

2023 Peer Review Final Report

August 2024

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Letter From the Director

Dear Colleagues,

The peer review was held before I came on board as director. I am thankful that the peer reviewers were able to come in and provide feedback to the Advanced Materials and Manufacturing Technologies Office (AMMTO), a new office built on a strong historical foundation. The draft peer review report has been very helpful to me as I've been working with the office to develop and implement our path forward.

Like the peer review panel, I am “impressed by the breadth and depth of AMMTO programs, enthusiasm and knowledge of staff, and quality of technology projects presented.”

What intrigues and inspires me about AMMTO is our place in the greater innovation ecosystem; we work hand in hand with industry, academia, the national laboratories, and across the federal government. The research, development, and demonstration we do in AMMTO helps catalyze follow-on investments and larger pilot demonstrations supported by other offices. In other words, AMMTO is the incubator of research, development, demonstration, and deployment that serves as the launchpad to commercialization and deployment on a greater scale.

AMMTO increases our impact through our interagency work. We represent DOE on the National Science and Technology Council Subcommittee on Advanced Manufacturing and helped to shape the National Strategy for Advanced Manufacturing that is guiding work across the interagency. AMMTO directly collaborates with other agencies including the Department of Commerce (DOC), the Department of Defense (DOD), the National Science Foundation (NSF), the Environmental Protection Agency (EPA), and the Department of Interior (DOI) to chart the course for topics including large castings and forgings, smart manufacturing, microelectronics, critical materials, materials and products circularity, advanced materials, and battery manufacturing.

We are uniquely positioned to serve as this connector because we've been laying the groundwork for decades. And now we are at a critical juncture to accelerate our clean energy future with these innovative technologies. We are better equipped than ever before because of the investments we've made. I am very pleased that the peer review panel recognized the importance of AMMTO's role in innovation ecosystems and had some good suggestions on how we can position ourselves to catalyze more impact by inspiring our consortia and national labs.

I am also very interested in strengthening AMMTO's ability to look ahead and anticipate national needs, sharpening our strategic approach, as suggested by the panel.

We have several upcoming initiatives and activities that are responsive to the peer review panel's comments.

We are preparing to issue technology strategies and roadmaps on topics such as smart manufacturing, microelectronics, power electronics, critical materials, circular economy, and education and workforce development, among other areas critical to clean energy manufacturing. These reports will help us sharpen our technical approach and improve our communications regarding our direction.

We are preparing to host a stakeholder listening session in the fall. At this meeting, we plan to work on strengthening relationships across our innovation ecosystem through our consortia and broader portfolio to learn from one another and work together on a path forward.

We are developing a set of messaging for the office that capitalizes on the universality of our mission as we prepare to navigate coming years. This will help us productively collaborate across our diverse innovation ecosystems.

I would like to thank the peer reviewers for their hard work and supportive, constructive comments. I look forward to crossing paths with each of them in coming years.

Sincerely,

Christopher Saldaña
Director, AMMTO

Authors

The review panelists included:

(Panel Chair) Barbara Kenny, Consultant and Former Program Director, National Science Foundation

Eric Forsythe, Associate Director for Management Resources, National Institute of Standards and Technology CHIPS Office

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Jeremy Mehta, Advanced Materials and Manufacturing Technologies Office.

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List of Acronyms

AMMTO	Advanced Materials and Manufacturing Technologies Office
BOTTLE	Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment
CABLE	Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and thermal applications
CESMII	Clean Energy Smart Manufacturing Innovation Institute
CFTF	Carbon Fiber Technology Facility
CMI Hub	Critical Materials Innovation Hub
CyManII	Cybersecurity Manufacturing Innovation Institute
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
FOA	Funding Opportunity Announcement
IACMI	Institute for Advanced Composites Manufacturing Innovation
IEDO	Industrial Efficiency and Decarbonization Office
LEEP	Lab-Embedded Entrepreneurship Program
MDF	Manufacturing Demonstration Facility
NASA	National Aeronautics and Space Administration
ORNL	Oak Ridge National Laboratory
R&D	Research and development
SEED	Students for Energy and Entrepreneurial Development

Executive Summary

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) requires each of its programs to conduct periodic peer reviews to enhance EERE program planning. May 16–18, 2023, the EERE Advanced Materials and Manufacturing Technologies Office (AMMTO) held an in-person peer review of its program activities in which an independent panel of experts provided AMMTO with feedback on how well the new office's programs align with its overarching goals and mission statement, identified possible course correction, and shared information. This review marks AMMTO's first in-person peer review since the Advanced Manufacturing Office evolved into AMMTO and the Industrial Decarbonization and Efficiency Office.

A review at this stage allows the office to ensure that its portfolio is aligned with the overall EERE mission, the direction of industry, and the needs of the United States as a global manufacturing player. EERE sought detailed recommendations from the review panel to support the early development of the new office.

Overall, the team was impressed by the breadth and depth of AMMTO programs, enthusiasm and knowledge of staff, and quality of technology projects presented (both in posters and via presentations). A detailed summary of observations, findings, impact, and recommendations is contained in the following report. At a high level, recommendations to AMMTO from the review panel included the following.

AMMTO's collaborations and interaction with industry and academia are exciting and should continue. However, serving the needs of industry (serving) while also engaging in novel and new research (leading) requires an intentional and thoughtful allocation of resources to achieve the right balance.

The office's work results in economic benefits to the country, including strengthening the position of the United States as a global manufacturer; this should be emphasized along with the anticipated beneficial climate impact.

AMMTO could more specifically address the topics of diversity, equity, and inclusion and energy justice, perhaps within the broader efforts of stakeholder and community engagement.

Regarding the logistics of the peer review, additional roundtable sessions and information on posters and presentations in advance of the review would assist the reviewers' planning process and provide a better forum for knowledge sharing.

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1 Background

The Advanced Materials and Manufacturing Technologies Office (AMMTO) held a peer review May 16–18, 2023, the office’s first since its establishment in October 2022, when the Efficiency and Renewable Energy Office’s (EERE) Advanced Manufacturing Office reformed into AMMTO and the Industrial Efficiency and Decarbonization Office (IEDO).

AMMTO’s current portfolio is spread over many subprograms, topic areas, and activities made up of a combination of programs and activities established in the previous Advanced Manufacturing Office structure as well as new or renewed activities established in the AMMTO mission statement.

Table 1. AMMTO Funding Portfolio

Office or Subprogram	Fiscal Year 2023 Enacted ^a
Next-Generation Materials and Processes	\$90,000,000
Advanced Manufacturing Processes and Systems	\$64,500,000
High-Performance Materials	\$25,500,000
Secure and Sustainable Materials	\$40,000,000
Critical Materials	\$26,000,000
Circular Economies Technologies	\$14,000,000
Energy Technology Manufacturing and Workforce	\$53,500,000
Energy Conversion and Storage Manufacturing	\$20,500,000
Semiconductors, Electronics, and Other Technology Manufacturing	\$15,500,000
Entrepreneurial Ecosystems and Advanced Manufacturing Workforce	\$17,500,000
AMMTO Total	\$183,500,000

^a This table shows the **estimated** enacted funding for Fiscal Year 2023 by office, program, and subprogram. Additional information on the organization of subprograms can be found online.¹

This report was compiled based on feedback from the industry, academic, and federal experts who made up the AMMTO review panel (see the list of authors).

1.1 Purpose

AMMTO supports the research, development, and validation of next-generation materials and manufacturing technologies needed to increase U.S. industrial competitiveness and drive economywide decarbonization. As a recently organized office, it is vital for AMMTO’s research development and funding to align with the diverse, evolving needs of industry, academia, and the national laboratories in pursuit of that purpose. AMMTO intends to use this peer review report to guide engagement with industry and the public to ensure that its development goals and leadership efforts stay congruent with the needs of the private sector.

¹ Advanced Materials and Manufacturing Technologies Office. 2023. “AMMTO Programs.” U.S. Department of Energy. Accessed Aug. 11, 2023. <https://www.energy.gov/eere/ammto/ammto-programs>.

The future of both the nation and the world is dependent on manufacturing and energy. AMMTO is adapting its portfolio to “meet the moment” and best serve the nation to fulfill its commitment to national leadership in support of a globally competitive U.S. manufacturing sector that accelerates the adoption of innovative materials and manufacturing technologies to create a clean, decarbonized economy. Collaboration is essential to achieve these goals, and input and expertise from all manufacturing sectors are needed for this endeavor to succeed.

Feedback from the review panel, summarized in this peer review report, will be used to refine, adjust, strengthen, and solidify AMMTO’s identity and role in advanced manufacturing and the federal government.

1.2 Structure of the Review

This peer review was held over a three-day period. An initial plenary session by leadership on the roles and identities of both AMMTO and IEDO was given on the first day. While they are now two separate offices, both evolved from the Advanced Manufacturing Office to best support American manufacturing and steer industry towards improved energy efficiency and decarbonization. The review’s schedule included presentations and talks by technical managers on their overall portfolios, followed by poster sessions dedicated to specific research projects. The days were divided by subprogram—see the high-level schedule (Figure 1).

Tue, May 16		Wed, May 17		Thu, May 18	
Secure and Sustainable Materials	Joint Plenary Event	Next Generation Materials and Processes	Digital Manufacturing	Energy Technologies and Manufacturing Workforce	Semiconductors & Power Electronics
	Lunch		Posters with Lunch		Energy Conversion & Storage Part 1
	Critical Materials		Advanced Materials and Processes		Posters with Lunch
	Circular Economy		Poster Session		Energy Conversion & Storage Part 2
	Poster Session		Reception		Workforce Development & Entrepreneurship
					Poster Session
				Innovation Ecosystems and Stakeholder Engagement	

Figure 1. The peer review schedule

AMMTO invited the review panel to ask questions following each talk and meet with poster presenters during dedicated sessions. The review panel has had access to all presented material to facilitate writing of this report, and all presentation material is available to the public.²

² Advanced Materials and Manufacturing Technologies Office. 2023. “AMMTO Peer Reviews.” U.S. Department of Energy. Accessed Aug. 11, 2023. <https://www.energy.gov/eere/ammto/ammto-peer-reviews>.

Review panel feedback is organized in order of presentations, as indicated by the high-level schedule. A summary of the rationale for each subheader and topic precedes each section. For each section, the reviewers state their general observations, their technical findings related to each topic area, the perceived impact of these portfolio sections, and their recommendations for changes and the future direction of the portfolio.

2 Programmatic Methods for Funding and Execution

2.1 The Office's Role Moving Forward

AMMTO must clearly define its role as a leader in the United States' shift to a carbon-neutral society, aligning with national goals and setting the direction for specific technological goals to feed innovation ecosystems. How can AMMTO best utilize an investment of millions to impact industries worth hundreds of billions, and how can AMMTO balance the necessary *push* for technology with the *pull* of the needs of industry?

2.1.1 Observations

AMMTO has a breadth of programs and topics that focus on rapidly accelerating domestic production and manufacturing of clean energy technology while drastically reducing carbon emissions. The review panel was impressed with AMMTO's overall trajectory, as well as the staff's enthusiasm, and saw a powerful message in the linked efforts of both the AMMTO and IEDO offices.

2.1.2 Findings

The programs related to carbon-neutral economies are technically sound and provided strong impact statements. Technical program activities clearly address the intended impact, and their research results are well aligned. The programs related to carbon-neutral economies have clearly defined material goals and align with AMMTO's mission.

The technical programs in decarbonization synthesize specific program results to demonstrate the programs' overall success and impact on the global mission. The program results are typically at a research scale. At times, the presentations would benefit from additional details or qualifiers for the aggregate metric of success. For example, the metric of success in decarbonization implied that the research is already at full scale.

2.1.3 Impact

Securing the domestic supply chains for clean energy is vital. Each AMMTO program has a clear impact on the carbon-neutral economy mission. The presentations demonstrated a strong understanding of the subject and included a vision for small and medium-sized businesses. They addressed industry goals in the context of advancing economy-wide decarbonization and increasing U.S. manufacturing competitiveness in

the long term. These goals align with those of other agencies and present an opportunity for investment coordination.

2.1.4 Recommendations

Programs like decarbonization deal with both critical technical challenges and business-related (or economically driven) challenges. AMMTO should place a greater emphasis on these non-technical challenges.

To make a greater impact, AMMTO's presentations would benefit from a clearer distinction between the big-picture problem AMMTO is trying to resolve (e.g., reducing energy consumption in computation) and the part of that problem a specific program is addressing. These programs need to address the results of AMMTO's scaling up for manufacturing to reach its decarbonization goals, and their results should shape AMMTO's next steps. This could include conducting additional research relevant to the program and AMMTO mission, transitioning to a scaled-up DOE portfolio or helping industry investment or private equity take the next steps in a scale up to manufacturing transitioning from DOE investments.

Presentations need a clear funding scale, and the projected impacts need to be consistent with each program's scope. Their conclusions should be able to be scaled to achieve the long-term AMMTO goal, avoiding the implication that the programs only require minimal funding to meet the global objective.

Additionally, the programs would benefit from requirement statements from large-scale industries stakeholders. What drives internal costs with industry, economists, and the U.S. Department of Commerce's internal teams as stakeholders? How can development in advanced manufacturing for the clean energy sector address the nation's important competitive drives compared to those of our economic competitors?

IEDO wants to reduce emissions while AMMTO wants to increase manufacturing capability. Presenting AMMTO and IEDO as having intertwined missions is a helpful way to frame their work and coordinate between them.

Additionally, AMMTO needs to define its mission more clearly. Is its goal to develop low- and zero-emission manufacturing of new materials needed for a carbon-neutral society? Or is it to reduce the carbon footprint of manufacturing in general? It seems both should be represented in its presentations and programs.

2.2 Comments on Consortia

AMMTO could leverage the success of its partner institutes and national laboratories. For example, PowerAmerica's success in translating advancements in technology to job creation could be expanded to other institutes and national laboratories.

2.2.1 Observations

DOE has established several Institutes and issued funding opportunity announcements (FOAs) solely for national laboratories to develop technologies and help collaborative

research and clean energy transition. This review highlighted the DOE Manufacturing USA Institutes, presenting them as critical portfolio contributions. Observations on six of the institutes and centers are as follows.

Manufacturing Demonstration Facility

The Manufacturing Demonstration Facility (MDF) has a good model for transitioning to clean energy and turning the resulting industry impact into a valuable return on investment to Oak Ridge National Laboratory (ORNL). Its facility and digital advances are well-organized. Additionally, MDF's partnership with the University of Maine seemed advantageous and well-coordinated.

Institute for Advanced Composites Manufacturing Innovation

The Institute for Advanced Composites Manufacturing Innovation (IACMI) partners with MDF at ORNL. IACMI has a strong membership and workforce and provides internships through its facility. Notably, this facility allows industry to de-risk before scaleup. IACMI has a certification training program from Utah for technicians, funded by the U.S. Department of Defense.

Carbon Fiber Technology Facility

The Carbon Fiber Technology Facility (CFTF) presented a strong vision and impacts and leverages data science in its work. CFTF partners with IACMI and transfers processes seamlessly back and forth. CFTF would benefit from a \$5-million-per-year investment in a facility to enable precursor-to-part validation studies to develop detailed material characterization and process control standards for industry partners.

Critical Materials Innovation Hub

The Critical Materials Innovation Hub (CMI Hub) has been making significant contributions to the community and represents a strong portion of the DOE portfolio. For some technology segments, it is worth explicitly stating what critical materials are relevant to the technology segments.

Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment Consortium

The Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment (BOTTLE™) Consortium has limited involvement with subject matter experts and features limited projects engaged with industry. It has no fee for membership, meaning more limited funding, which may limit its ability to share information and its broader impacts.

PowerAmerica Institute

The PowerAmerica Institute is the AMMTO institute focused on wide bandgap semiconductors and the adoption of critical materials, such as silicon carbide and gallium nitride power electronics.

2.2.2 Findings

AMMTO should find ways to integrate the Institutes and consortia more strongly to advance its mission, or instead use Next-Generation Materials and Processes' (NGMP) approach, in which a single consortium covers a broader space with different execution tactics. Both approaches have merit. There are multiple approaches for the consortium to share roadmaps, investments, and membership while remaining an independent operation. In this way, AMMTO should align technical advancement challenges with industry needs.

National laboratories as an engine of discovery are an important part of the innovation ecosystem. AMMTO should build on their capability for technology translation and workforce development. Students for Energy and Entrepreneurial Development (SEED) and Lab-Embedded Entrepreneurship Program (LEEP) are excellent examples. The Clean Energy Smart Manufacturing Innovation Institute (CESMII) is doing a lot, but the benefits are only shared with member institutions. Even for small to medium-sized enterprises, membership is relatively expensive (\$20,000–\$50,000) and may not be feasible. CESMII needs to find innovative solutions, incentives, and an added budget for subject matter experts.

2.2.3 Impact

PowerAmerica's demonstration of translating research results to job creation is very impressive, especially in bringing back manufacturing to the United States. Additionally, the MDF at ORNL has demonstrated over \$20:\$1 validated historical return on AMMTO investment. National laboratories are a golden opportunity to transition technologies toward industry-engaged efforts and challenges with scaleup, and investments from AMMTO in programs like LEEP and PowerAmerica have led to great improvements in the manufacturing workforce. Continuing to support such initiatives will strengthen these impacts.

2.2.4 Recommendations

AMMTO must consider the implications of the DOE Manufacturing USA institutes being too close to and too driven by industry versus the type of transformations needed for industry to meet clean energy and environment needs. The institutes must design these new manufacturing efforts to be flexible as technology continues to evolve.

Our national laboratory system has considerable resources and forms a bridge between academia and industry that could be leveraged further. DOE is a natural choice to lead a national strategy that other agencies could tie into, especially given the opportunity for reducing industrial emissions. In particular, the circular economy is an obvious leadership area for DOE. AMMTO should strategically think about the Institutes' areas of focus based on DOE leadership and climate change priorities and make sure they evolve over time so new silos aren't constructed.

Many potential collaboration spaces exist between CESMII and MDF. For instance, MDF could function as a maker of space for the Institutes that require specific additive instruments.

2.3 Comments on Funding Opportunities

Funding limitations are a well-known constraint in the field of research and development (R&D). There must be a funding balance between large and small projects. Bureaucracy burdens may limit bidders, but a catch-all FOA could help fill gaps unaddressed by technology managers.

2.3.1 Observations

Presentations from individual projects, institutes, and national laboratories illustrate the impressive breadth and depth of AMMTO-funded activities. Most key energy and environmental challenges have been covered under the various AMMTO portfolios, even though some gaps exist.

2.3.2 Findings

AMMTO programs have the opportunity to clarify or actively develop strategies to integrate basic research roadmaps with their work and develop procedures to align with transition programs to higher technological readiness levels and manufacturing readiness levels.

For institutes like Reducing EMbodied-energy And Decreasing Emissions, DOE could reconsider the distribution of types of projects. These investments should not be too driven by existing industry needs, which may need to evolve to fit AMMTO's clean energy goals.

It is great that AMMTO and DOE leadership have the initiative to develop innovation ecosystems and stakeholder engagement. Industry should be one of the most important of these stakeholders, in addition to government agencies and nonprofits. AMMTO should embed circular design and circular economy in its approach.

2.3.3 Impact

AMMTO should take a clear lesson from the project portfolios it has funded: its involvement lasts long after an invention is completed. If a project loses its technological leadership too early, it will be more expensive and difficult to transition to manufacturing and job creation. AMMTO should include a mechanism in its program structures to account for this.

2.3.4 Recommendations

Overall Recommendations

DOE should invest in parallel solutions to tackle clean energy challenges from multiple angles at once. For instance, DOE focuses on lithium-ion batteries for energy storage and gives very little funding for alternatives. DOE should also consider programs that incentivize universities and community colleges to partner with small to medium-sized enterprises via Fraunhofer-type arrangements or other European avenues.

From Industry Pain Points to Funding Opportunity Announcements

DOE should leverage its contacts in industry to identify their pain points and translate them back to basic and applied research opportunities. Cross-validation with industry is also important, and DOE needs to facilitate low-fidelity prototyping. Technologies that can reduce supply chain risk are critical and need more emphasis as well. Industry has a strong need to facilitate a path to manufacturing, especially by designing manufacturing to be more modular and trying to anticipate needs and flexibility to support future innovations.

Manufacturer Exchange

As part of developing innovation ecosystems, it may be very beneficial to establish a national or even international manufacturer exchange to facilitate the finding and capability exhibition of various suppliers and act as an information-knowledge ecosystem.

Catch-All Funding Opportunity Announcements and Quick Exploration Grants

There are considerable gaps between manufacturing (e.g., EERE) and the basic research supported by DOE Basic Energy Sciences, the National Science Foundation, Army Research Office, Air Force Office of Scientific Research, and Office of Naval Research, even including the Advanced Research Projects Agency—Energy. DOE should issue open or catch-all FOAs to pick up excellent ideas and technologies that do not fit the existing FOA topics and encourage the development of 5- and 10-year roadmaps aimed at de-risking transformative technologies like the current Defense Advanced Research Projects Agency's Disruptioneering Program.

Project and Institute Continuation

Ideally, after three years, a project will be successful and either a Small Business Innovation Research grant, a DOE commercialization grant, or an industry partner will fund and continue it. The reality is that only a very small fraction of research projects will be completed within three years, and most of them don't have sufficient results or maturity for the next step.

Funding mechanisms should have the flexibility to be reviewed frequently to course-correct and add or subtract resources as necessary to effect any changes in direction. For example, an overall 10-year commitment should have real checkpoints each year where substantive changes can be made and 3-year evaluations that help the program evolve. Metrics and analysis to decide on the success, continuation, or sunset of a project must be established and implemented moving forward.

Balancing Individual Projects and Institutes

DOE should maintain a healthy balance between individual proposals (i.e., projects) and large Institutes. Many innovations and breakthroughs come out of individual projects, and such funding should be maintained.

Paper Reduction Act

Current EERE proposals and review processes are some of the most burdensome amongst all federal organizations, demanding the most pages when all the required files are being added together. EERE should shorten the required proposal pages by half, for example by removing the statement of project objectives from proposal submission requirements until after award reward negotiation. Bureaucracy reduction will help achieve EERE's vision and mission in a timely fashion.

2.4 Comments on Flexibility and Endurance

AMMTO's mission and vision statements are focused on the priorities of the current administration. It must design programs and offices to be robust enough to survive inevitable administration changes and shifting priorities.

2.4.1 Observations

The presentations relayed by Deputy Secretary David Turk show that AMMTO is focused on current administration priorities. AMMTO understands the impact and importance of the manufacturing industry (generating over 1 million jobs and representing 11 percent of U.S. GDP), reshoring efforts via Made in America, and clean and sustainable manufacturing (with 1/3 of current carbon emissions coming from the manufacturing sector).

2.4.2 Findings

AMMTO has taken on the current administration priorities related to clean and sustainable manufacturing. For example, AMMTO is participating in power electronics roadmapping efforts to meet administration goals to lower greenhouse gas emissions. And, of course, the reviewers observed many Institutes and initiatives that are aligned with meeting administration goals.

2.4.3 Impact

The impact that DOE, and AMMTO in particular, can make on clean and sustainable manufacturing for the United States is immense. This is essential for the vibrant economy of the country and the health and wellbeing of our planet. AMMTO can be an exemplar for DOE and serve as the lead organization in this effort, bringing a variety of government agencies, industries, nonprofits, academia, and communities together around this critical topic.

2.4.4 Recommendations

AMMTO must make concerted efforts to develop strategies that will minimize or eliminate risks stemming from a future administration's goals shifting away from advances in clean and sustainable manufacturing. AMMTO and DOE should explicitly take on this topic not only for the upcoming year but for the foreseeable future. It is essential to structure programs to survive administration changes and maintain relevancy. The review panel has recommendations to these ends:

- Bring thought leaders together across agencies and make this topic a priority, not only environmentally, but economically.
- Engage with the public to foster an understanding of the many benefits of clean energy and advanced manufacturing. Bipartisan support will help maintain AMMTO priorities through administration changes.
- Consider the scope and naming conventions of current offices and new project areas and develop a liaison role to Congress.

3 Engagement

3.1 Comments on developing innovation ecosystems

The projects and programs at AMMTO are not operating in a vacuum. It is necessary to develop and consider the entire innovation ecosystem and all stakeholders—both with other government agencies and industry—to drive large scale adoption and change.

3.1.1 Observations

DOE is driving extensive and important research across all technology readiness levels for materials and manufacturing. Much of this work is highly relevant for meeting near-term climate goals and the transition to clean energy. It will be important for AMMTO to establish its own identity and demonstrate how new materials can be moved forward more effectively in development. There remains a significant need for new materials alongside the challenge of bringing them into use. Overall, technology presentations were very impressive with a good focus on efficiency and environmental stability.

While DOE had a number of exploratory efforts, only a handful were considered transformational. AMMTO could be leveraged to expedite transition and adoption of new technology. Collaboration is lacking within DOE and with national laboratories, federal agencies, and small- to medium-sized enterprises.

3.1.2 Findings

Collaboration between federal agencies and the greater community (including academia and industry) is needed. International partnerships are also critical to solving global problems. The national laboratory system is an obvious starting place for leadership, given their resources and workforce skill sets.

3.1.3 Impact

The impact of these current innovation ecosystems is limited to creative support rather than comprehensive development. This contrasts with other countries that pick up and develop technology. Cross-validation is necessary and helps build connective tissue (e.g., people and resources) to develop a robust translational pathway from discovery to development to manufacturing. Strong connections could be formed with National Science Foundation Small Business IR or Division of Translational Impacts.

3.1.4 Recommendations

AMMTO must take immediate action to assess what mechanisms need to be put in place for partnering with federal agencies. Currently, this process is not clear and takes considerable effort due to lack of resources and organizational structure. The review committee has the following recommendations:

- Federal agencies need to incentive collaborations with the use of additional joint requests for proposals and prizes.
- Increasing the speed and ease of developing partnerships between agencies and external stakeholders (e.g., through funding incentives) will increase the flow of ideas.
- AMMTO should develop a network of innovators, such as the network of universities already connected with their communities, to share best practices.³

3.2 Comments on partnerships

Partnerships and collaboration with stakeholders in industry, government, and the greater manufacturing community are key to generating maximum impact from technology research developments.

3.2.1 Observations

Deputy Secretary Turk placed high importance on partnerships—specifically community partnerships (e.g., environmental groups and labor groups)—for whom funding is a major barrier. He emphasized being intentional and intensive through the Office of State and Community Energy Programs. Public-private partnerships were described in several AMMTO programs and funding mechanisms (e.g., roll-to-roll, Manufacturing USA institutes, MDF, participation in the Federal Strategy on Advanced Manufacturing, and interagency partnerships like the U.S. Department of Defense, National Institute of Science and Technology, National Science Foundation, and the U.S. departments of Labor and Education), and collaborations with industry. Beyond R&D, several workforce development, science, technology, engineering, and mathematics (STEM) education, and diversity, equity, and inclusion initiatives also rely heavily on partnerships.

3.2.2 Findings

The impact of current partnerships is substantial and is part of nearly every funding program.

3.2.3 Impact

Partnerships are key to the Institutes and to AMMTO's endeavors. The community benefits plan that is mandated with competitive grants is a great strength. AMMTO

³ The White House, "Readout of the White House Forum on Campus and Community-Scale Climate Change Solutions," March 15, 2023, <https://www.whitehouse.gov/ostp/news-updates/2023/03/15/readout-of-the-white-house-forum-on-campus-and-community-scale-climate-change-solutions/>.

should continue this trend by educating communities at the grassroots and federal level to ensure that local communities have a stake in these partnerships.

3.2.4 Recommendations

While many partnerships already exist, the review committee noted that there is room to deepen partnerships. In some places, it was unclear how developed partnerships are, specifically with NSF. The review committee has the following recommendations:

- Look for partnership beyond that of agency leadership; connecting at the program level will also be beneficial.
- Engage in cybersecurity/smart manufacturing partnerships with the U.S. Department of Homeland Security (DHS).
- Consider other agencies' priorities and mission needs, such as the Office of Science (developing U.S.-based jobs), DOD, NIST, and the National Aeronautics and Space Administration (NASA). There are opportunities for synergy and collaboration without competition or overlap.
- Continue to engage in collaborations with the private sector to ensure that the focus on industry pain points is relevant.
- Continue to engage rural communities and historically black colleges and universities (HBCUs). There may be ways to engage directly with community members holding positions in local government focusing on work specific to climate and sustainability.

4 Technical Innovations

4.1 Critical Materials

Critical materials have been gaining traction and public notice under the new administration and with the global shift towards decarbonization, but there are still many gaps in understanding and defining critical materials and the role they will play in Industry 4.0.⁴

4.1.1 Observations

The presentations on critical materials demonstrated a strong understanding and vision for secure and sustainable materials. It would be very valuable to further refine the message to align funding levels and specific parts of the roadmap gaps being addressed. AMMTO should align funding scope and technical scope and define how they fit into its larger vision.

⁴ [Industry 4.0](#) represents the next stage in the evolution of industry; integrating the Internet of Things, artificial intelligence (AI) and machine learning, digital threads, cloud computing, data analytics, and other novel smart manufacturing innovations.

4.1.2 Findings

There are substantial gaps in upstream and mid-stream research in the United States. For some technology segments, it is important to be explicit regarding the critical materials that are relevant to the technology segments. Education and workforce development is needed for critical materials, especially for upstream and mid-stream technologies. AMMTO may also need to increase R&D funding for individual projects beyond CMI Hub activities.

The Ames Lab presented on a novel aluminum-cerium and metal matrix for dry storage nuclear fuel (powder extruded powders) and power train cylinder liner (casting). Strong technical results and perspectives for future technical challenges. The program presented next steps to transition critical materials.

4.1.3 Impact

Critical materials R&D is essential to achieve the goals of securing domestic supply chains, advancing economy-wide decarbonization, and increasing U.S. manufacturing competitiveness.

4.1.4 Recommendations

It may be worthwhile to take a more holistic, system-level approach to critical materials solutions. For instance, wind turbines usually fail through gearboxes, but in the process, the rare-earth generators are scarified. More durable gearboxes will help wind turbines last longer and make more use of the rare-earth magnets. Wind turbines should also be designed with periodic and intentional replacement of the gearboxes to extend the life of the entire turbines. Examples can be found in jet engine and gas turbine blade replacement and refurbishment, extending their service life significantly. Can similar approaches be developed for clean energy systems such as wind turbines and electrical motors that currently use substantial amount of the heavy rare-earth elements? Similar approaches may be considered for other critical materials as well.

DOE should expand the multipronged approach to overcome the challenges associated with critical materials. It should release more FOAs or FOA topics on alternative solutions as well. For instance, even though rare-earth-magnet-free induction motors are currently less efficient and bulkier, more R&D may be warranted to improve their performances as well as to find applications in less critical systems to free up rare-earth elements for more essential applications.

4.2 Circular Economy

Developing a robust circular economy is essential to achieving the goals of increased manufacturing efficiency while still following through on goals to reduce carbon emissions.

4.2.1 Observations

Circular economy is a critical area of focus on a national and international basis, and AMMTO is well positioned to deliver on it.

4.2.2 Findings

AMMTO is aware of key issues, but more efforts are needed in implementing transformational ideas that will take us from a linear to a circular approach.

4.2.3 Impact

AMMTO should provide more effort at the earliest stages of research translation, with a focus on low-fidelity prototyping guided by solving an overall problem (e.g., reducing industrial emissions) by real out-of-the-box thinking, rather than maintaining a current model that is not working. To achieve long-term climate impacts, AMMTO needs transformative thinking and entirely new ways of operating, followed by tying these new methods into established industry partnership and other translational pathways. Areas where manufacturing is being rerouted back to the United States are an opportunity to “leapfrog” to new, cleaner, more efficient manufacturing technologies that are modular and allow for flexibility in innovation moving forward.

Too many industries get caught in slowing innovation due to sunk capital costs that no longer suit innovative new manufacturing approaches. There are benefits to designing the system to be circular, modular, and flexible in nature. There are also clear opportunities for AMMTO to adjust priorities for long-term impact by embedding circular economy into their approach. AMMTO can amplify engagement with and influence on the innovation ecosystem by leading all aspects of the circular economy and joining materials and manufacturing innovation.

4.2.4 Recommendations

While AMMTO needs to facilitate a path to manufacturing, innovators can help design manufacturing to be more modular and try to anticipate needs and flexibility to support future innovations.

AMMTO should increase collaboration with fundamental research initiatives at National Science Foundation that can transform how we design and produce materials to bring more new materials into use. Specifically, it should be active in any National Science Foundation workshops and convenings and make a stronger connection with critical materials efforts at National Science Foundation, which are growing and leading to international initiatives. AMMTO should play an active role in the circular economy interagency working group and international activities to tie their resources to this effort, especially given the overall opportunity for reducing industrial emissions that is needed in the very near term. AMMTO should also bring together the key stakeholders in a convergence-accelerator-style ideation workshop that drills down on specific deliverables in a 3-year time frame within the context of a 10-year vision for achieving a circular economy. This should be continually reviewed and tailored to projects (e.g., exploratory, transformational) so that real progress can be achieved over time.

4.3 Digital Manufacturing

Digitization is a major technology being driven by Industry 4.0. U.S. manufacturing is lagging behind most of its global competitors in this field. Digital manufacturing plays a role in almost all AMMTO projects and is essential to advancing manufacturing.

4.3.1 Observations

Digital manufacturing is a focus of many of the initiatives and Institutes aligned with AMMTO. Even when not the primary focus, this topic is woven into many of AMMTO's efforts.

4.3.2 Findings

MDF and their University of Maine projects continue to demonstrate a strong portfolio of collaboration. It is very logical to see CESMII and Digital Manufacturing and Cybersecurity Institute collaborations presented to keep funding and institutional identities separate.

The budget priorities in this area were unclear despite digital manufacturing being cited as a priority by many groups. AMMTO's strategic plan and vision should flesh this out to present to Congress in 2024.

4.3.3 Impact

Digital manufacturing is a topic of national importance and impacts the nation's ability to remain competitive globally. It is imperative that the entire U.S. manufacturing ecosystem vibrantly participates in the international marketplace.

4.3.4 Recommendations

Given our nation's insufficient adoption and application of smart manufacturing, there may be more opportunities for Institutes to focus on digital programs. These programs should coordinate roadmaps within the same ecosystem to provide more than one view. The review committee has the following recommendations:

- Pursue collaboration across other agencies (e.g., the American Society of Mechanical Engineers, Society of Manufacturing Engineers, Institute of Industrial and Systems Engineers, National Institute of Standards and Technology) on technical challenges.
- Work to increase access for small- to medium-sized enterprises to participate; progress, adoption, and standards should not be exclusive to a single institution. CESMII is a powerful Institute but has limited access due to membership fees.
- With opportunities presented by MDF, work across federal agencies and lead the change to push the United States into the digital age of Industry 4.0.

- Communicate and prioritize going digital with other federal agencies. Cross-agency collaborations could make a more wholistic systems-oriented approach (and including tax incentives would be a helpful bonus).

4.4 Advanced Materials and Processes

The NGMP programs focus on digital manufacturing, advanced processes, and high-performance materials. The program portfolio emphasizes technology and resource development for smart and cybersecure manufacturing and high-performance computing for manufacturing. The program seeks to strengthen and expand existing advanced materials and processes, while also strengthening integration between CESMII, the Cybersecurity Manufacturing Innovation Institute (CyManII), and DOE lab programs. These goals will support advances in clean energy transition and economy-wide decarbonization, manufacturing competitiveness and domestic production of clean energy technologies, and workforce development. The program will realize the goals through specific, targeted FOAs, laboratory-directed funding, prize-based competitions, and Small Business Innovation Research programs.

4.4.1 Observations

DOE laboratory and manufacturing innovation Institute consortia (IACMI, CFTF, CyManII, CESMII, and MDF) were presented as collaborative models and distinct technology lanes. Advanced materials and processes demonstrate strong leadership and vision for the development portfolio. The consortia appear to share roadmaps and investment funding but not membership. There appear to be opportunities for additional collaboration between institutes and other consortia.

4.4.2 Findings

Next-Generation Materials and Processes

This program does a good job demonstrating broad milestones and results, like energy savings by program, giving an interesting top-level perspective of their impact.

Manufacturing Demonstration Facility

DOE designated user facilities focused on performing early-stage research and development to improve energy and material efficiency and productivity, with a major focus on additive manufacturing. The MDF program brings a unique combination of analysis tools and simulations to industry-contributed additive manufacturing tools. The program has established strong metrics-based results that should be leveraged in other public-private partnerships. While parallel DOE programs, such as CESMII, were mentioned, the links between them could be strengthened.

Shear Assisted Processing and Extrusion

This process focuses on tooling and demonstrating new materials. It has interesting scaling prototyping of low-volume production and space to recycle scrap at the Pacific Northwest National Laboratory facility to create end products.

Institute for Advanced Composites Manufacturing Innovation

This institute presented a robust facility, strong membership, and infrastructure for workforce internships. IACMI partners with MDF at ORNL. MDF is a facility where industry can de-risk before scale up. IACMI has a certification training program from Utah for technicians (U.S. Department of Defense funding).

Carbon Fiber Technology Facility

This is DOE's designated carbon fiber innovation user facility for identifying high-potential, low-cost raw materials, including textile, lignin, polymer, and hydrocarbon-based precursors. It presented strong vision and impacts.

Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and thermal applications

Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and thermal applications (CABLE) works to fulfill DOE energy reduction and electrification missions by using copper and composite materials to enhance conductor cable performance. DOE research investments can be found in low-cost superconductor cables, analysis around cooling costs, and analysis of commercialization barriers.

Advanced Bearing Materials for Harsh Service Conditions

This program shows strong technical results and perspectives for future technical challenges. It has strong leveraging from partners, total cost versus number of partners, and long-term partnerships.

Metal Oxide Coating Protection for Bearings

This is a good program that engages small business and has an interesting mix of laboratories and business investments in its portfolio.

Machine-Learning-Enhanced Graded Materials

This program had a good technical presentation, applicable to both DOE's and NGMP's mission.

4.4.3 Impact

Each of these programs represents a strong contribution to the DOE goals and overall portfolio of programs. The programs had strong presentations demonstrating broad milestones, deliverables, and impacts such as overall energy saved by the entire program or by specific projects. This type of impact metric is a good practice to articulate technical results back to the DOE mission. These programs have collaborative models and distinct technology lanes already in place.

4.4.4 Recommendations

Presentations on technical progress would be strengthened if they all described the challenges to achieving commercialization. Often, these challenges are both technical and business-related. For small-scale projects in particular, it is important to understand next steps, potential additional funding, or any necessary elements outside their scope, like establishing industry standards or increasing a critical supply chain need.

AMMTO must address existing technology gaps. While there has been significant investment in batteries and material for semiconductor devices, there hasn't been enough investment in power electronic systems, including but not limited to charging technologies or circuit topologies. For advanced materials, this might include important materials and integrated circuit substrates, such epi-p-type silicon carbide wafers.

4.5 Semiconductors and Power Electronics

The current administration has pushed for the development of semiconductors and related technologies to maintain competitiveness with the international manufacturing market and to help secure the U.S. supply chain.

4.5.1 Observations

DOE's prior investment in power electronics and semiconductors include PowerAmerica, which has shown a great impact in advancing the next generation of wide-bandgap semiconductors. DOE's 2023 budget includes a \$15.5 million investment in semiconductors, electronics, and other technology manufacturing.

4.5.2 Findings

PowerAmerica has made a significant contribution in bringing manufacturing back to the United States and will be reviewed for a possible renewal. In addition, a roadmap for power electronics for clean energy will be launched.

4.5.3 Impact

Power electronics are vital for economy-wide electrification for decarbonization. The impact of advanced power electronics includes reducing the weight and cost of ownership, as well as enabling faster charging of electric vehicles. Enhancing the efficiency and performance of wind and solar energy conversion systems are other key impacts through advanced power electronics devices, circuits, and systems.

PowerAmerica's executive director presented an example of taking a leading technological innovation and keeping the manufacturing of it in the United States. This represents another important impact of PowerAmerica: translating research results to domestic job creation.

For microelectronics, an analysis and research summary would be especially important.

4.5.4 Recommendations

AMMTO needs to build an innovation ecosystem to ensure that the technology transition is not lost and is translated to direct job creation in high-tech manufacturing. Roadmapping is an excellent opportunity to create networks of stakeholders. This type of investment is valuable and continuing to fund these initiatives is very advantageous.

AMMTO needs to create 5- and 10-or-more-year roadmaps and de-risk transformative technologies, even if the industry isn't flagging them. Power electronics and microelectronics research roadmapping needs to coordinate with other players such as the U.S. Department of Defense, NASA, and National Institute of Standards and Technology. Anything having to do with electrical transmission or distribution should be coordinated with DOE and the Office of Electricity.

AMMTO should provide a technology-segment-specific perspective for materials challenges and ongoing research. For example, AMMTO can work with microelectronics industry groups to examine materials relevant to the full supply chain (e.g., materials in semiconductors and per- and polyfluoroalkyl substances, stainless steel for chambers, pump oil, ceramics, ultra-high-purity and surface properties). AMMTO should be explicit about what materials are relevant to each technology segment. Sometimes decision makers are not intimately familiar with essential materials deep inside the supply chain. For microelectronics, in particular, an analysis and research summary would be especially important.

4.6 Energy conversion and storage

The current administration has made a great effort to develop energy storage technologies to sustain U.S. competitiveness with the international manufacturing market and secure the U.S. supply chain.

4.6.1 Observations

AMMTO has made significant prior investments in energy conversion and storage, through FOAs and lab calls in collaboration with the Office of Electricity and the Vehicle Technology Office to accelerate manufacturability for the next generation of lithium-ion and flow batteries. AMMTO's budget for 2023 includes a \$34 million investment in energy conversion and storage.

4.6.2 Findings

AMMTO demonstrates leadership in manufacturing and supply chains through programs, such as Energy Storage Grand Challenge and Long Duration Storage Shot, as well as the Federal Consortium on Advanced Batteries. AMMTO plans to continue investing in lithium-ion battery manufacturing, flow battery manufacturing, and solid-state lithium battery manufacturing.

4.6.3 Impact

AMMTO funding has led to innovative manufacturing processes to enable flow batteries with unmatched capital costs, roll-to-roll manufacturing of metallic electrodes and

bipolar plates for flow batteries, metal chelate flow battery system manufacturing, and continuous flow synthesis of low-cost and long-lifetime aqueous organic flow battery reactants.

4.6.4 Recommendations

AMMTO needs a roadmap of how to move from a cell level to a modular and package level. Parameters and performance metrics differ widely across these stages, but most current efforts only present the cell-level data, which in many cases might not be the best figure of merit when scaling up is needed.

A clear and advantageous collaboration between energy storage experts and power electronics experts could lead to significant impacts. Power electronics experts can help energy storage experts manufacture larger-scale energy storage units suitable for mobile and stationary systems, as scaling up has more to do with power management and system balancing than pure chemistry and technological advancements.

4.7 Technology gaps

The current AMMTO portfolio covers a large range of programs and topics. There is some parallel work happening in certain thrust areas that could benefit from increased collaboration.

4.7.1 Observations

The scope of AMMTO's current programs is impressive, from rapidly accelerating domestic production and manufacturing of clean energy technology to drastically reducing carbon emissions. Some of AMMTO's activities take place within the same technical spaces, particularly between national laboratory investments and extramural programs and consortia.

4.7.2 Findings

AMMTO observed that there are different approaches for the same thrust areas, which are supported based on a balance across a variety of key technical challenges and available opportunities.

4.7.3 Impact

Overall, the presentations showcased the AMMTO organization extremely well, laying out a technical impact for the office, demonstrating a broad portfolio of activities, and showing how and why these portfolios are critical to realizing AMMTO's goals.

4.7.4 Recommendations

It may be useful to include a funding table across different technology efforts, demonstrating the amount of support for each technology. Furthermore, a table that shows the type of mechanism to support different technology efforts would also be useful.

PowerAmerica has been successful in advancing wide bandgap semiconductors; however, it needs to revolutionize the manufacturing of circuits and systems.

Another revolution in power electronics is needed to comprehensively address electro-thermal co-design, co-optimization, and co-packaging to demonstrate and enable new manufacturing methods, which would require significant investment.

AMMTO should gather the many varied programs and initiatives according to focus area for a more targeted look at how each area is covered and where there may be gaps or collaboration opportunities.

5 Workforce Development

A complication to all manufacturing technologies and fields is the lack of skilled workforce, a problem that has only been increasing with the growing speed of technology development. AMMTO has begun to partake in a variety of workforce development programs and is doing notable work to incorporate this into the innovation ecosystem.

5.1 Workforce Development

Education and workforce development is a core element in AMMTO's mission to foster a robust future of advanced manufacturing in the energy economy.

5.1.1 Observations

AMMTO has an impressive and broad-reaching array of workforce development programs in place. The review team heard briefings about CESMII's range of smart manufacturing workforce development programs, the Oak Ridge Institute for Science Education internship programs, the Battery Workforce Initiative, efforts to engage historically Black colleges and universities, and LEEP.

5.1.2 Findings

AMMTO's entrepreneurship programs, SEED and LEEP, are particularly noteworthy and help develop innovation ecosystems around advanced manufacturing technologies. Along those lines, PowerAmerica, one of the manufacturing institutes supported by AMMTO, was impressive in its ability to transfer its technology development in silicon carbide and gallium nitride to keep manufacturing jobs within the United States, and its workforce development program played a role in that successful transfer. CESMII also has an impressive portfolio of workforce development programs: its efforts to partner with historically Black colleges and universities to develop ideas for senior design projects is a good approach to diversifying the engineering workforce of the future. AMMTO is also partnering with other agencies (e.g., the U.S. Department of Defense, National Institute of Standards and Technology, National Science Foundation, U.S. Department of Education, U.S. Department of Labor, Economic Development Administration) to boost complementary programming and reduce duplicative efforts. One excellent example of this is the partnership with U.S. Department of Labor and other stakeholders on the Battery Workforce Initiative.

5.1.3 Impact

Workforce development is a key component of successful technology development and translation to societal benefit. The broad array of AMMTO programs impacts every part of the pipeline, from K–12 efforts to university to continuing education for current employees, all of which help to facilitate technology and economic advancements. One example are the entrepreneurial programs SEED and LEEP, which are effective for workforce development and are part of the overall effort to develop innovation ecosystems.

5.1.4 Recommendations

Based on the presentations and discussions with AMMTO personnel and presenters, the reviewers have the following recommendations:

- AMMTO should develop a theme to understand cultural workforce differences between globally leading nations to identify best practices to train workers. Workforce development programs in general (not just within DOE) have a blind spot when it comes to the cultural differences between the U.S. workforce and our economic competitors. In understanding these differences, AMMTO has an opportunity to augment domestic working habits that could boost productivity. Other government agencies have expertise which may be relevant to this effort, such as the U.S. Department of Commerce and the U.S. Department of State.
- The manufacturing institutes' workforce development efforts may be missing smaller companies that lack the resources to join the Institutes as members. Could more incentives be offered for training and progress to small- to medium-sized enterprises, such as partnership programs with universities and community colleges?
- AMMTO and IEDO should coordinate between their workforce development programs. It was not clear from the presentations how workforce development efforts are split between the two organizations.
- AMMTO should continue efforts to form partnerships to advance STEM education, particularly with National Science Foundation, National Institute of Standards and Technology, U.S. Department of Defense, U.S. Department of Education, etc. It should encourage partnerships at the program officer level and develop opportunities for program officers from various agencies with a common interest to work together. Additionally, AMMTO could consider working with the Department of State to develop programs for immigrants to receive training in manufacturing areas with worker shortages. This could bolster the manufacturing workforce while reducing the economic burden on communities supporting families without jobs.

- It would be useful to develop a database of all AMMTO's and IEDO's educational efforts that could be shared with others. This could include the effort to develop a database of historically Black colleges and universities and their research interests, which would be shared with larger universities and companies looking to form partnerships. Also, AMMTO should emphasize its efforts to establish certificate or credentialing programs, or gaps where these efforts are needed.
- AMMTO should consider including factory workers in its efforts to generate creative solutions to manufacturing problems and workforce training needs.

6 Stakeholder Engagement

Involving all stakeholders at all levels of the community, especially those in historically underrepresented and rural areas, is essential to developing a robust manufacturing ecosystem that includes the skilled workforce necessary for the transition to Industry 4.0.

6.1.1 Observations

AMMTO's presentations showed a significant interest in learning about and developing innovation ecosystems around clean energy manufacturing technology. Innovation ecosystems require the interaction of stakeholders, and thus, AMMTO personnel are also interested in identifying and engaging the right people, organizations, and stakeholders in the ecosystem(s) they want to develop.

6.1.2 Findings

There is clear interest in the community in AMMTO and IEDO technology areas, as judged by the overwhelming attendance at the review meeting. AMMTO has identified stakeholders and established partnerships in several areas, including partnering with the U.S. Department of Labor to develop a workforce for battery manufacturing and joining other agencies for technology roadmapping efforts. IEDO has a full-time science communicator; it may be useful for AMMTO to have a similar role to focus on communications with stakeholders. It is important to increase national visibility and make the case for the importance of the mission to the public, along with how DOE is contributing to the solutions.

6.1.3 Impact

Identifying and interacting with the right stakeholders is important for the ultimate success of the AMMTO mission to create technologies for zero-carbon manufacturing. In the words of one reviewer, "It is great that AMMTO and DOE leadership have the initiative to develop innovation ecosystems and stakeholder engagement."

6.1.4 Recommendations

Manufacturing USA has a natural cross-agency network through which DOE could broaden its message to other agencies and stakeholders. For example, the Manufacturing USA network would benefit from developing a broad stakeholder mission

and vision across the manufacturing development landscape. DOE leadership could then present such a vision to a broader set of stakeholders to include agencies like the U.S. Department of Commerce and the National Institute of Standards and Technology. AMMTO could integrate other areas in DOE into a cross-agency strategy through this broad perspective.

With efforts like the Office of State and Community Energy Programs, AMMTO is engaging local communities to achieve net-zero goals. The reviewers encourage AMMTO to expand its efforts with the following suggestions.

- It may be useful to revisit the industry/ government/ academia ecosystem language to include specific references to local communities (e.g., industry, government, and academia).
- AMMTO should incorporate a competitive, economic motivation into its messaging of climate responsibility to make its urgency and necessity resonate more broadly with the public.
- AMMTO should look for partnership opportunities with local communities such as in workforce training programs at local community colleges. Local community government may have a dedicated, funded position to explore climate resiliency solutions for the community and that is a perfect person with whom to begin conversations.
- AMMTO should also consider looking for opportunities to explicitly engage rural communities, potentially as an energy justice vision. For instance, some rural areas still have distribution voltage at 4160 volts, which is insufficient to sustain a set of people charging their electric vehicles and equipment. Other AMMTO technology areas could specifically benefit a rural audience, such as 3D printing for fast, local, and low-cost production of farm equipment parts.
- AMMTO should consider partnering with social scientists (e.g., the National Science Foundation Directorate for Social and Behavioral and Economic Sciences) to support efforts that require people to change their behaviors in addition to adopting new technologies. One example of this is the plastics industry (e.g., water bottles) where there could be a reduction in overall use rather than just recycling or reuse. Finland's Manufacturing Performance Days (occurring every other year) are an excellent example of fostering collaboration among stakeholders and workforce development.

7 Open Discussion, Additional Thoughts, and Addendum

7.1 General Meeting Presentations, Posters, Operations

The joint review meeting of AMMTO and IEDO attracted over 400 attendees, many more than originally expected. This demonstrates a large interest in the important work of the two offices. The venue was crowded due to this unexpectedly large number of attendees, but the staff managed well, and the sessions generally ran on time and on schedule.

7.1.1 Findings

Overall, the team was impressed by the breadth and depth of programs, enthusiasm and knowledge of staff, and quality of technology projects presented (both in posters and via presentations). Topics included technical impact for the office, the portfolio of activities, and how and why these portfolios are critical to realize the organizations' goals. The balance of presentations between technical deep-dives and higher-level overviews appeared to be about right.

7.1.2 Impact

In addition to gaining formal feedback from a review team, this meeting offered many important informal opportunities for networking between attendees and between government program officers from different agencies. Though hard to quantify, these informal connections are extremely important. The meeting also offered an opportunity for AMMTO to hone its messaging and reflect on its structure and goals as it developed the agenda and presentations for the meeting.

7.1.3 Recommendations

With so many attendees, a lot of wisdom in the room was not formally captured. AMMTO should create a structured roundtable session, with one reviewer and one note-taker per roundtable and an overall session organizer with a series of discussion questions and a time limit for each discussion. These discussions would inform reviewers' impressions as they integrate information from the review to write the report, and the raw data from the discussions would be captured by the note takers at each table. Both attendees' and AMMTO staff's experiences would be valuable to capture in these discussions.

Although most presentations focused on giving general overviews of the projects, in some cases providing specific technical accomplishments is more useful in understanding their impact. Such details could be included as an appendix for review purposes, if possible.

The topics of diversity, equity, and inclusion, as well as energy justice could be more specifically addressed, perhaps within the broader topics of stakeholder or community engagement.

The reviewers appreciated the poster sessions, especially as they were organized by program portfolios (matching the portfolio of presentations received that day) because they offered an opportunity for a deeper technical dive into the topics and one-on-one discussions with knowledgeable researchers. However, in the future AMMTO should provide a list of poster presentations as part of its reviewer packet so that reviewers can plan their schedule accordingly. It would also be helpful to inform attendees if a particular topic will be delivered via poster, poster plus presentation, or only presentation, and the selection criteria for how topics will be delivered.

More AMMTO presentations should begin with a clearer distinction between the big-picture problem AMMTO is trying to resolve (e.g., reducing energy consumption in computation) and why, and then what part of the problem a specific program or portfolio is addressing. They should also address why that part of the problem was chosen as an investment focus, as well as the size of the investment. Finally, presentations should review results or anticipated results and their economic and climate impact.

It would be helpful to have a chart of various funding mechanisms for AMMTO programs showing which mechanisms are used for which programs. This graphic would give insight into the balance of funding mechanisms across the organization (e.g., is one mechanism over-used or under-used?).

It would also be helpful to plan one or two executive sessions of about 30 minutes, in which the review panel can meet privately and discuss findings. The day-before meeting and the day-after, informal wrap-up were helpful, as was the remote attendance option.

It is important to make sure the reviewers are in the loop for venue, meeting registration, and schedule notifications and updates, especially reviewers from out of state who have to make hotel and plane reservations. The reviewers were unaware of the day-before and day-after meetings until the week before the event, and thus, some were not able to participate.

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