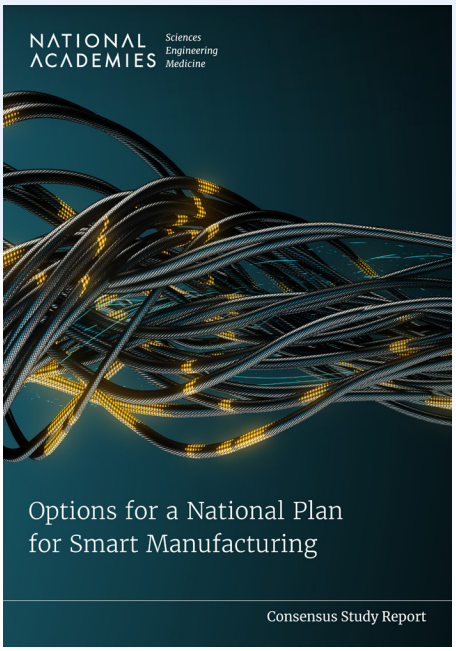
Options for a National Plan for Smart Manufacturing



Smart manufacturing involves refining and improving traditional manufacturing processes by incorporating advanced sensor feedback and computing technologies to improve the productivity, precision, efficiency, and sustainability of the workforce, factories, and supply chains. Deploying smart manufacturing technologies has the potential to offer significant economic advantages for the nation as well as new high-paying and secure job opportunities for the U.S. workforce.

At the request of Congress and the Department of Energy (DOE), the National Academies of Sciences, Engineering, and Medicine organized a study to evaluate options for a national plan to promote and support smart manufacturing in the United States. The report explores promising technologies transforming the manufacturing sector and identifies the research and resources needed to accelerate smart manufacturing adoption industry-wide while establishing the United States as a global leader in the field. The report finds that **continuous education and workforce development are paramount to the success of smart manufacturing and ultimately the U.S. manufacturing ecosystem,** from large multinational corporations to small and medium-sized enterprises. Learn more and download the full report at https://nap.nationalacademies.org/catalog/27260.

EDUCATION AND WORKFORCE DEVELOPMENT

Given the fast-moving nature of the smart manufacturing field, it is critical to ensure that the current and future manufacturing workforce in the United States is relevant, robust, competitive, and adaptable. However, existing efforts to train and educate the manufacturing workforce are fragmented and insufficient.

A national plan for smart manufacturing should offer a holistic, boldly orchestrated national approach to solve workforce challenges and support existing workforce development efforts. An effective initiative could take the form of an independent nongovernmental institute or organization, such as a smart manufacturing education and training academy. Such an organization could help set standards for smart manufacturing education, develop curricula, provide advice on how to close the gap between training programs and industrial needs, and forecast skills needed for the future workforce.

DATA MANAGEMENT AND INFRASTRUCTURE

The ability to seamlessly share expertise and data across government agencies and companies engaged in smart manufacturing is necessary to maximize industry innovation and U.S. competitiveness. However, the U.S. smart manufacturing sector lacks a technical infrastructure and common mechanisms to securely exchange analytics and communicate best practices across the industry. The lack of readily available curated data hampers the evolution of the industry and makes it difficult for smaller companies to adopt smart manufacturing technologies. It is imperative that small- and medium-sized companies adopt smart manufacturing technologies alongside large enterprises so that the entire U.S. manufacturing ecosystem benefits from this technological advancement.

A national plan for smart manufacturing should urgently support the establishment of national transformative data infrastructure, tools, and mechanisms to assist with (1) cultivating, selectively sharing, and securing the use of data in real time and at scale; and (2) sharing best practices to promote industry-wide technical data standards. A secure digital "Cyber Interstate" could serve as a conduit to connect the wider smart manufacturing community and ensure U.S. global competitiveness in a sustainable way.

Fully implementing the Cyber Interstate would require adopting new business structures and cybersecurity practices to allow companies to take advantage of being networked and interconnected while mitigating the cyber risks. There is a critical need for standards to facilitate data sharing across the smart manufacturing industry.

The report recommends that **DOE, in partnership with the National Institute of Standards and Technology, the Department of Defense, and manufacturing institutes, should establish manufacturing CASE (Calibration, Autonomy, Security, Evaluation) Data Banks for the next generation of secure manufacturing architectures.** These data banks could house rigorously validated and thoroughly curated data contributed by the manufacturing community (across industry, academia, and government) with the goal of securely and selectively sharing state-of-the-art process information related to manufacturing products and operations throughout the supply chain.

ADVANCED TECHNOLOGY NEEDS AND INTERDISCIPLINARY COLLABORATION

Technology needs for smart manufacturing cover nearly all disciplines of science, engineering, and social sciences. To support research and development in these interdisciplinary areas, **DOE and other federal agencies should fund programs and consortia to work at the intersections of critical technologies, manufacturing processes, and industry sectors.**

The report identifies six interdisciplinary technologies that are in high demand for the smart manufacturing community and suggests the following funding opportunities:

- **Human–machine co-piloting:** Establish programs that investigate how humans can maintain situational awareness in complex smart manufacturing deployments, make informed decisions, and efficiently interact with machines and other coworkers.

- **Sensing:** Promote research to ensure consistency between digital models and their physical counterparts; explore additive manufacturing to improve adaptivity and accessibility of sensors for high-fidelity data acquisition; and encourage the

development of robust, reliable, and cost-effective smart sensors.

- **Artificial intelligence and machine learning (AI/ML):** Fund research and development that can reduce the computational cost using advanced AI/ML methods and create AI/ML diagnostic tools validated by data; and fund research in generative AI to facilitate smart manufacturing workflow.

- **Platforms:** Support continued investment and research in operational technology and information technology integration through platforms and general-purpose tools.

- **Digital twins:** Fund programs that develop the modules for digital twins using DOE-coordinated manufacturing data banks; and employ manufacturing research institutes in the United States to point manufacturers to cases where digital twins have been successfully used to increase productivity and efficiency.

- **Uncertainty quantification:** Fund research that develops methods to incorporate uncertainty quantification into data curation and modeling processes.

SUSTAINABILITY

Smart manufacturing technologies have the potential to greatly improve energy efficiency and environmental sustainability for the U.S. manufacturing sector. However, given the availability of cheap energy in the United States, companies are not currently incentivized to invest in smart manufacturing.

As U.S. policies related to energy efficiency evolve, a cultural change is needed to start incentivizing energy efficiency and sustainability in U.S. manufacturing. A systematic process for tracking energy, emissions, and materials in individual factories and across supply chains would help quantify sustainability gains (which could be measured as the energy needed to manufacture a part or as the product's carbon footprint). **DOE, in consultation with other relevant federal departments and agencies, should develop a framework to quantify the broader sustainability benefits of implementing secure smart manufacturing.**

Sustainability encompasses three pillars: environment, economy, and society. As the United States moves forward and implements new policies, it is important that social consequences be considered as important as economic or environmental impacts. In particular, smart manufacturing programs should make every effort to ensure that specific groups are not disadvantaged, advantaged, or penalized as processes change. For example, the creation of the Cyber Interstate should ensure that small-to-medium manufacturers, especially in rural areas, are not "left out."

The intersection of sustainability and smart manufacturing technologies will inevitably be a core curricular component for all national smart manufacturing training programs, thus training workers that can simultaneously advance U.S. manufacturing competitiveness and U.S. climate change objectives, while improving energy efficiency in U.S. industries.

COMMITTEE ON THE NATIONAL PLAN FOR SMART MANUFACTURING **Thomas R. Kurfess (NAE)** (*Chair*), Georgia Institute of Technology; **Billy B. Bardin,** Dow Inc.; **Richard D. Braatz (NAE),** Massachusetts Institute of Technology; **Jian Cao (NAE),** Northwestern University; **Krystel K. Castillo-Villar,** The University of Texas at San Antonio and Cybersecurity Manufacturing Innovation Institute; **Lili Cheng (NAE),** Microsoft; **James F. Davis,** University of California, Los Angeles; **Robert X. Gao,** Case Western Reserve University; **Satyandra K. Gupta,** University of Southern California; **Susan N. Houseman,** W.E. Upjohn Institute for Employment Research; **Jeannine Kunz,** SME; **Stuart E. Lawrence III,** Titan Robotics Inc.; **Blake D. Moret,** Rockwell Automation; **Chinedum E. Okwudire,** University of Michigan; **Melissa Orme,** The Boeing Company; **William E. Spriggs** (deceased on June 6, 2023), Howard University; **John W. Sutherland (NAE),** Purdue University; **Karen A. Thole,** The Pennsylvania State University

STAFF **Erik B. Svedberg,** Study Director and Scholar; **Michelle Schwalbe,** Director, National Materials and Manufacturing Board and Board on Mathematical Sciences and Analytics; **Steven Darbes,** Program Officer; **Amisha Jinandra,** Senior Research Analyst; **Joseph Palmer,** Senior Project Assistant

FOR MORE INFORMATION

This Consensus Study Report Highlights was prepared by the National Academies' National Materials and Manufacturing Board based on the report *Options for a National Plan for Smart Manufacturing* (2023).

The study was sponsored by the Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for this project.

To read the full report, visit https://nap.nationalacademies.org/catalog/27260.

Division on Engineering and Physical Sciences

NATIONAL ACADEMIES *Sciences Engineering Medicine*

Copyright 2023 by the National Academy of Sciences. All rights reserved.