for reuse where appropriate. These efforts strengthen our ability to mine, process, refine, recycle and substitute critical materials affordably and reduce our reliance on foreign sources, ensuring material availability to our manufacturers.

Advance cost-effective processing and separation technologies to reduce the cost of production. Reduce reliance on critical materials by investigating substitutes and material alternatives where possible, and develop the means to recycle critical elements by innovating manufacturing processes.

Assure Access to Medical Products through Domestic Manufacturing

Advanced manufacturing for health-regulated pharmaceutical and biotechnology products, including drugs, biologics, and devices, has significant economic and national security implications. According to one industry study, medical device manufacturers and the pharmaceutical industry contribute over $1 trillion annually to the U.S. economy in direct sales and high-wage jobs[11]. In addition to their direct contributions to the U.S. GDP, these industries make substantial indirect contributions to improved public health outcomes that are more difficult to quantify.

The United States needs to fully leverage existing approaches and catalyze new efforts to address gaps in the end-to-end innovation ecosystem for the domestic manufacturing of health-regulated products. Research, measurements, and standards that promote pre-competitive, cross-cutting technologies to support faster and more cost-effective development cycles are needed to de-risk the transition of industry to a more flexibly scaled and modular infrastructure. These advances will ensure a more responsive domestic manufacturing capability.

The technical priorities for this objective are low-cost distributed manufacturing; continuous manufacturing; and biofabrication of tissue and organs.

Low-Cost, Distributed Manufacturing. Manufacturing of traditional, small molecule pharmaceuticals, such as generic antimicrobial drugs and to a lesser extent, vaccines, has been offshored, largely to India and Asia, as the U.S. pharmaceutical industry has transitioned to biologically-produced advanced therapies with higher complexity and market value. This creates a potential national security risk, since these medical countermeasures may be needed at times when foreign supplies are inaccessible. There is an additional public health need for a scalable, responsive, cost-effective, and distributed domestic capability to manufacture enough drugs and biologics so all U.S. citizens have affordable, local access to the best available therapies. These small-scale production capabilities are also critical to making precision medicine and treatment of "orphan" diseases accessible.

Although philanthropic foundations with the goal of global access to medicines in low-resourced countries are investing in more cost-effective manufacturing for drugs and biologics, there is a need to push for manufacturing innovation that strengthens the business drivers for *domestic* production of drugs and biologics with high public health value but low commercial value.

Expand domestic drug production capability to lessen the risk of drug shortages and provide cost-effective, small-scale manufacture of drugs and biologics. Encourage development of new therapies and devices by providing a faster production pathway from bench to clinic.

Continuous Manufacturing. Drug manufacturing is traditionally accomplished in large batches, with extensive testing of each batch to ensure consistent quality of the final product. In batch production, any problem with raw material ingredients or processing can scrap entire batches of medicine or result in expensive product recalls.

Continuous manufacturing (CM) is the integration of manufacturing process elements into a single computer-controlled system that constantly regulates the product flow and recovery as raw materials are input to and flow through the manufacturing process. CM is a new production paradigm in specialty chemical and pharmaceutical manufacturing that improves product uniformity, increases sustainability, and achieves the flexibility to produce a greater variety of drug products

11 *http://phrma-docs.phrma.org/files/dmfile/PhRMA_GoBoldly_Economic_Impact.pdf*

and critical specialty chemicals using smaller, more efficient manufacturing sites. CM also enables shorter production runs, making small volume runs of specialty drugs and on-demand production of commodity drugs possible. There are challenges to CM adoption that justify a concerted effort to make the continuous manufacturing of pharmaceuticals and specialty chemicals a national priority. In particular, research is needed to overcome the technological challenges of integrating sensors and processing hardware with the control software that allows computers to continuously verify product quality from millisecond to millisecond.

Develop new approaches to change current "batch-centric" pharmaceutical manufacturing to a seamlessly integrated, continuous unit operations manufacturing production model that maintains consistent product quality.

Biofabrication of Tissue and Organs. The United States holds a strong lead in biotechnology and biofabrication technology at the basic science and academic levels. The biggest challenges to ensuring technological superiority in healthcare and bio-based security are in transitioning federally funded R&D breakthroughs into manufacturable, scalable products and retaining the associated advanced manufacturing facilities and expertise within the United States. Development of processes and platform technologies for reproducible and scalable tissue manufacturing should be a primary focus.

At the fundamental level, much progress has been made in biological additive manufacturing (i.e., the precision placement of viable human cells for tissue engineering), but the manufacture of artificial biological organs depends on the discovery of the fundamental biomolecular signaling mechanisms that instruct cells to assemble into functioning organs that integrate multiple cell types. As these challenges are overcome, a future benefiting all citizens emerges where organ donor lists are short and manageable due to the ability to manufacture organs using a patient's own cells.

Develop standards, identify starting materials, and automate manufacturing processes to enhance biofabrication technologies and advance a vision of manufactured tissues and organs using a patient's own cells.

Maintain Leadership in Electronics Design and Fabrication

Semiconductors are the foundation of the microelectronics that power information and communication technology, consumer electronics, online business, and social media. Advances in semiconductor technology are critical for almost every sector of the economy and many critical systems for national security. Innovations in complementary metal oxide semiconductor (CMOS) technology have been the driving force behind the exponential increase in transistor density and, concurrently, reduction in the power per transistor. The industry is now facing fundamental performance limitations of the CMOS technology, diversification of the market beyond processors and memory, and intense global competition. Therefore, there is a critical need to develop fundamental materials, devices, and interconnect solutions to enable future computing and storage paradigms beyond conventional CMOS semiconductors and the ubiquitous von Neumann computer architecture and classical information processing/storage methods.

The technical priorities for this objective are semiconductor design tools and fabrication; and new materials, devices, and architectures.

Semiconductor Design Tools and Fabrication. A significant barrier to innovation in the semi- conductor and microelectronics industry is a lack of affordable access to design tools and fabrication foundries for integrated circuits that use advanced semiconductor materials and processes. The specialized equipment needed to design and produce multilayer structures with novel materials is extremely costly to purchase and maintain and requires highly-trained operators. For these reasons, such facilities do not represent prudent investment choices for individual design firms, as the machines must be engaged in continuous production to justify their high cost.

The continuous production requirement limits the exploration of new fabrication materials and designs, since the time required for a changeover to new processes interrupts high-value production. In addition, introducing new materials into a conventional semiconductor foundry can contaminate an entire facility, making it unsuitable for further production. There is a need to establish semiconductor foundries and the associated design tools to give designers throughout the United States access to the fabrication services needed to experiment with and commercialize circuit designs in advanced semiconductor materials. Broad access to facilities for fabricating computing hardware from exotic materials, insulators, and biological cells is needed to research, develop, and efficiently implement the new computer architectures that will be used in future neural computers.

Prioritize investment in capabilities to ensure that new microelectronics technologies are retained and manufactured domestically. Beginning with the prototyping stage, investigate ways to provide agile manufacturing capabilities that allow the creation of new devices and testing of new materials. Create models that give more access to design tools and domestic microelectronics foundries.

New Materials, Devices, and Architectures. For over 50 years, much of the increased computing capabilities, advances in communication, and improved standard of living around the globe has been enabled by the exponential growth in electronics performance, captured in Moore's law, which states that computing performance will double every two years by doubling the number of transistors on a chip. Since 2012, the ability to continue this growth has been challenged by theoretical limitations on the smallest manufacturable feature size of transistors. The quest for continued performance gains requires further development of new technologies, including 3D systems-on-chip integration, tunneling field-effect transistors, spintronics, integrated photonics, integration of III-V compound semiconductors with silicon-based devices, and quantum information systems. Board-level technologies are also a priority, including 3D printing with integrated electronics, die-bonded flexible-hybrid circuits, and roll-to-roll manufacturing. Research should also include precision sensing (including time, space, gravity, and electromagnetism), health and asset monitoring sensors, photovoltaics, and medical devices. Finally, investment in quantum computing must continue to be a priority to maintain global leadership in future complex electronics design and computing capabilities.*Prioritize support for semiconductor and electronics research and expand the scope of investment to include board-level manufacturing technologies.*

Strengthen Opportunities for Food and Agricultural Manufacturing

Manufacturing of food and agricultural products is critical for resilient production of safe and nutritious foods and vitally important for the domestic rural economy. As stated in the recent report from the Interagency Task Force on Agriculture and Rural Prosperity[12], by 2050 the U.S. population is projected to increase to almost 400 million people, and rising incomes worldwide will translate into historic global growth in food demand. To feed a hungry world, we will need to harness innovation to increase output across American farmlands. In addition to increased crop yields, technological innovation can improve crop quality, nutritional value, and food safety.

Manufacturing provides a higher share of jobs and earnings in rural areas than in urban areas of the country, and food manufacturing is the largest subsector of rural manufacturing, accounting for over 18 percent of rural manufacturing employment in 2015. The United States will develop technologies to enable U.S. food production and manufacturing to feed an ever-growing population, protect the food supply chain, and improve bio-based product manufacturing[13].

The technical priorities for this objective are processing, testing, and traceability in food safety; production and supply chain for food security; and improved cost and functionality of bio-based products.

Processing, Testing, and Traceability in Food Safety. Advanced manufacturing plays an important role in agricultural production, food processing and food safety. The safety of the food supply is vitally important, and improved food manufacturing practices are needed to reduce uncertainty, improve inspection, and instill traceability into the supply chain. Food manufacturing encompasses engineering, processing technologies, packaging, sanitation, robotics, nanotechnology, sensors, high-speed automation, mathematical modeling, digital imaging, quality/safety inspections, and other disciplines. There are opportunities to adapt new technologies to streamline and improve quality in conventional manufacturing processes to improve food production. These advances have the potential to increase food quality, lower the cost of safe and nutritious foods, and improve the environmental sustainability of food production.

Facilitate and transfer smart and digital manufacturing concepts to food manufacturing, including the use of digital imaging, automation, advanced detection, and digital threads to improve supply chain integrity.

Production and Supply Chain for Food Security. Americans take the security of their food supply for granted, but growing demand, climatic change, and geopolitical pressures increasingly put our food security at risk. The Nation must treat food security as an important aspect of national security to strengthen access to sustainable agriculture and nutritious foods. Considering the rapid growth in the technologies and engineering involved in food production and processing, advanced food manufacturing can help the United States maintain the high safety, quality, and nutritional value we have come to expect of the

12 https://www.usda.gov/sites/default/files/documents/rural-prosperity-report.pdf
13 https://www.ers.usda.gov/publications/pub-details/?pubid=84757

U.S. food supply. Appropriate Federal agencies will work closely and engage in public-private partnerships to accelerate advancements in food manufacturing through co-investments.

Support strengthening domestic food production – a key manufacturing sector – by ensuring a robust supply chain with efficient and equitable distribution. Implement next generation quality control systems to ensure that nutritious and safe food is available to all U.S. citizens.

Improved Cost and Functionality of Bio-Based Products. In addition to food safety and food security, the United States produces a wide array of non-food agricultural products, including textiles, building materials, bioenergy, and bio-based chemicals and materials. New manufacturing approaches are needed to drive down the cost and improve the functionality of these products. Innovation priorities for the United States include multi-product biorefineries, cellulose nanomaterials, added-value forestry products, protected agriculture, and other technologies. Other manufacturing priorities are equally important for food and non-food applications, such as advances in seed production from the mathematical optimization of plant breeding, improving plant productivity and resilience, lowering costs of processing and conversion, ensuring worker safety, and improving efficiencies throughout the supply chain. Advanced processing and supply chain integration are needed to improve the functionality and lower the cost of bio-based products.

Conduct R&D at the junction of plant breeding, genomics, and bio-based product development. Adapt high-throughput automation to develop and screen for plant characteristics, such as improved yield of added-value products and increased crop resilience in regionally-appropriate environments.

Goal 2: Educate, Train, and Connect the Manufacturing Workforce

The manufacturing sector is facing wide gaps between emerging jobs and workers with the needed skills. Traditional educational and technical skills are no longer sufficient. New technological literacies and cognitive capacities such as data competence and systems thinking will be needed for the work of tomorrow. One recent study estimates that by 2025, 3.5 million new jobs will open in manufacturing— 2.7 million of which will be created from baby boomer retirements, and 2 million of which will go unfilled[14]. Yet many young people who may benefit the most from those high-skill, high-paying jobs are missing out due to outdated presumptions that all manufacturing jobs are still repetitive, labor-intensive, and low-paying, or concerns about the future of such jobs in America. Many students and their families undervalue or misunderstand technical careers and the growing need for a skilled, technical workforce, thus dismissing valuable options at community colleges and technical schools.

To address these challenges, the United States must pay attention to enhancing and developing key human capital strategies that will support the next generation of advanced manufacturing technologies, with an emphasis on developing educational pathways that reflect the current environment of integrated manufacturing in engineering and science programs. The advanced manufacturing workforce needs to have the capability to effectively design, customize, and implement advanced manufacturing methods to increase productivity and develop new products.

To achieve sustained economic growth, it is vital that efforts to enhance a globally competitive U.S. manufacturing talent pipeline grow and are directed towards the workforce needs for advanced manufacturing priorities outlined above for Goal 1. The Administration is committed to educating tomorrow's manufacturing workforce; expanding technical career education; promoting training, apprenticeship, and access to valid, industry-recognized, competency-based credentials; and matching skilled workers with industries that need them[15].

To prepare the STEM workforce for future manufacturing jobs, national investments should prioritize life-long STEM education—across elementary, high school, career and technical education (CTE), community colleges, universities, academic laboratories—and include diversified platforms for hands-on learning and self-directed learning. Other priorities for investment include apprenticeships, internships, traineeships, and other applied earn-and-learn models. These programs fill a critical role for building an educated talent pipeline and allow members of the current or displaced workforce opportunities to re-train in a new field or advance within their current profession. Some of these programs are already being facilitated through private-public partnerships among industry, government, and educational institutions. However, U.S. Federal, State, and local

14 *http://www.themanufacturinginstitute.org/~/media/827DBC76533942679A15EF7067A704CD.ashx*

15 *https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-committed-preparing- americas-workers-jobs-today-tomorrow/*

policymakers need to pursue workforce strategies that build up smart and digital manufacturing ecosystems and deliver effective returns on investment.

The following strategic objectives for the next four years have been identified under Goal 2:

1. Attract and grow tomorrow's manufacturing workforce;
2. Update and expand career and technical education pathways;
3. Promote apprenticeship and access to industry-recognized credentials; and
4. Match skilled workers with the industries that need them.

Attract and Grow Tomorrow's Manufacturing Workforce

Building the future STEM workforce requires a commitment to primary and secondary schools, CTE, postsecondary, graduate, and postgraduate programs. Access to populations that are underrepresented should be expanded, especially by increasing mathematics/science/technology magnet programs at the middle-school level, and improving curricula for business, information technology, data management and protection, software design, automation, and student technology leadership programs, among others. In CTE, specific attention should be applied to curricula in additive manufacturing, computer-aided design, and engineering.

The private sector will benefit by collaborating with educational institutions and sharing competency-based needs so that future workers can encompass a wide array of core and technical STEM-oriented skills needed for advanced manufacturing. In addition to improving training and the resulting pathways to employment, such partnerships should also work to better educate students and their parents about the benefits of advanced manufacturing careers. For example, participating in Manufacturing Day (the first Friday of October) can contribute to improved public perceptions about manufacturing and promote technical career pathways. Each October, manufacturers nationwide open their doors to communities, educators, students, and parents to showcase today's manufacturing and inspire future generations of innovators to join the manufacturing workforce.

The program priorities for this objective are manufacturing-focused foundational STEM education; manufacturing engineering education; and industry and academia partnerships.

Manufacturing-Focused Foundational STEM Education. As evident by one 2017 study[16], there is a troublesome disconnect between what schools teach and the types of skills needed in the manufacturing job market both now and in the near future. Available evidence also suggests that formal and informal engineering education both in and after school can stimulate broader interest and improve learning in mathematics and science, as well as improve understanding of engineering and technology. However, only one third of parents encourage their children to pursue a manufacturing career because of perceptions that manufacturing jobs are not strong career paths.

The educational outreach efforts of the Manufacturing USA institutes[17]—Federally funded, public-private partnerships—have helped to transform the image of manufacturing from “dirty, dark, and dangerous” to “smart, sustainable, and safe” for students and their parents. In fiscal year (FY) 2017, nearly 200,000 students, teachers and manufacturing practitioners were engaged in an institute project, internship, certification, or training program in a range of advanced manufacturing technologies. Additional activities to increase public awareness initiatives are required to show that manufacturing provides a variety of exciting and creative careers.

Provide school districts with the appropriate resources to incorporate manufacturing and engineering technology education programs into their science standards, engage and retain younger students in STEM, particularly across underrepresented groups, and better inform parents and other members of the public on the benefits of manufacturing and advanced technology careers.

Manufacturing Engineering Education. America's manufacturers need highly-skilled technical workers with excellent critical thinking and innovation skills to maintain a competitive advantage in the global marketplace and adequately support the development of advanced manufacturing technologies. It is clear that education beyond high school is required for high-paying manufacturing jobs. Continued investments in Federal initiatives like the DoD Manufacturing Engineering Educational Program

16 *https://www2.deloitte.com/us/en/pages/manufacturing/articles/public-perception-of-the-manufacturing- industry.html*
17 *https://www.manufacturingusa.com/*

and the NSF Advanced Technological Education program are needed to provide education beyond high school and expand the talent pipeline.

Establish a strong talent pipeline ready for advanced manufacturing by increasing investments in manufacturing engineering education that leads to two-year, four-year, and advanced degrees. Create more technical curricula and research programs that prepare graduates to tackle real-life challenges and innovate future novel manufacturing technologies.

Industry and Academia Partnerships. Investments should encourage public-private collaboration to ensure relevance of the curricula for the manufacturing sector. New technologies like robotics, laser cutters, engravers, and 3D printers have become more in demand and accessible to students and consumers through school-based competitions and community-based technology centers (e.g., makerspaces and fab labs). These technologies have created a tremendous impact on non-traditional education by promoting critical thinking and problem-solving skills among students and teachers. Community-based digital fabrication initiatives, especially with entrepreneurship components, are changing small batch manufacturing, producing innovative products, and have the potential of retaining the associated advanced manufacturing activities and expertise within the United States.

Strengthen public-private partnerships to include industry-relevant training in advanced manufacturing curricula with opportunities for students and teachers to receive mentorship from industry members, keep up to date on new technologies, and share educational materials.

Update and Expand Career and Technical Education Pathways

To be successful in the manufacturing workforce, individuals need strong technical skills, a solid academic foundation, and core employability skills, whether they enter the workforce directly from high school or after completing some further education after high school. The recent recession impacted how the U.S. population and younger generations are investing in education. Entrepreneurial thinking and creative ways to access capital using technology platforms or IIoT are placing the issue of skyrocketing college tuitions at the forefront of many household conversations. Unlike most other advanced economies, the United States lacks formal mechanisms that require governments, educators, labor representatives, and employers to coordinate on workforce development policies and practices at the national level. This lack of coordination makes it crucially important to support secondary-to-postsecondary CTE, project-based curricula, competency-based training, career pathways, and self-directed learning programs. These non-traditional learning pathways are critical to advanced manufacturing and enable better mobility for workers to transition from declining industries into new, growing technologies. Further coordination is also needed with two-year community college programs and four-year university and college programs, particularly in the areas of software design, engineering technology, systems engineering, robotics, and more science/technology related fields such as biotechnology.

The program priorities for this objective are career and technical education; and training a skilled technical workforce.

Career and Technical Education. Student exposure to hands-on, project-based learning approaches builds the critical skills needed to support the U.S. manufacturing sector's increased emphasis on product design and customization, and encourages students to imagine, create, innovate, and collaborate through the process of R&D, testing, and demonstrating their ideas. The Strengthening Career and Technical Education for the 21st Century Act[18], signed into law in July 2018 by President Trump[19],

amends and extends the Carl D. Perkins Career and Technical Education Act, which is the principal source of support for CTE at the high school and postsecondary levels. The new law offers States, communities, and manufacturing industry leaders an important opportunity to rethink and revitalize CTE to address the skills gap. Importantly, the new law gives States, school districts, and community colleges greater flexibility in how they use their Federal funds. Prioritizing programs such as the revised Carl D. Perkins Career and Technical Education Act will increase student access across secondary and postsecondary levels to high-quality technical education and credentialing. These efforts will ensure that educated, trained, and credentialed individuals will be able to effectively fill tomorrow's high-demand and well-paying occupations in advanced manufacturing. State and local workforce boards have the responsibility to increase hybrid activities integrating science/engineering/ CTE programs that create pathways to teach high school students, displaced workers, and unemployed individuals.

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18 https://www.congress.gov/115/bills/hr2353/BILLS-115hr2353enr.pdf

19 https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-committed-preparing- americas-workers-jobs-today-tomorrow/

Leverage opportunities in the reauthorized Carl D. Perkins Career and Technical Education Act to promote high-quality advanced manufacturing programs aligned to local demands and incorporating strategies allowing students to work and learn through apprenticeships.

Training a Skilled Technical Workforce. The current U.S. system for accessing training is complex, making it difficult for even highly motivated individuals. The Workforce Innovation and Opportunity Act (WIOA) is providing a strong State-administered and locally-implemented job training system that assists with implementing many identified solutions that have proven results[20]. The United States should focus on enhancing WIOA's support for the manufacturing sector by utilizing Federal investments already in place that can effectively train and retrain a skilled manufacturing workforce.

Promote a renewed focus on apprenticeship programs, work-based learning, and technical training that offers pathways for workers to gain advanced manufacturing competencies and technical skills through increased coordination among Federal, State, and local governments, educational institutions, and the private sector.

Promote Apprenticeship and Access to Industry-Recognized Credentials

Apprenticeships provide an opportunity for individuals to earn while they learn and obtain relevant workplace skills and industry-recognized, competency-based credentials without incurring the debt that can come with a four-year degree. However, apprenticeships are underutilized, with only 0.3 percent of the workforce in the United States going through registered apprenticeship programs[21]. President Trump has called for the expansion of apprenticeship programs and reform of ineffective education and workforce development programs with the goal of promoting affordable education and rewarding jobs for American workers[22].

Individuals who complete apprenticeship programs should receive nationally portable, industry-recognized, and stackable credentials. The industry-recognized model is especially important for the advanced manufacturing sector where registered apprenticeship programs are lacking or nonexistent. It is also important to modify apprenticeship grant funding to include all apprenticeship models that enable States, educational institutions, and the private sector to work together to grow apprenticeships across in-demand sectors of the economy. In addition, a registry of apprenticeship and credentialing programs should be made available for those who are seeking further training in advanced manufacturing.

The program priorities for this objective are manufacturing apprenticeships; and registry of apprenticeship and credentialing programs.

Manufacturing Apprenticeships. The accelerated development of high quality, industry-recognized apprenticeship programs will open new opportunities in advanced manufacturing for American workers, allowing them to earn portable, industry-recognized credentials and certifications. Obtaining advanced credentials can give workers access to family-sustaining jobs, while reviving the strength and vitality of our Nation's manufacturing base. The Task Force on Expanding Apprenticeships[23], comprised of members from industry, labor, education, and non-profit organizations, recently provided recommendations to the President on how to build and take to scale apprenticeships in industries that have not traditionally used the apprenticeship model. These recommendations aim to promote effective paths to implementing earn-and-learn strategies, as needed for a skilled workforce.

Accelerate the development of quality industry-recognized apprenticeship programs to provide manufacturing workers with greater access to portable, industry-recognized, competency-based credentials.

Registry of Apprenticeship and Credentialing Programs. Many apprenticeship programs are available through local, regional, and national organizations, including both the public and private sector. However, it is often difficult for individuals to identify a program that fits her or his needs and schedule. A central repository or registry could assist employers in finding job seekers with the right credentials to fulfill workforce needs. It could also further increase exposure to credentialing programs for U.S. veterans like SkillBridge, a program that provides training in areas such as welding, pipe-fitting, and IT, or apprenticeship-like programs such as the Veterans to Energy Careers, which provides paid internships in alternative energy research to veterans. Establishing such a repository will need prioritized support from States and local communities to increase the number of

20 *https://www.doleta.gov/wioa/*
21 *https://www.dol.gov/apprenticeship/docs/task-force-apprenticeship-expansion-report.pdf*
22 *https://www.whitehouse.gov/presidential-actions/3245/*
23 *https://www.dol.gov/apprenticeship/task-force.htm*

individuals participating in and completing these programs.

Establish and maintain a central repository or registry that assists job seekers with identifying manufacturing-related apprenticeships and industry-recognized credentials[24].

Match Skilled Workers with the Industries that Need Them

While worker preparation is essential, the value of these efforts will diminish if the Nation fails to establish platforms that connect skilled manufacturing workers to employers. Workers looking for employment should be able to seamlessly connect with employers looking for skilled employees in their communities, regional districts, and States. Leveraging existing programs, such as the WIOA American Job Centers (also known as One-Stop Career Centers)[25], is the key to matching regional opportunities like apprenticeships, training, and credentialing to build skilled workers and connect them with in-demand manufacturers.

The program priorities for this objective are workforce diversity; and workforce assessment.

Workforce Diversity. Systems for workforce preparation are having trouble keeping up with the rapid rate of innovation and up-skilling in industry. Employers will need specific strategies for increasing efforts to engage minorities. To reach those populations, there must be outreach to Historically Black Colleges and Universities, Minority Serving Institutions, and disadvantaged-focused non-profits, along with entities that target and encourage career development among women. Additionally, more than 200,000 U.S. service members return to civilian life each year. Veterans are well trained, have extensive skills and technical aptitude, and show up on time, ready to work. But the skills of a tank mechanic or a Patriot missile battery technician do not line up with many of the skills manufacturing companies need.

Collaborate with industry and other stakeholders to diversify the advanced manufacturing workforce by developing more effective strategies for training and recruiting underrepresented groups, and for transitioning veterans out of the service into this workforce.

Workforce Assessment. Maintaining and sustaining a competitive manufacturing workforce requires national policies that encourage and provide opportunities for workers to gain the education and skills needed in a technologically advanced economy. Protocols for analyzing the manufacturing workforce should be periodically evaluated and improved to better align States and the Federal Government with the skills that will be in demand in the future. Data is also needed to ensure that more evidence-based practices are incorporated into the development of a manufacturing workforce, thereby capturing strong returns on Federal investments.

Continue assessing the state of U.S. manufacturing and the national approach to producing a workforce that is self-sustaining and globally competitive.

Goal 3: Expand the Capabilities of the Domestic Manufacturing Supply Chain

The U.S. manufacturing supply chain is a complex system of large and small manufacturers, integrators, raw materials producers, logistics firms, and companies providing other support services (accounting, finance, legal counsel, etc.). These companies, many of them outside the United States, form interdependent networks that provide a wide variety of finished goods to U.S. and global customers. The advent of digitization and the IT revolution caused manufacturing supply chains to become less location-specific and increasingly globalized. Although this revolution has generated many benefits, in some sectors offshoring has made it difficult for manufacturers to operate domestically. It is of paramount importance to recognize that in order for the technology and talent developed in the United States to benefit the Nation, there must be a healthy domestic supply chain able to absorb them.

Virtually all manufacturing establishments in the United States, and especially those involved in the supply chain, are small and medium-sized manufacturers (SMMs) with fewer than 500 employees[26]. These manufacturing establishments are critical to local and regional economies in the country, and at times of economic hardships, their decline can negatively impact their local communities. It is therefore crucial to ensure that these companies can fully participate in advanced manufacturing.

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24 Apprenticeship.gov was launched during the final preparation of this plan.

25 https://www.dol.gov/general/topic/training/onestop

26 https://www.census.gov/programs-surveys/cbp/library/visualizations.html

As discussed above and in the report *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States*[27], U.S. manufacturers face a diverse array of challenges that includes foreign competition (often subsidized by foreign governments), lack of sufficient access to skilled labor, keeping up with the rapid pace of technological change and innovation, cybersecurity threats, financial constraints, loss of domestic supply chains, and more. Challenges also vary for large manufacturers—which often rely on complex, decentralized supply chains—as well as small manufacturers that have limited resources.

Action is required on several fronts to ensure that the Nation has the robust, advanced manufacturing supply chains it needs to be secure and prosperous. First, the SMMs need to be the primary Federal focus for supply chain development. This focus should include growing a larger and more cyber-secure- supply chain, supported through federally convened public-private-partnerships. Second, the United States must foster new business development and connect our fragmented silos of innovation with advanced manufacturing ecosystems—where pre-competitive applied research can be done by multiple members of the supply chain, thus pooling risk to achieve greater returns. These innovation ecosystems and related efforts need to foster new manufacturing business development and faster R&D transition to advanced manufactured products. Third, the United States must strengthen the supply chains that support our defense industrial base. This objective will require better leveraging of existing authorities such as Buy American and Foreign Military Sales as well as expanding dual-use technologies. Finally, it is important that America's rural communities, where advanced manufacturing technologies and processes can be tailored for the important agricultural sector, can be sustained and thrive.

The following strategic objectives for the next four years have been identified under Goal 3:

1. Increase the role of small and medium-sized manufacturers in advanced manufacturing;
2. Encourage ecosystems of manufacturing innovation;
3. Strengthen the defense manufacturing base; and
4. Strengthen advanced manufacturing for rural communities.

Increase the Role of Small and Medium-Sized Manufacturers in Advanced Manufacturing

SMMs represent key parts of all supply chains. No product gets made that does not require inputs from another supplier, and many of the outputs go into the creation of components, assemblies, subsystems, and systems that make up simple and complex products and services. SMMs can be key sources of innovation in the form of new products, new processes, and new business models. It is imperative that SMMs be connected to sources of technologies, technical infrastructure, and specialized knowledge through vendors, universities, Federal laboratories, Manufacturing USA institutes, and others. SMMs also need trusted advisors who can provide appropriate advice on the real possibilities of new technologies[28].

The program priorities for this objective are supply chain growth; cybersecurity outreach and awareness; and public-private partnerships.

Supply Chain Growth. New technologies will impact what future manufacturing supply chains look like and how they will function. Previous Federal investments have resulted in a wide variety of technologies that, when brought together, fundamentally changed how manufacturers exchange business and production information and data through the supply chain, as well as within companies. Preparing for these changes at the SMM level means understanding and leveraging new technologies that expand and enhance production, such as additive and biological-based manufacturing; uses of big data, digital logistics and the IIoT; leveraging networked commerce to improve access to manufacturing services; and accessing secure and reliable high-speed communication.

Enhance outreach and education efforts consistent with how SMMs learn about and adopt innovations. This enhancement will ensure that agency technology transition programs have a focus on small and medium-sized manufacturers.

Cybersecurity Outreach and Awareness. Cybersecurity is a national problem for which public-private partnerships like USDA's Rural Development Cooperative Services (Research and Extension)[29] and the DOC's Manufacturing Extension Partnership are readily available conduits to reach SMMs throughout the country. The U.S. Patent and Trademark Office also provides outreach

27 *https://defense.gov/StrengtheningDefenseIndustrialBase*
28 *Some of these services are available to SMMs through the Manufacturing Extension Partnership (MEP); see https://www.nist.gov/mep.*
29 *https://www.usda.gov/topics/rural/cooperative-research-and-extension-services*

and education to stakeholders seeking patent protection in the cyber and network security sectors. The recently announced Cyber Hub for Manufacturing within the DoD Digital Manufacturing and Design Innovation Institute (one of the Manufacturing USA institutes) will address manufacturing-related cybersecurity vulnerabilities and conduct outreach to support adoption of best practices[30]. These programs should be accessed more broadly to conduct outreach events to raise the awareness and understanding of the need for good cybersecurity, help companies with voluntary self-assessments, and transfer research findings and expertise from the Federal Government's experts (e.g., NIST) to SMMs. Incentives for small manufacturers to assess and mitigate their cybersecurity risks such as small business vouchers could be provided to get SMMs on the path to better cybersecurity. Additional outreach and education is required for SMMs via new or existing business assistance programs.

Provide cybersecurity expertise and tools to SMMs for protection of the Nation's most valuable commodity—our intellectual property. Promote greater awareness and understanding of the unique problem of securing highly connected manufacturing facilities and explore incentives for SMMs to assess and mitigate their cybersecurity risks.

Public-Private Partnerships. SMMs are often not aware of the formation of public-private partnerships, and those that are do not always see the benefits of participation in these collaboratives and consortia. The benefits include becoming aware of major and minor technological changes that will affect their businesses; providing input into the research agenda of the consortium/collaborative so the results can be adopted by SMMs; being able to track the trajectory of a new technology to know when to make an investment in it; and engaging in R&D activities with potential customers, thus enhancing the SMM's reputation as an innovative supplier to those customers.

Use of a process similar to that developed by RTI International[31] and used as part of a series of projects with the Federal Laboratory Consortium would ensure consistent engagement of a wide variety of advanced manufacturing ecosystem players, understanding of the technologies and the associated industry value chains, identification and alignment with industry needs, and leveraging of Federal and regional programs and assets.

Continue to use Federal convening powers to ensure that all relevant parties, particularly SMMs, are fully engaged during the formative stages of public-private consortia and collaboratives.

Encourage Ecosystems of Manufacturing Innovation

The manufacturing ecosystem comprises a rich tapestry of manufacturing enterprises of all types and sizes, with each having an important role to play. In addition to large manufacturers, start-up companies and high-tech enterprises can be sources of disruptive innovations, leading to new products, new processes, new business models, and the creation and development of new markets. Such companies frequently have challenges in scaling from prototype to commercial practice, if they decide to become manufacturers, or in finding production partners, if they decide to outsource their production. Government agencies at the State and Federal level can and should support efforts with both funding and advice on "Making it in America." Services such as technology-driven market intelligence can help companies identify customers and markets for products and services based on their technology assets.

Public-private partnerships engage with the complete spectrum of ecosystem players, understand and align with industry needs, and leverage existing regional assets. Regions form collaboratives or consortia to either drive economic development in a particular place and/or advance a particular technology. It is important to distinguish between research consortia (precompetitive research initiatives formed to fill particular gaps in knowledge or technology development), economic development cluster initiatives (based on assets in a particular sector focused on growing that sector through retention and attraction), and collaboratives for advanced manufacturing innovation (focused on dissemination, adoption, and commercialization of advanced manufacturing technologies to drive innovation and economic growth). The United States needs a mix of these types of consortia in order to be the global leader in advanced manufacturing.

The program priorities for this objective are manufacturing innovation ecosystems; new business formation and growth; and R&D transition.

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30 https://www.manufacturingusa.com/resources/dmdii-launches-cyber-hub-manufacturing

31 https://www.nist.gov/blogs/manufacturing-innovation-blog/getting-state-wide-manufacturing-network- process

Manufacturing Innovation Ecosystems. In the past, the Federal Government has formed R&D consortia around a technology or capability that they funded and primarily directed, only to witness the capability being diminished or lost once the Federal funding ceased. This failure in large part was due to the consortia not being industry-focused, and therefore not receiving critical sustaining funding by industry. The Federal Government—particularly agencies that support advanced system development such as DoD and NASA—could not rely on a vibrant supply chain without continuing to supply the majority of the funding.

Public-private partnerships, primarily driven by industry and with a focus on both commercial and defense manufacturing processes and products, can minimize this problem caused by an ecosystem tethered only to Federal funding. The dual commercial-defense focus helps sustain the manufacturing innovation ecosystems and keep them vibrant in the United States. DoD can harvest the fruits of these public-private partnerships without having to rely solely on its own funding. These partnerships not only are able to provide cutting-edge technology solutions but also lower cost as the initial applied research is shared by a number of parties.

Expand the creation and utilization of manufacturing collaboratives and consortia for both technology and economic development. Create additional public-private partnerships focused on technologies critical to America's future competitiveness.

New Business Formation and Growth. It takes too long for breakthrough technologies to find their way to market. Federal programs aimed at assisting small business are particularly important in manufacturing, where private capital is scarce. The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs provide capital to small companies with new ideas. The SBIR and STTR programs are entrepreneur-friendly, as the government does not take an equity stake, preferring the long-term payoff from tax revenues generated from sales of successful products. SBIR and STTR programs are indigenous to many government agencies[32].

The NSF Innovation Corps (I-Corps™) Program is complementary to SBIR/STTR in providing intensive training in the market discovery required to move new discoveries toward commercialization[33]. Many other agencies have adopted the I-Corps model by developing similar programs that are focused on supporting translational research, so that agency-supported research can be commercialized as products or services to benefit the public. The DoD Rapid Innovation Fund is designed to transition small business technologies into defense acquisition programs by funding mature technology ideas[34]. The goals of the Rapid Innovation Fund reflect DoD's emphasis on rapid, responsive acquisition and the engagement of small business innovative technologies that resolve operational challenges or address critical national security needs. The Mentor-Protégé Program is the oldest continuously operating Federal program in existence that partners small businesses with larger companies[35].

Prioritize programs that provide key support for new business formation and growth, including entrepreneurial training and mentoring for scientists and engineers.

R&D Transition. The manufacturing sector must be able to rapidly adapt manufacturing capabilities that leverage the advances occurring at a fast pace in the R&D sector. This priority is not unique to advanced manufacturing—it is a priority across all R&D areas supported by the Federal Government. The critical role of technology transfer and the importance of facilitating the transition of technologies from the laboratory to the market is recognized in the President's Management Agenda as a Cross-Agency Priority (CAP) Goal[36].

Federal agencies will ramp up their coordination efforts through the Lab-to-Market CAP Goal to tackle the challenge of improving technology transfer. They will focus on five strategies: (1) identify regulatory impediments and administrative improvements in Federal technology-transfer policies and practices; (2) increase engagement with private sector technology development experts and investors; (3) build a more entrepreneurial R&D workforce; (4) support innovative tools and services for technology transfer; and (5) improve understanding of global science and technology trends and benchmarks.

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32 https://www.sbir.gov/sites/default/files/FY15_SBIR-STTR_Annual_Report.pdf
33 https://www.nsf.gov/news/special_reports/i-corps/
34 https://business.defense.gov/Programs/RIF/
35 https://www.sba.gov/federal-contracting/contracting-assistance-programs/all-small-mentor-protege- program
36 http://www.performance.gov/pma

Within the advanced manufacturing R&D community, it will be particularly important to proactively engage with the companies likely to further develop and implement new technologies to facilitate effective paths forward. Standards are also an important priority for accelerating the widespread commercialization of new technologies in the global manufacturing industry. Similarly, advancements in measurement science capabilities are an essential element to advances in manufacturing technology, required to support their repeatability and wide-spread adoption.

Coordinate across the agencies and between Federal technology transfer-related policy groups to identify technologies suitable for transition from laboratory to market within the United States. Prioritize funding for research into measurement science and standards development to speed the transition of R&D to commercial practice.

Strengthen the Defense Manufacturing Base

For more than 50 years the DoD has led development of the game-changing technologies that have ensured U.S. military dominance and underpinned economic competitiveness and innovation in the private sector. Technologies such as advanced composites, microelectronics, radar, global positioning system (GPS), the internet, and advanced alloys have touched the lives of almost every person on the planet and made America a global leader. Each of these disruptive technologies resulted from short-term military requirements paired with far-reaching science and technology objectives, and each featured advanced manufacturing technologies that enabled their game changing development.

Helping SMMs understand the dynamics of Federal contracts is crucial for those wanting to work in the defense sector, requiring more outreach from DoD assistance programs. The DoD has the authority to conduct pilot efforts to acquire innovative commercial items, technologies, and services using Other Transaction Authority. More initiatives like these need to occur to fully utilize the talents of non-traditional manufacturers.

The program priorities for this objective are disruptive dual-use capabilities; buy American; and leveraging existing authorities.

Disruptive Dual-Use Capabilities. Dual-use technologies provide larger markets for domestic manufacturers, allowing them to engage in more R&D for new products. There are strong advantages that accrue to the DoD through widespread adoption of dual-use technologies: a broader and more stable defense industrial base; dramatic procurement cost reduction; and reduced risk. An example is high-performance microelectronics, where the DoD annual demand is often less than one day of production and the cost of a semiconductor foundry is $5 billion. The production of consumer products underwrites the cost of manufacturing defense products by using the same manufacturing facilities. In the case of microelectronics, DoD can use these facilities as trusted foundries, secure in the knowledge that the products are certified at source and there are no counterfeits in the supply chain for critical systems.

Effectively pursuing dual-use technologies will spur innovation and technology development in the commercial sector as well, contributing to economic stability, long-term growth, and prosperity.

Pursue dual-use technologies to spur innovation and technology development in both the defense and commercial supply chains, contributing to economic stability, long-term growth, and a robust national defense.

Buy American. President Trump's "Buy American and Hire American" Executive Order[37] specifies increased enforcement of "Buy American" laws in the United States by all Federal agencies. This policy can be used to support domestic supply chains in important areas. Such support can revitalize certain supply chains necessary for both defense and commercial manufacturers. Buy American policies should also be harmonized and updated, to reflect the components and materials that are critical to the military today. These policies should be reviewed to ensure they keep pace with the technologies and materials that are critical to our defense industrial base today.

Expand technology and supplier scouting programs to identify domestic sources capable of producing parts identical or similar to those being imported in order to alleviate the need for waivers.

Leveraging Existing Authorities. There are a number of special financial authorities that could be more widely exercised for advanced manufacturing within the defense manufacturing base. The Defense Production Act of 1950 (DPA), as amended (50 USC 4502)[38] was enacted in response to domestic manufacturing challenges to ensure the vitality of the domestic industrial

37 *https://www.whitehouse.gov/presidential-actions/presidential-executive-order-buy-american-hire-american/*
38 *https://www.gpo.gov/fdsys/pkg/USCODE-2009-title50/html/USCODE-2009-title50-app-defensepr.htm*

base. The DPA provides the President with an array of authorities to shape national defense preparedness programs and to take appropriate steps to maintain and enhance the domestic industrial base. Currently DoD is the only Federal agency with an existing capability to execute the special requisition authorities under DPA Title III, but other Government agencies can partner with the DoD to address their needs. The Homeland Security Act of 2002, as amended (6 USC 101)[39], provides incentives for the development and deployment of anti-terrorism technologies by creating systems of risk and litigation management. These incentives ensure that the threat of liability does not deter potential manufacturers or sellers of effective anti-terrorism technologies from developing, manufacturing, and commercializing technologies that could save lives.

American defense manufacturers rely on strong foreign military sales to help complement their DoD business. These sales help sustain advanced manufacturing ecosystems and build sufficient surge capacity, providing a buffer when DoD acquisitions are reduced, and spreading development and other overhead costs across a wider customer base. Unfortunately, unnecessary obstacles due to outdated policies continue to inhibit growth in foreign military sales, eroding rather than extending our defense industrial base. More of such sales leads to more domestic manufacturing, which translates into lower costs for DoD weapons systems by virtue of the higher volumes being produced.

Expand use of existing authorities to ensure domestic manufacturing sources for commercial products critical to national security. Evaluate Foreign Military Sales policies and processes to ensure that they are streamlined without compromising national security.

Strengthen Advanced Manufacturing for Rural Communities

The manufacturing sector anchors rural economies across the country and is especially important to rural America, where it accounts for a larger share of employment and earnings than in urban areas[40]. The Federal Government supports programs that are specifically tailored to increasing the strength and resilience of the manufacturing sector in rural regions. For example, facilitating rural prosperity and economic development is identified as one of USDA's principal Strategic Goals[41]. USDA programs provide a comprehensive support system for rural prosperity, including many programs that are also important to advanced manufacturing, such as STEM education, workforce development, rural infrastructure, and grants and loans for businesses and research organizations involved in rural development.

The program priorities for this objective are advanced manufacturing for rural prosperity; and capital access, investment, and business assistance.

Advanced Manufacturing for Rural Prosperity. The 2017 report from the Task Force on Agriculture and Rural Prosperity highlighted the importance of the manufacturing sector to rural America and identified the following five key priority areas for rural prosperity: e-connectivity for rural America; improving quality of life; supporting a rural workforce; harnessing technological innovation; and rural economic development[42]. The USDA is actively working to support these priority areas.

The USDA's Economic Research Service released a suite of research on rural manufacturing resilience and the importance of manufacturing to the rural economy[43], and this data should be considered by regional, State, and Federal policymakers to better understand the manufacturing sector in rural America. Other USDA programs, such as the Rural Business-Cooperative Service[44], are providing technical assistance grants for manufacturers developing innovative value-added agricultural products for broader markets.

Leverage strategic partnerships among Federal agencies, State and local governments, non-profits, and the private sector to increase efficiency and effectiveness at facilitating rural prosperity through manufacturing development and growth.

Capital Access, Investment, and Business Assistance. A thriving rural advanced manufacturing sector depends on timely access to capital and other forms of business assistance. In an effort to advance Federal support in these areas, the USDA and

39 *https://www.gpo.gov/fdsys/granule/USCODE-2010-title6/USCODE-2010-title6-chap1-sec101, which includes the Support Anti-Terrorism by Fostering Effective Technologies Act, commonly known as the SAFETY Act*
40 *https://www.ers.usda.gov/publications/pub-details/?pubid=80893*
41 *https://www.usda.gov/our-agency/about-usda/strategic-goals*
42 *https://www.usda.gov/sites/default/files/documents/rural-prosperity-report.pdf*
43 *https://www.ers.usda.gov/publications/pub-details/?pubid=84757*
44 *https://www.rd.usda.gov/about-rd/agencies/rural-business-cooperative-service*

SBA recently entered a Memorandum of Understandingbuilding on priorities identified by the Interagency Task Force on Rural Prosperity. The interagency collaboration will work to improve capital access and investment in rural areas, establish innovation clusters, improve rural technical assistance, enhance tools for rural businesses to access global markets, and increase the benefits of the Tax Cuts and Job Act of 2017, among other goals. Advanced manufacturing programs should echo these priorities and those identified in the Interagency Task Force on Rural Prosperity, such as improved tax codes, infrastructure, and programs that support increases in agricultural, forestry, and food production. These priorities are critical support systems for manufacturers in rural communities. Direct investments are needed in community and commercial infrastructure that supports rural economies, such as those provided by the USDA Rural Utility Service, including broadband high-speed internet connectivity for schools and libraries, healthcare and wellness facilities, as well as power, telecommunications, water, and waste-management systems.

Assist rural areas in developing the planning, leadership, technical, and professional expertise needed to sustain and grow rural economies, leverage multi-sector or multi-jurisdictional partnerships, and advance regional collaboration.