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ANTICIPATING THE WAVE:

TMS Study Examines Potential of Artificial Intelligence

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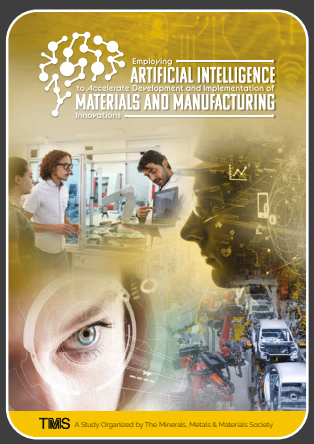

Artificial intelligence offers unprecedented opportunities in materials science and manufacturing. The latest TMS science and technology accelerator study charts a course.

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Employing Artificial Intelligence to Accelerate Development and Implementation of Materials and Manufacturing Innovations is available to all for free download. Access your copy today at **www.tms.org/Studies**.

Artificial intelligence (AI) has the potential to revolutionize how materials and materials-related manufacturing research, development, and innovations are accomplished, and to significantly accelerate their pace, as well. Materials professionals with an interest in AI will find *Employing Artificial Intelligence to Accelerate Development and Implementation of Materials and Manufacturing Innovations* worth reading. Published in April 2022 on behalf of the Office of Naval Research and the National Institute of Science and Technology, it is the result of a 13-month study that began in April 2021. I served as chair of the 11-person lead study team, which was made up of internationally known subject matter experts from various materials, manufacturing, and AI-related backgrounds who represented academia, national laboratories, and industry. Together, we completed eight virtual workshops, a series of online meetings, as well as homework assignments.

The lead study team delivered its initial recommendations to a small satellite team, who took a deep dive into a selection of target areas and met to develop those areas further. In the final stages, an independent review team of experts offered feedback on a draft of the final report. The outcome represents a consensus of the community of experts in this area.

The report's goal is to address a wide range of issues surrounding the deployment of AI in the development and implementation of materials and manufacturing. As a TMS accelerator report, it is meant to help the community bring this promising new technology to materials practice.

ABOUT THE AUTHOR

Elizabeth Holm is a professor and Department Chair of Materials Science and Engineering at the University of Michigan. She served as the 2013 TMS President, is a 2019 TMS Fellow, and was most recently honored with the 2022 AIME Honorary Membership Award and 2022 TMS Structural Materials Division Distinguished Scientist/Engineer Award, in addition to her numerous other awards and honors. She is currently the President-Elect of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME).

MEET THE STUDY TEAM - Thank you to all the following volunteers for their service.

Lead Expert Study Team

- Elizabeth A. Holm, Study Chair, *University of Michigan*
- Surya Kalidindi, *Georgia Institute of Technology*
- Adam Kopper, *Mercury Marine*
- Kenneth A. Loparo, *Case Western Reserve University*
- Benji Maruyama, *U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate*
- Elsa Olivetti, *Massachusetts Institute of Technology*
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Expert Satellite Team

- Sean Donegan, *Air Force Research Laboratory*
- Mike Groeber, *The Ohio State University*
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- Brian DeCost, *National Institute of Standards and Technology*
- Jaafar El-Awady, *Johns Hopkins University*
- Henry Kvinge, *Pacific Northwest National Laboratory*
- Renata Rawlings-Goss, *Georgia Institute of Technology*
- Alok Sutradhar, *The Ohio State University*

VALUE PROPOSITION

Interest in AI is growing in society, from our campuses to our news headlines. We have to understand how materials science and engineering (MSE) can intersect with AI to bring benefits across the materials community. From the start, the report presents an overarching value proposition for using AI in support of innovations, as shown in Table 1.

Table 1. Summary of the value proposition of utilizing AI in materials and manufacturing environments (right column) grouped by thematic implementation area (left column).

Thematic Area	Value Proposition
Resource Optimization & Automation Greater efficiency and effectiveness of research and development efforts	**Autonomous research** • Guides and accelerates autonomous experimentation and computational modeling efforts • Directs which experiments are most effective to run
	Greater resource efficiency Automates "routine" tasks and improves time allocation of human researchers
	Better product quality Improves product quality and yield (e.g., via defect detection)
	Augmented decision-making AI-driven analytics enable faster and cheaper decision-making with greater precision
Pattern Analysis & Prediction Identification of data trends, and property-chemistry-structure correlations	**Rapid materials discovery** High-dimensional synthesis mapping enables rapid exploration of design spaces
	Extraction of novel science Enables discovery of new scientific principles unseen by humans
	Faster materials qualification Accelerates efforts to qualify new materials, processes, or components (e.g., via deep learning of multi-modal data)
	Accelerated delivery of new materials and processes Accelerates the implementation of new and innovative materials systems and manufacturing process methodologies
	Integration of diverse or disparate information sets e.g., multiscale, multi-fidelity experimental and simulation data sets
Greater Research Accessibility Increased accessibly of materials research through online platforms, open-source tools, data, and more effective modes of teaching and learning	**Equitable use and access** Brings together underserved communities by providing K-12 schools and universities (e.g., Minority Institutions (MIs) and Historically Black Colleges and Universities (HBCUs)) with affordable and accessible equipment and training resources for all communities
	Inclusive engagement • Attracts students and professionals of all types • AI has a lower cost of entry (e.g., compared with traditional manufacturing technologies) for small businesses, including women- and minority-owned businesses
	Diversity of ideas Enables connections across disciplines and areas of expertise

To build the value proposition, the lead study team identified the key application areas and domains that hold great promise for the application of AI in materials and manufacturing. These include materials discovery and design; predictive maintenance and condition monitoring; materials characterization, imaging, and quality assessments; autonomous experimentation and decision-making; support for designing/selecting experiments; synchrotron beamline experimental data acquisition; anomaly detection in manufacturing processes; additive manufacturing process optimization and control; hybrid manufacturing, novel planning, and set-up.

For each of the areas and domains, the "Gaps, Barriers, and R&D Enablers" chapter presents a succinct outline of impediments to deployment, as summarized in Table 2.

Table 2. Summary of the key challenge areas currently limiting the integration of AI into materials and manufacturing environments (left column) as well as the specific gaps and barriers which need to be addressed (right column)

Key Challenge Area		Gaps/Barriers
A	Need for greater flexibility, reliability, and trustworthiness of AI algorithms	Limited interpretability, uncertainty quantification (UQ), and trust in AI predictions
		Need for algorithms that adapt to varying levels of complexity, as related to small, heterogenous, multimodal, and/or incomplete datasets
		Need for artificial intelligence/machine learning (AI/ML) models to integrate physical mechanisms and expert knowledge
B	Experiments that are difficult to automate or make autonomous	Robot-friendly hardware and software interfaces are required for autonomous experimentation
		Most characterization tools use proprietary data formats
C	Lack of large-scale investments in AI for materials and materials processing/manufacturing innovations	Dedicated, sustainable, large-scale investments are required
		Materials research funding typically does not support AI-related components of materials research
		Funding opportunities typically separate AI from materials discovery and development
D	Lack of AI-related data infrastructure and best practices for capitalizing on such data	Revising existing manufacturing operations to capitalize on data collection to support AI methods is difficult
		Data needs to be collected in a format that is conducive to sharing and interoperability
		Lack of incentives for manufacturers to share data

RECOMMENDATIONS AND ACTION PLANS

At the heart of the report, you will find eight recommended priority action plans with detailed tasks. Importantly, the report includes discussions on how to implement the recommendations. These discussions are relevant to all sectors and aim to foster a tight link between industry, government, and academia. A section of the report called "AI Resources Associated with Industry" is specifically called out. We want to make sure industry is integral to the collaboration.

Diversity, equity, and inclusion opportunities are also addressed here. MSE has not been a diverse community historically but, looking forward, the budding new field of AI has the potential to include individuals and communities who have not traditionally been represented in MSE. We want to be proactive to ensure we make this new branch of materials science extend to everyone.

OUTCOMES

TMS has completed science and technology accelerator studies in the past, with reports being available to freely download at www.tms.org/studies. Built on this template, the AI report will help develop new initiatives, such as webinars, short courses, specialty conferences, workshops, consortia, and additional studies. It also will enable the coordination of groups with complimentary interests.

Follow-up activities will further stimulate the impact of this science and technology accelerator report to continue moving the needle on leveraging the great potential of AI in materials and manufacturing innovations. TMS will continue to monitor and support the study and its related initiatives.

LONG-TERM VISION

AI pervades surprising areas of daily life and it is quickly extending to MSE. The lead study team perceives that in 10 years there will be a substantial sea change in the implementation of AI-based methods, such as machine-learning, data science, and computer vision. AI-based tools will become commonplace in MSE, from the classroom to the factory floor.

AI has immense potential not just *in* materials science but *specifically* in materials science. I encourage you all to download the report and spend time reviewing the recommendations and action plans. *Employing Artificial Intelligence to Accelerate Development and Implementation of Materials and Manufacturing Innovations* is an accessible and timely tool designed to help our community to fully understand and realize this potential.

Editor's Note: *This article is based on a presentation that Elizabeth Holm gave at the inaugural World Congress on Artificial Intelligence in Materials and Manufacturing on April 5, 2022.*