U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE

2023 IEDO Peer Review Report

July 2024

Disclaimer

Letter From the Director

Dear colleagues,

On behalf of the U.S. Department of Energy (DOE) Industrial Efficiency and Decarbonization Office (IEDO), we are pleased to share the report from our 2023 peer review. Peer review provides us with invaluable insight into our office strategy and program direction from a diverse group of external thought leaders. The findings and actionable recommendations from peer review inform our decision making and help us maintain a constant state of evolution and growth.

We hosted the 2023 peer review in May, notably the first peer review since the inception of IEDO (stemming from the reorganization of the former Advanced Manufacturing Office [AMO]). As the debut of our office—and the redefined mission, vision, and strategic blueprint that came with it—this peer review marked an important milestone in our origin story. It was the first opportunity to unveil our ambitious plans for leveraging targeted research, development, and technical assistance as an answer to U.S. industrial emissions. As such, we asked reviewers to evaluate our strategic direction for the future, drawing from the foundation of projects and analysis initiated under AMO.

The thoughtful, well-crafted recommendations enclosed speak to the expertise of the reviewers, their devotion to understanding where we are as an office, and their commitment to helping us get where we want to go. We appreciate the dedication of the reviewers from preparation through conclusion of the report.

Overall, the reviewers found our vision to be compelling, well-defined, and most importantly, ready to act upon. The reviewers provided us with a wealth of suggestions for improvement, which we've carefully considered and, in many cases, have already begun to implement. We've summarized these recommendations and actions we are taking in the following sections.

Collaborating Across DOE and the Federal Government

Reviewers emphasized the need for IEDO to increase DOE and governmentwide collaboration to achieve deep decarbonization of the industrial sector. We have been increasing our activities across DOE and the entire federal government to overcome the key barriers to achieving a sustainable industrial sector. In the last year, IEDO helped launch and plays a leading role in two departmentwide, industrial programs to establish a unified industrial decarbonization strategy and maximize impact across the full innovation pipeline—from the inception of a promising idea in the lab to the commercialization and adoption of a transformative technology on the factory floor.

The first, Technologies for Industrial Emissions Reduction Development (TIEReD) Program[1] leverages the unique expertise of eight DOE offices working in the fundamental science and research and development (R&D) spaces to ensure that we're pursuing many different technical solutions in parallel. Recently through TIEReD, IEDO joined the Bioenergy, Advanced Materials and Manufacturing, and the Hydrogen and Fuel Cell technologies offices to assess low-carbon feedstocks. TIEReD also helped facilitate collaboration between IEDO and the Fossil Energy and Carbon Management Office and Hydrogen and Fuel Cell Technologies Office in IEDO's 2024 Energy-and-Emissions-Intensive Industries funding opportunities announcement.[2]

The second, the Industrial Technologies Joint Strategy Team,[3] works across DOE to bridge gaps between industrial research and development and large-scale demonstrations and deployment. IEDO subject matter experts have been instrumental in the analysis to inform department strategy and collaborations in energy-and-emission-intensive industries, such as chemicals, cement, and steel.

These coordination mechanisms are essential to helping to ensure that IEDO's technical expertise on industrial technologies—from both the research and commercial technical assistance lenses—are effectively utilized to guide DOE's broader investments in the systems that will enable industrial decarbonization.

In addition to these two programs, IEDO also co-led the development of the Industrial Heat Shot™ and Clean Fuels and Products Shot™.[4] These DOE Energy Earthshots™ initiatives establish ambitious industrial targets for DOE that address key challenges for the industrial sector.

IEDO also works regularly with government partners to gain broader perspective and expertise on challenges within the industrial sector. For example, IEDO collaborates closely with the U.S. Environmental Protection Agency (EPA) to share energy management information and resources to help manufacturers and other large energy users increase their efficiency and reduce emissions.

Additionally, IEDO also participates in three interagency working groups to increase collaboration on work at the nexus of energy, water, and agriculture. These working groups include representatives from the EPA, the U.S. Department of Agriculture,

---

[1] Advanced Manufacturing Office. 2023. *Decarbonizing America's Industrial Sector. U.S. Department of Energy*. Washington, D.C.: U.S. Department of Energy. DOE/EE-2702. https://www.energy.gov/eere/amo/articles/decarbonizing-americas-industrial-sector.
[2] Industrial Efficiency and Decarbonization Office. 2024. "IEDO FY24 Energy and Emissions Intensive Industries FOA." U.S. Department of Energy. Accessed May 2024. https://www.energy.gov/eere/iedo/iedo-fy24-energy-and-emissions-intensive-industries-foa.
[3] U.S. Department of Energy. 2023. "Industrial Technology Programs Across the U.S. Department of Energy." Industrial Technologies. Accessed May 2024. https://www.energy.gov/industrial-technologies/industrial-technology-programs-across-us-department-energy.
[4] U.S. Department of Energy. 2023. "Industrial Technologies Energy Earthshots™." Industrial Technologies. Accessed May 2024. https://www.energy.gov/industrial-technologies/industrial-technologies-energy-earthshotstm.

National Science Foundation, U.S. Department of Defense, and U.S. Department of the Interior. IEDO also collaborated with the U.S. Department of Agriculture to launch its Controlled Environment Agriculture accelerator[5] to develop new models for low-emission American agriculture.

Informing Strategy With Industry Analysis and Real-Time Project Evaluation

Reviewers highlighted the importance of continual, forward-looking, and comprehensive analysis and project evaluation to inform IEDO's strategy. This recommendation aligns closely with our strategic analysis priorities and active program management to help us plan for the future.

Our new framework shifts our analysis from a historic look back at the industrial sector and emissions data to one looking toward the industrial sector of the future. We recently launched an ambitious new effort[6] to identify cost-effective and industry-specific strategic pathways to achieve a thriving U.S. industrial sector with net-zero greenhouse gas emissions by 2050. In addition to assessing existing energy and emissions data and analyzing the challenges and opportunities for decarbonizing the current industrial sector, we're moving towards real-time analysis that will anticipate new and evolving opportunities and disruptors. This scenario planning for the future will help us remain agile and responsive to overcoming near-, medium- and long-term decarbonization barriers in a rapidly changing industry.

Identifying Economic and Non-Economic Factors that Influence Industry Decision Making

As suggested by the reviewers, our team is widening the lens we use to inform our strategy and evaluate current and future investment decisions. We are broadening our evaluation perspective to consider the entire industrial ecosystem, including the business principles that impact the commercial viability and adoption timeline for technologies. From our 2023 funding opportunity, we selected projects that incorporate collaborations with industry consortium to engage regional steel and chemicals manufacturers.

In addition to these critical business principles, we're also committed to understanding the industrial diversity across the United States. In our analysis and investment framework, we're considering the challenges and opportunities to commercializing industrial technologies that these regional differences present.

---

[5] Industrial Efficiency and Decarbonization Office. 2023. "Water, Energy, and the Future of Farming." U.S. Department of Energy. Posted Sept. 28, 2023. https://www.energy.gov/eere/iedo/articles/water-energy-and-future-farming.

[6] Industrial Efficiency and Decarbonization Office. 2023. "Industrial Decarbonization Pathways Modeling." U.S. Department of Energy. Accessed May 2024. https://www.energy.gov/eere/iedo/industrial-decarbonization-pathways-modeling.

Finally, we are exploring other factors that impact decision making and technology adoption across manufacturing facilities. IEDO is collaborating with the National Academies of Sciences, Engineering, and Medicine to establish a plan for incorporating interdisciplinary social sciences and behavioral research into our strategic planning and analysis.[7]

Investing in Incremental Change To Transform Industry

The reviewers also conveyed the need for us to incorporate incremental progress into our strategy to transform to a net-zero industrial sector by 2050. These incremental solutions are particularly effective for cost-effective technologies that can be incorporated into larger systems and industrial processes. We are investing in incremental investments that can reduce emissions and improve efficiency in the short-term, but will continue to be relevant in the future like improvements in recovery and use of waste heat, use of new materials in manufacturing processes or products like catalysts or supplementary cementing materials, and development of hydrogen and natural gas flexible technologies. However, given the aggressive pace and scale of a full industrial transformation, we are limiting our investments in interim solutions to remain focused on technologies or suites of technologies consistent with our emissions objectives. We are cautious about advancing technologies that may leave significant stranded capital assets in a near-zero industrial economy.

Creating a Culture of Connectivity and Bold Ideas

We are pleased that reviewers noted the expertise, passion, and professionalism of IEDO team members. Since IEDO's inception in October 2022, we have hired 38 new staff and five fellows, who each bring unique skillsets to IEDO, including our brand-new deputy director, Paul Gauche. As we continue to build our team, we are cultivating a culture of bold innovation and empowering team members to become change agents across DOE and the U.S. industrial sector more broadly. For example, in February 2024, we held our first "IdeaFest," an officewide initiative that provides a platform for IEDO team members to workshop new ideas with their peers.

Reviewers also highlighted the importance of charging IEDO team members with ownership of stakeholder outreach and relationship building. This aligns with our strategy to create more opportunities for our team to engage in meaningful two-way dialogue with manufacturers and other stakeholder groups across the sector. In 2023, we held eight stakeholder workshops, numerous industrial and academic site visits, and countless one-on-one stakeholder meetings.[8] We are committed to "on-the-ground" work with our stakeholders to better understand and support manufacturers as the

---

[7] Industrial Efficiency and Decarbonization Office. 2024. "Developing and Assessing Ideas for Social and Behavioral Research to Speed Efficient and Equitable Industrial Decarbonization." U.S. Department of Energy. Accessed May 2024. https://www.energy.gov/eere/iedo/events/developing-and-assessing-ideas-social-and-behavioral-research-speed-efficient-and.

[8] Industrial Efficiency and Decarbonization Office. 2024. "IEDO Past Events." U.S. Department of Energy. Accessed May 2024. https://www.energy.gov/eere/iedo/iedo-past-events.

industry evolves. As suggested by the reviewers, we are also considering implementing cross-office how-to-engage plans to help team members tailor their outreach strategy to specific stakeholder groups ranging from manufacturers of all sizes to academia to entrepreneurs and financiers.

To empower our staff, and accelerate our impact with our stakeholders, we are committed to process and operations improvements. We're particularly focused on developing creative strategies to reducing barriers for partners to have access to our resources, improving transparency of available opportunities and funding decisions, improving the accessibility of our programs to different kinds of organizations, and increasing the variety of mechanisms we have to accelerate how innovations can make their way into the market.

If you were able to attend our 2023 peer review, we want to thank you for devoting your time and energy to making our office stronger. If you were not able to attend, I encourage you to view the presentations and posters presented during the peer review on our website.[9]

Whether you are new to IEDO and our mission or we share a long history of collaboration, we want to work with you more in 2024 and beyond. Our partnerships with the communities we serve are invaluable to success. We are committed to working together to transform the industrial sector.

Sincerely,

Avi Shultz
Director of the Industrial Efficiency and Decarbonization Office

[9] Industrial Efficiency and Decarbonization Office. 2023. "2023 Peer Review Report and Materials." U.S. Department of Energy. Accessed May 2024. https://www.energy.gov/eere/iedo/2023-peer-review-report-and-materials.

Authors

The authors of this report are:

(Chair) Denise Swink, Independent Consultant

Catherine Collison, Energy Engineering Principal Consultant, The Chemours Company

Chendhil Periasamy, Vice President of Energy Transition, Air Liquide

Sarah Deslauriers, Vice President, Resilience & Sustainability Practice Director, Carollo Engineers

Michelle Pastel, Senior Manager, Manufacturing 4.0, Corning, Inc.

Lance Fountaine, Global Industry Consultant, Rockwell Automation

Neal Elliott, Director Emeritus, American Council for an Energy-Efficient Economy

Acknowledgments

The authors would like to acknowledge the valuable guidance and input provided during this report and the peer review meeting. The authors are grateful to the following list of contributors. Their feedback, guidance, and review proved invaluable.

Contributors:

Jack Holmes, Nexight Group

Karsten Daponte, Nexight Group

Magdalene Fogarasi, Nexight Group.

The authors would also like to acknowledge the peer review planning team for their efforts in organizing the event, including:

Felicia Lucci, Industrial Efficiency and Decarbonization Office

Jeremy Mehta, Advanced Materials and Manufacturing Technology Office

Karsten Daponte, Nexight Group

Magdalene Fogarasi, Nexight Group

Simone Hill-Lee, The Building People

Matherly Gainer, Industrial Efficiency and Decarbonization Office

Keith Jamison, Industrial Efficiency and Decarbonization Office.

Zachary Pritchard, Industrial Efficiency and Decarbonization Office

Ethan Rogers, Industrial Efficiency and Decarbonization Office

Ross Brindle, Nexight Group.

This report was prepared by Nexight Group for the U.S. Department of Energy's Industrial Efficiency and Decarbonization Office within the Office of Energy Efficiency and Renewable Energy.

List of Acronyms

AMO	Advanced Manufacturing Office
AMMTO	Advanced Materials and Manufacturing Technologies Office
APS	Adoption Plan
ASP	Applied Strategic Planning
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EPA	U.S. Environmental Protection Agency
FOA	Funding opportunity announcement
IP	Intellectual property
NAWI	National Alliance for Water Innovation
NOx	Nitric oxide and nitrogen dioxide
OSHA	Occupational Safety and Health Administration
PFAS	Per- and polyfluoroalkyl substances
RAPID	Rapid Advancement in Process Intensification Deployment
R&D	Research and development
TAWD	Technical Assistance and Workforce Development

Table of Contents

List of Figures

List of Tables

1 Prologue

In October 2022, the U.S. Department of Energy (DOE) Advanced Manufacturing Office (AMO) reorganized into the Industrial Efficiency and Decarbonization Office (IEDO) and the Advanced Materials and Manufacturing Technologies Office (AMMTO). This reorganization aimed to more effectively solve two distinct manufacturing challenges that will help the United States achieve its long-term goals—to decarbonize the industrial sector and to accelerate the manufacturing of clean energy technologies. The formation of IEDO and the development of its mission and vision was accomplished with strong reliance on analytics and strategic planning, including the release of the *Industrial Decarbonization Roadmap*, published in September 2022.[10] Recruiting and hiring for the new office was accelerated to meet IEDO's needs. The current project portfolio was managed to bring the previous organization's projects to a productive closure, build on the strengths of the program, and prioritize development of funding execution to lay the foundation for programs and portfolios supporting and accelerating the new organization's objectives.

The reviewers applaud the thoughtfulness of the new organizational leaders, who believed a peer review, which could provide feedback and comment on their reimagined program direction, would be timely and helpful to shift course and/or adjust current efforts.

In early spring 2023, AMO leaders compiled scoping documents on the goals, objectives, and timing of a program review. They placed major emphasis on "specific adjustments that could be made to our focus, priorities, and/or approaches that would increase our impact." The office recruited two external review panels relatively quickly, one each for the new offices, IEDO and AMMTO. The panels began organizing in April 2023 and the review was held in early May 2023. IEDO's Program Review Panel was given the following charging statement: "We are interested in your perspectives on the direction for the office and how best we can position ourselves to have the most impact on industrial efficiency and decarbonization, both now and into the future."

Given this background, it is very important to recognize that the focus of this peer review was on IEDO's mission, vision, and strategic direction for the future. The former AMO project portfolio was, in large part, winding down from the previous organization's research program investments. The IEDO panel was only briefed on projects from the previous program (in closure) and recently awarded projects by the new organization (just beginning), all of which were found to be amenable to the new organization's priorities and direction. The briefing placed substantial focus on the new programs' goals, structures, and implementation strategies. Short project briefs (supported by substantial backup documentation) were provided in a corollary fashion.

---

[10] U.S. Department of Energy. 2023. "DOE Industrial Decarbonization Roadmap." Industrial Technologies. Accessed May 2024. https://www.energy.gov/industrial-technologies/doe-industrial-decarbonization-roadmap.

Our panel agrees that this was an exciting and poignant time to be able to contribute to IEDO's new and very challenging endeavors. In the following peer review report, we describe how IEDO can extend and improve efforts already underway and where IEDO can most effectively focus on transforming how they do their business, thereby achieving their goals. IEDO's strategic vision appears well articulated. It is time to transform the business to achieve its vision and goals, raising all boats in the harbor.

We note that the seven IEDO panel members brought together enthusiasm, support, and broad/deep experience to this effort. They collected and prepared a tremendous amount of information, which was then culled and analyzed to create this report collegially. IEDO management orchestrated the collection of large amounts of background information, and Nexight staff provided overall support. Kudos to all!

2 Introduction

On May 16–18, 2023, the U.S. Department of Energy's (DOE) former Advanced Manufacturing Office (AMO) hosted the Advanced Materials and Manufacturing Technologies Office (AMMTO)–Industrial Efficiency and Decarbonization Office (IEDO) Joint Peer Review in Crystal City, Virginia, with over 400 participants from the breadth of its partnership communities. This is the review and recommendations report from the IEDO Program Review Panel. It is the result of four days of briefing and exchanges at the actual review meeting, as well as numerous virtual meetings and discussions pre- and post-review. The panel organized around five themes suggested by IEDO management: (1) organization and strategy, (2) technology innovation, (3) program balance, (4) communications and engagement, and (5) execution. Observations, key takeaways, impacts, and recommendations are highlighted for each. This resulted in a total of 20 recommendations.

In this section, the recommendations are summarized into two major categories: (1) organization, strategies, and implementation and (2) communication and outreach. A crosswalk to the original detailed content appears in Table 1, which relates the summaries to the detailed recommendations in our Section 3 Detailed Narrative of Recommendations. We strongly encourage you to read Section 3, as it is full of rich explanations and first-hand knowledge sharing.

The new industry required to achieve and sustain a zero-carbon goal must have transformative characteristics: resilience in operations, disruptions and expansion; continual performance improvements in agility and adaptability of products and services; integrated systems and operations throughout corporate organizations and structures; transparent supply chains integrated through macro-, meso-, and micro-levels; and flexible, self-learning workforces, equipment, technology and operations.

Ultimately, the review panel anticipates that IEDO, in addressing its recommendations, will have stronger impacts on broadening, deepening, and accelerating industry's decarbonization journey to achieve their goals.

2.1 Organization, Strategies, and Implementation

2.1.1 Applied Strategic Planning

The panel agreed that IEDO's efforts to strategically define industrial decarbonization opportunities are well done and should be extended. IEDO should continue refreshing and expanding sources and should include regional characterization capabilities—particularly regional and state timing of infrastructure availability and expansion (e.g., hydrogen and electricity supplies and delivery capabilities). IEDO should pursue further development of companion interim tandem and hybrid solutions before zero emission technology can be developed or installed. IEDO should target decarbonization of national priority green-field industries such as semiconductor chips, solar panels, batteries, and electric vehicle batteries. It should also seek to understand the difference in opportunities and challenges in grassroots versus AMO legacy development and deployment. Note that grassroots opportunities should include the influence of their product purchasing power on IEDO target industries. It would also be useful for IEDO to have a formal process and database to assess the potential and timing for disruptive technologies to become opportunities rather than challenges for IEDO's portfolio investments. Likewise, IEDO should give attention to opportunities to adopt low-hanging fruit in domestic and international locations. A how-to guide should be developed for funding opportunity announcement (FOA) managers referencing applications for exercising these applied strategic planning (ASP) resources in FOA development and solicitation reviews.

2.1.2 Leveraging

IEDO should catalogue and actively reference and use industry transformative best practices for agile innovation, execution and partnering models (e.g., getting decision makers involved as participants, training, certifications, partnering with Institutes to run solicitations, and broad team participation). We note that Technical Assistance and Workforce Development (TAWD), National Alliance for Water Innovation (NAWI), and Rapid Advancement in Process Intensification Deployment (RAPID) Institute certainly have offerings to leverage common use of approaches, systems, and personnel.

2.1.3 Portfolio Balance and Management

To be successful in achieving its goals, IEDO needs to more fully characterize portfolio projects to improve understanding and allow better management of program balance. Additional project characterizations should include business case, value proposition, risks assessment, project potential, adoption speed, adoption dependencies, partnerships, and technologies used. Scoring for breadth of impact and speed of adoption would be helpful, as well. It is important to tightly link this effort to the ASP framework. More specifically, this effort should be used to establish an "IEDO adoption timeline for impact. IEDO should maintain and annually update this impact timeline to develop a clearer picture of performance against the broader IEDO energy and decarbonization objectives.

2.1.4 Be Wise

The panel was commissioned to look for “blind spots” and “better approaches.” Importantly, some of the report’s recommendations center on the lack of IEDO’s awareness and/or attention to manufacturers’ challenges to adopting technologies. Regulations, resource availability, windows for updating and modernizing, workforce availability, etc. all represent active risks for interruptions in the 24/7 manufacturing operation environments, resulting in aversions to implementation for many potential partners. Although IEDO sponsors R&D, this new knowledge will be useless if any combination of these challenges makes the technology nonviable. It is thus imperative that IEDO takes a system-of-systems approach in developing impact assessment tools and guides (at the micro-, meso-, and macro-level interfaces), which are provided to IEDO program and project managers for pre-project and -technology investment assessments. IEDO should consider creating a template for an Adoption Plan (AP), which can be scaled for use from the program to the technology to the project level. The AP should be developed jointly with partners (e.g., companies, innovators, industry groups, project partners, and communities). It should pay attention to technology pipeline feeds, issues and resolutions, opportunities, and interconnections to be leveraged along the adoption journey for technologies or systems. APs could be used as a negotiation and documentation vehicle for exchange and support between AMMTO and IEDO. The APs could also be used to support technology-gap needs and assessments for DOE demonstration programs, expediting confirmation of needs and servicing of results.

Continuing the topic of the system-of-systems interfaces, IEDO has great opportunities throughout the industrial and manufacturing sector to initiate and implement its programs, projects, and activities via a reuse library containing insertable, “intelligent” building blocks of software and systems tools to minimize repeat funding for the same capabilities and help standardize an IEDO pool of capabilities. IEDO’s focus should be on incorporating fourth Industrial Revolution technologies to position U.S. industries to be globally competitive, safer, and sustainable in the long term.

2.1.5 Move Out

Innovate and expedite business processes by beginning design with the outcomes desired in relatively unconstrained environments then by working with government and partners to quickly execute new approaches in tune with priorities and needs for a successful set of programs and projects. Higher priorities for recruiting and hiring could be based on the private sector’s best-practice model of selecting new hires, making an offer within one week, and bringing them onboard within another two weeks. IEDO should also prime candidates for hiring and participating in solicitations.

Create a FOA model template that is used across IEDO to cultivate project portfolios, driving improvement in deployment readiness while helping partners get comfortable with a consistent type of IEDO request, thereby increasing their ease of future participation.

Build partnering/teaming structure opportunities that are flexible and agile to achieve programmatic needs. For example, self-governed, horizontal, vertical, circular, or cross-cutting teams with regional foci may be the most opportune approach to maximizing speed and effectiveness. In a similar vein, technology- or industry-specific roadmaps are good tools for R&D planning, as you have shown. However, cross-cutting and multisector teams will likely need agile and flexible project and program planning and management tools that can be quickly developed, modified, and deployed (e.g., hub developments for hydrogen distribution). They are more likely to get industry decision makers directly involved, too.

2.2 Communications and Outreach

IEDO needs to demonstrate its understanding that a new industry world order must evolve to achieve zero-carbon goals and that this will require unique journeys by all involved. Importantly, IEDO also needs to demonstrate that it can be a premier, reliable partner with industry members (and the entire system-of-systems that industry operates in) to help de-risk their journeys while achieving corporate goals. That means many IEDO performance metrics must not only reflect its role as purveyor of technology and expertise, but also demonstrate its role as a partner in its thinking, behavior, strategies, practices, partnerships, and co-investments.

IEDO's communications and outreach efforts and activities must be clearly and intentionally designed and implemented to avoid criticism of "dabbling" while establishing IEDO's image as a present and active partner (not just a participant) that can be relied upon to facilitate achieving common objectives. This requires targeted planning and management of opportunities and outcomes because the universe of connectivity in industrial and manufacturing relationships is vast, and IEDO must target their efforts to catalyze the strongest reverberations of the outcomes it precipitates. The following discussion highlights the panel's recommendations for executing and achieving that outcome.

2.2.1 Intentional Involvement

IEDO should create prioritized action plans for interagency, DOE-wide, and AMMTO–IEDO collaborations in achieving improved efficiencies and outcomes. These relationships should be shared broadly and deeply at the regional, state, local, and community levels—and certainly within IEDO. As appropriate, IEDO should create prioritized action plans with partners at all levels, too. It should develop an intentional system upfront to provide connections between and among these relationships and their desired outcomes.

Develop a how-to-engage document for different partners and/or communities (e.g., large, medium, and small industry companies; entrepreneurs and innovators; financiers; large, medium, and small academic institutions; state and local governments; nonprofit organizations) by using cross-IEDO teams to demonstrate understanding of partners' needs and personalizing services and connections in delivering programs. IEDO should develop companion how-to-engage outreach plans, delivered by cross-IEDO teams, capturing feedback through regular updates. Every IEDO employee should recognize,

understand, and demonstrate using these documents. In addition, clear linkages must be maintained with other action plans and ASP resources throughout IEDO.

2.2.2 Culture Change

Discussions of the expansion of TAWD's roles and responsibilities are included in the panel's recommendations. However, that expanded role goes together with a broadening of communications and outreach responsibilities for every IEDO staff member to be an ambassador for the office. We recommend that everyone, individually, be responsible for integration, communication, and outreach (both internally and externally) and consider expanding TAWD's functions, even raising them to a broadened level within DOE's Office of Energy Efficiency and Renewable Energy (EERE). The overall message is for IEDO to broaden communications and outreach responsibilities to everyone while expanding and developing TAWD's impressive, though sometimes unsuccessful, approach for industry engagement to a more focused, integrated approach linking with APs, how-to-engage plans, etc.

2.2.3 Informed Partnerships

Establish more intentional plans for how IEDO engages with industrial companies and manufacturing value chains, including nurturing existing relationships and building new ones. Understanding in greater detail the challenges associated with incorporating zero--greenhouse-gas-emitting solutions in each application will inform a program wide focus that transcends any specific project while allowing the unique requirements for successful adoption and deployment to be layered on top of the common denominator solution. A project portfolio should include a larger program focus and a multifaceted roadmap for success (maybe an ASP tool?).

IEDO should help de-risk emerging technology development by establishing pathways for partners to address regulatory compliance challenges; consider stakeholder-specific outreach and communication needs (including facilitating broader partnering opportunities); and seek to understand, communicate, and consider impacts of regulatory rulemakings on the success of IEDO's program goals and impacts.

2.3 Closing Summary Table

The recommendations in Section 2 are a synthesis of several distinct recommendations, which are explained in detail in Section 3 and distinctly annotated with recommendation number(s). Table 1 below cross references the detailed recommendations that comprise the high-level recommendations presented in this Section 2. We strongly encourage those interested in exploring a summarized Section 2 recommendation in more detail look up the relevant detailed Section 3 recommendation number(s) in the top row of Table 1 and explore their discussions in Section 3.

Table 1. Mapping of Macro-Level Recommendations to Micro-Level Recommendations

Recommendation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Applied Strategic Planning	x		x					x	x	x						x				
Leveraging	x				x	x						x				x	x			
Portfolio Balance and Management						x		x			x		x	x						
Be Wise		x			x	x					x		x							x
Move Out					x		x					x	x				x	x		x
Intentional Involvement					x		x				x	x			x	x			x	
Culture Change				x	x		x		x			x								
Informed Partnerships		x		x			x	x	x	x		x	x			x			x	

3 Detailed Narrative of Recommendations

3.1 Organization and Strategy

3.1.1 Further Incorporate Forward-looking Opportunities (Recommendation 1)

Observation

IEDO has performed extensive assessments of historical and current greenhouse gas emitters. Looking to the past provides important background information about what got us to the state of greenhouse gas emissions today, but what is missing is the forward-looking view.

Key Takeaways

Acting on historical data is effective if there is a subsequent assessment evaluating if these legacy industries and process technologies in use yesterday will continue to be present and utilized in the United States for the next 15 or more years.

Impact

Looking at historical data tells us about the past but does not tell us what the future holds, which could lead to investing in technological research and development (R&D) that, by the time it is complete, is no longer relevant.

Recommendation (Transformational)

In addition to the strategic assessments of historical and current greenhouse gas emitters, we suggest investments in strategic planning for: (1) future greenhouse gas-emitting industries so they can go in clean from the beginning when the capacity investment is made; (2) pending impacts of disruptor technologies; and (3) domestic and international easy-to-address opportunities. Here are our suggestions on how to get started.

There are growing industries and new industries coming to the United States. IEDO should look at what our federal and state governments are incentivizing to grow strategic industries for the United States (e.g., solar panel production and fabrication, semiconductor production, electric vehicle manufacturing, and suppliers) and evaluate how IEDO can enable these greenfield investments to contribute to our zero-greenhouse gas-emissions goal by 2050 as they are built. There is less inertia to overcome, and the cost to build green from the beginning is lower than expecting less-clean technology to be removed after investment and an additional capital investment to be made to achieve clean production. IEDO should explore what products and services these new industries could specify for the purpose of decarbonizing product life cycles, both self-generated and purchased from their supply chains.

Realizing no one has perfectly clear clairvoyance to forecast the future, do your best to understand near-term, mid-term, and long-term trends and potential disruptors. Assess how they might change what is being done today and what might be added in the future. Then assess how it would impact current initiatives underway in IEDO; if a disruptor were to occur, how would it impact your current development and investment roadmap? This is best examined as a group to get a broader perspective, build on each other's perspectives, and develop common understanding. Refresh your trends and disruptors map quarterly and when major events, disruptors, and trends emerge. Update your roadmap and priorities accordingly (see more information on *Scenario Planning* by Roch Parayre at The Sweeney Agency). Find simple opportunities to progress to the 2032 and 2050 objectives by seeking out early adopting local and international locations that are ahead of the average U.S. industry in reducing greenhouse gas emissions and using clean energy. A prime example of this is the onsite clean hydrogen generation from electrolysis, which is not in scope for IEDO today but is a technology currently being developed in the European Union.

3.1.2 Build Partnerships With Industry (Recommendation 2)

Observation

There is a saying in manufacturing that to really understand the problem and effectively design a solution, you must be present on the manufacturing floor. Despite our best

efforts to drive consistency in manufacturing, there are still differences between plants due to the diversity of processes, vintage of equipment used, actions carried out by different operators, and a plant's unique position within its value chain. The emissions data evaluated by IEDO is gathered and shared by the DOE Environmentally Extended Input-Output for Industrial Decarbonization Analysis tool, which is far removed from industry itself.

Key Takeaways

Today, it appears IEDO needs to gain a deeper level of understanding of how industries really operate, which leads to the level of emissions that appear in the data. It is unclear if IEDO understands the full breadth of change that will be required to reduce greenhouse gas emissions, which goes beyond just process technology innovation to technology implementation considerations.

Impact

Without the big-picture understanding of how manufacturing operates over time, what is required for the industry to make the change, and when it is practical for manufacturing facilities to implement the change in their processes, the actual time industry members would need to integrate the technology changes into their operations may not align with IEDO's timing assumptions, resulting in missed IEDO objectives for 2032 and 2050.

Recommendation (Transformational)

To further enable the adoption of your current and future investments, engage with operators to understand the realities of how the industry operates today and engage with industry members in operations and finance to understand what a workable solution would entail. Adding to the comments about ensuring that infrastructure is in place to enable the adoption of IEDO investments, we suggest increasing your understanding of when industry could adopt the new technologies IEDO is fostering. For example, manufacturing assets have a life expectancy, after which point the manufacturer will have to shut down production and make a capital investment to replace or rebuild the worn asset. Understanding the life expectancy of the offending assets will provide better estimates of the likelihood and timing of adoption to improve energy efficiency and greenhouse gas emissions.

3.1.3 One Size Does Not Fit All (Recommendation 3)

Observation

Strategic analysis did a great job of presenting how they are informing the pathway to decarbonization for 2050.

Key Takeaways

It was generally acknowledged that the United States industry is large and diverse in the solutions needed for each area. However, it will be necessary for strategic analysis to provide regional granularity by sector, fuel, resource, infrastructure, and regulatory considerations.

Impact

Regional location infrastructure and state and local government programs and regulatory specifics are not universal and may require different solutions and timing to be impactful and adoptable.

Recommendation (Continuous Improvement)

Strategic analysis should provide regional granularity to help inform the sector specific groups (e.g., the electric grid in Texas, predicted hydrogen availability in Appalachia), specifically with proposing solutions in electrification and low-carbon fuels and feedstocks. Additionally, the presentation on the steel industry did a great job in highlighting that the steel industry will be ready for a radical shift when their equipment gets to the end of its life. It would be good if this type of information was available for the other specific sectors to take into consideration (e.g., when to expect most industrial boilers to retire versus when electric grid infrastructure will expand in a region).

3.1.4 Bridge the Divide—Exponentially (Recommendation 4)

Observation

TAWD is IEDO's group focused on connecting the project outcomes with industry. Unlike its peer organizations in IEDO that are focused on applied R&D and technical de-risking, TAWD engages four steps down the road focused on accelerating adoption after DOE's Office of Clean Energy Demonstrations and Loan Programs Office further advance the maturity of the technology.

Key Takeaways

Industry's adoption of decarbonization mindsets and technologies will require many years of support to accomplish the transformation of industry, which consists of early adopters on the quickest end of the technology adoption curve as well as the laggers on the slowest end of this spectrum. TAWD's outreach funding will likely expire before IEDO's decarbonization goals are met.

Impact

The incorporation of IEDO's technology innovation into industry will be truncated if it does not support companies on technology implementation details, resulting in a reduced impact by IEDO's investments and the continued presence of the offending greenhouse gas emitters. Failure to address this issue will put our country's and IEDO's emissions-reduction goals at significant risk.

Recommendation (Transformational)

In order for TAWD's outreach function to meet industry's needs, it should be further centralized and organized within EERE or at a higher office in DOE to have longevity and represent the broad scope decarbonizing industries will require. None of the proposed transformations are easily dropped in without impacting the systems of systems at many levels that exist (materials, process, technologies, supply chains, etc.).

No two industries' decarbonizing journey will require the exact same changes. If TAWD's methodologies were expanded to represent all things required to achieve industrial efficiency and decarbonization, then partnering would become simpler for industry to engage. And the messaging would be consistent and require less piecing together by diverse industry members to build their roadmap from the building blocks produced by the government to assist them in their tailored decarbonizing journey. As an added benefit, raising workforce development and technical assistance to this level would require the groups within EERE to collaborate, forcing communication to identify the building blocks necessary to achieve our country's decarbonization goals and jointly outline the roadmaps for each step of the journey. This cross-organizational communication would highlight missing components and begin to drive collaborative portfolios within DOE and highlight dependencies to be addressed outside of DOE.

3.1.5 Leverage Industry-Transforming Wisdom (Recommendation 5)

Observation

IEDO's technology innovation approaches are not leveraging several points of wisdom already applied or being pursued by industry that accelerate the speed of business.

Key Takeaways

To be competitive in the global market, industries must be willing to change. This requires continuously improving, abandoning obsolete practices, and becoming more agile to remain relevant in the ever-changing global markets and supply chains.

Impact

DOE's technology readiness level (TRL) stages are lengthy and do not leverage agile methodologies now employed by the technology industries, effectively slowing innovation and the rate of achieving its targeted impact. IEDO's technical projects are also not incorporating smart manufacturing approaches and technologies into their solutions, positioning the U.S. industry to be uncompetitive in the global marketplace with legacy systems and methodologies.

Recommendation (Transformational)

Build awareness of the practices leveraged by IEDO that are disconnected from transformative best practices the most successful industries use that you serve. Work with your leadership to build a plan for change that provides IEDO and the industries its working to transform, with impact for the effort in the following ways:

- There are capabilities and tools that will be used on multiple projects, such as physics-based modeling, machine learning, hybrid modeling, software, advanced analytics, sensing technologies, advanced controls, and computational platforms and environments. Unless the IEDO project aims to specifically build one of these cross-cutting tools and capabilities for reuse, we suggest providing a framework for cross-cutting capabilities and specifications to be used on each project so that less of IEDO's funds are spent on recreating things that already

exist and, rather, provide the advancement of core capabilities already in place while accomplishing the project's primary objective. These frameworks and specifications would be informed by staff networks that meet quarterly with the objective of sharing knowledge, tools, challenges, and jointly agreeing on a roadmap for future development. Reuse is a best practice in software development and has been adopted by smart manufacturing to enable rapid development and deployment, cost-efficient sustainment, and lower cost through economies of scale.

- Consider building a function, perhaps at the EERE level or higher, whose responsibility is to provide overarching technology-independent best practices. Infuse this new organization, and thus IEDO and its peers, with transformative organizational leaders and successful industry innovators whose business survival has been dependent on speed and agility. Incorporate leading-edge software product developers and smart manufacturing transformation leaders to develop an agile reusable framework to be leveraged across EERE's technology innovations projects to reduce spend on one-off software solutions, disparate models, and siloed systems to increase speed of development, and deployment; and lower cost of systems entering the marketplace for deployment.
- Build wisdom in your operations, technology development, and adoption, concentrating on acceleration types of efforts. Generate technology, systems, and data to develop and deploy flexible, self-healing systems built in from the start. Employ modernization strategies in all technology and systems plans (e.g., few or no disruptions for insertion, real-time adjustment for excursions or changes in product specifications) while simultaneously optimizing performance. Integrate and learn across programs in both operating and technical areas, such as modularity, teaming arrangements, integrating systems, and models.

3.1.6 Setting the Table (Recommendation 6)

Observation

During the IEDO peer review strategy presentations, it was evident that extensive analysis occurs on past greenhouse gas emissions sources and potential decarbonizing technology assessments to inform and align with the industrial decarbonization pillars and roadmap. It was also evident that IEDO's programs leverage and inform the strategy outputs while driving deeper into the specific technologies for the DOE targeted industries. However, it appears there is a need to extend the strategy, program, and project approaches to include some critical best practices important in the manufacturing industry in project management, portfolio management, and IEDO office strategy.

Key Takeaways

There is a wealth of program and project planning and execution knowledge and experience in IEDO, EERE, DOE, and throughout the U.S. government and associated project execution supply chain. As expected, IEDO's role in technology innovation is mapped against the government standard TRLs and the program and project management processes communicate and assess the TRLs' relevant areas. IEDO assesses emissions data by industry sector seeking the largest greenhouse gas- and carbon-emitting offenders and pinpoints the root cause. It then develops roadmaps and project calls aimed at eliminating the source on a timeline to meet IEDO's carbon-elimination goal by 2050.

Impact

IEDO project investments are at risk of achieving impact. Although commercialization is outside of IEDO's scope, IEDO must incorporate commercial-industry-driving principles into its programs, project assessments, and processes to improve probability of acceptance and adoption of its technology innovation investments.

Recommendation (Continuous Improvement)

Achieving industry adoption and deployment of the greenhouse gas- and carbon-elimination technologies requires IEDO to extend its program and project management practices to include essential commercial related principles, such as business case, value proposition, impact on products produced and process performance, regulation and tax barriers, access to robust equipment (e.g., presence of supply chain, intellectual property necessary to practice), to name a few. Incorporating industries' business principles into IEDO's internal strategy development, portfolio management, and project call deliverables will allow IEDO to better understand and meet the needs of the targeted industry, increasing the likelihood of each investment contributing to the achievement of IEDO objectives. Although this would add to the amount of work IEDO needs to perform, the time and cost is offset by proven commercial industries' best practices in program and project management, which have evolved out of the necessity to reduce cost and improve speed to improve profitability. Some of public and private industries' best practices applied to all programs and projects are further outlined as follows. IEDO should:

- Expand risk management to include targeted adopting industries' perspective. To do so, the office can:
    - Use the technical, execution, market, political/social, organizational risk assessment process and checklist.
    - Document adoption risks for IEDO's technologies.
    - Develop risk mitigation opportunities for each risk.
    - Develop Venn diagrams of organizational dependencies for successful adoption and deployment that address the risks.
    - Assess mitigation options, select the most likely path for successful risk mitigation, and document the risk mitigation plan.

    - Develop a comprehensive plan for ensuring adoption of IEDO's investments to succeed in IEDO's goals.

- Cull models of best practices from current and past portfolios and refresh practices annually.
- Create a development through adoption plan for each project, updated annually.
- Build on existing portfolio processes and expand the collection and use of metadata to further inform direction and decision making. The office can:
    - Fine where the project fits in the IEDO portfolio framework. (This happens today.)
    - Identify the stage or status of the research. Is it just starting or near completion? (This happens today.)
    - Evaluate the project potential, including transitional, next generation, and leapfrog.
    - Consider the potential for speed of adoption—from rapid, low-cost scale to major process redevelopment and capital investment—and anything in between (may be related to overall project potential)
    - Look for adoption dependencies—whether there is a reliance on infrastructure.
    - Expand the use of rigorous global technology and prior art searches prior to project awards and conducting develop-versus-buy-access analyses when potentially suitable intellectual property (IP) is found. When "develop" is selected, continue to require quarterly IP assessment updates because many around the world are also pursuing carbon-reduction solutions.
    - Describe other partnerships, such as those with other departments in the DOE, broader government programs, or identified industry groups/companies.
    - Describe the technologies in use and relationships with others. Does the project or focus area have synergies with other projects or opportunities? An example could be using analytics or artificial intelligence (AI) tools, which could help drive synergy and collaboration for reuse of platform technologies.
    - Confirming uniqueness via a rigorous global technology and prior art search to adopt rather than reinventing anything.

3.1.7 “If It’s To Be, It’s Up To Me!” (Recommendation 7)

Observation

Throughout the presentations and question-and-answer sessions during the IEDO peer review in May 2023, each presenter adeptly covered the background of their program, the problem to solve, and the project portfolio to address the issues. However, when IEDO members were asked questions about a need for change in an area outside of IEDO's scope, the responses generally conveyed that the resolution was outside of IEDO's control.

Key Takeaways

Although we all acknowledge that not everything is IEDO's direct responsibility, there are supporting and adjacent organizations IEDO depends on to accomplish its goals.

Impact

DOE's deliverables are at significant risk because action is required by other organizations that are not yet engaged to enable the achievement of IEDO's goals.

Recommendation (Transformational)

A culture change is needed for IEDO to succeed in achieving a decarbonized industry by 2050. Everyone is empowered and responsible for integration and connecting, whereas TAWD provides the reusable communication materials, systems, and resources to increase each person's efficiency in building bridges and partnerships to drive down the risk and increase the probabilities of success.

To add to the expanded risk assessment and mitigation plans outlined in the Recommendation 6 (Section 3.1.6), work with your leaders and seek their assistance in making introductions and fostering alliances to accomplish synergistic objectives. Extend the use of partnerships with other departments in DOE, broader government programs, or identified industry groups/companies to aggregate capabilities outside of IEDO. This recommendation is aimed at deliberately focusing on each person in IEDO changing from an out-of-my-scope mindset and developing skills and awareness to build bridges in all areas necessary to succeed in the accomplishment of the recommendations in this report—all of which are aimed to increase IEDO's effectiveness and impact.

Work together to refresh and define for clarity, roles, and responsibilities with each partner to collectively achieve the overarching goal of a zero-carbon-emissions industry by 2050 through efficient, streamlined processes with right-sized bureaucracy administered by IEDO, partners, and supporting organizations (including everything from project processes to procurement and hiring).

3.2 Technical Innovation

3.2.1 Partnering Like Never Before (Recommendation 8)

Observation

IEDO is very focused on the target industries to be decarbonized and the technology innovations to reduce carbon emissions and improve energy efficiency. However, there is a reluctance to assess and address the companion solutions that must be in place to meet IEDO, EERE, DOE, and the U.S. government's decarbonization goals. As examples, this can refer to infrastructure required for successful implementation (e.g., electricity or hydrogen supply) and the U.S. Environmental Protection Agency's (EPA's) regulations must be addressed for IEDO's technology to be adopted.

Key Takeaways

In some applications, IEDO is encouraging greater use of electrification as a cleaner source of energy. However, the U.S. grid is unable to meet the increased electricity demand without action on the part of an array of federal, state, and local entities. At the federal level, DOE's Office of Electricity and Grid Deployment Office, together with the Federal Energy Regulatory Commission, play pivotal roles in shaping the technical, market and regulatory future of electricity sector as well as interstate transmission planning. At the regional level, the electric reliability councils coordinate on grid reliability and capacity planning, while in many parts of the country regional transmission organizations, such as the Pennsylvania-New Jersey-Maryland Interconnection, coordinate wholesale electricity markets. Most of the retail market exists at the state or local levels, with investor-owned utilities regulated by state public utility commissions that oversee rates, planning, and customer programs, including industrial programs. Rural cooperatives and municipal utilities are regulated by their members and their local government playing much the same roles as public utility commissions.

With all these players, it is important to work with their associations, including the National Electric Reliability Corporation, National Association of Regulated Utility Commissioners, National Rural Electric Cooperatives Association, and American Public Power Association. In addition, the Electric Power Research Institute and the Edison Electric Institute play important roles representing, informing, and educating the utility industry.

Impact

As U.S. industry members assess the viability, cost, and impact of adopting technologies incubated by IEDO, the local electrical and hydrogen energy supply capacity will be assessed against the forecasted increased demand of the cleaner energy source. Lack of supply will be viewed as a significant risk by industry and a very costly to mitigate. This will further increase headwinds for new technology adoption and delay reducing carbon emissions.

Recommendation (Transformational)

Reducing the use of higher carbon-emitting energies will require industry members to innovate new processes, develop robust new material compositions, and perform long-term business investment. For each IEDO technology investment, define what must be true for industry to utilize IEDO's new technology. Establish a plan to partner wherever needed to create an onramp for meeting industry where their ownership begins.

3.2.2 Risk to Implementation (Recommendation 9)

Observation

A critical element often missing from consideration during the development stage of technology is a system accounting for the upstream, operations phase, and downstream impacts while considering existing and developing regulations that may limit or prohibit the use of a developing technology if not mitigated (which is easier and more cost-effective to do early in the development process). Although the technical and nontechnical barriers, the risk to the industry's bottom line, and the need to collaborate to address them were acknowledged by DOE, we have learned from efforts in California (which are also driven by greenhouse gas emissions reduction and decarbonization targets) that there are unexpected barriers presenting a high risk to technology implementation.

Key Takeaways

For example, there is a push for low-carbon fuel production (e.g., biomethane from anaerobic co-digestion of sewage sludge and food waste) to displace fossil-fuel-based diesel in trucks to achieve NOx reductions in ozone non-attainment areas by federal deadlines. And there are incentives to do so. However, newly adopted zero-emissions-vehicle regulations in California (which also targets greenhouse gas emissions reductions but will be delayed due to supply chain and infrastructure delays) are prohibiting the expansion of biomethane-fueled, low-carbon and low-NOx vehicles, making it impossible to achieve federal mandates. Additionally, wastewater agencies will no longer accept food waste diverted from landfills to their anaerobic digesters because they cannot beneficially use the additional biogas/biomethane as a transportation fuel (identified as the most cost-effective beneficial use). Without a market, there is no incentive to process additional feedstock.

Impact

In turn, methane reductions at landfills will not be realized because the food waste will remain in the landfills due to the inability to permit enough compost facilities without enough emissions-reduction credits in any given basin.

Recommendation (Continuous Improvement)

There is a real need to collaborate with stakeholders early in the technology development process—specifically policy directors and permit engineers, along with (domestic and international) practitioners—to identify risk potential.

3.2.3 Leverage Tandem and Hybrid Solutions (Recommendation 10)

Observation

There is significant focus on using clean fuel sources, waste energy reuse, and bio-product conversion for something useful rather than producing something and letting it go to waste.

Key Takeaways

IEDO's technology portfolio has many long-term technology efforts seeking the full conversion to clean energy sources with few investments in nearer team, incrementally improving investments.

Impact

There are few incremental technology investments to increase the probability of success in achieving 2032 objectives. IEDO's technology portfolio largely consists of high-cost, high-return projects with a high risk of failure. Additionally, the push to decarbonize often leads to considering hydrogen as a fuel source for stationary technology because it can be a zero-emission fuel. However, high-temperature burning can lead to more NOx emissions.

Recommendation (Continuous Improvement)

Conduct potential problem analyses of proposed solutions and be prepared to leverage alternative tandem and hybrid solutions, such as carbon capture, in combination with other solutions, such as electrification of energy efficiency, until the 100% zero-carbon fuel or combinations thereof can be used. This will reduce the likelihood of unintended consequences of clean energy and help to more rapidly improve Earth's atmospheric condition. R&D will be needed to connect these multiple processes to bridge the gap until full zero-carbon fuels and processes will be economical and technology readiness level capable.

It is critical to consider not only the life cycle of greenhouse gases and decarbonization but also the other potential outcomes of operations and material and chemical use and to keep these considerations in balance with community resilience considerations.

There are limits to cross-cutting technology implementation that will need attention and require targeted industry and application development. Recognize that cross-cutting technology is a starting place, but to have an impact, it is not the end point. Focusing on single industries will be essential as a second phase of cross-cutting technology development for adoption and successful implementation. For example, using hydrogen fuel to melt glass is very different from firing ceramic in a hydrogen-powered kiln, which is different again from steel production. The combustion of hydrogen produces water vapor, which will have different effects on manufacturing processes and the product attributes they produce. Hydrogen combustion may also increase formation of NOx, which will have to be dealt with.

Therefore, do not focus just on hydrogen, ammonia, biofuels, electric, and processes that require lower-quality heat alone, but rather, look also at hybrid approaches to achieve low- to no-carbon combustion. Also evaluate working with industry to establish more flexible processes for future fuel compatibility while integrating carbon capture in parallel until the 100% zero-carbon fuel or combinations thereof can be used.

3.3 Program Balance

3.3.1 IEDO Framework (Recommendation 11)

Observation

During the kick-off meeting, we were introduced to the IEDO framework. It consisted of TAWD, an energy-intensive industry focus, and a cross-industry project focus. As the peer review team participated throughout the week, we saw that there were opportunities to further develop metadata around the project portfolio.

Key Takeaways

There are synergies across the IEDO project portfolio that should be further explored for better sharing of knowledge, lessons learned, and opportunity for impact. Further defining the framework and related metadata will help identify and act on these synergies and could also help paint a clearer picture of the impact across industry.

Impact

By defining opportunities to leverage technology, project approaches, and lessons learned, IEDO can potentially accelerate project results. Additional metadata could also help clarify the impact timeline on the industries they serve.

Recommendation (Continuous Improvement)

There is a need to continue the development of the IEDO program and project framework, which is addressed in the Organization, Strategies, and Implementation section (Section 2.1). Any program focus or project should clearly align within the framework, and it should also be clear where there are touch points across the broader DOE landscape. This is in progress, but the concept needs to stay at the forefront as you proceed with new FOAs.

Program and Projects Metadata

There is broader metadata that should be captured for each specific project and focus area. Some potential metadata that could be captured includes:

- Where the project fits in the IEDO portfolio framework. (This happens today.)
- The stage or status of the research, from those just starting to those near completion. (This happens today.)
- The project potential, including transitional, next generation, and leapfrog.

- The potential for speed of adoption, from rapid, low-cost scales to major process redevelopment and capital investments—and anything in between (which may be related to the overall project potential).
- Adoption dependencies. Is there a reliance on infrastructure?.
- Partnerships with other departments in DOE, broader government programs, or identified industry groups/companies.
- The technologies in use. Does the project and focus area have synergies with other projects or opportunities? For example, that could the use of analytics or artificial intelligence tools, which could help drive synergy and collaboration for reuse of platform technologies.

3.3.2 Overarching Program(s) and Funding (Recommendation 12)

Observation

The peer review team was very pleased to see the focus on TAWD. It is well recognized that much of industry engagement is about learning, education, and alignment across the participating companies. There are already at least two best practices already established with RAPID and NAWI.

Key Takeaways

It would be beneficial to extend these best practices across other industries and dedicate an ongoing focus through a program such as TAWD.

Impact

Extending the TAWD concept into broader industry focused teams should improve engagement and collaboration across the industry. It should also build a more trusted industry partnership instead of a set of individual relationships on a company-by-company basis. We realize this partnership and collaboration may be challenging across some industries but believe, in time, IEDO could effectively extend the best-practice model. This should also help drive buy-in from specific projects and accelerate desired outcomes.

Recommendation (Continuous Improvement)

It is recognized that not everything within the IEDO portfolio is a research project. This is especially the case with the focus of TAWD. There is a need to have a broader relationship and partnership with target industries that considers things such as education, sharing of best practices, and collaboration. There should be ongoing funding for such program activities that should be part of year-over-year budgets.

3.3.3 IEDO Adoption Timeline Impact (Recommendation 13)

Observation

The IEDO program and project portfolio are continuing to evolve in a positive way. Even with this improvement, however, there is not a good understanding of the significance of impact and the broader timeline to achieving objectives.

Key Takeaways

We realize IEDO is a complex pursuit that will never have a precise outcome schedule. It is important, however, that they start to work across their industry partnerships to define a proposed schedule of results. This will likely require additional metadata with the portfolio but should start to paint a picture of broader expectations and more tangible results.

Impact

The peer review team believes that industry will be more engaged and motivated if they see what is recognized as a tangible results schedule. This should help drive participation and broader buy-in from industry that will bolster support and investment.

Recommendation (Transformational)

It would be useful to partner with industry (possibly through TAWD) to develop an impact timeline. Although we recognize that this timeline will continuously evolve as active IEDO projects and initiatives come to fruition, it is important that companies and industries start to build plans and commitments to achieve the higher-level energy and decarbonization objectives. This timeline will be representative of the broader impact that IEDO is trying to achieve. The adoption timeline should consider best practices, technologies ready for deployment now, and horizon impacts for projects and breakthroughs in the pipeline. This recommendation is also supported by the prior recommendation related to metadata. The peer review team believes timeline impact is one of the key attributes within this metadata. The impact timeline should also be maintained as the portfolio evolves to consider the impact of project pitfalls or even potential leapfrogging.

3.3.4 Project Portfolio Rebalance (Recommendation 14)

Observation

It is recognized that the current IEDO project portfolio was established based on the work of the prior parent organization. With the shift to IEDO, however, it is expected there will be some shift in priorities and focus areas within the new organization.

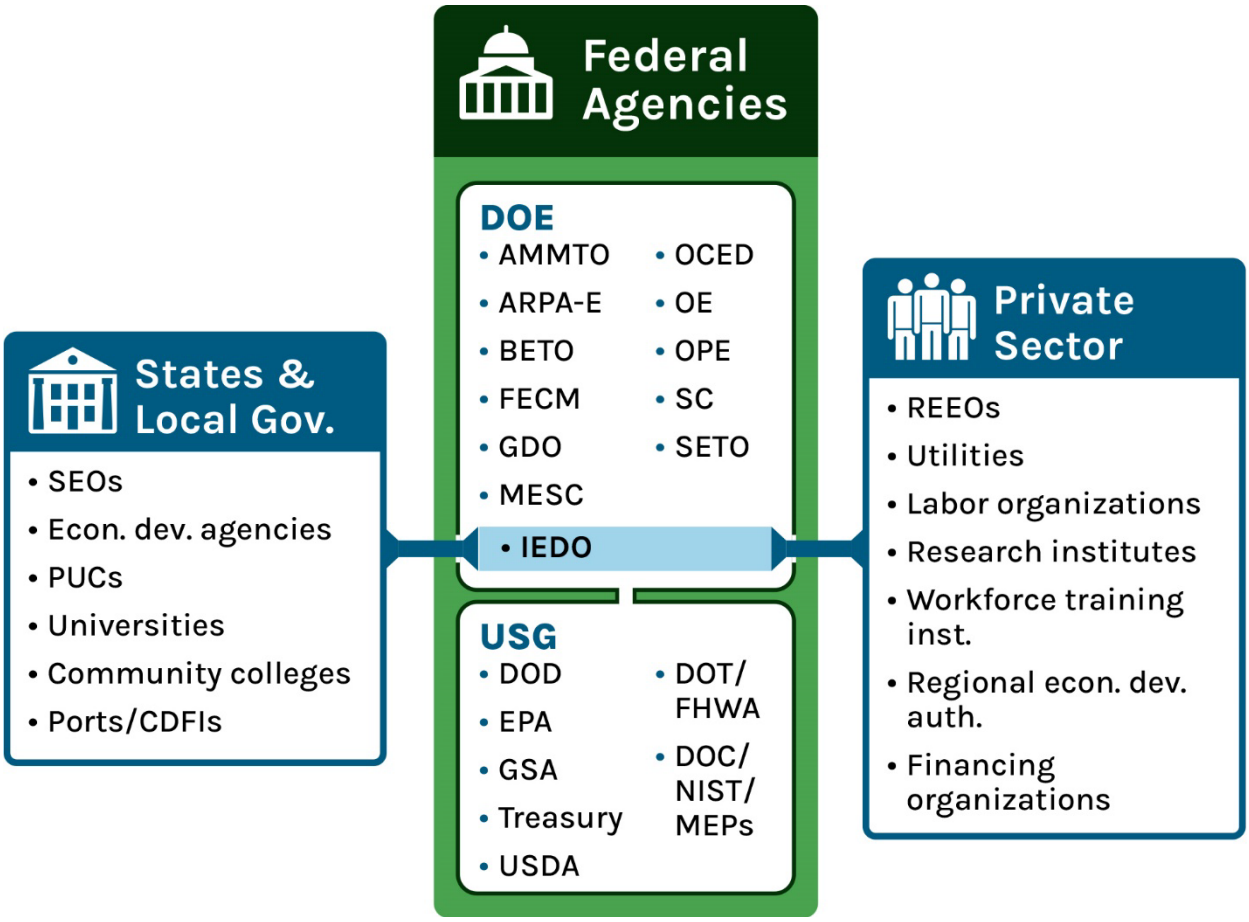

Figure 1. DOE offices, federal agencies, state and local government entities, and nongovernment organization are part of the industrial ecosystem.

Key Takeaways

The opportunity to shift focus will probably be best suited to the upcoming 2023 and 2024 FOAs.

Impact

The creation of IEDO should lead to a well-defined and focused project portfolio that feeds the objectives of the newly focused organization. The IEDO portfolio should be a vehicle to industrial efficiency and decarbonization results.

Recommendation (Continuous Improvement)

The portfolio should continue to be reevaluated, weighing existing in-process projects vs new FOAs. We recognize that the program is in transition, but the focus will need to evolve to strongly align to the new IEDO objectives.

3.4 Communications and Engagement

3.4.1 U.S. Department of Energy-Wide Federal Interagency and External Organization Communications and Engagement Plan (Recommendation 15) and Coordination (Recommendation 16)

Observation

On multiple occasions, when discussing engagement in activities outside EERE (whether within or outside of DOE), there was automatic abdication of responsibility by IEDO staff. However, it is critical to inform and coordinate not only within EERE but also across DOE offices and with other federal agencies (e.g., the EPA and U.S. Department of Agriculture) on a wide range of research, product specification, implementation, funding, and regulatory activities by developing communication and coordination plans that inform IEDO planning as well as identify opportunities to leverage relationships and capabilities.

Regulations are beginning to drive decarbonization activities at the state and national levels and will factor into decarbonization implementation actions. It is important to engage with regulatory agencies external to DOE at the state and local levels (e.g., state-level environment and/or public health agencies and air districts) to ensure DOE's efforts are closely coordinated with existing and developing regulatory requirements. Similarly, utility regulatory bodies are defining the future of electric power industry and access to clean power for electrification of industry.

It is important for IEDO to define its role relative to external organizations to ensure it does not inadvertently accept known barriers critical to its success or leave responsibilities to others without active engagement.

IEDO should recognize how critical partnerships are as well as addressing impacts to overburdened communities.

Although EERE may not be a jurisdiction of authority, the responsibility remains to inform and coordinate with those who hold that authority (e.g., the EPA, the Office of Electricity, and air districts).

Key Takeaways

IEDO and AMMTO are linked and will continue to have a close relationship. Understanding that relationship is important to ensure complementary activities and avoid tensions. Also, the Office of Clean Energy Demonstrations and the Office of Manufacturing and Energy Supply Chains rely on IEDO and AMMTO for technology support.

With the central role that electrification and hydrogen will play in decarbonization nationally, it is critical IEDO coordinate with other offices and external regulatory agencies on electricity and hydrogen project implementation—from technology demonstration to planning, through design integration and construction, as well as regulatory perspectives.

It is important to consider the array of external organizations and entities to develop communication and coordination plans that inform IEDO planning, as well as identify opportunities to leverage relationships and capabilities. Figure 1 identifies some of these key groupings of entities and organizations that should be considered in this planning process.

Impact

With the breadth of offices and agencies involved in industrial energy and climate issues, IEDO must be aware of their activities and opportunities for partnering and leveraging these efforts to further the office's programs. However, significant risk of duplication exists that could both waste resources and result in market confusion.

IEDO will need to understand and advise on regulatory requirements and resource availability to achieve its goals, even though they are outside the Office's purview. IEDO must also engage with others at DOE working on regulatory issues, such as the Office of Electricity and the Grid Deployment Office on utility system planning and operations and the Office of Fossil Energy and Carbon Management on hydrogen regulations. Since many regulatory issues are overseen by agencies outside DOE, it is also important that IEDO staff are engaged with the offices in the agencies that have responsibility over these issues, such as EPA, on topics ranging from regulations of refrigerants and per- and polyfluoroalkyl substances (usually shortened to PFAS) to the future ozone and nitrogen oxides standards, to other agencies (including the Occupational Safety and Health Administration [typically shortened to OSHA]) developing standards for hydrogen safety. IEDO's role is to provide an industrial perspective based on DOE research and to be aware of future regulatory actions and how they could impact decarbonization and efficiency in the future. Additionally, the industrial expertise of IEDO will help provide cohesiveness and clarity related to regulations from jurisdictions of authority. (i.e., there are gaps in and conflicting regulations and/or gaps in tax credits, which make them difficult to understand and be compliant). IEDO can utilize their expertise to close gaps and minimize paralysis from conflicting interpretations.

A lack of a comprehensive technical de-risking approach within the DOE landscape (e.g., not addressing existing and developing regulations or understanding funding opportunities external to DOE) can inadvertently limit successful implementation of a viable project essential to achieving carbon neutrality.

Recommendation 15 (Transformational)

To further establish IEDO's role as a catalyst for project implementation, a DOE-wide industrial decarbonization coordinating structure is critical and can serve as a model to other DOE offices toward greater effectiveness. To do this, IEDO can utilize DOE's organization chart (shown in Figure 2) to identify and target branches that need to be involved in any given project and leverage coordinating with each other. The 2022 organizational chart includes: EERE, the Office of Electricity, Office of Science, Office of Clean Energy Demonstrations, Grid Deployment Office, Office of Manufacturing and Energy Supply Chains, Loan Programs Office, Office of State and Community Energy

Programs, Office of Technology Transitions, Office of Policy, Advanced Research Program Administration – Energy, and the Assistant Secretary for International Affairs.

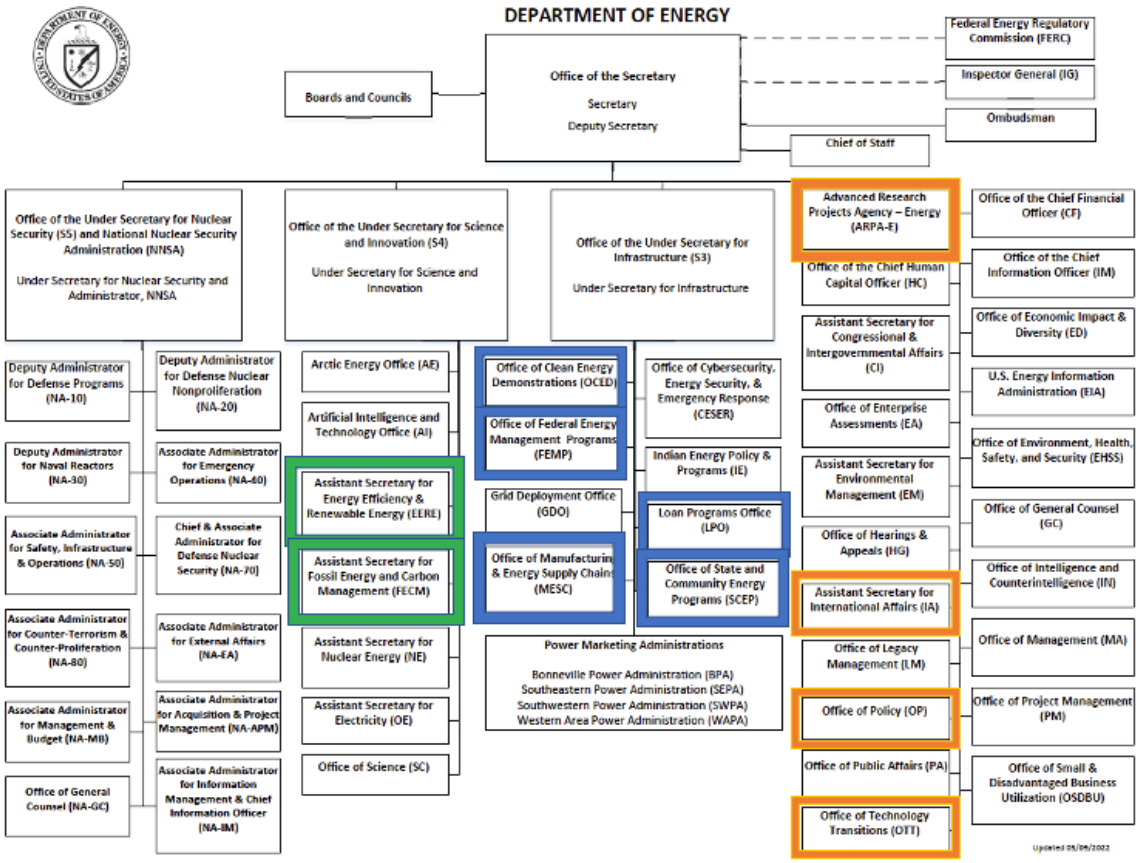

Figure 2. DOE offices directly or indirectly engage with industrial decarbonization technology and policy.

Recommendation 16 (Transformational)

IEDO needs to visualize themselves as the catalyst for successful scaling and implementation of technologies. It also needs to move the technology with the help of other offices into implementation while others bring feedback to IEDO, thereby accelerating technology adoption. This can be achieved by developing a communication and coordination plan to inform IEDO project implementation, including an approach for the identification of offices to be involved based on project type to leverage relationships and capabilities.

To do this, IEDO should map out the relationships that have the potential to impact the viability of DOE-developed technologies, prioritize these organizational relationships, and assign a staff liaison to track development at the identified key organizations and check in with contacts at the organization regularly, making them aware of planned IEDO activities and collecting information on the other organizations activities to report back to IEDO leadership and appropriate staff.

Implementing this catalytic vision, IEDO should share this mapping of activities and relationships with its internal and external partners through convenings and online tools

and resources. These efforts will enable coordination with partners and motivate actions to advance the mission of the office and the department. These activities will also help address the concerns expressed about transparency of activities of the department and provide tools that make industrial firms aware of activities and opportunities within the department advancing the goals of increasing adoption of efficiency and decarbonization technologies and practices.

Particular areas of coordination need to be prioritized and established, having a clear communication and engagement structure, as well as defining IEDO's role relative to other entities with a focus on enhancing relationships:

- Within IEDO
- Within EERE (across AMMTO, the Bioenergy Technologies Office, and IEDO)
- Across (18) DOE offices
- With other federal organizations and regulatory agencies (e.g., the EPA, the U.S. Department of Commerce and National Institute of Standards and Technology, the U.S. Department of Defense, General Services Administration, the U.S. Department of Transportation, and the U.S. Treasury).

Additionally, intra-agency coordination and roles to be considered as part of the communication and engagement structure should include:

- Industrial (nuclear, solar, wind, geothermal) electricity supply
- Hydrogen management and safety to be established with a unified strategy for managing hydrogen safety (as opposed to overlap with the Center for Hydrogen Safety) aligned with international standards.
- IEDO and AMMTO reviewing any materials that are necessary for their respective goals and communicating the threats (e.g., refrigerant regulations) to success to regulatory industries, such as the EPA.
- Federal purchasing specifications (General Services Administration, U.S. Department of Transportation and Federal Highway Administration, the EPA, and the U.S. Department of Defense) to be established.
- Office of State and Community Energy Programs, which facilitates community engagement, as well as existing networks of stakeholders (e.g., RAPID, NAWI), including facilitating partnerships among them as well as with a new and broader range of stakeholders and expanding stakeholder engagement to incorporate strategic planning leadership, state and local economic development organizations, rural communities, utilities, and environmental regulators.

- Identifying and leveraging funding opportunities administered by other agencies (e.g., the EPA, the U.S. Department of Commerce, the U.S. Department of Defense, the U.S. Department of Agriculture, the U.S. Treasury).

3.5 Execution

3.5.1 Improve procurement (Recommendation 17)

Observation

The procurement process is slow, cumbersome, and expensive to participate in, seriously limiting individual and team proposal coverage and adequacy as well as effective implementation of partnering and teaming arrangements.

Key Takeaways

Current procurement and solicitation mechanisms limit and impede timely, agile, effective partnerships with IEDO, as well as arrangements among partners. Small businesses and innovators (and even many medium and large businesses) may not have the staff or the administrative and financial infrastructure required to partner with IEDO. Researchers are unsure how to participate both administratively and programmatically.

Impact

Developing partnering mechanisms that are economically viable to compete and participate in will open doors for more innovative and relevant contributions, leading to more success for ready for deployment.

Recommendation

Pursue alternative solicitation and contracting strategies including but not limited to the following for each type of recommendation:

- **(Transformational)** Execute a partnership between IEDO and the Procurement Office with the full support of the Secretary of Energy and Deputy Secretary of Energy to develop within months (or less) a streamlined, business- and academia-friendly solicitation and management process, piloting on two or three FOAs.
    - Proposal documentation for responding would be held to 10–20 pages with minimal attachments, relying on readily available financial reports (e.g., Internal Revenue Service tax filings).
    - Award management would eliminate nonrelevant reporting requirements, management, and oversight and determine additional opportunities for streamlining and saving government and partners resources and time requirements to participate.

- **(Continuing improvement)** Pursue extended contracting mechanisms through hubs and institutes.
- **(Transformational)** Commit to investigating DOE-authorized, unused flexible partnership contracting vehicles, such as other transactions agreements, which have been used historically and actively by the U.S. Department of Defense and aerospace agencies.
- **(Transformational)** Develop and deploy throughout IEDO the FOA model for change, which calls for: integrated teaming from start to end, including students, academia, state and local governments, and plant through board industry members. NAWI and water sector programs have good examples. The FOA model for change could also call for: (1) development and support of curriculum and certification; (2) transparency of data sharing and integration by all team members throughout the project; (3) establishment of an integration team with the responsibility of describing how the effort is developed, managed, and executed, including deliverables; (4) encouragement of early, first-stage use of operating plant data and conditions, including second-stage testing and evaluation at multiple host sites (preferably covering different companies in different regions); and (5) optimization of the reuse of modeling and analytics platforms.

3.5.2 Prime the Pump! (Recommendation 18)

Observation

Personnel recruitment and hiring takes too long and often loses the best candidates along the way.

Key Takeaways

The current IEDO staff is overly extended to achieve their program/project objectives, which limits their abilities to take on better and novel program planning management and execution.

Impact

Although having access to subcontractors' expertise is helpful and needed to augment support, IEDO needs rapid recruitment and placement of employees to build an adequate staff implementing and managing their programs and projects to achieve their large and challenging visions and goals.

Recommendation (Transformational)

Reverse the current applicant screening process, instead having IEDO staff who are most familiar with job requirements perform initial screening. The Personnel Office can then apply their screening criteria to the relevant subset of applicants. IEDO should pursue further areas of improvement to achieve its goal of hiring within six months of

posting a job. These areas may include: (1) searching out best practices in public and private sector for hiring and recruiting; (2) putting out a broad call to generate cohorts of first-stage pre-certified candidates by emphasizing skills/talents needed in upcoming job postings; and (3) creating a cohort of final applicants who have received approval but have not yet been selected (normally in a pool of excellent candidates for a single job). It should be noted to successfully compete with the technology industry and employ the best and brightest talent, reducing the time from receipt of resume to offer will need to be significantly shortened.

3.5.3 Partnering plans (Recommendation 19)

Observation

IEDO needs easier and more effective ways to encourage and implement partnerships.

Key Takeaways

Potential partners are reluctant to partner with IEDO, lacking an understanding of where and how to create a partnership and what to base it on.

Impact

The mindsets of potential partners perceiving challenge and meaningfulness when working with IEDO could evolve positively to strengthen the breadth and depth of their accomplishments.

Recommendation (Transformational)

Develop specific how-to-engage documentation for different partner communities, including large/medium/small industries, entrepreneurs/innovators, financiers, large/medium/small academia, states, local governments, and nonprofit organizations. Make this documentation for all IEDO employees to recognize, understand, and market. Staff teams across IEDO (representatives from all offices from all staffing levels) should develop and deliver specific how-to-engage outreach plans, marketing each target audience with simple mechanisms to adjust updates from this process. For example, when addressing academia, why is there a lack of participation? More specifically, why is direct participation with IEDO lacking? What about partnering with industry lead teams? What are their strategies for integrating students from beginning to end in projects (and in project development)? What are their challenges in data and publishing transparency and sharing? What are the best ways of tapping into and understanding their capabilities in IEDO's transition from long-term research to research, development, and deployment? How can we best communicate program results and opportunities to them?

Explore new, novel partnering mechanisms with vertical, horizontal, and diagonal partnering teams ready to encourage regional specific technology or systems development and adoption. These teams would be ready to begin executing immediately and delivering swiftly. Reaching IEDO's zero-emissions decarbonization goal is going to require industries and their system of system networks to work across sectors and deep down into sector supply chains, requiring new relationships to be

created. IEDO should provide incentives for developing partnering teams to strengthen these relationships using simple, agile mechanisms. This should not be another hub or institute model (which are excellent for what their mission is). Consider insertion of wisdom-designed advanced technologies or systems in novel applications showcases. They must have an approach, particularly responding to unique regions' resource availability and needs, for example, insertion of advanced highly efficient low-carbon technologies or systems in multiple industries and/or plants with capabilities to receive, understand, and preset process operations in real time based on specific characteristics of receiving inputs. Then, the technology or system monitors excursions during processing, adjusting process steps in real time. Finally, the process or system transmits information and excursion results, along with final output characteristics to the next manufacturing step(s). Broad teams with comprehensive insertion outcomes and transferability would be required. These would be fairly quick hits, in available results communicated widely over one to three years. Candidates could be drying, melting, heating, and combination low-carbon heat generation.

3.5.4 Planning and Management Tool Kit (Recommendation 20)

Observation

IEDO needs to focus more on planning and management tools to raise their understanding and effectiveness of their impacts.

Key Takeaways

Much has been accomplished in IEDO organizational setup. Now, the office needs to expand its focus on planning and managing the programs, processes, and resources. This is not from a budget perspective but rather to optimize implementation.

Impact

IEDO and its partners will understand even more clearly how to continually improve its relationships and impacts.

Recommendation (Transformational)

Throughout this report, we have recommended a variety of tools to improve performance and outcomes. Consider collecting these tools and resources in IEDO's Toolbox. All the suggestions from the guides to give program and project managers better access to strategic planning resources (including communications plans, the program and project systems and databases, and the APs, among others) should be developed and managed as a single, synced integrated planning and management resource. With an approach like ASP, IEDO can design these resources to be responsive to multiple planning and management needs.

Begin by cataloging what tools you have now and assessing their effectiveness in responding to the needs pointed out in this report. Then create the IEDO toolbox agenda for modifications, additions, and integration. Your goal should be to achieve and maintain awareness and transparency of commitments, investments, and outcomes

amongst yourselves and with your partners—while delivering your responsibilities, commitments, and services as timely and as effectively as possible.

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

For more information, visit: energy.gov/eere

DOE/EE-2870 • July 2024