U.S. DEPARTMENT OF ENERGY

National Smart Manufacturing Strategic Plan

To Facilitate More Rapid Development, Deployment and Adoption of Smart Manufacturing Technologies

Report to Congress
July 2022

United States Department of Energy
Washington, DC 20585

Message from the Principal Deputy Assistant Secretary

This report, *National Smart Manufacturing Strategic Plan,* responds to language outlined in the Senate Energy and Water Development Appropriations Bill 2019, Report 115-258, on page 75, which states:

> *The Committee directs the Department to develop a national smart manufacturing plan that will identify areas where the Department can facilitate more rapid development, deployment, and adoption of smart manufacturing technologies. The Department shall submit a plan to the Committees on Appropriations of both Houses of Congress not later than 180 days after the enactment of this act.*

This report is being provided to:

- **The Honorable Patrick Leahy**
  Chairman, Senate Committee on Appropriations

- **The Honorable Richard Shelby**
  Vice-Chairman, Senate Committee on Appropriations

- **The Honorable Dianne Feinstein**
  Chair, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable John Kennedy**
  Ranking Member, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable Rosa DeLauro**
  Chair, House Committee on Appropriations

- **The Honorable Kay Granger**
  Ranking Member, House Committee on Appropriations

- **The Honorable Marcy Kaptur**
  Chair, Subcommittee on Energy and Water Development
  House Committee on Appropriations

- **The Honorable Mike Simpson**
  Ranking Member, Subcommittee on Energy and Water Development
  House Committee on Appropriations

If you have any questions or need additional information, please contact me or Ms. Katie Donley, Deputy Director for External Coordination, Office of the Chief Financial Officer, at (202) 586-0176.

Sincerely,

Kelly Speakes-Backman Digitally signed by Kelly Speakes-Backman
Date: 2022.07.07 08:31:12 -04'00'

Kelly J. Speakes-Backman
Principal Deputy Assistant Secretary
Energy Efficiency and Renewable Energy

Executive Summary

Smart manufacturing technologies provide real-time data and insight to improve the productivity, efficiency, and competitiveness of U.S. manufacturing, creating the potential for new jobs in the manufacturing sector. These technologies can support U.S. manufacturers' ability to increase throughput and energy efficiency, and decrease waste, defects, and costs.

A wide range of manufacturing and industrial subsectors, particularly energy-intensive and energy-dependent industries, have the potential to benefit from smart manufacturing technologies. There are technical improvements still needed to reduce the costs and barriers (trained workforce and upskilling, software-hardware integration, cost, and technical barriers to deployment of advanced sensors, computing, and communication technologies for existing manufacturing assets) to the adoption of smart manufacturing technologies, especially to small and medium-sized manufacturers, and subsequently, increase the overall adoption rate of smart manufacturing technologies. This report outlines the Department of Energy's (DOE) strategic plan to accelerate the development and implementation of smart manufacturing technologies in the United States and the actions DOE has taken to use these technologies in smart manufacturing for the United States.

DOE's plan to facilitate more rapid development, deployment and widespread adoption of smart manufacturing technologies derive from the 2018 *Strategy for American Leadership in Advanced Manufacturing.* The strategy outlines a vision for America's leadership in advanced manufacturing including the development of intelligent manufacturing systems to optimize manufacturing facilities and support the manufacturing of transformative materials.

DOE's Clean Energy Smart Manufacturing Innovation Institute (CESMII), a Manufacturing USA Institute, focuses on accelerating the development and adoption of advanced sensors, controls, platforms, and models needed for smart manufacturing. The objective is to enhance U.S. manufacturing productivity and global competitiveness through the research and development of these technologies. Smart manufacturing has the potential to improve the overall performance, energy productivity, and efficiency of manufacturing, fostering the economic competitiveness of the manufacturing sector.

National Smart Manufacturing Strategic Plan to Facilitate More Rapid Development, Deployment, and Adoption of Smart Manufacturing Technologies

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I. Congressional Language

This report, *National Smart Manufacturing Strategic Plan,* responds to the language outlined in the Senate Energy and Water Development Appropriations Bill 2019, Report 115-258, on page 75, which states:

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II. Introduction

Smart manufacturing is the merging of advanced new information and communications technologies with the manufacturing environment to achieve real-time management of energy, production, and costs in processes—at the level of the machine, factory, or enterprise. Smart manufacturing technologies provide real-time data and insight to improve the overall productivity, efficiency, and competitiveness of U.S. manufacturing, creating the potential for new jobs in the manufacturing sector.

Broader deployment of smart manufacturing technologies can positively impact the entire U.S. manufacturing sector and make industries from steel production to aerospace manufacturing to food production more competitive through intelligent communications systems, real-time energy savings, increased energy productivity, and greenhouse gas reduction. The greatest opportunity for smart manufacturing lies in energy-intensive industries (those with high energy consumption) and energy-dependent industries (those where energy is a significant cost input). Fully implemented smart manufacturing technologies can also improve integration with the electric grid, thus enabling smart demand response capabilities.

III. State of Technology for Smart Manufacturing

Smart manufacturing technologies include advanced sensors, controls, platforms, and modeling for manufacturing and represent an emerging opportunity for the U.S. manufacturing sector.[1] Data, information technology, and advanced models and control systems make it possible to dynamically and proactively manage energy together with other aspects of the manufacturing

[1] U.S. Department of Energy, Advanced Manufacturing Office. *Advanced Sensors, Controls, Platforms and Modeling for Manufacturing: Technology Assessment* (2015), pages 3-12. https://www.energy.gov/sites/prod/files/2019/06/f63/Advanced%20Manufacturing%20Technology%20Assessment%20-%20Advanced%20Sensors%20Controls%20Platforms%20and%20Modeling%20for%20Manufacturing.pdf

environment, such as machine configurations, to manage production volume and quality, minimize defects, and avoid abnormal situations that result in energy losses.

While aspects of smart manufacturing have been successfully implemented in the chemical industry, there are technological, cost, and knowledge barriers to broader smart manufacturing implementation across manufacturing. Such barriers include value proposition, incompatibility with existing operations and business structure, technical limitations in sensing and control, hardware and software lock-in issues, data availability and format, and cybersecurity risk.

Current smart manufacturing implementations are mostly at the manufacturing plant level within the manufacturing systems depicted in Figure 1. There is a critical need for research and development (R&D) to make access to cutting-edge physical and virtual tools affordable, develop expertise to reduce the cost and risk of commercialization, address technical challenges, and provide data for a business case. The need is for the development of cost-effective technologies and solutions that collect, share, and process the increasing amounts of information in real-time, improve data management, and that can be used to monitor, control, and ultimately reduce life cycle energy in many sectors of the economy.

While the industry is making progress in developing and implementing smart manufacturing technologies, the systemic cyber-physical infrastructure, standards, and protocols needed to deliver and deploy a large-scale smart manufacturing environment remains to be developed. The cost of developing and implementing open software platforms and technologies based on common standards remains high, creating a significant barrier to deployment, particularly for small- and medium-sized enterprises.

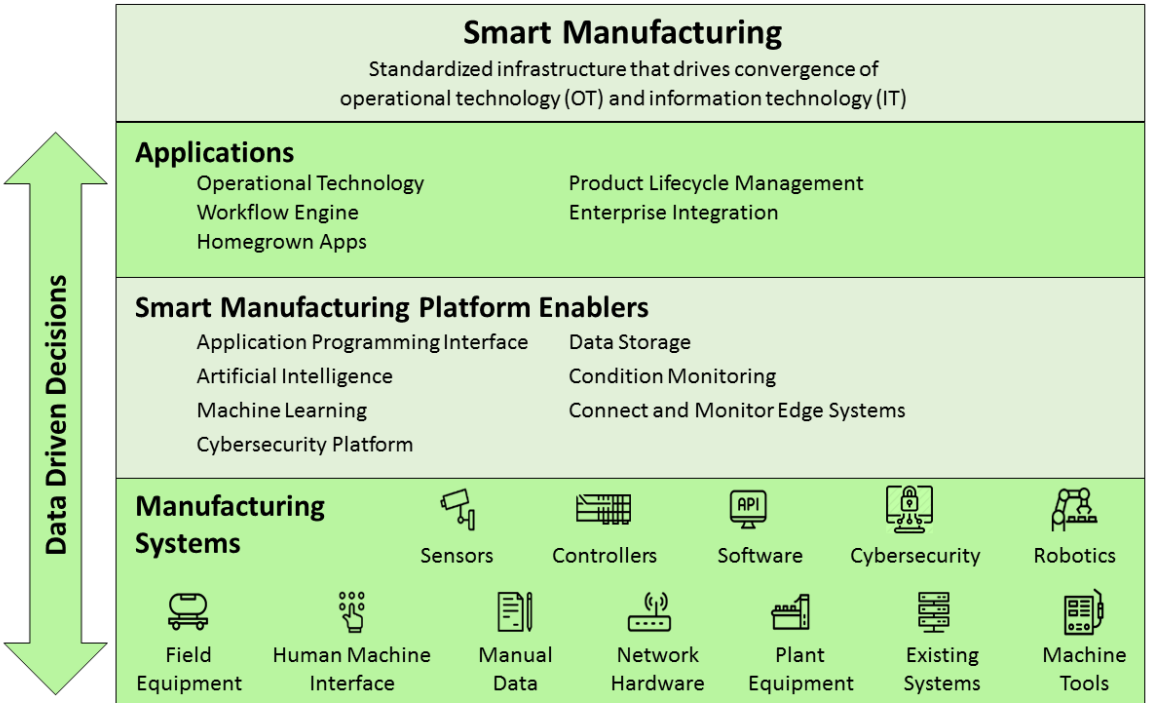

Figure 1: Smart Manufacturing Implementation

IV. National Smart Manufacturing Strategic Plan

The Advanced Manufacturing Office (AMO) is part of the Department of Energy's Office of Energy Efficiency and Renewable Energy. AMO's mission is to catalyze research, development, and adoption of energy-related advanced manufacturing technologies and practices to drive U.S. economic competitiveness and an equitable transition to a decarbonized energy system by 2050.

AMO recognizes that the rapid development, deployment, and adoption of smart manufacturing technologies is a high priority for increasing economic competitiveness, efficiency, and energy productivity in all U.S. manufacturing sectors, and decreasing greenhouse gas emissions. AMO evaluated the opportunity of smart manufacturing in a 2015 technology assessment.[2] The assessment notes a 2014 study by the American Council for Energy Efficient Economy (ACEEE) that indicates the industrial sector could save between $7 billion and $25 billion in energy costs per year, with smart manufacturing technology investments resulting in an average of 20 percent expected savings for manufacturers.[3]

[2] U.S. Department of Energy, Advanced Manufacturing Office. *Advanced Sensors, Controls, Platforms and Modeling for Manufacturing: Technology Assessment* (2015), page 12. (See footnote 1).

[3] American Council for and Energy-Efficient Economy. *The Energy Savings Potential of Smart Manufacturing* (2014). http://aceee.org/sites/default/files/publications/researchreports/ie1403.pdf

DOE's national strategy to facilitate more rapid development, deployment, and adoption of advanced manufacturing technologies, including smart manufacturing technologies, was adopted from the strategy and goals of the 2018 *Strategy for American Leadership in Advanced Manufacturing:*[4]

Goal 1: Develop and Transition New Manufacturing Technologies

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

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

These goals were developed with DOE's active participation in the Committee on Technology, Subcommittee on Advanced Manufacturing, of the National Science & Technology Council. DOE's efforts on smart manufacturing, and all advanced manufacturing efforts, are coordinated with the efforts of other Federal agencies through this shared Federal strategy. These efforts build upon the accomplishments achieved since the publication of the previous Federal advanced manufacturing strategic plan in 2012.[5] DOE works specifically with Manufacturing USA Institutes and the agencies funding these institutes, including the Department of Defense and Department of Commerce.

Smart manufacturing aims to reduce manufacturing costs from the perspective of real-time energy management, energy productivity, and process energy efficiency. Smart manufacturing technologies can facilitate the adoption of advanced industrial robotics, artificial intelligence, and cyber security technologies. Smart manufacturing can transform material development technologies through sensing and then adjusting to correct anomalies to enhance and increase product quality.

The implementation of smart manufacturing technology represents an emerging opportunity faced broadly by the U.S. manufacturing sector. There are opportunities to merge new information and communications technologies with the manufacturing environment for real-time facilities management, to optimize production, and to reduce energy use and costs. Smart manufacturing can integrate within and across the unit operation, factory, and enterprise.

Implementation of smart manufacturing and its increased internet and data connectivity requirements comes with increased cybersecurity risks. To increase the adoption of

[4] National Science & Technology Council, Committee on Technology, Subcommittee on Advanced Manufacturing. *Strategy for American Leadership in Advanced Manufacturing* (2018). https://www.manufacturing.gov/news/announcements/2018/10/strategy-american-leadership-advanced-manufacturing

[5] National Science & Technology Council, Interagency working group on Advanced Manufacturing. *A National Strategic Plan for Advanced Manufacturing* (2012). https://www.energy.gov/sites/prod/files/2013/11/f4/nstc_feb2012.pdf

technologies that increase energy efficiency in manufacturing, DOE selected a new Manufacturing USA Institute called Cybersecurity Manufacturing Innovation Institute (CyManII). This new institute was launched in 2020. CyManII will address cybersecurity in manufacturing automation, supply chain, and other areas to secure implementation of smart manufacturing and other technologies that can increase U.S. manufacturing energy efficiency and competitiveness.

Smart manufacturing is specifically focused on reducing energy costs for selected manufacturing processes in a manner that improves overall process efficiency and optimizes productivity. DOE's efforts aim to create a networked data-focused process platform that combines innovative modeling and simulation with advanced sensing and controls. The platform will integrate efficient intelligence in real-time across an entire production operation. The primary emphasis is on minimizing energy and material use for energy-intensive manufacturing sectors.

V. Implementing the Smart Manufacturing Strategic Plan

The AMO's first effort on smart manufacturing was the funding of an "Industrial Scale Demonstration of Smart Manufacturing to Achieve Transformational Energy Productivity Gains." [6] The project took place from 2013 to 2017 and was led by the University of Texas at Austin. The project produced two industry-scale demonstrations to optimize energy productivity. The first smart manufacturing demonstration was at an energy-intensive chemical manufacturing facility producing hydrogen through steam methane reforming. The project showed that smart manufacturing systems installed at typical steam methane reforming facilities could yield waste heat reductions of 15-20 percent. The other smart manufacturing demonstration was in an energy-intensive forging, heat-treating, and machining line operation, and resulted in fuel savings of over 15 percent. These two smart manufacturing demonstrations estimated that a payback period on the investment is possible within one year for energy-intensive manufacturing applications such as these.[7]

AMO hosted an Industry Day Workshop[8] in 2015 to gather stakeholder input on smart manufacturing as a focus area for a potential Manufacturing USA Institute. Over 100 stakeholders participated in the workshop to express interest, ask questions, and provide feedback regarding collaborating on smart manufacturing R&D through an institute that would

[6] Project technical report: https://www.osti.gov/biblio/1454266-industrial-scale-demonstration-smart-manufacturing-achieving-transformational-energy-productivity-gains

[7] Project technical report page 115: https://www.osti.gov/biblio/1454266-industrial-scale-demonstration-smart-manufacturing-achieving-transformational-energy-productivity-gains

[8] DOE AMO Smart Manufacturing Institute Industry Day Workshop and Proceedings, February 25, 2015: https://www.energy.gov/eere/amo/articles/smart-manufacturing-institute-industry-day-workshop

have a strong focus on implementing the goals in the 2012 National Strategic Plan for Advanced Manufacturing.[9]

In 2016, DOE established the Clean Energy Smart Manufacturing Innovation Institute (CESMII). CESMII is committed to transforming the U.S. manufacturing sector and increasing U.S. manufacturing competitiveness through the application of smart manufacturing technologies.[10] CESMII partners with private and public sector organizations to (1) develop, test, and validate advanced sensors, controls, platforms, and modeling for manufacturing; and (2) facilitate the implementation of energy-efficient manufacturing solutions through the integration of operations technologies and information technologies. CESMII is currently supported by DOE and is now in the final budget period ending in December 2023, with a request for six months extension.

CESMII developed a sustainability strategy for continuation past initial DOE Federal funding through identifying potential revenue streams. The strategy is based on driving broad adoption of smart manufacturing technologies and practices by solving energy productivity problems faced by members, developing unique and innovative smart manufacturing technologies, and providing trusted knowledge on smart manufacturing. The sustainability strategy is yielding some initial results in terms of App-based solutions through MarketPlace[11] (similar to App stores of Google, and Apple) and education and workforce training.

At the national level, a broader approach to implement all three goals of the national advanced manufacturing strategic plan is being carried out by DOE and other government agencies. As a portion of the broader approach, the following efforts through the investment in CESMII align well with the three goals:

Goal 1: Develop and Transition New Manufacturing Technologies

- CESMII launched eight R&D projects in 2019 through the first request for proposals.[12] Some of the industries benefitting from these projects include the energy-intensive industries of steel casting, chemical processing, and cement manufacturing, as well as aerospace additive manufacturing. The individual projects are developing data analytics and data management, machine learning, process modeling, defect elimination, and process monitoring & control. All these projects include energy efficiency, energy management, and energy waste elimination as objectives.

[9] National Science & Technology Council, Interagency working group on Advanced Manufacturing. *A National Strategic Plan for Advanced Manufacturing* (2012). https://www.energy.gov/sites/prod/files/2013/11/f4/nstc_feb2012.pdf

[10] Clean Energy Smart Manufacturing Innovation Institute: https://www.cesmii.org/

[11] https://www.cesmii.org/technology-sm-marketplace/

[12] Details of projects, Clean Energy Smart Manufacturing Innovation Institute: https://www.cesmii.org/roadmap-projects/

- In 2020, projects began from a second request for proposals focused on enabling R&D projects. An additional eight R&D projects were selected to develop sensors and predictive control; real-time, non-invasive, process monitoring; and advanced process models, sensors, and data integration architecture. [13] Specific project partners represent industries including pulp and paper, forging, semiconductors, and pharmaceuticals.
- Additional requests for proposals were released in 2020, 2021. These requests for proposals fund projects that will develop capabilities for a U.S. smart manufacturing platform, and industry application projects. The project selections have been announced and are ongoing[14]. The results and solutions from the projects are being tested by the industry partners and are in the process of being deployed in actual industry settings.

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

- CESMII supports projects to train students to enter the smart manufacturing workforce and to re-train the existing manufacturing workforce for smart manufacturing. Two education and workforce development projects were initiated in 2019, one led by a community college and one by a four-year college. These projects are identifying the smart manufacturing core competencies needed by operators, technicians, engineers, and managers; leveraging existing education and workforce training systems to deploy new smart manufacturing certification programs needed by the workforce; and developing learning modules and manufacturing process simulators for community colleges, four-year universities, and K-12 school districts. Some of these projects are still ongoing with pandemic related extensions and new projects have been added related to education and curriculum development.
- An additional four smart manufacturing education and workforce development projects were selected in 2020 and began in early 2021. These university-led projects are developing hands-on curricula for smart manufacturing technologies; establishing a smart manufacturing training module; creating a smart manufacturing curriculum and certificate program and developing smart manufacturing curricula for undergraduate manufacturing engineering. The smart manufacturing curriculum project is ongoing. The goal of this project is to design an Accreditation Board for Engineering and Technology (ABET) accredited B.S. degree program aligned with the digitalization strategies of smart manufacturing to produce graduates capable of facilitating change in the U.S. manufacturing industry. This curriculum will be made

[13]U.S. Department of Energy, Energy Department Manufacturing Institute Selects Projects to Advance U.S. Leadership in Smart Manufacturing: https://www.energy.gov/eere/articles/energy-department-manufacturing-institute-selects-projects-advance-us-leadership-smart.

[14] https://www.cesmii.org/cesmii-funded-projects-overview/

available to academic members of CESMII, and industry members will benefit from well-trained students as their potential workforce.

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

- CESMII is leveraging $70 million in DOE Federal funding with $70 million in private investment through a consortium of partners and members. The Institute is operated by the University of California, Los Angeles. The Institute has over 100 members including large original equipment manufacturers, small and medium-sized enterprises, academia, and not-for-profit organizations.

- This DOE-established institute has developed a smart manufacturing roadmap,[15] created through active participation from members, manufacturing stakeholders, and DOE. The roadmap incorporates key elements from DOE's plan to facilitate more rapid development, deployment, and adoption of smart manufacturing technologies. The roadmap lays out strategic objectives and challenges for smart manufacturing that need to be addressed through technology R&D, education and workforce development, and domestic manufacturing supply chain collaboration.

The smart manufacturing roadmap was developed to accelerate R&D and foster collaboration and sharing of knowledge. The roadmap aims to facilitate the implementation of new manufacturing solutions and the integration of operational technologies and information technologies (OT/IT). It simultaneously addresses knowledge gaps and advances innovation in smart manufacturing technology, processes, and workforce. It was designed to optimize overall performance and increase the energy productivity of manufacturing.

The roadmap is structured around four strategies:

1. Incorporate business practices that facilitate widespread smart manufacturing integration by developing a clear and compelling value proposition and mitigating adoption risks. This strategy provides tools and best practices for smart manufacturing integration.
2. Support technologies through collaborative R&D to advance smart manufacturing technologies, including advanced sensors, data analytics tools, process controls, models, and computational platforms.
3. Focus on workforce development to build and sustain a skilled and innovative workforce with expertise in smart manufacturing technologies and practices. This is achieved through developing interdisciplinary training resources and programs.

[15] Roadmap, Clean Energy Smart Manufacturing Innovation Institute: https://www.cesmii.org/cesmii-roadmap

4. Develop smart manufacturing infrastructure by building a unified platform for OT/IT integration through an innovation ecosystem for hardware and software systems for manufacturing.

Implementing smart manufacturing technologies for both legacy systems and new manufacturing systems, especially in Process Industry for industrial decarbonization, has the potential for reducing 20-25 percent greenhouse gases in both in-process emissions and emissions for process heating using fossil fuels. Systems integration of smart manufacturing technology can allow reliable and cost-effective solutions for demonstrating energy-efficient, low carbon manufacturing technologies and electrification in the industrial sector (focusing on hard to decarbonize sectors) such as 1) iron and steel, 2) cement, and 3) refineries.

More research is needed to successfully transition to a future net-zero emissions energy system to implement smart manufacturing through systems integration (intelligent cyber-physical manufacturing system). The implementation of a smart manufacturing system combined with artificial intelligence and machine learning can demonstrate the advanced modeling and simulation of net-zero emissions (both direct and indirect emissions – greenhouse gas protocol at Scope1 and Scope 2)).

VI. Conclusion

Smart manufacturing will enhance the global competitiveness of the U.S. manufacturing sector by increasing the productivity and efficiency of manufacturing. Smart manufacturing will also foster sustainable manufacturing through reductions of plant scrap, increased resource efficiency, and energy savings.

DOE, through AMO, is working with CESMII on technology R&D, workforce development, and U.S. supply chain collaboration to rapidly make smart manufacturing the norm in American manufacturing. DOE's investment and involvement in CESMII are developing smart manufacturing technologies and an industry-smart manufacturing platform.

CESMII's projects are strategically selected to accelerate smart manufacturing adoption and industry transformation. Specific emphasis is being placed on energy-intensive and energy-dependent industries, as well as clean energy and energy-efficient product manufacturing industries.

The metrics-based goals for CESMII are to (1) achieve a 15 percent improvement in energy efficiency in first-of-a-kind demonstrations at manufacturing plants or of major processes; (2) reduce the cost of implementing smart manufacturing technologies by 50 percent compared to 2015 typical technology, and (3) show significant industry adoption of smart manufacturing technology within five years.

In addition, DOE is further advancing smart manufacturing through investments in R&D projects at the DOE National Laboratories.

All of these smart manufacturing investments and efforts are an implementation of the three goals of the Federal strategic plan outlined in the 2018 *Strategy for American Leadership in Advanced Manufacturing.*